Intermediate
Radio Amateur Course
(2019 Syllabus)

Cambridge and District Amateur Radio Club (CDARC)

February 2020

Acknowledgements

The Cambridge & District Amateur Radio Club (CDARC)

who have helped to produce this material for the course.

Recommended Reading

This course is structured around:

The RSGB book – “Intermediate Licence Manual”

You should obtain a copy to help you with your own studies.

NB! You will need to invest at least 25 hours of study before taking the examination. You must already hold a Foundation Licence.

Purpose Of These Slides

These slides are a supplement to the RSGB book:

"Intermediate Licence Manual"

and provide a further explanation to some of the topics.

Jargon

You will have already passed your Foundation Licence and have had some operating experience.

However there will probably be some terms, phrases and abbreviations that you have yet to come across.

If we use any terms in this course with which you are not familiar please stop us and ask for an explanation in plain English!

Course Topics

1 Licensing Conditions
2 Technical Basics
3 Transmitters and Receivers
4 Feeders and Antennas
5 Propagation
6 EMC
7 Operating Practices and Procedures
8 Safety
9 Measurements and Construction

This slide set is in syllabus order

SECTION 1
Licence Conditions

1A Nature of Amateur Radio

Ofcom owns the licencing system. They issue you with a licence. If you are in breach of the licence conditions Ofcom may revoke your licence:

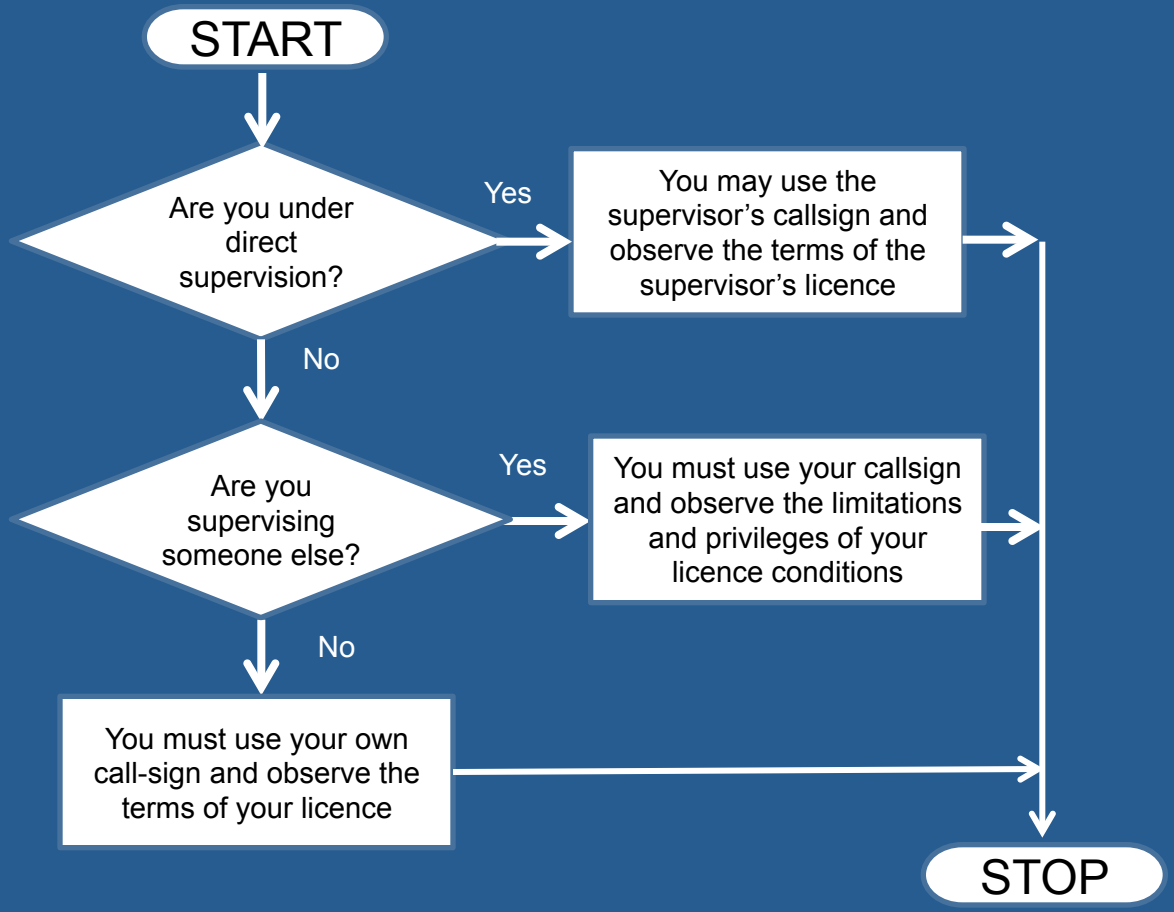
In particular you must:

- Inform Ofcom immediately if you change your registered station address.

- Validate your licence on the Ofcom website at least once every five years.

1B Operators and Supervision

Using Another, UK-Licenced Amateur's Equipment



As an Intermediate licence holder you may supervise another, licenced UK Amateur.

However there are requirements to observe.

You may not supervise an unlicenced person – such as in sending greetings messages or supervising a Foundation licence practical assessment. Anybody whom you supervise must be a UK licenced amateur.

1C Messages

Messages on Behalf of a User Service

As a service to the community radio amateurs are allowed to pass messages for the “User Services”. The ones you need to remember are:

Police
Fire Service
British Red Cross
St Andrew’s Ambulance Association
Salvation Army
Utilities
Coast Guard
Ambulance
St John Ambulance
WRVS
Any Government Department

Passing Messages

In an an international disaster you may pass messages internationally on behalf of un-licensed persons. Under such conditions non-amateur stations may be heard on amateur bands.

You may pass messages on behalf of a user service. You may permit a member of the user service to use your equipment to pass messages.

Except under the direction of a member of the user service, who may obscure the meaning of a message to preserve confidentiality, you must pass all your messages in plain language.

Transmitting For General Reception

You may not broadcast for general reception.

You may transmit a CQ call because the intention here is to establish contact with another licenced amateur.

In a “net” you must have made contact by identifying yourself.

1D Apparatus, Inspection and Closedown

Undue Interference

Transmissions from the station must not cause undue interference to other radio users.

The Licensee must reduce any emissions causing interference, to the satisfaction of a person authorised by Ofcom.

This may include a reduction in transmit power or any other action required to reduce emissions to an acceptable level

Mandatory Log Keeping, Modifications, Reduction in Power and Closedown.

A person, duly authorised by Ofcom, may require you to keep a log of all transmissions.

Ofcom can also require you to reduce your output power, modify your equipment or close down your station.

1E Unattended and Remote Control Operation

Unattended Operation

The licensee may conduct unattended operation of a beacon, for the purposes of direction-finding competitions, or for digital communications provided operation is consistent with the terms of the Licence.

Unattended operation does not include providing for general use by other amateurs.

The licensee may conduct remote control operation of the main station in a manner consistent with the terms of the Licence.

The remote control link must be by radio in an amateur band, limited to 500mW pep e.r.p. maximum transmit power.

The remote control link should be above 30MHz.

The remote control link must be failsafe to avoid unintended transmissions and adequately secure to ensure the station remains compliant with the terms of the Licence

1F CEPT and International Administrations

CEPT and Other Administrations

The CEPT (European Conference on Posts and Telecommunications) does not routinely recognize an Intermediate Licence.

Other administrations also do not recognize an Intermediate Licence.

1G Licence Schedule

The Schedule to the Licence.

You must be able to identify the relevant information (LF, HF, VHF, UHF) in the schedule to the Intermediate Licence.

A copy of the schedule will be available during the examination.

Section 2.
TECHNICAL ASPECTS

2A Fundamental Theory

Component Tolerances

Electrical components such as resistors, capacitors and inductors are marked with a value. This value is a “nominal” value. Components marked with an identical value will show a spread of values when accurately measured.

The range, occupied by these values, is known as the tolerance band. Tolerances limits are usually defined as a percentage of the nominal value.

For example: A resistor is marked as 3.3kΩ (3,300 ohms) +/- 10%

10% of 3,300 is 330

This means that the resistor value could be anywhere between (3,300 + 330) ohms or (3,300 – 330) ohms.

In other words any value from: 2,970Ω to 3,630Ω

Units and Abbreviations

Topic	Unit	Abbreviations
Potential Difference	Volts	V
Current	Ampère	I, i, A
Power	Watts	P, W
Resistance	Ohms	Ω, R
Capacitance	Farads	F
Inductance	Henry	L, H
Frequency	Hertz	Hz

Multiple and Sub-Multiple Prefixes

In general in radio and electrical work the basic unit is often either too large or too small to be used directly. This can lead to either very big or very small numbers having to be used in calculations. *(ie numbers containing lots of zeros before or after the decimal point.)*

To avoid this we use multipliers and sub-multipliers to "soak-up" the zeros.

There is an accepted convention for these prefixes . This is that they are in powers of 10^3 ie multiples of 1000.

Common Prefixes

Prefix	Multiplier	Power of Ten
pico (p)	0.000 000 000 001	10E-12 (10^{-12})
nano (n)	0.000 000 001	10E-9
micro (μ)	0.000 001	10E-6
milli (m)	0.001	10E-3
kilo (k)	1000	10E3 (10^{3})
Mega (M)	1 000 000	10E6
Giga (G)	1 000 000 000	10E9

Note: pico, nano, micro, milli, kilo, are always written in lower case.
Mega and Giga are always written with an initial capital letter.

Non-Standard Prefixes

This will not be examined. However for completeness these appear below.

centi-	(c)	x100	10E-2
deci-	(d)	x10	10E-1
hecto-	(h)	x10,000	10E4

Examples:

Centigrade, centimetre;
Decibel;
Hectare. (100m x 100m = 10,000 square metres = 1 hectare)

These are based on multiples other than 10E3 so are non-standard but they are in common use.

Potential Difference, Current and Resistance

Resistance is the property of a component, device or circuit which opposes the flow of current through it.

Resistance has the units of ohms (Ω).

Potential Difference and current are related to Resistance by the equation:

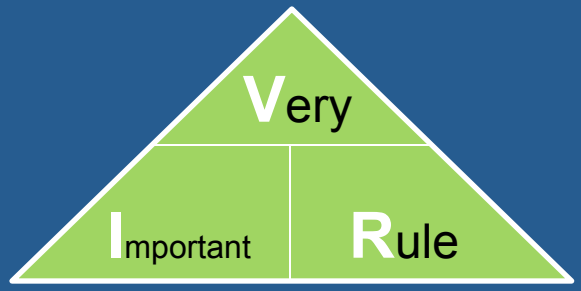
Potential Difference = Current x Resistance

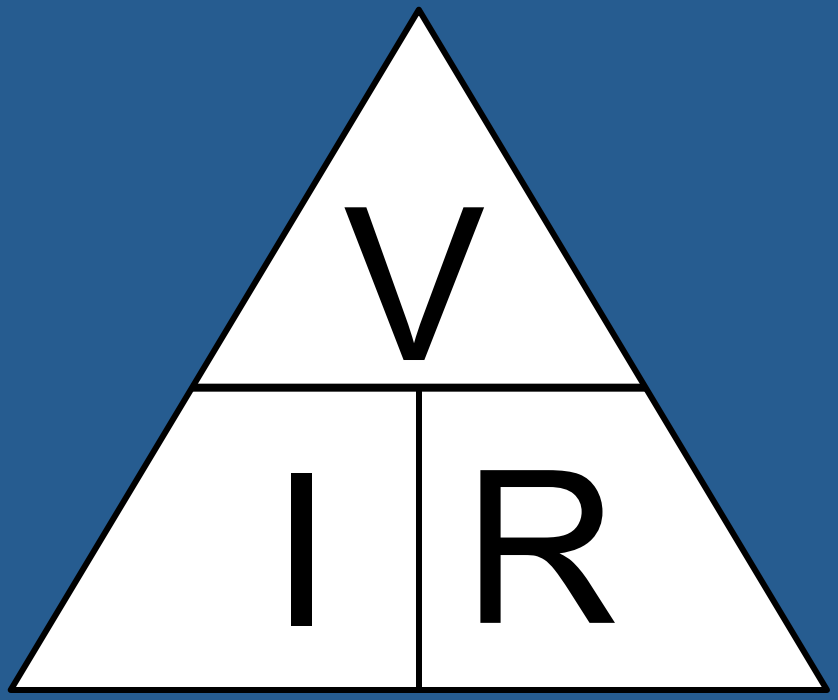
$$V = I \times R \quad \textit{(OHMS LAW)}$$

eg. I = 2 Amps; R = 10Ω; Given that V = I x R then V = 2 x 10; V = 20 Volts.

Or, put another way, a potential difference of 20 Volts applied across a resistance of 10Ω will cause a current of 2 Ampères to flow through it. (Or, 2A flowing through a resistor will cause a potential difference of 20V to appear across it.)

Ohms Law Triangle





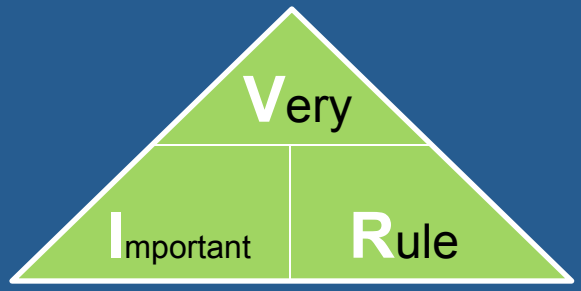
$V = I \times R$

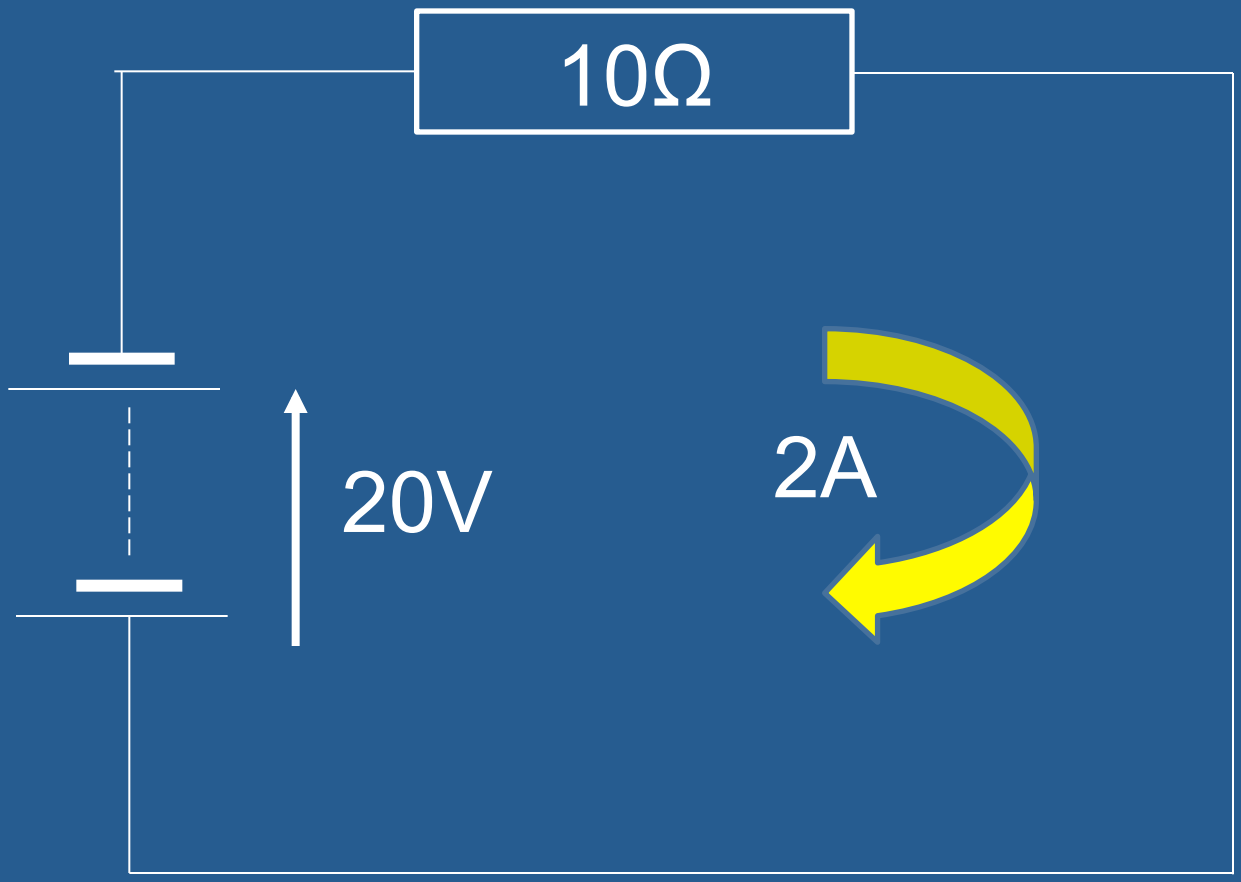
$I = V / R$

$R = V / I$

eg. V = 5V, I = 10 mA; Given that R = V / I then R = 5 / 0.01, R = 500Ω

(Watch the multiplier prefixes. Always convert to the base number if you are not sure!)


Very
Important
Rule


10Ω
20V
2A

Ohms Law Examples (V = I x R)

Complete the table below using Ohms Law.

(WATCH THE UNITS!!!)

Voltage V	Current	Resistance Ω
	1 Amp	30
	1mA	3000
	2mA	10,000
50	10mA	
18	3	
10		1000
1mV		0.1

2C Resistors

Resistors

Resistors are two-terminal, passive devices. It does not matter which way round you connect them in a circuit. The symbol for a resistor is:



The value of a resistor (leaded components) is indicated by coloured bands around the device

In circuit diagrams the value is written close to the symbol. For example:



3k3 = 3,300Ω = 3.3k = 3.3kΩ

3k3 is the preferred method of writing the value

Series Connexion of Resistors

The series connexion of resistors is where two or more are daisy-chained, head to tail with each other.



You can connect two or more resistors in this way. The final result is still a two-terminal device which has an equivalent resistance (R_e) equal to the sum of the individual resistance values. So, for two resistors in series the equivalent resistance is:

$R_e = (R_1 + R_2)$;

Three resistors in series has an $R_e = (R_1 + R_2 + R_3)$;

For n resistors in series the general expression is: $R_e = \sum_{n=1}^{n} R_n$

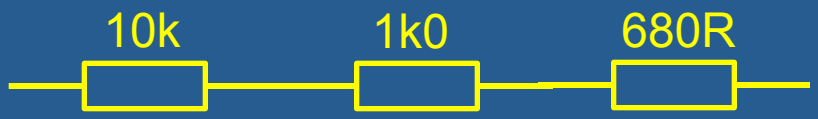
Series Connexion: Example



Re = 3k3 + 4k7 = 3300 + 4700 = 8k0 or 8000Ω



Re = 2k2 + 560 = 2200 + 560 = 2k76 or 2760Ω



Re = 10k + 1k0 + 680 = 11k68 or 11,680Ω

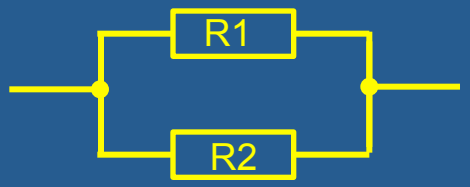
NB! Beware of mixed prefixes! (M, k, R)

(10M + 33k) is: 10,033K or 10M033 or 10,033,000Ω

Resistors in Parallel

As well as series connexion you can connect resistors in parallel. This also gives a two terminal device with an equivalent resistance R_e .

(However this R_e is a different value to the R_e formed by two resistors in series.)



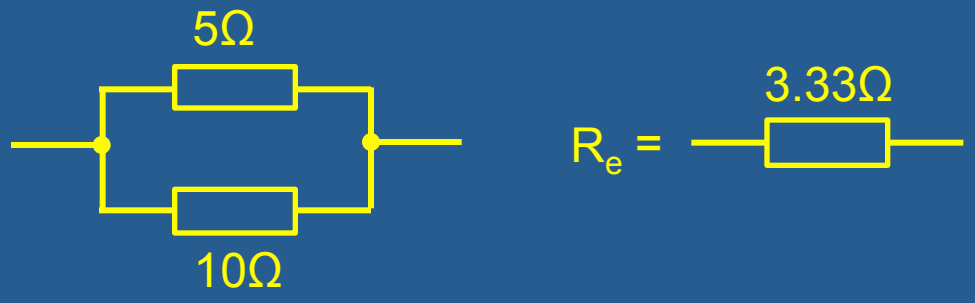
$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2}$$

In general the equivalent resistor for several resistors in parallel is: $\frac{1}{R_e} = \sum_{n=1}^{n} \frac{1}{R_n}$

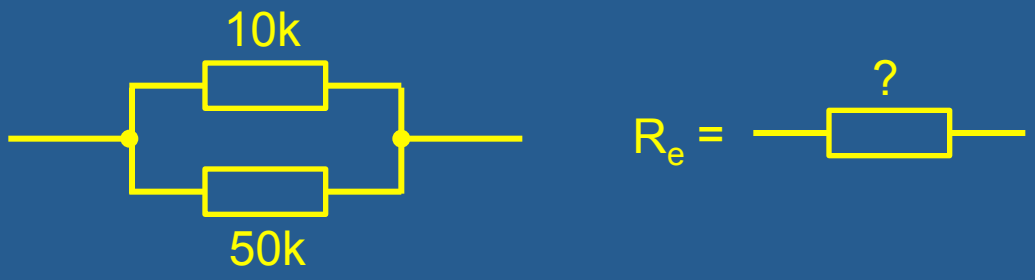
eg. $R_1 = 5\Omega$ and $R_2 = 10\Omega$;

1/Re = 1/R1 + 1/R2;
1/Re = 1/5 + 1/10
1/Re = 2/10 + 1/10
1/Re = 3/10
Re = 10/3

$R_e = 3.33\Omega$



Resistors in Parallel: Worked Example



$1/R_e = (1 / 10{,}000 + 1 / 50{,}000)$

$1/R_e = (5 / 50{,}000 + 1 / 50{,}000)$

$1/R_e = (6 / 50{,}000)$

$R_e = (50{,}000 / 6)$

$R_e = 8k33$

Check: The value for R_e must always be less than the smallest value of resistance in the parallel combination.

Resistors In Parallel: Try These

(a): 10k, 33k

(b): 27k, 47k

(c): 27k, 39k, 56k

(d): 10k, 10k

(e): 10k, 10k, 10k

What is special about the R_e resulting from identical resistor values in parallel?

Identical Resistors In Parallel

Two 10Ω resistors in parallel.

1 / Re = 1 /10 + 1 /10

1 / Re = 2 /10

Re = 10 / 2

Re = 5Ω

Three 10Ω resistors in parallel

1 / Re = 1 / 10 + 1 / 10 + 1 / 10

1 / Re = 3 / 10

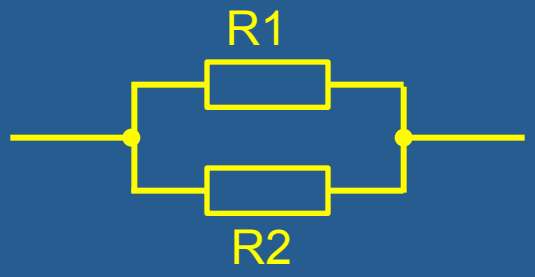
Re = 10 / 3

Re = 3.33Ω

If, and only if, identical resistors are connected in parallel then the final value is equal to an element value divided by the number of resistors in the parallel combination. The final value is always less than an element value.

Four 12Ω in parallel give 12/4 = 3Ω
Three 12Ω in parallel give 12/3 = 4Ω
Two 12Ω in parallel gives 12/2 = 6Ω

Alternative Equation For Parallel Resistors



R_e = ?

$$R_e = \left\{ \frac{R1 \times R2}{R1 + R2} \right\}$$

For example: R1 = 10R and R2 = 5R

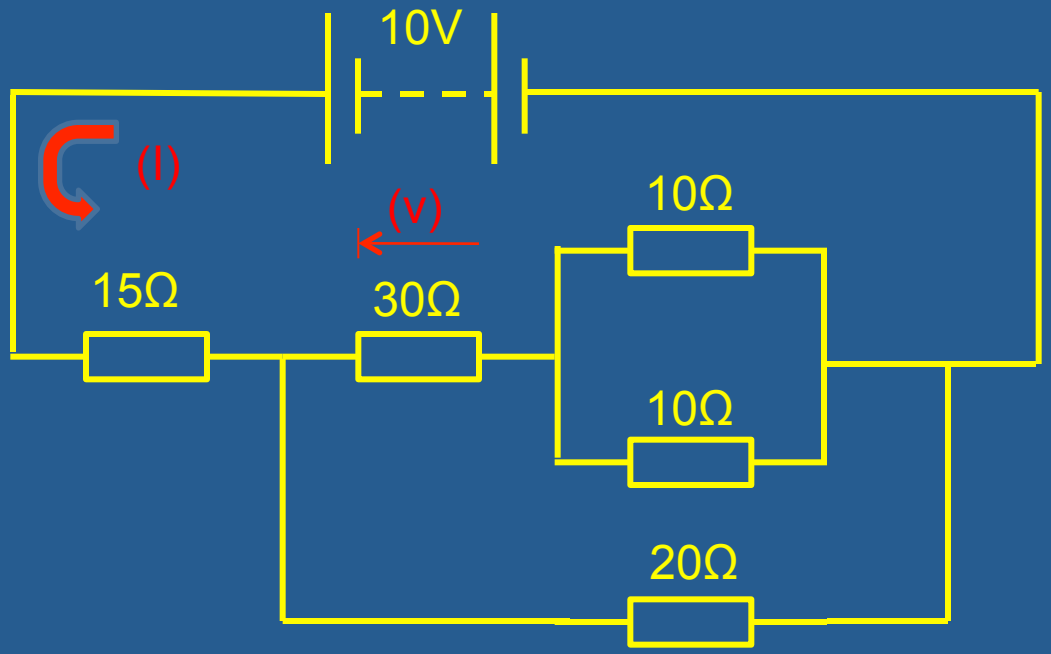
R_e = [(10 x 5) / (10+ 5)]

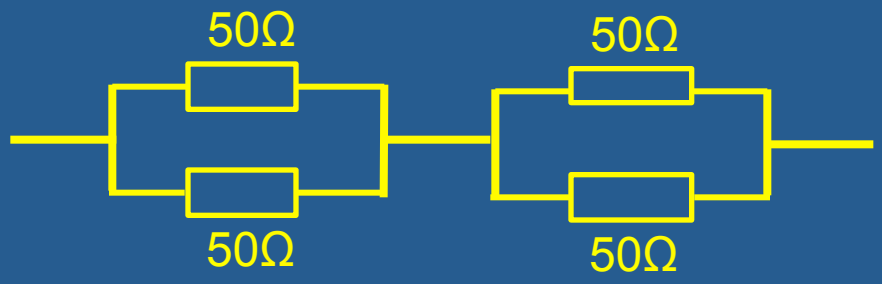
R_e = (50 / 15)

R_e = 3R33

For more than two resistors in parallel work out the value for the first pair. Then use this value in parallel with R3, then the value of this combination in parallel with R4 and so on.

Resistive Networks and Ohms Law





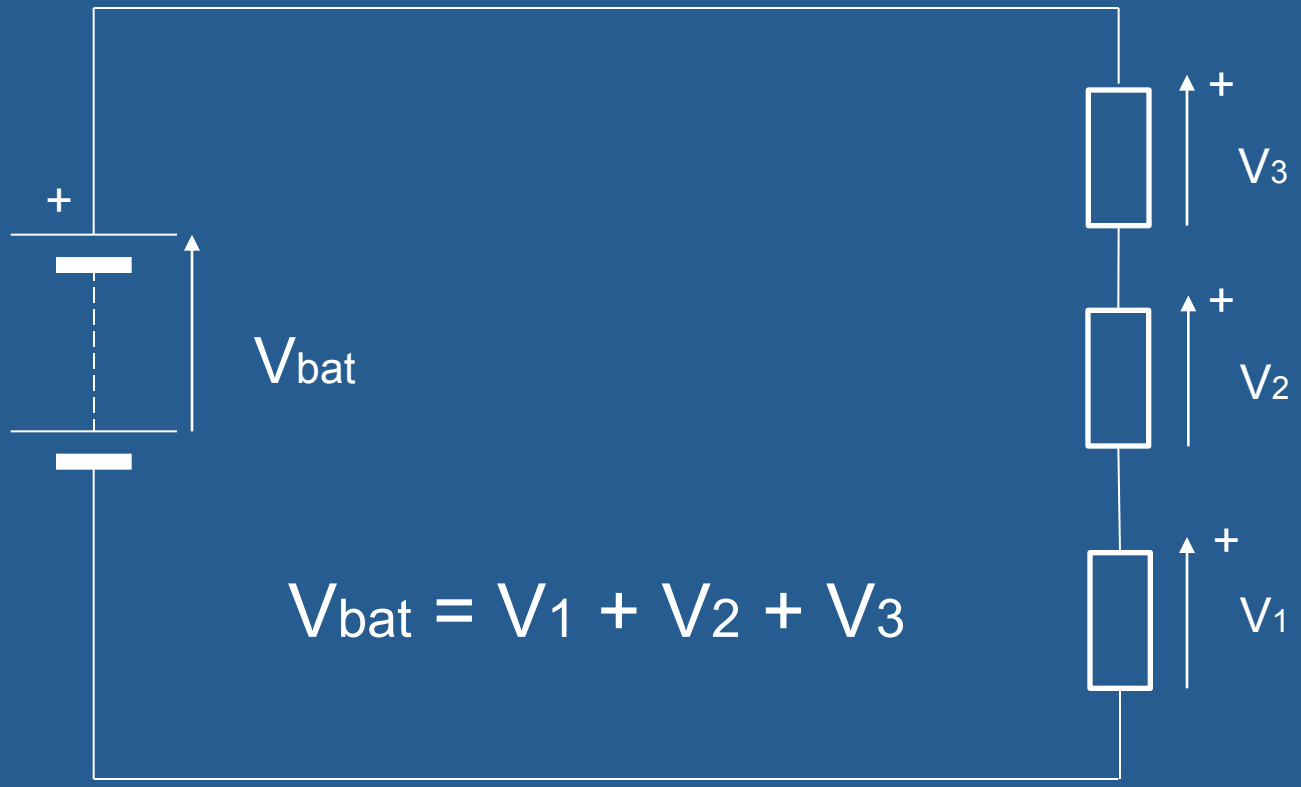
1. Calculate the total current (I) delivered by the battery.

2. What is the voltage (V) across the 30Ω resistor?. *(This is not as difficult as it may first look!)*

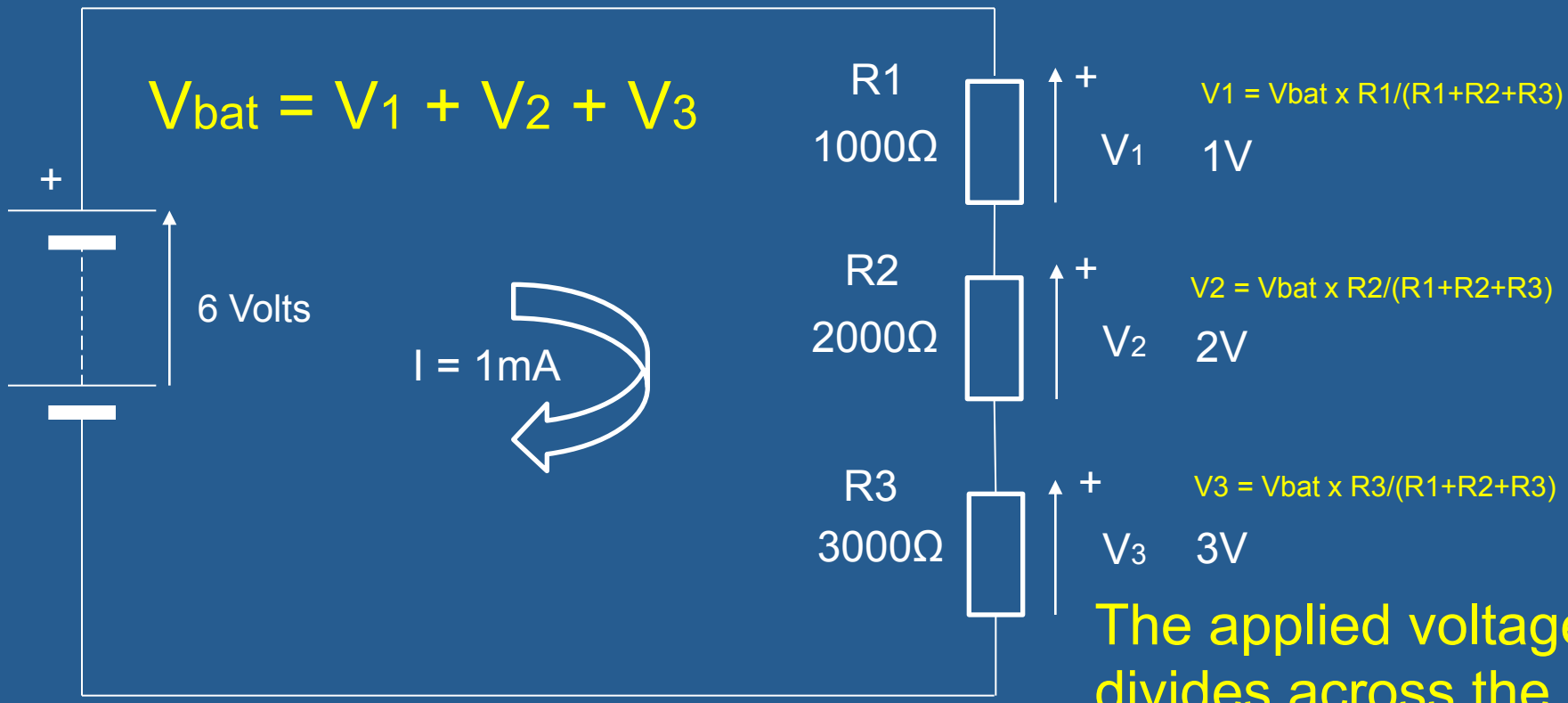
What is the equivalent value in ohms (R_e) of this combination?

The Resistive Potential Divider

The sum of the voltage drops across the circuit elements around a circuit equals the applied voltage.



The Resistive Potential Divider: Example



Circuit resistance = (1000 + 2000 + 3000)Ω = 6000Ω
Circuit current (I) = (6/6000)A = 1mA
V_3 = 3000 x 0.001 Volts = 3V
V_2 = 2000 x 0.001 Volts = 2V
V_1 = 1000 x 0.001 Volts = 1V

The applied voltage divides across the resistors in the same ratio as the resistors in the potential divider.

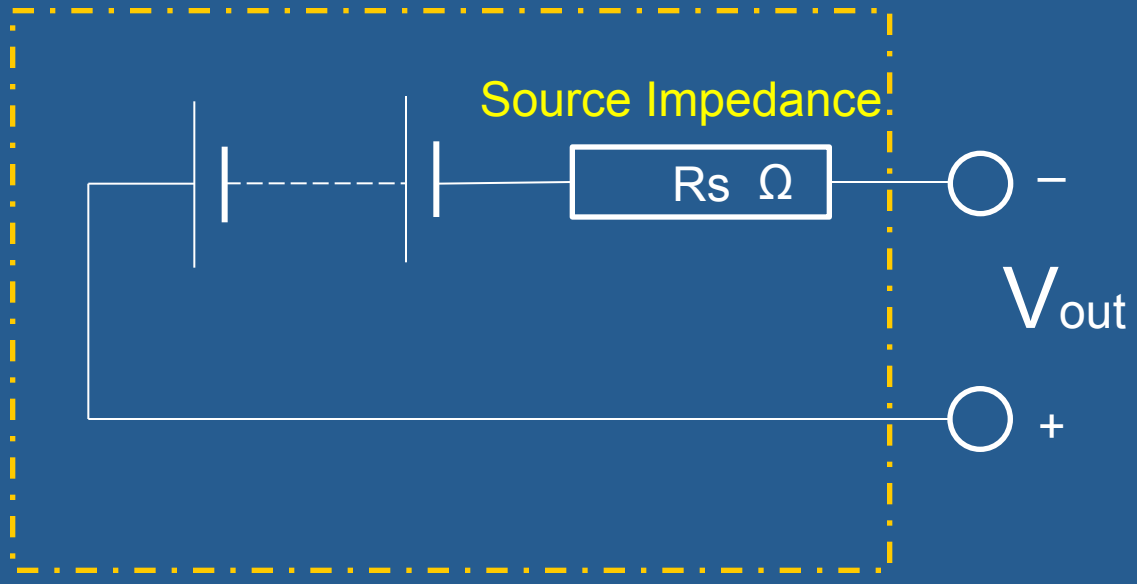
Potential Difference and Electromotive Force

A Potential Difference (PD) is the voltage that appears across a circuit element or between circuit elements as a result of a current passing through the element and causing a voltage difference.

An Electromotive Force (EMF) is the voltage appearing across a voltage source (such as a battery) which causes a current flow through a circuit when the connexion is made.

Source Impedance

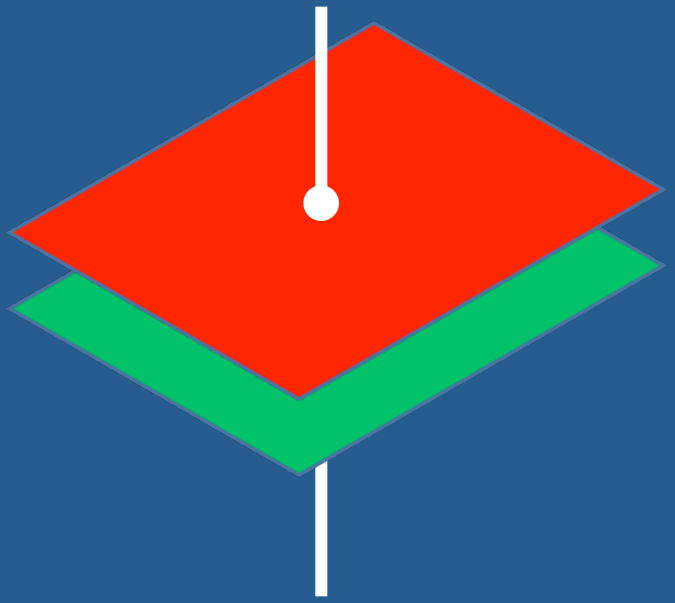
Practical sources of voltage and current – eg a lead-acid battery – differ from the ideal in that they have an intrinsic resistance due to their chemistry or construction. This distributed, internal resistance looks like a single, embedded resistance within the voltage or current source.



The source impedance limits the current or voltage that the source can supply to an external circuit.

An ideal voltage source has an infinite source impedance. An ideal current source has zero source impedance.

The Capacitor



The value (Farads) that a parallel plate capacitor has is dependent upon three factors:

1. The area (A) of the plates;
2. The distance (d) between the plates;
3. The dielectric between the plates.

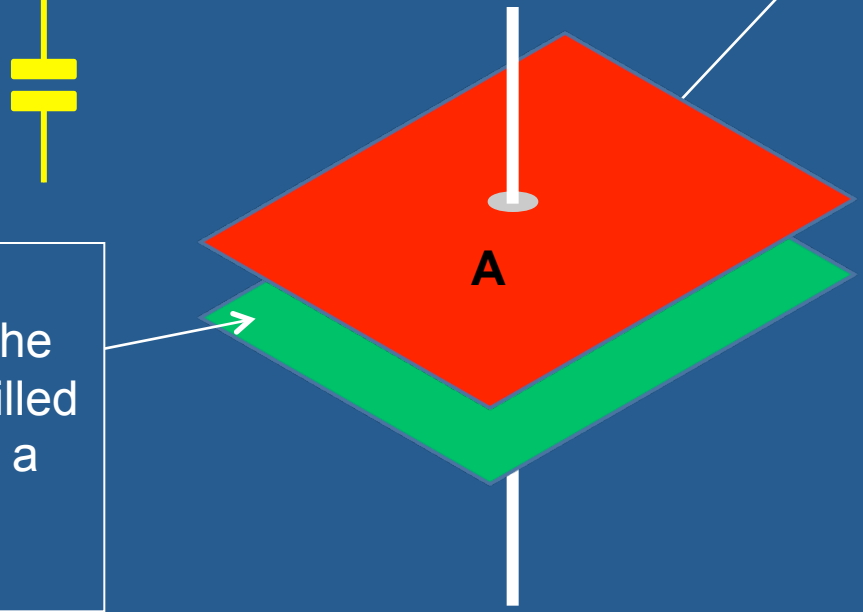
The bigger the area of the plates and the closer together that they are the correspondingly bigger is the value of the capacitor that is formed.

Inserting a dielectric (plastic, mica, etc) between the plates also increases the value of the capacitance above that when the plates are separated by air or a vacuum.

Capacitors store **Electric Charge**. The bigger the capacitance the more charge can be stored for a given applied voltage.

2D Reactive Components

Capacitance Value



Area of plate = **A** square metres

Separation between the plates is **d** metres

The gap between the plates is filled with air or a dielectric material

The value of such a capacitor is:

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

Where C is in Farads

The Dielectric

$$C = \frac{A\varepsilon_0\varepsilon_r}{d}$$

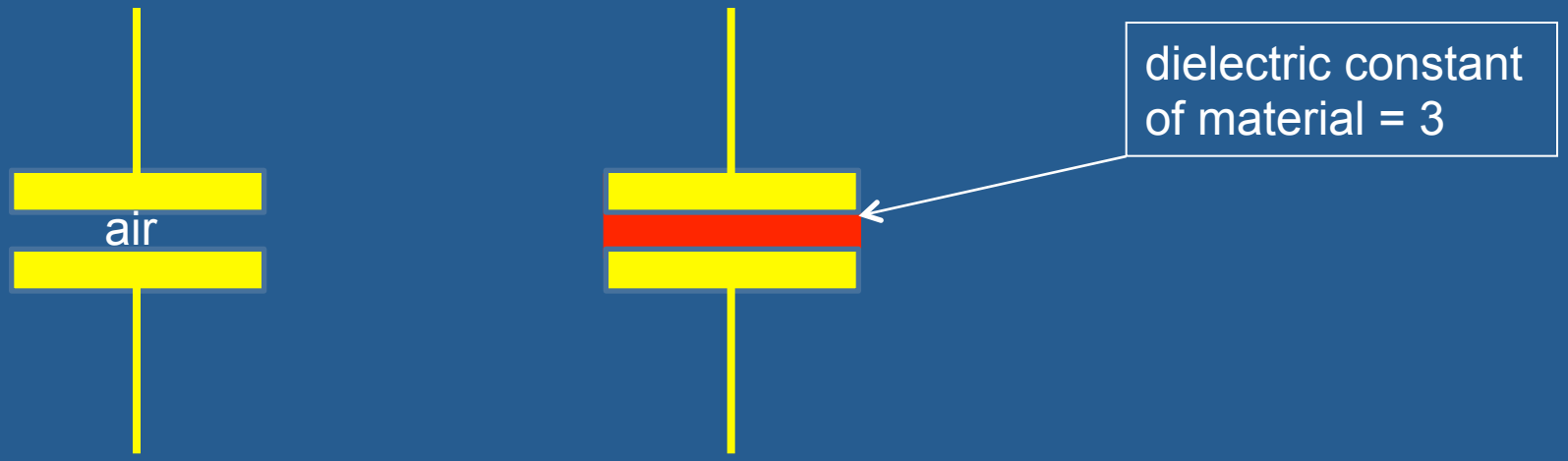
These two terms apply to the *dielectric* which lies between the two plates.
(The A and d terms are somewhat easier to understand.)

ε_0 This is the *vacuum permittivity* of free space. It is a measure of how much (physical) resistance is encountered in forming an electric field.

Vacuum Permittivity $\varepsilon_0 = 8.85 \times 10^{-12}$ Farads/metre

ε_r This is the *relative permittivity* of a substance. This is also called the dielectric constant. So, paper which has a dielectric constant of about 2.3 relative to that of a vacuum would increase the value of a plate capacitor by a factor of 2.3 if it were inserted between the plates instead of leaving air to fill the gap. (It's actual permittivity is simply $2.3\varepsilon_0$)

ε_r In Practice

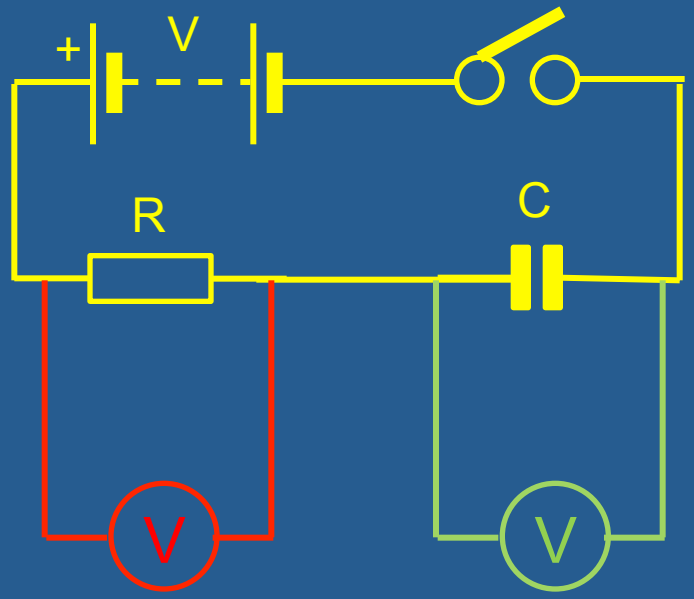


Area of plates = 1 square metre, separation distance = 0.01 metre.

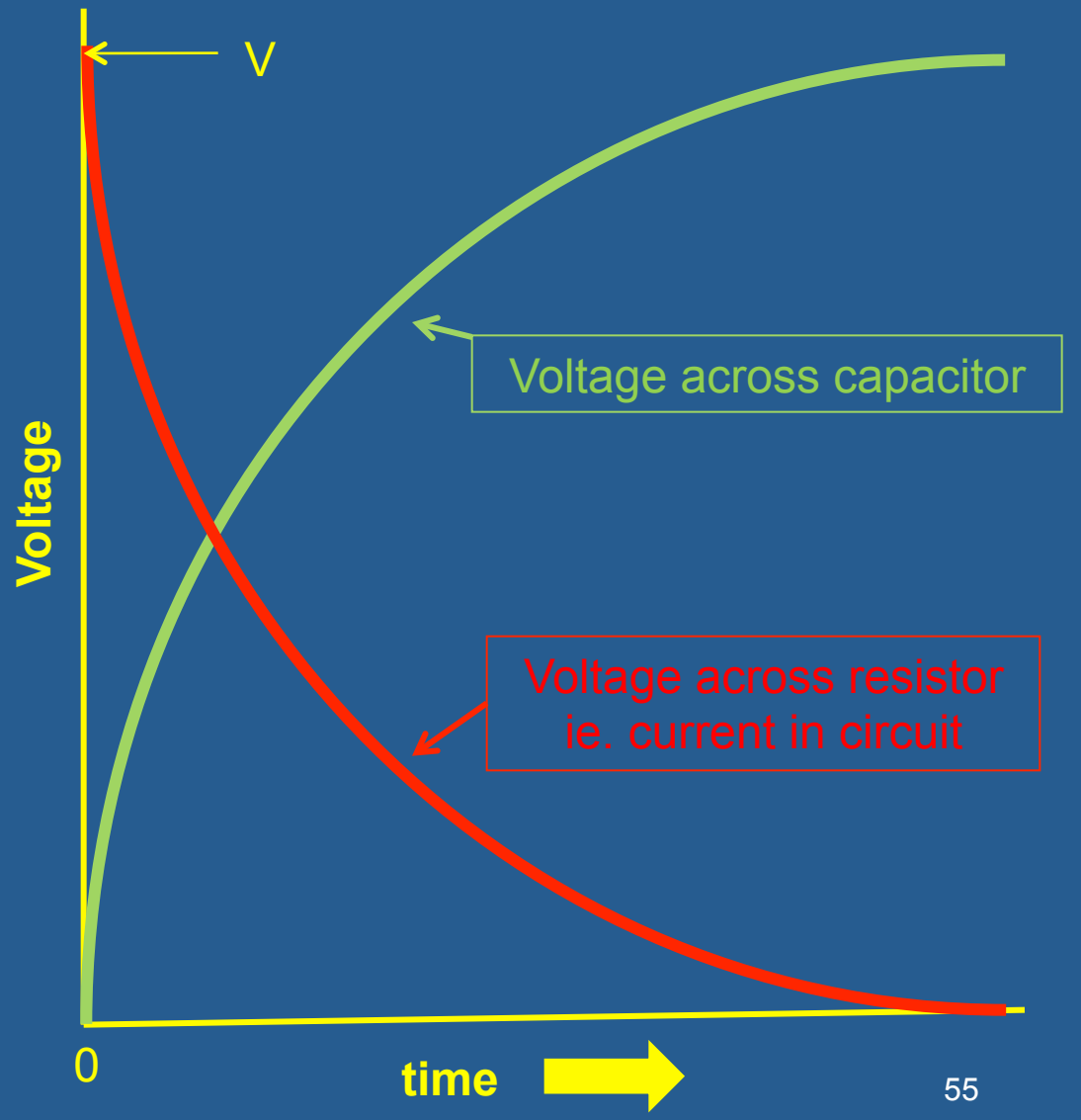
Value of air-spaced capacitor = {(1 x 8.85E-12 x 1) / 0.01} = 885 pF

Value of dielectric-spaced capacitor = {1 x 8.85E-12 x 3) / 0.01} = 2655 pF

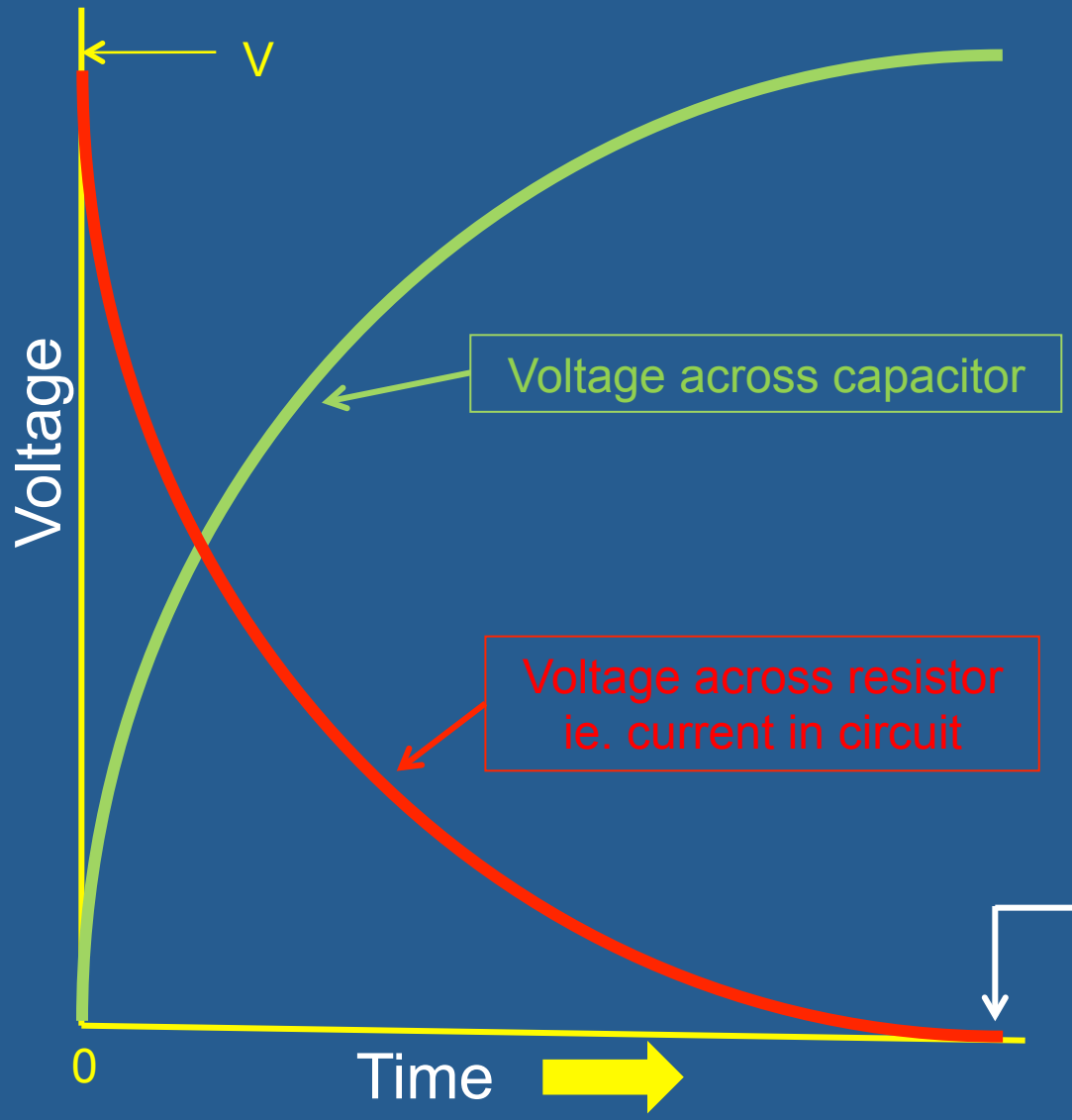
The dc Response Of A Capacitor



The switch is closed at t=0. Initially the capacitor appears to have 0Ω resistance and the current is limited by the value of R. The voltage then rises exponentially across C to reach V and falls exponentially across R. to reach 0V



Charging and DC Blocking



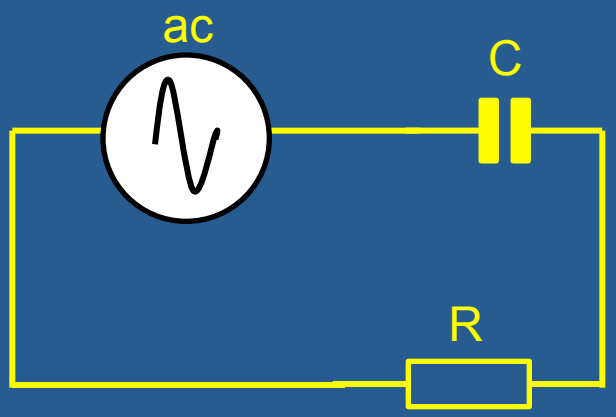
When the switch is closed current flows from the battery through R and C. C begins to charge. As the charge on C builds the current drops exponentially. Eventually C becomes fully-charged and no further current flows.

A fully-charged capacitor will "block" the flow of further dc current in a circuit.

The time it takes for C to become fully-charged depends upon the value of C and R

Flow of further dc current blocked from this point onwards

The ac Response Of A Capacitor



When supplied with an alternating current (ac) the capacitor will alternately charge and discharge in sympathy with the supply. As the supply reverses in polarity the capacitor can charge and discharge.

The net effect of this movement of charge is, of course, a current which flows in the circuit. Thus, under ac conditions, a capacitor will effectively pass a current.

Thus a capacitor will *not block* ac signals. This allows a capacitor to pass signals (*to couple*) one part of a circuit to another without upsetting any dc bias voltages – which it will block.

Polarised Capacitors

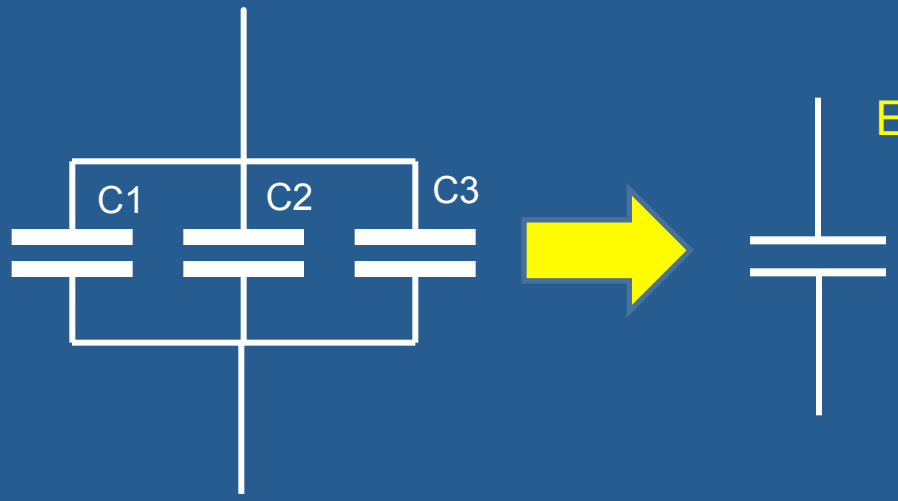


Large value capacitors are polarised devices. This means that they have a positive and negative terminal. (They will not work if their polarity is reversed.) The positive terminal must always be kept at a more positive potential with respect to the negative.

These capacitors will destroy themselves spectacularly and noisily if they are connected with reverse polarity!

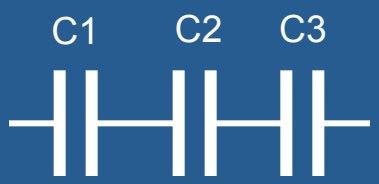
They also have a rated voltage which must not be exceeded.

Capacitors in Series and Parallel



Equivalent Capacitor Ce

$$Ce = C1 + C2 + C3$$



Equivalent Capacitor Ce

$$1/Ce = 1/C1 + 1/C2 + 1/C3$$

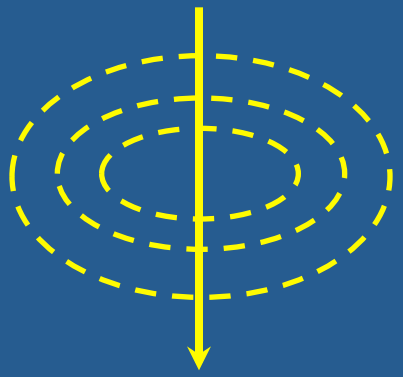
Inductors

An inductor is usually a coil with one or more turns of wire wound around a circular former. (Sometimes, with stiff wire the former is removed and the coil shape is self-supporting.



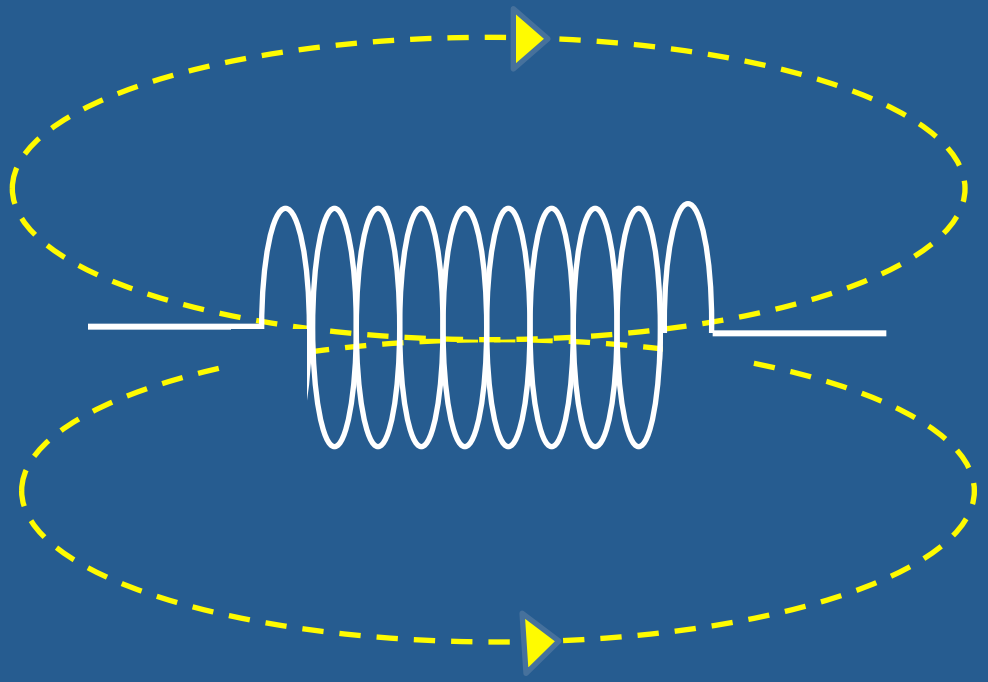
The characteristics of a coil come from:

n: the number of turns;
L: the winding length;
D: the coil diameter



A current flowing down a wire will produce a uniform, circular, magnetic field around the wire.

Energy Stored In A Magnetic Field

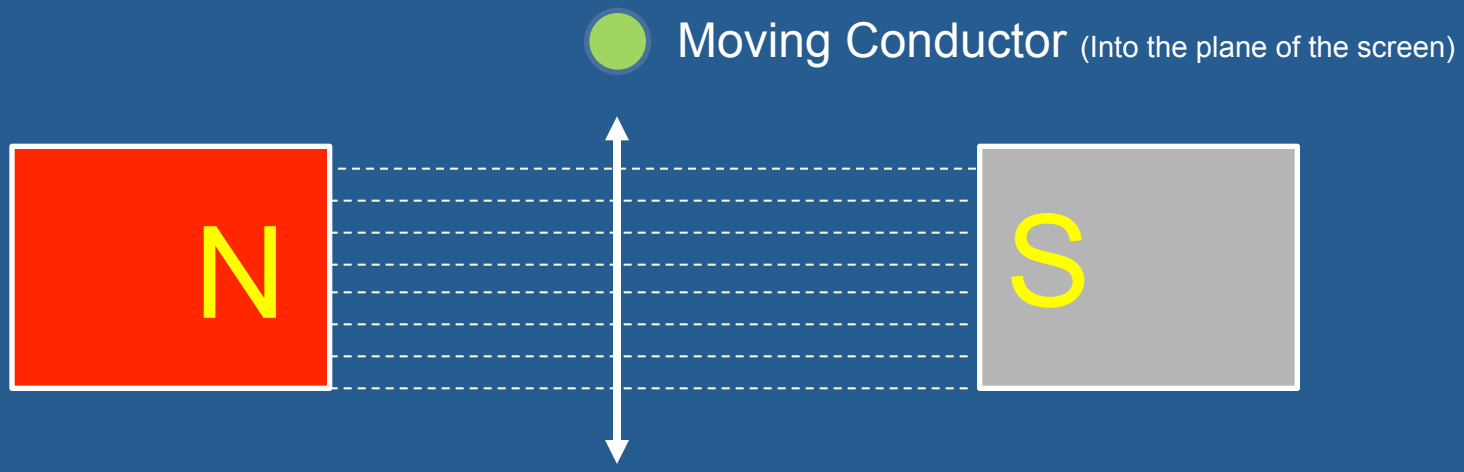


A coil (solenoid) concentrates the magnetic field lines along the axis of the coil. These field lines store energy magnetically. This ability to store energy is a property of inductance.

The value of the inductance depends upon the number of turns, coil diameter, length and spacing of the winding and any material inside the coil (ferrite etc)

Inductance is measured in HENRIES.

Relative Motion Of A Conductor In A Magnetic Field

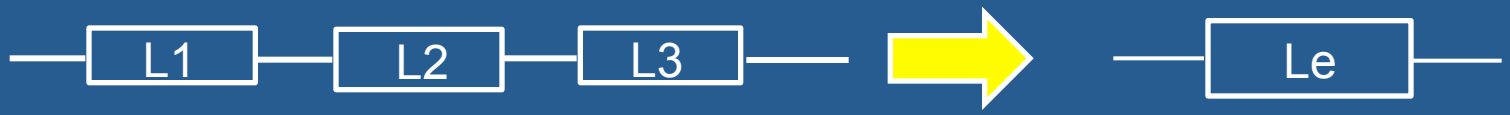


A moving conductor which cuts magnetic lines of force will generate a voltage across its ends.

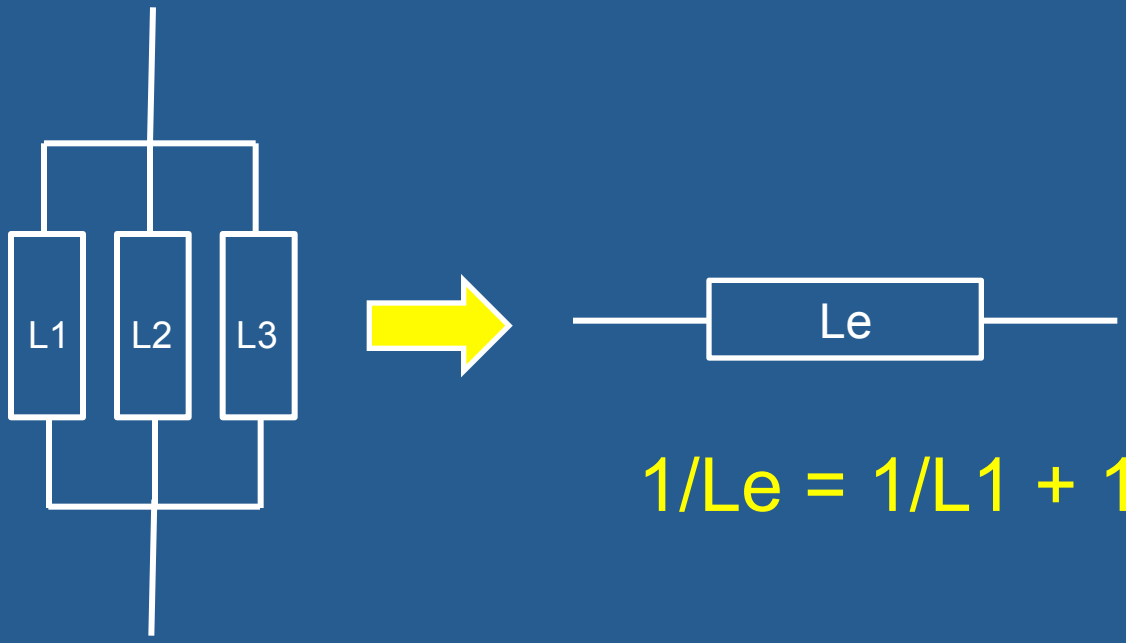
The magnitude of the voltage depends upon the speed of the conductor and the strength of the magnetic field.

Forming the conductor into a coil will generate a larger voltage.

Inductors In Series And Parallel

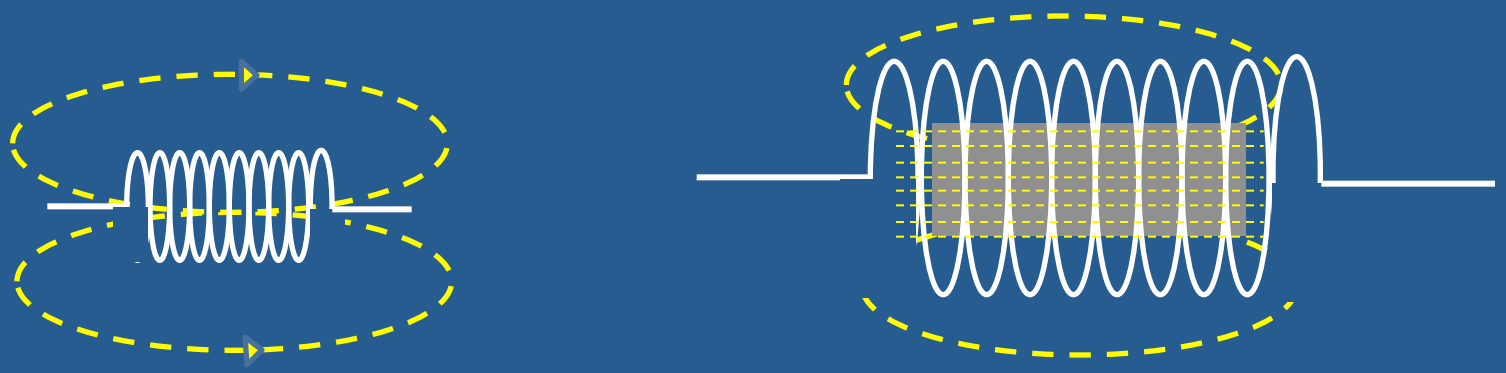


$$Le = L1 + L2 + L3$$



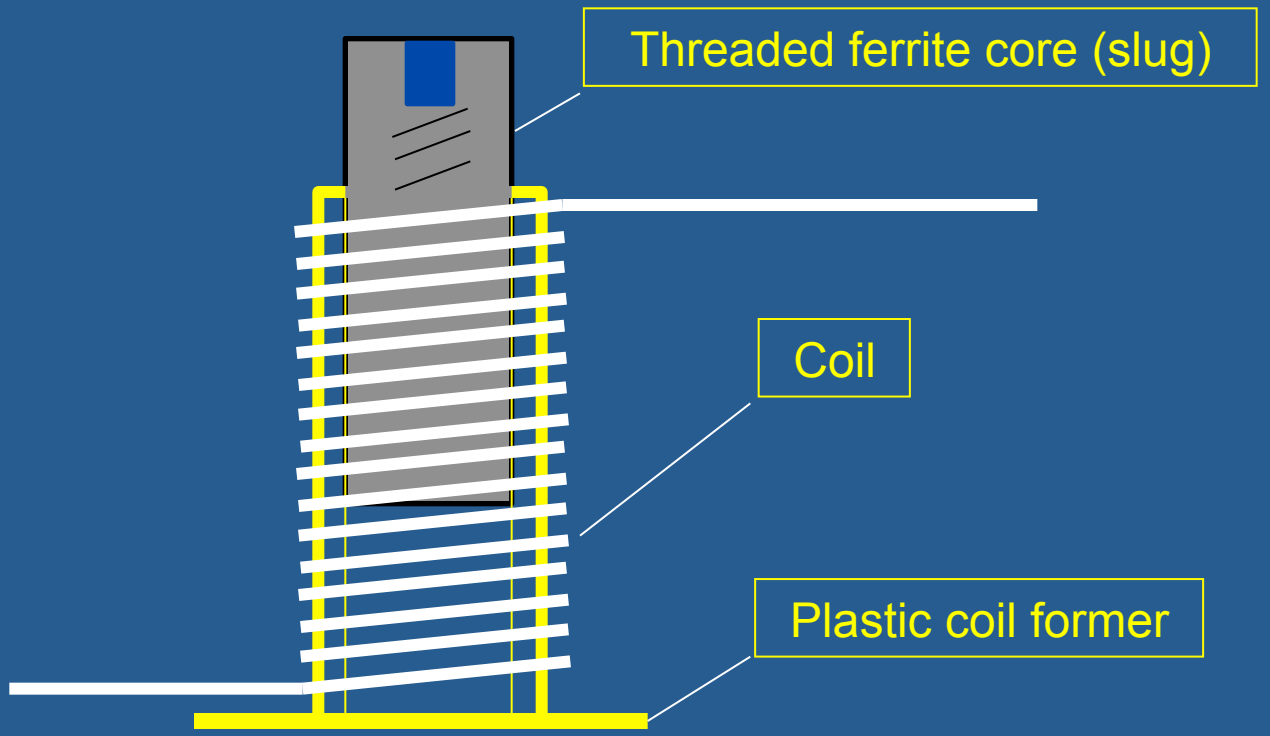
$$1/Le = 1/L1 + 1/L2 + 1/L3$$

High Permeability Cores And Slug Tuning



Winding the coil on a ferrite former will increase the inductance of the coil. Ferrite material in particular allows the magnetic field lines to establish themselves more easily than in air. This concentrates the magnetic lines of force and hence the magnetic field within the coil. A ferrite-cored coil can store more energy for a given current flow through it than an air-cored coil of the same dimension.

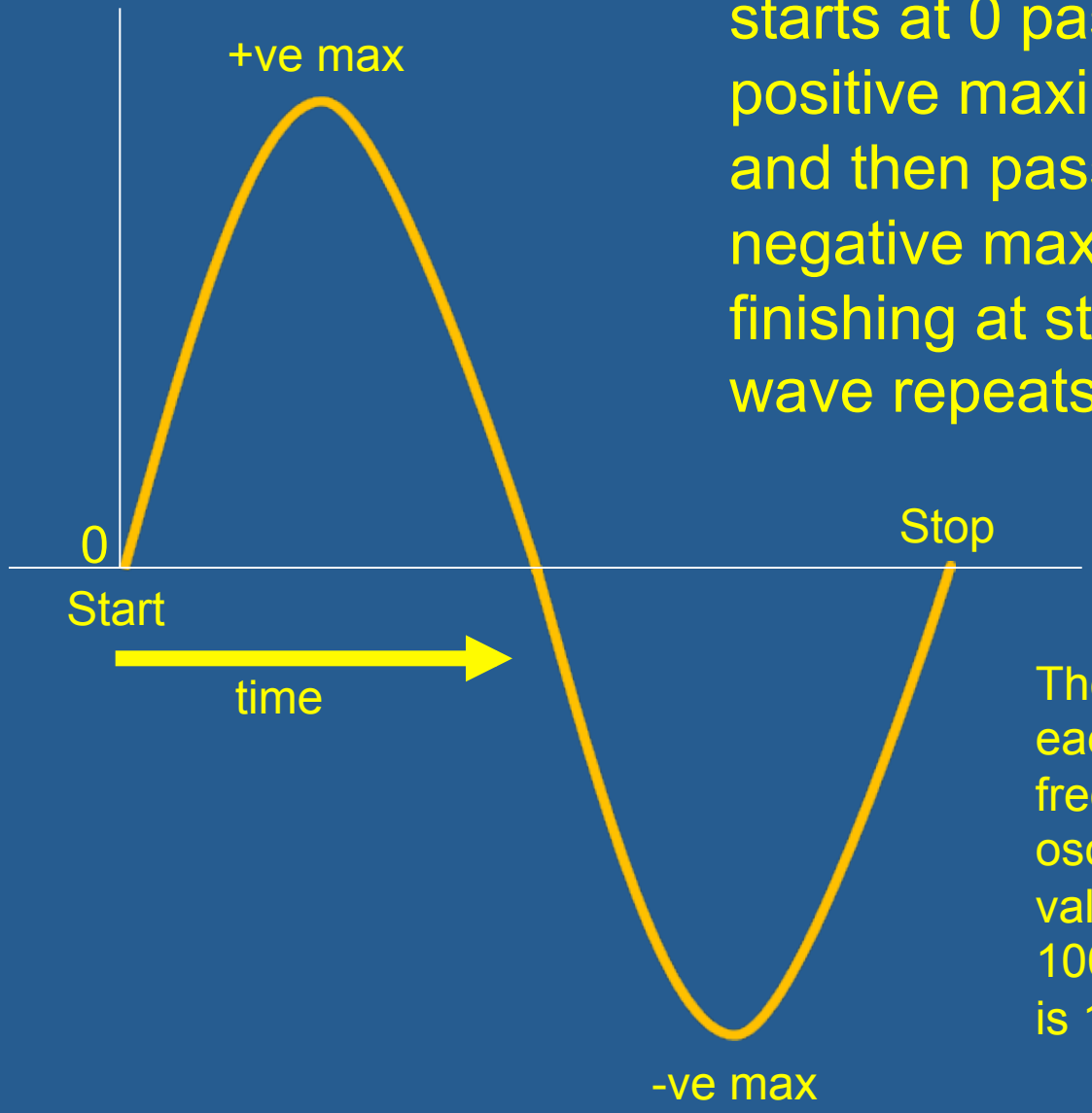
Slug Tuning



Particularly at HF and above, where the coil size is relatively small, a coil may be “slug-tuned”. The coil is wound on a plastic former. A ferrite core may be screwed inside the former. The value of the required inductance may be precisely set by varying the depth to which the slug is screwed into the former.

2E AC Theory

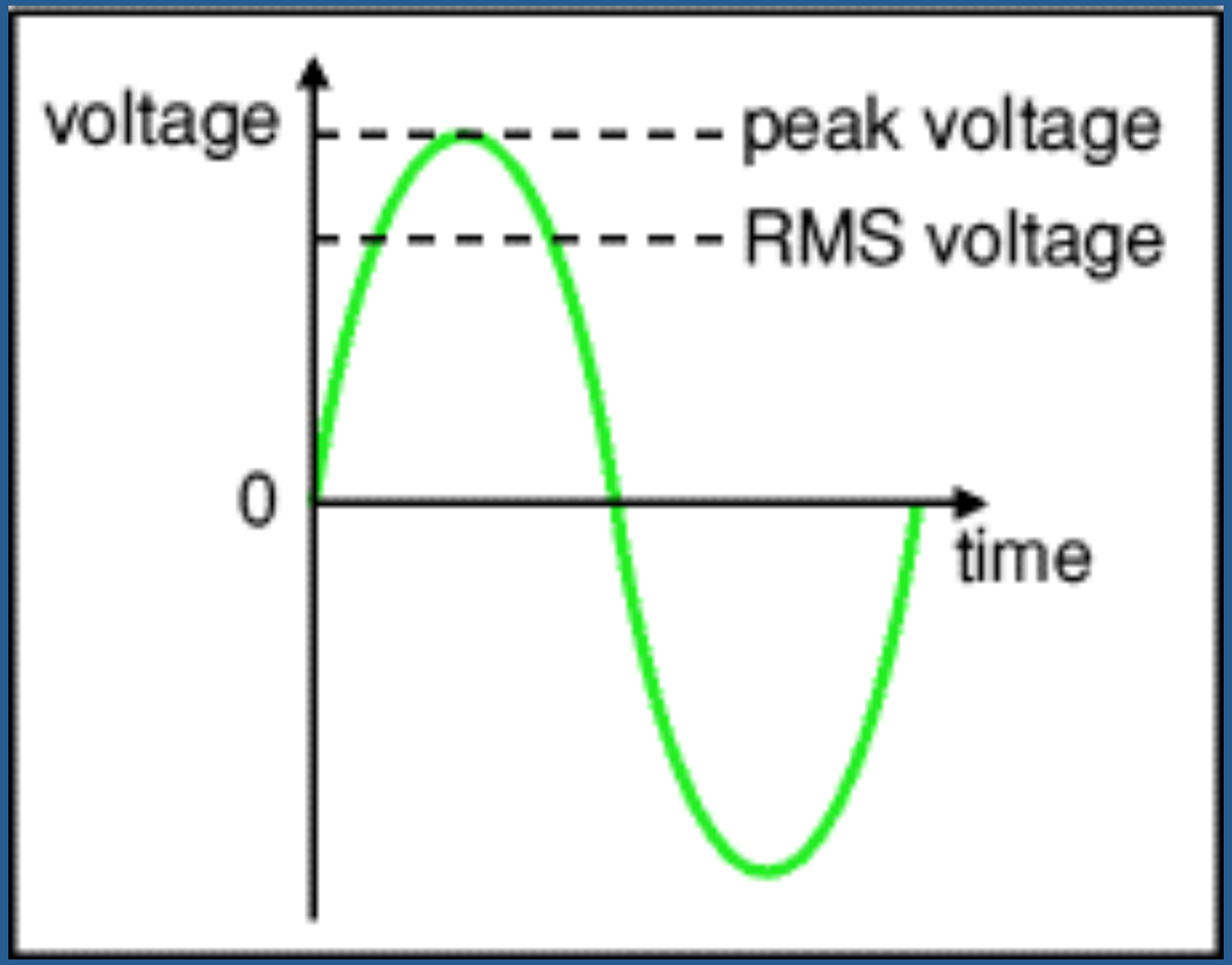
The Sine Wave



One oscillation of the wave starts at 0 passes through a positive maximum, returns to 0 and then passes through a negative maximum before finishing at stop. A continuous wave repeats this pattern.

The number of oscillations each second is the frequency of the wave. One oscillation per second has a value of 1 Hertz (1Hz). 100 oscillations per second is 100Hz and so on.

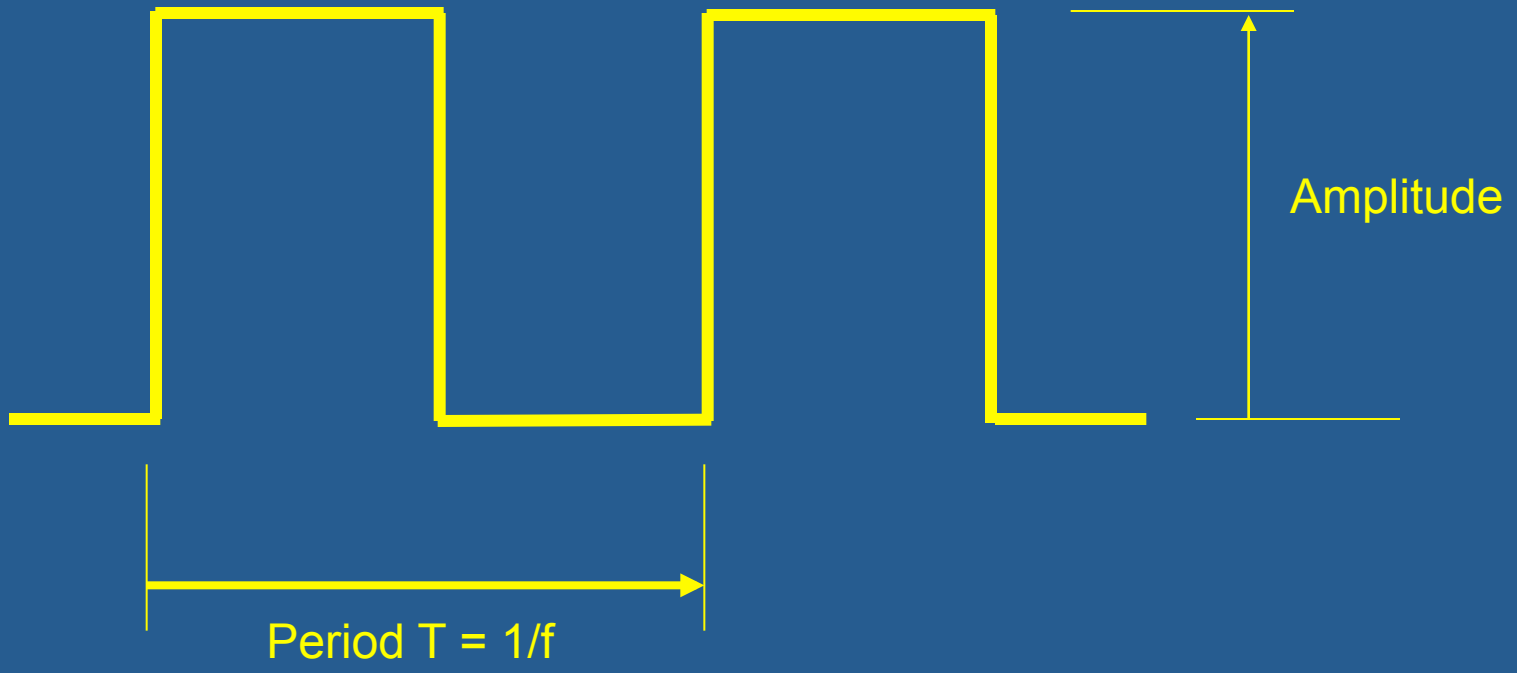
Defining a Sine Wave



To define a sine wave you need to know the frequency and the peak value it attains.

The peak value is also called the Amplitude of the wave.

The Square Wave



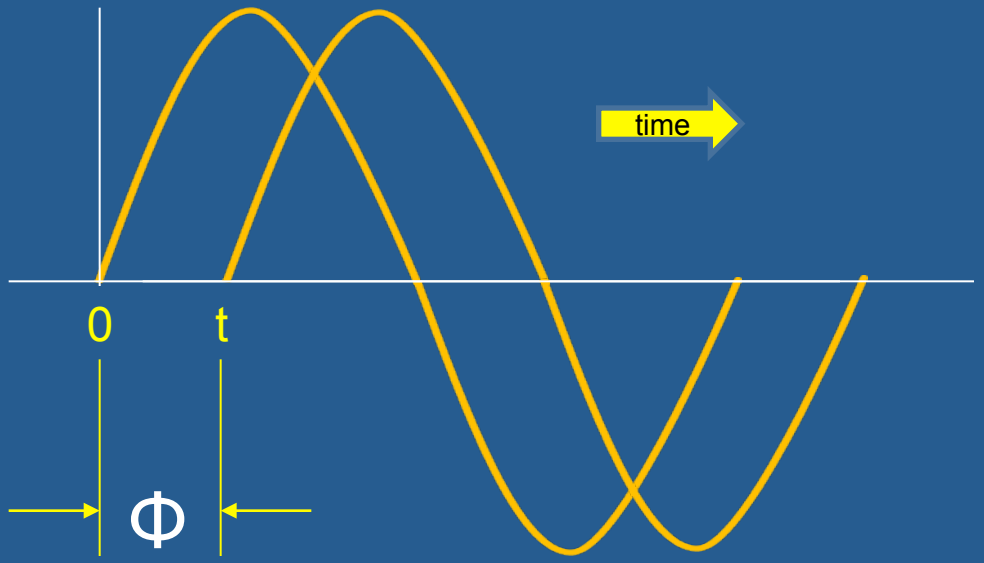
The frequency (f) of the square wave is also measured in Hertz (Hz). The time for one complete oscillation (T) of the wave is called the period.

$$T = 1/f \quad \text{and} \quad f = 1/T$$

Phase Difference

If two identical sine waves both start at time 0 they will oscillate in tandem and be indistinguishable from each other. One complete oscillation is equivalent to 360 degrees. (Sine waves are a circular function.)

If, however, the second wave starts to oscillate at time = t (after the first wave has commenced at time = 0) there will be a measurable separation (Φ) between them. This separation is measured in degrees and is the phase difference or phase shift.



The symbol for phase is the Greek letter “phi” (Φ)

Current and Voltage in a Resistor

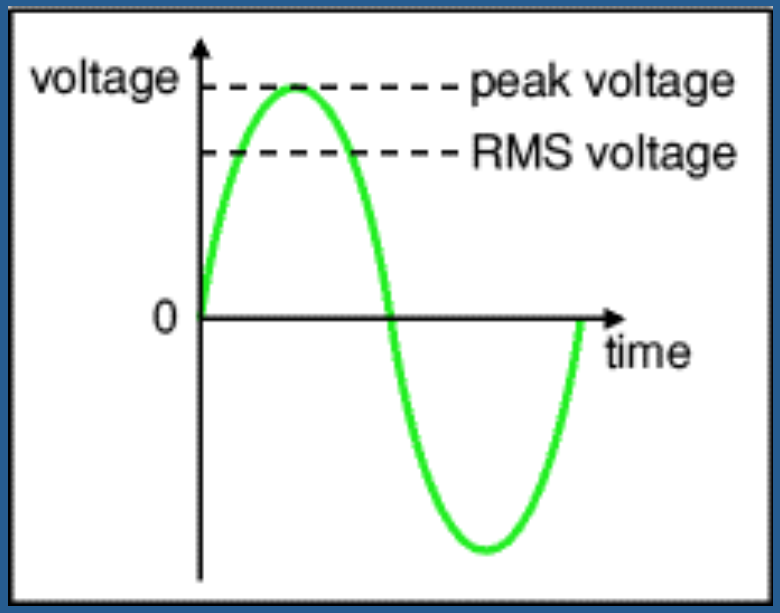
In a resistor the potential difference across the resistor and the current through it are always in phase.

The instantaneous power being dissipated in a resistor follows the shape of the sine wave. The AC power therefore varies over the cycle.

There is a relationship which links the mean power in an AC circuit with an equivalent DC circuit which dissipates the same level of power.

The Root Mean Square (RMS) value of the AC wave equates to its equivalent DC value.

The RMS Value (0.707 x Peak Value)



The RMS voltage (Root Mean Square) is the DC supply voltage that would deliver the same power to the load if it replaced the AC voltage.

Now, you can't feed every piece of equipment with either AC or DC voltage and expect it to work. So we'll use an incandescent lamp.

This lamp would be as bright when fed with the AC voltage as when you feed it with the RMS (DC equivalent) voltage.

If you *simply average* an AC voltage or current over several cycles you will get the answer 0. This is because there are as many positive-going cycles as there are negative-going. *(eg. If over the course of one month and starting from zero you pay out from your bank account the same as you pay in then the average monthly amount in your account will be £0)*

RMS Value: Calculation Method

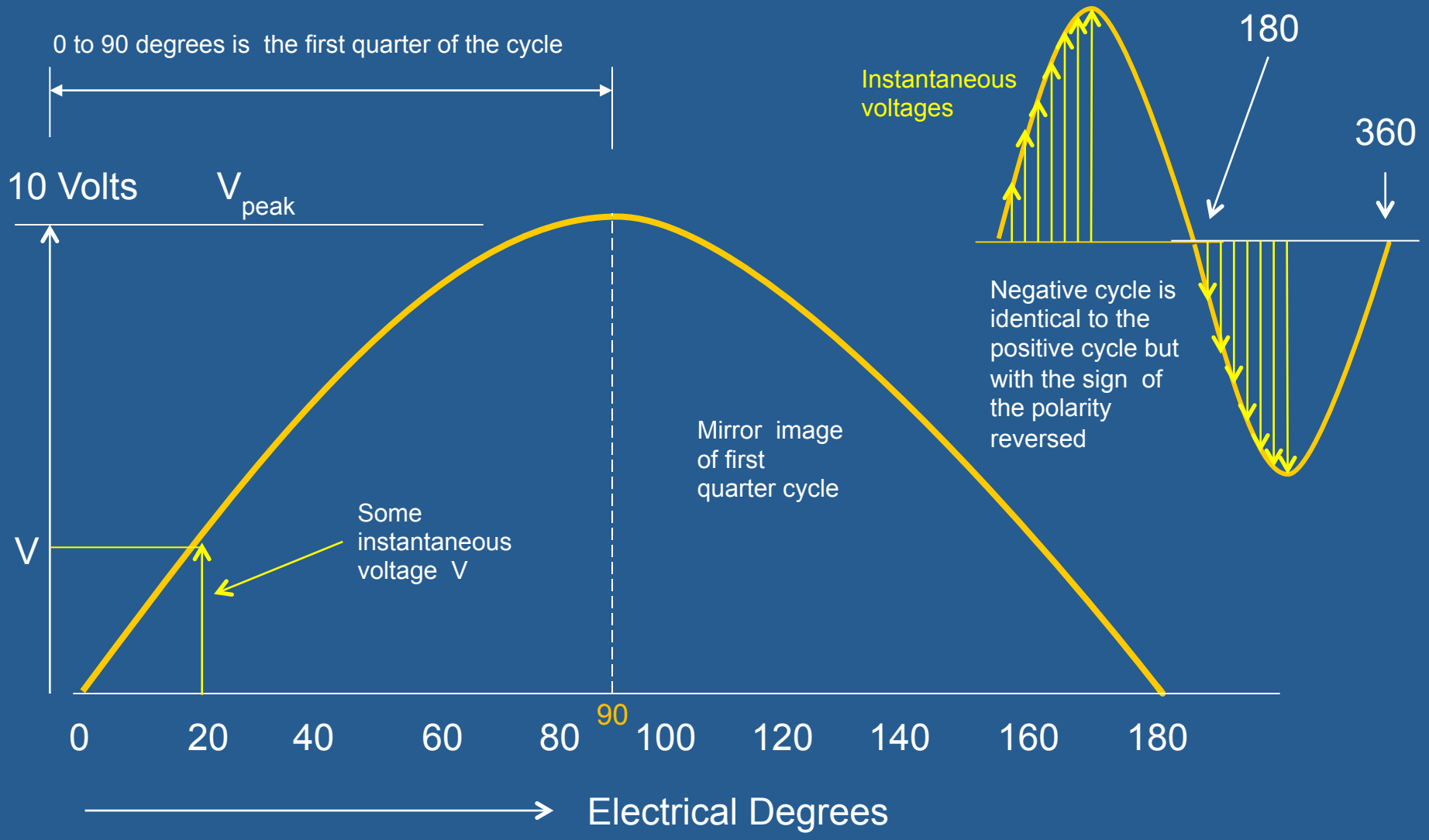
To calculate power you need to multiply voltage and current. But the voltage and current are constantly changing in an AC supply. What values do you use to calculate the average or mean power (the DC equivalent) being delivered to the load by an AC supply?

Because there are negative-going cycles does not mean that the power delivered on a positive-going cycle is cancelled on the negative-going cycle and somehow “sucked back out!”. It just means that the direction of the current flow is reversed. The power delivered is not affected.

What we need to do is to find a mean level of voltage or current over a half cycle regardless of whether the cycle is a positive or a negative one.

To overcome the *“negative sign problem”* we simply square the instantaneous values over a half cycle, add them up, find the mean and then take the square root of that mean. This sounds complicated but it isn’t really. The diagram and the Excel spread sheets on the next three slides shows the result.

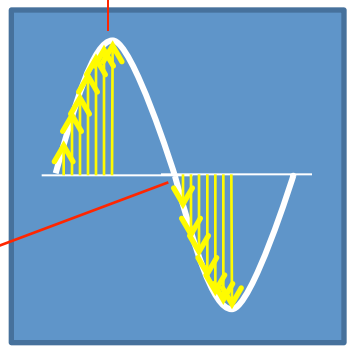
How The AC Wave Is Analysed



Positive Half Cycle

Electrical Degrees	Radians	Instantaneous Voltage V	V^2
0	0.00	0.00	0.00
10	0.17	1.74	3.01
20	0.35	3.42	11.69
30	0.52	5.00	24.99
40	0.70	6.43	41.31
50	0.87	7.66	58.67
60	1.05	8.66	74.99
70	1.22	9.40	88.29
80	1.40	9.85	96.98
90	1.57	10.00	100.00
100	1.75	9.85	96.99
110	1.92	9.40	88.32
120	2.09	8.66	75.02
130	2.27	7.66	58.71
140	2.44	6.43	41.35
150	2.62	5.00	25.03
160	2.79	3.42	11.72
170	2.97	1.74	3.03
180	3.14	0.00	0.00

NB!
90 degrees = π/2 radians
180 degrees = π radians
270 degrees = 3π/2 radians
360 degrees = 2π radians



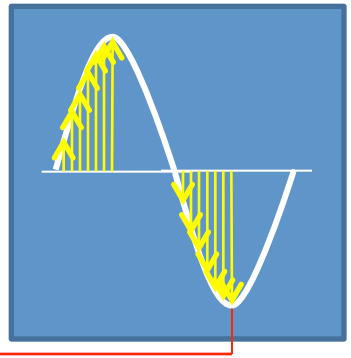
π radians = 180 degrees

Peak Voltage is 10 Volts

900.11	Total of Readings
50.01	Mean or Average
7.07	Square Root of Mean (RMS)

Negative Half Cycle

Electrical Degrees	Radians	Instantaneous Voltage V	V^2
190	3.32	-1.73	3.00
200	3.49	-3.42	11.67
210	3.66	-5.00	24.96
220	3.84	-6.42	41.27
230	4.01	-7.66	58.63
240	4.19	-8.66	74.95
250	4.36	-9.40	88.27
260	4.54	-9.85	96.97
270	4.71	-10.00	100.00
280	4.89	-9.85	97.01
290	5.06	-9.40	88.34
300	5.24	-8.66	75.06
310	5.41	-7.66	58.75
320	5.58	-6.43	41.39
330	5.76	-5.01	25.06
340	5.93	-3.43	11.75
350	6.11	-1.74	3.04
360	6.28	-0.01	0.00



NB!
90 degrees = π/2 radians
180 degrees = π radians
270 degrees = 3π/2 radians
360 degrees = 2π radians

900.11	Total of Readings
50.01	Mean or Average
7.07	Square Root of Mean

Peak Voltage is 10 Volts

The RMS Value

The RMS value of an AC sine wave is:

0.707 x Peak Value

(If you have a 10V AC supply *[V peak = 10V]* across a resistor then the equivalent DC voltage to give the same, mean power output will be 7.07Volts DC. applied across the resistor)

Reactance

In a DC (direct current) circuit the resistance of a component opposes the flow of current. (A resistor for example.)

The same resistor in an AC (alternating current) circuit will oppose the current flow in a similar way – except that you need to remember to use the RMS values of current and voltage in any power calculation.

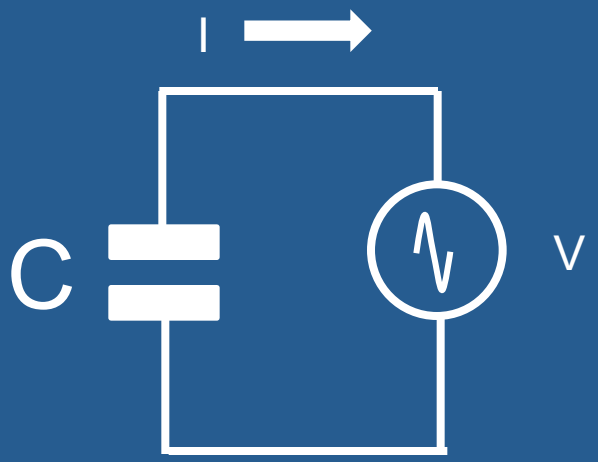
Inductors and *capacitors* will allow an AC current to pass through them but they oppose the flow in a more complex way than pure resistance. (Indeed a fully-charged capacitance will allow no DC current to flow through it.)

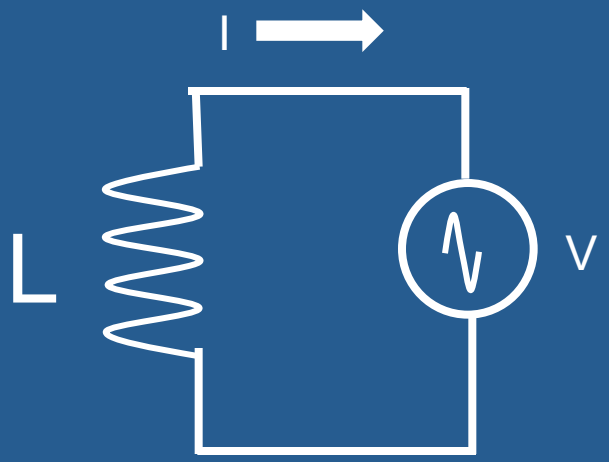
Different values of inductance and capacitance oppose the flow of an AC current to differing extents.

To describe the opposition to AC current flow and to differentiate this characteristic of inductors and capacitors from resistors the term *REACTANCE* is used.

Reactance only applies to inductors and capacitors in an AC circuit.

Inductive and Capacitive Reactance (X_L & X_C)





$$X_c = V_{rms} / I_{rms}$$

$$X_L = V_{rms} / I_{rms}$$

The reactance X is measured in Ohms.

Reactance is the ratio of the RMS Voltage to the RMS Current.

Capacitive Reactance

For a pure capacitor its reactance varies as the frequency varies. The reactance falls as the frequency increases. The reactance Xc is defined as:

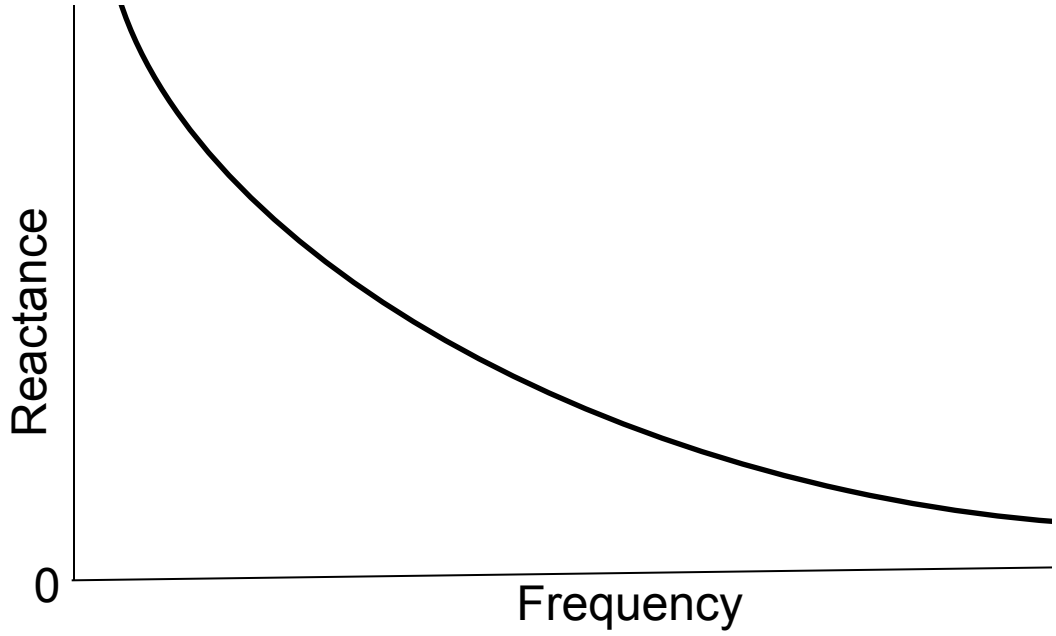
$$Xc = \frac{1}{(2 \times \pi \times f \times C)}$$

This is also equal to the ratio of the way the RMS voltage varies with the RMS current as the capacitor charges and discharges.

Graphical Representation of Xc

As the frequency increases the capacitive reactance gets smaller and smaller.

As the frequency approaches zero (DC) the capacitive reactance approaches infinity.



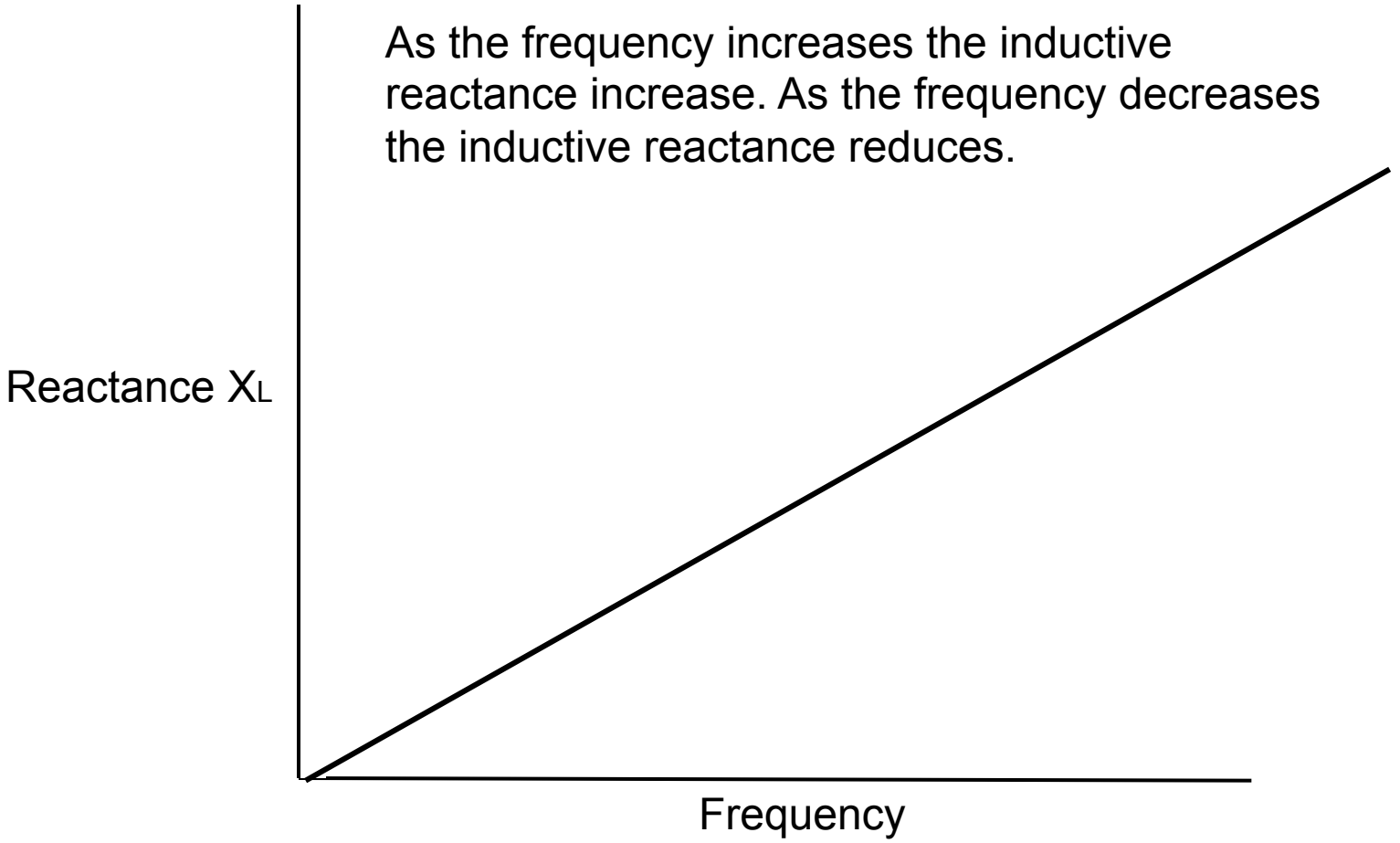
Inductive Reactance

For a pure inductance its reactance varies as the frequency varies. The reactance rises as the frequency increases. The reactance X_L is defined as:

$$X_L = 2 \times \pi \times f \times L$$

This is also equal to the ratio of the way the RMS voltage varies with the RMS current as the inductor stores and discharges its magnetic field (Energy). It takes time for the magnetic field to grow and decrease.

Graphical Representation of X_L



Supplementary Note

In the analysis of AC circuits you will frequently encounter these three terms multiplied together:

$$2 \times \pi \times f$$

This is the frequency of the wave expressed in radians. There are 2π radians in 360 degrees. This radial frequency is given the symbol ω *(lower case ohmega).* Hence you will see:

$$\omega = 2 \times \pi \times f$$

Phase Difference Between V and I

If, in a purely inductive or capacitive AC circuit, you were to measure the voltage across and the current through an inductor or capacitor you would notice a further effect.

There would be a phase shift between the voltage and the current. In a purely inductive or capacitive circuit this phase shift would be 90 degrees.

In a capacitive circuit the current would lead the voltage by 90 degrees. In an inductive circuit the current will lag the voltage by 90 degrees.

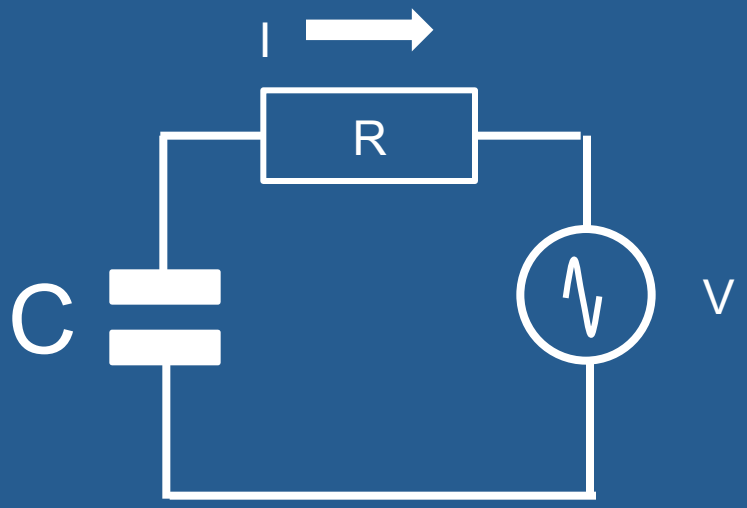
Impedance (Z)

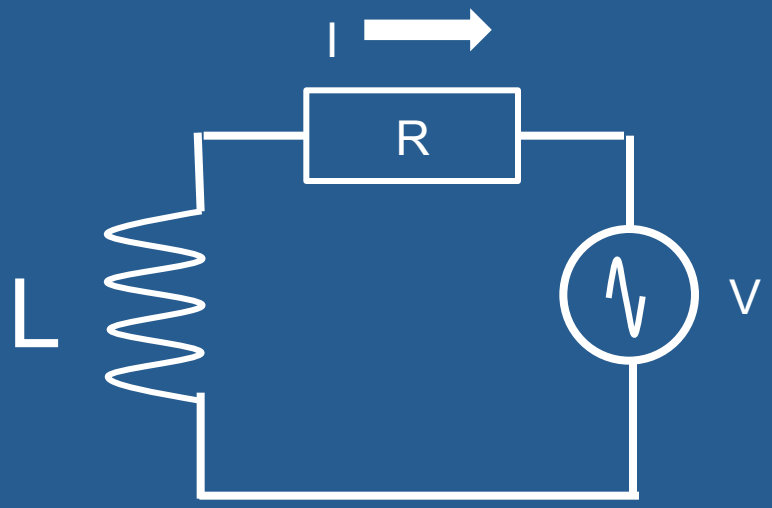
Realistically every component or conductor will always have some value of resistance – except at absolute zero. (-273 degrees Celsius or 0K.)

For individual wound components you can generally ignore the resistance as it will be tiny in comparison to the reactance.

However, practical circuits contain both reactance and resistance. Their combined effect – which determines the resultant current flow (say) - is termed the *IMPEDANCE.* (Z). Z is measured in Ohms.

IMPEDANCE (Z)





The IMPEDANCE of both circuits is still defined by the same form of the equation:.

$$Z = V_{rms} / I_{rms}$$

NB! Although *Resistance* and *Reactance* are both measured in Ohms you cannot simply add them together to find the *resultant impedance* of circuit. *(The calculation is a vector sum.)*

Energy Flows in Circuits With Impedance

In a circuit with impedance the energy will transfer between the capacitors and the inductors where it is stored whilst at the same time being dissipated in the resistive part of the circuit.

In such circuits the ratio of the RMS voltage to the RMS current is the Impedance.

However, you cannot simply add the reactances to the resistances to find an overall impedance. They are vector quantities.

Velocity of Waves

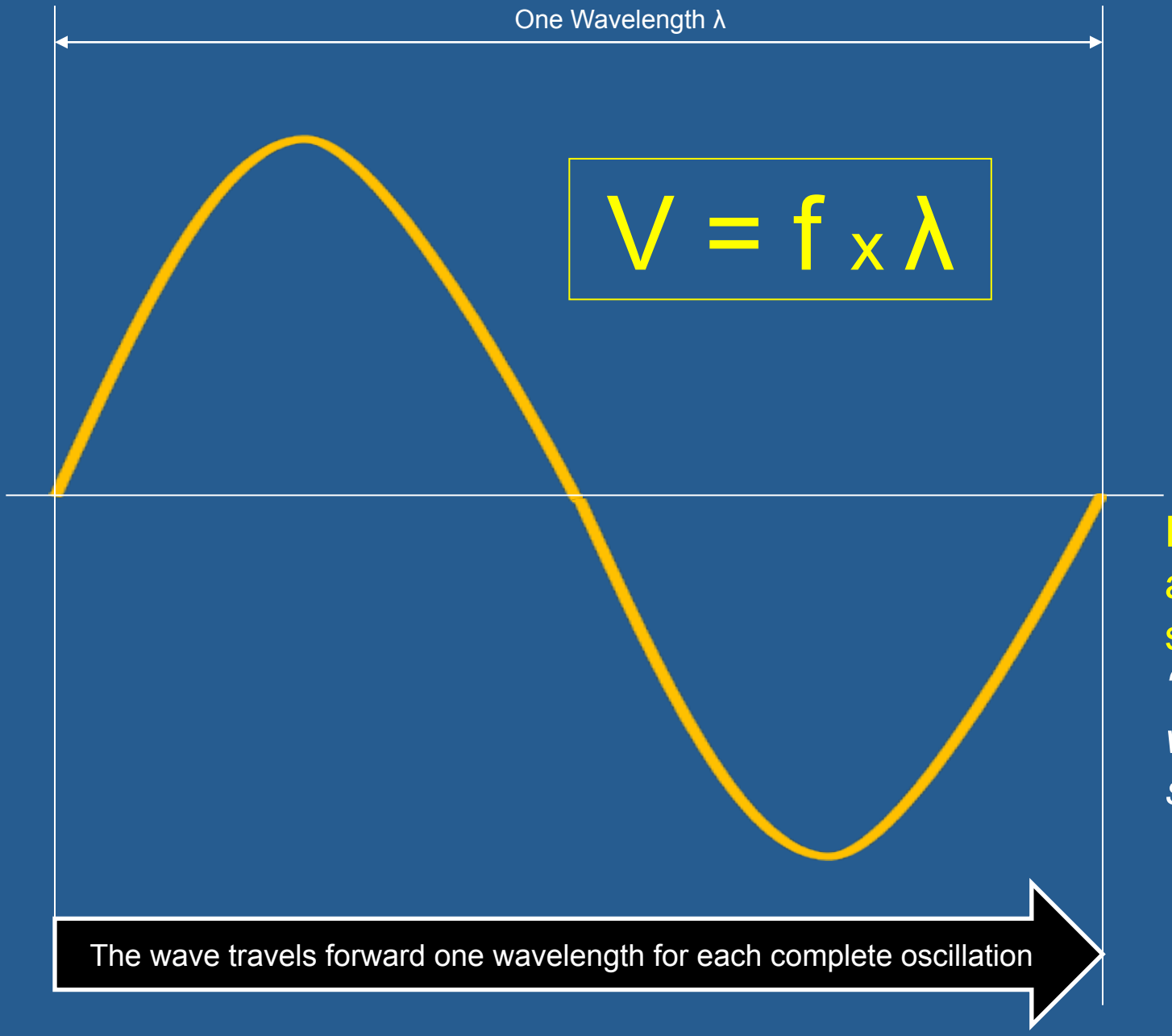
One oscillation takes place over one wavelength of the wave. The wave moves forward one wavelength for each oscillation.

The wavelength is measured in metres.

So, if a wave has a wavelength of 10 metres and is oscillating at 100Hz it will travel (10 x 100) metres every second.

This is a velocity of 1000 m / second.

$$V = f \times \lambda$$



Frequency is another way of saying –
"the number of wavelengths per second"

Velocity, Frequency and Wavelength

Radio waves travel at the speed of light (c). The speed of light is a constant.

This is (very nearly) 300,000,000 metres / second.

Knowing this you only need to know either the frequency or the wavelength to be able to calculate the other.

$$f = c/\lambda \qquad \lambda = c/f$$

Conductors Carrying RF

Where a conductor is carrying an RF signal which has a wavelength comparable to the length of the conductor the magnitude and direction of the current and voltage at any point in time will vary in a sinusoidal manner along the length of the conductor.

2F Digital Signals

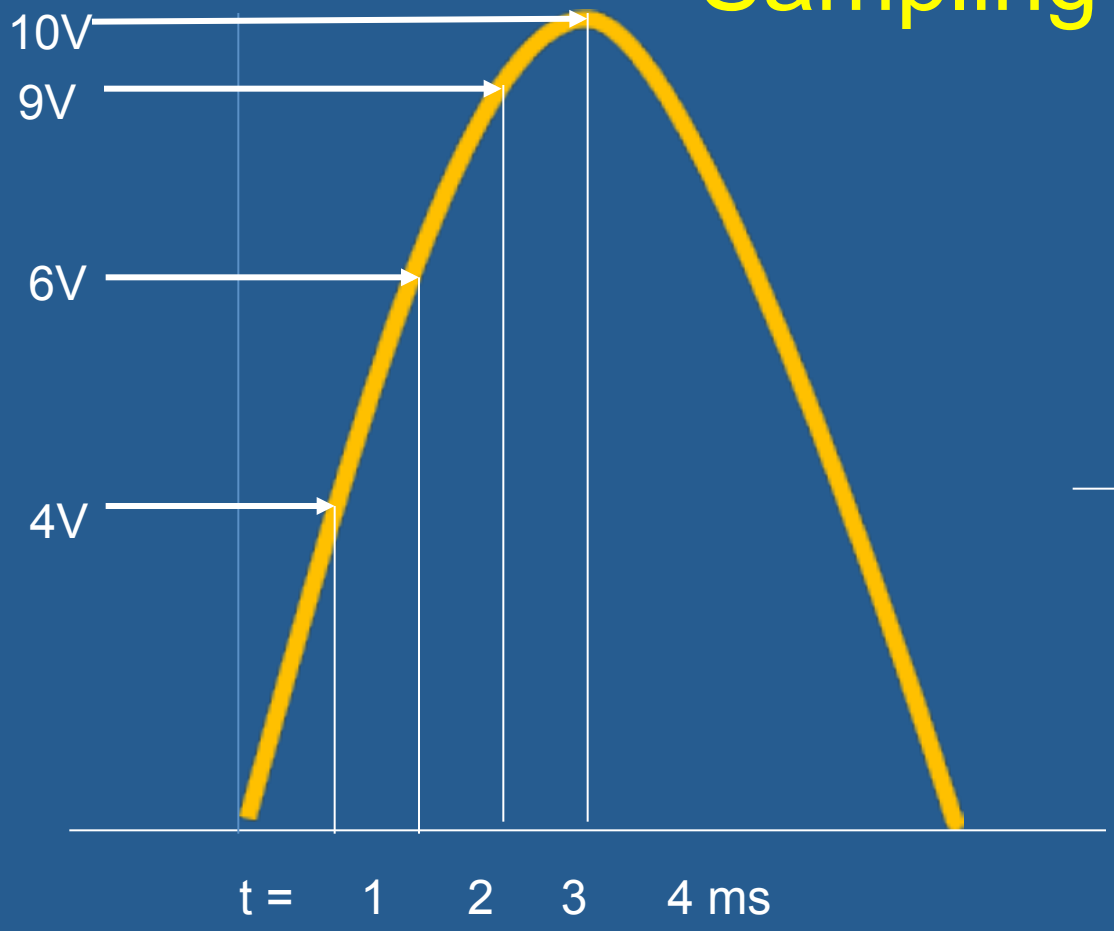
Digital Signals and Sampling

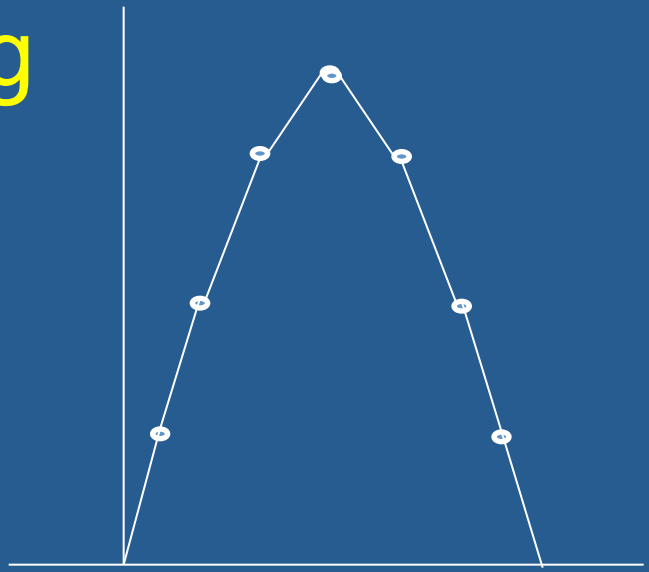
Digital signals convey information in discrete, number packets.

Very often you will need to convert an analogue (continuously varying) signal into a digital signal or, at the other end of a link, say, from a digital signal to an analogue one to drive a loudspeaker.

Doing this completely accurately is impossible. However, you can do it to a sufficient level of accuracy such that you cannot tell the difference or detect any degradation of information.

Sampling





If you can take more samples each second and if you can also improve the resolution to which you can measure the voltage (more bits) then the increasingly accurate (faithful) will be the reconstructed waveform. You pay for this by needing increased signal bandwidth and complexity.

Minimum (Nyquist) Sampling Rate

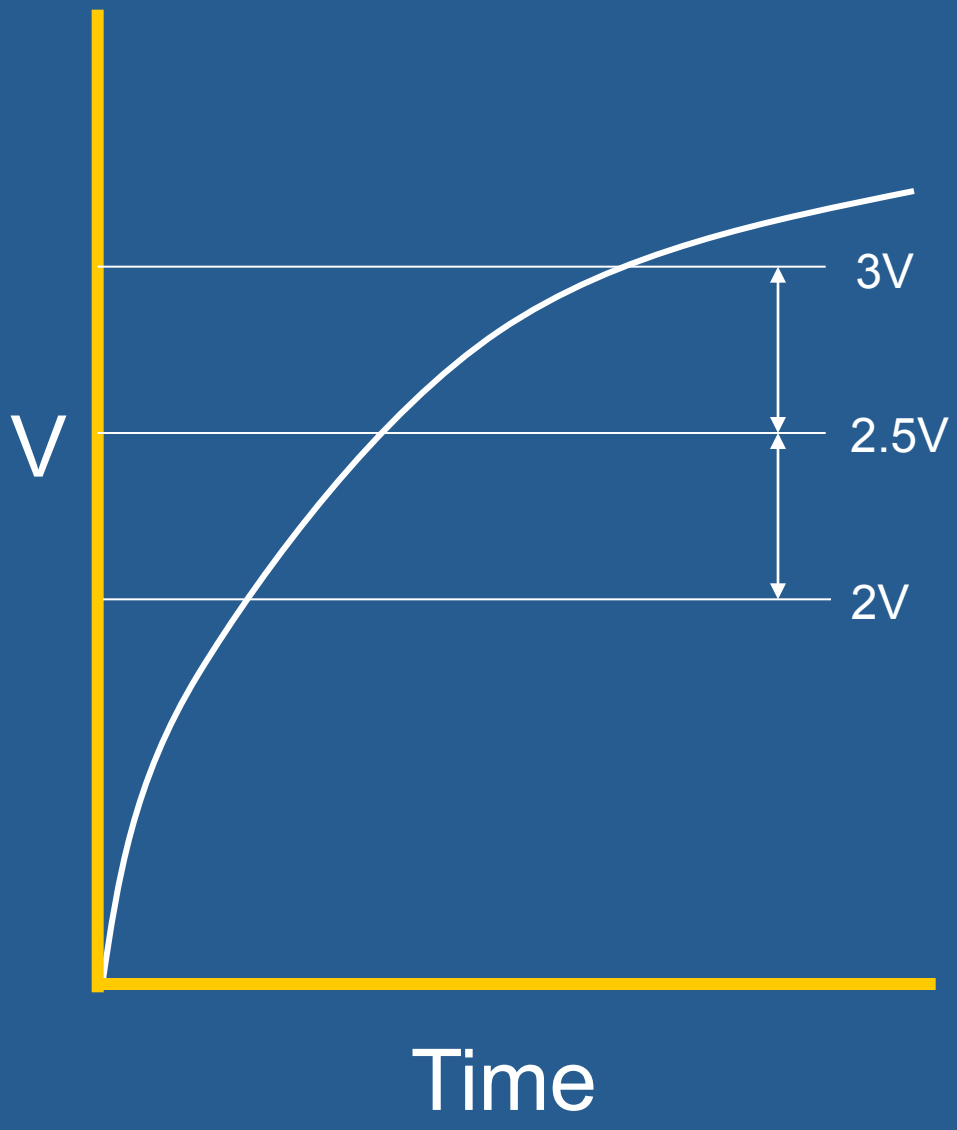
Sampling a signal at twice the signal frequency produces an acceptable digital representation of the signal.

For example if my expected maximum signal frequency in an audio signal from a microphone was 3.5kHz I would need to sample (quantise) it at:

$$3.5\text{kHz} \times 2 = 7\text{kHz}$$

This is known as the Nyquist sampling rate.

Quantisation Error



If my Analogue to Digital Converter (ADC) has a resolution of 1V it can only output a digital number relating to a whole number voltage. For example 2V or 3V or 4V etc. It cannot accurately resolve values in between these whole numbers.

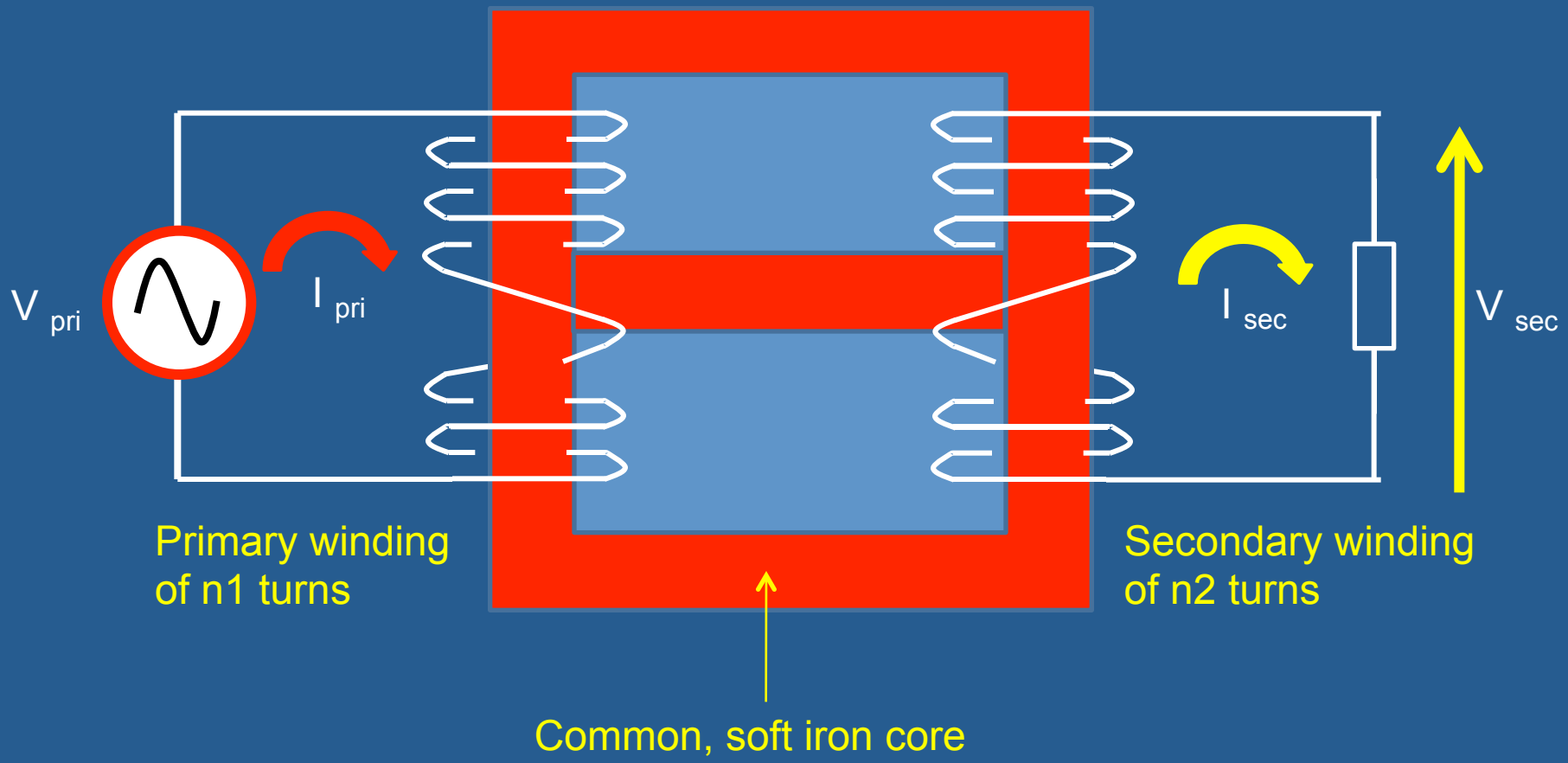
What does it do, say, if the sampled voltage is 2.5V? Depending upon the logic it will probably output 3V as the answer. The error will be 0.5V in this instance. If the voltage was 2.01V at the sampling time the error would be almost 1V if the ADC output was still a number equating to 3V.

If I can progressively improve the resolution (more output bits from the ADC) to within 0.5V, 0.25V, 0.125V and so on the quantisation error drops accordingly. *BUT I have to send more bits.*

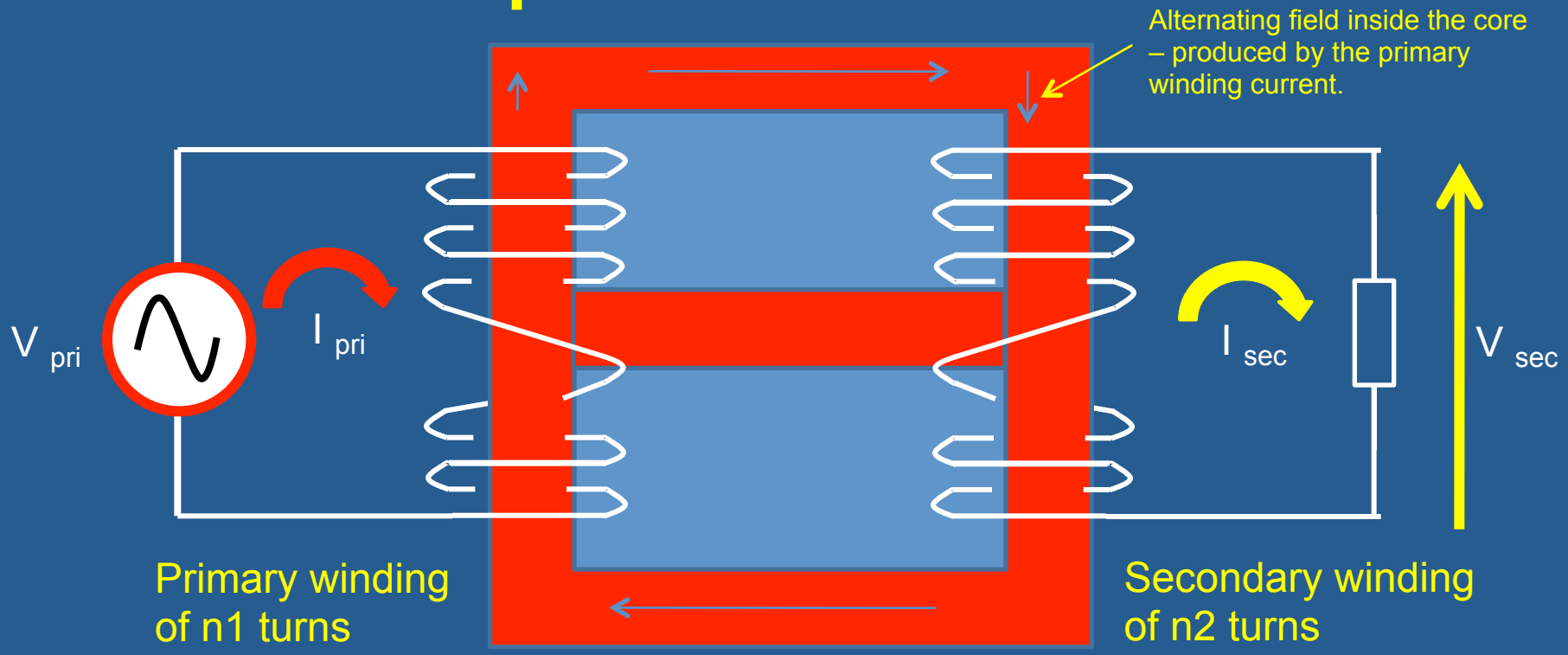
2G Transformers

Transformers

A simple transformer comprises two, separate coils of wire that share a common, soft iron core



Transformer Operation



When the primary winding is energised with an ac supply the current flowing in the primary windings creates a magnetic field in the core which alternates at the same frequency as the supply. This current is constrained within the iron core of the transformer. This fluctuating field induces a voltage in the secondary windings of the transformer. There is no direct connexion between the primary and secondary windings. They are linked magnetically. It is an ac device. You cannot have a dc transformer.

Transformer – Key Relationships

$$\left[\frac{V_{pri}}{V_{sec}}\right] = \left[\frac{n_{pri}}{n_{sec}}\right] = \left[\frac{I_{sec}}{I_{pri}}\right]$$

Voltage ratio

Turns ratio

Current ratio

Step-Up Transformer

By having a turns ratio (n1 : n2) between the primary and secondary which is something other than unity you can make the induced secondary voltage differ from the primary voltage.

For example: A transformer has a primary voltage of 230 Volts. There are 200 turns on the primary winding and 1000 turns on the secondary winding. What will the secondary voltage be?

$$\left[\frac{n_{pri}}{n_{sec}}\right] = \left[\frac{V_{pri}}{V_{sec}}\right] = (200 / 1000) = (230 / V_{sec})$$

$$V_{sec} = (230 \times 1000) / 200$$

$$V_{sec} = 1{,}150 \text{ Volts}$$

ie $V_{sec} = V_{pri}$ x winding ratio

Step-Down Transformer

A transformer has 200 turns on the primary and 40 turns on the secondary winding. The primary voltage is 230 Volts. What is the secondary voltage?

$$\left[\frac{n_{pri}}{n_{sec}}\right] = \left[\frac{V_{pri}}{V_{sec}}\right]$$

$$200 / 40 = 230 / V_{sec}$$

$$V_{sec} = (40 \times 230) / 200$$

$$V_{sec} = 46 \text{ Volts}$$

ie $V_{sec} = V_{pri}$ / winding ratio

Power Transfer

In an ideal transformer the *power delivered* to the primary will be identical to the *power extracted* from the secondary.

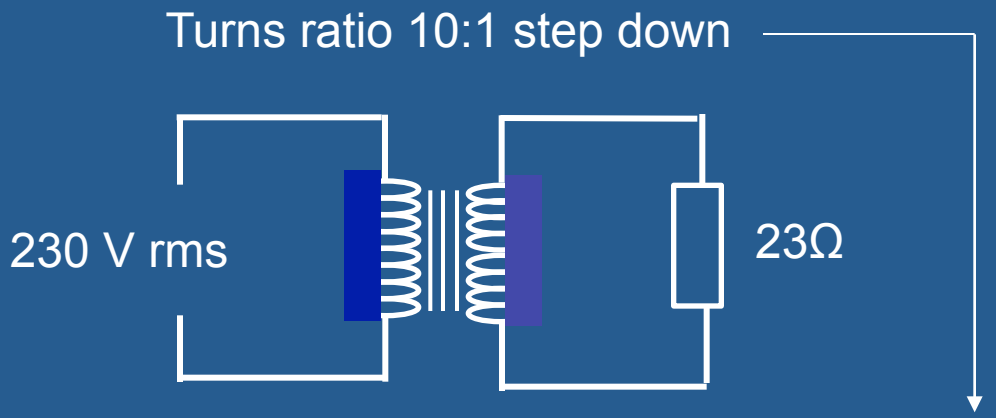
However, there are inevitable losses. In practice, however, you can generally ignore these.

So:

$$(V_{pri} \times I_{pri}) = (V_{sec} \times I_{sec})$$

If the secondary voltage is stepped down (up) by a factor of 5 then the secondary current is stepped up (down) by the same factor to maintain constant power across the transformer. *(Remember! Use RMS values for power calculations.)*

Transformer Power Transfer



The transformer secondary voltage will be (230 / 10) volts. ie 23 Volts.

The secondary current will be (23 Volts / 23Ω) amps. ie 1 Ampère.

The secondary power will be (23 Volts x 1A) Watts. ie 23 Watts

The primary power is also 23 Watts (neglecting losses)

The primary current will be (23 Watts / 230 Volts) amps. ie 0.1 Ampères

The secondary current is x10 the primary current at 1/10th of the primary voltage

RF Transformers

At radio frequencies (RF) the core of the transformer is made from ferrite rather than soft iron. This reduces the losses through improved efficiency.

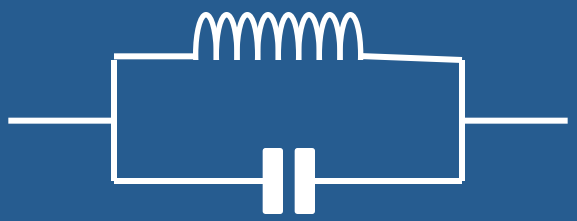
2H Tuned Circuits and Resonance

Tuned Circuits

A combination of an inductor and a capacitor in either a series or parallel combination will form a tuned or resonant circuit.



Series resonant or acceptor circuit

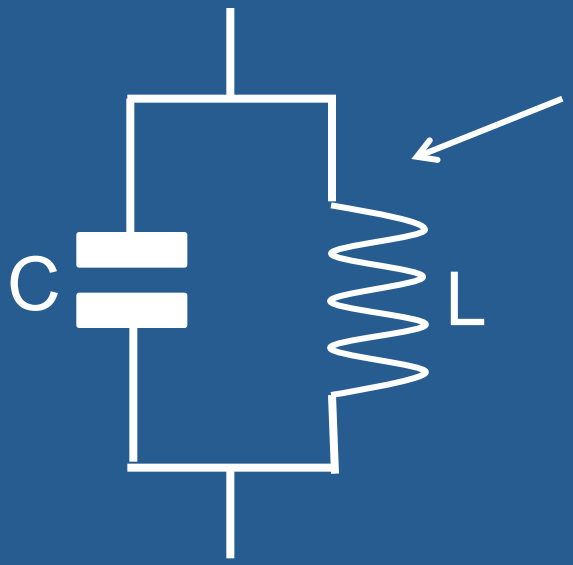


Parallel resonant or rejector circuit

The values of the inductor and the capacitor determine the actual resonant frequency.

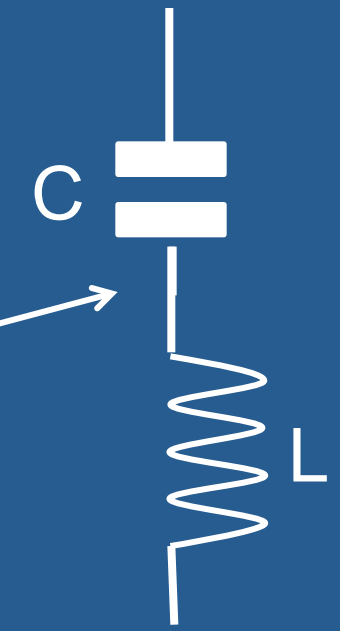
At resonance a series resonant tuned circuit has a low impedance (ac resistance). The parallel tuned circuit at resonance has a high impedance

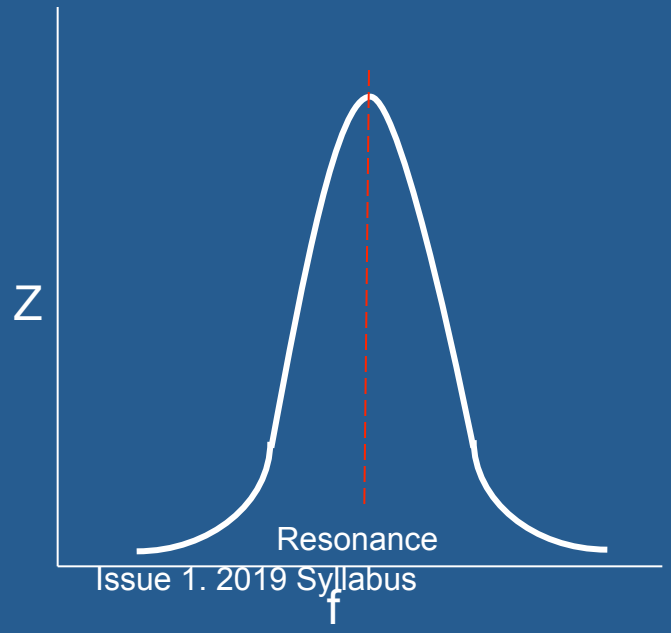
Tuned Circuits: Impedance Curves

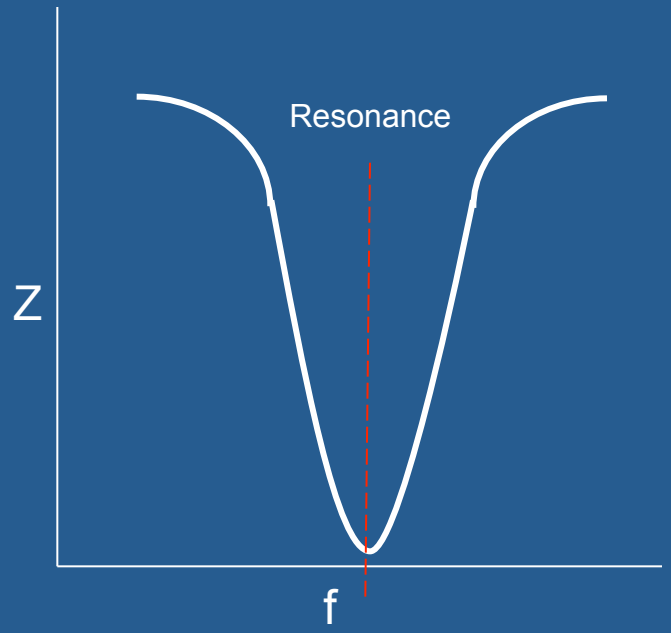


In the *parallel tuned* circuit the Impedance *Z* reaches a *maximum* at the *Resonant Frequency. (Rejector)*

In the *series tuned* circuit the Impedance *Z* reaches a *minimum* at the *Resonant Frequency (Acceptor)*







Resonant Frequency

The energy stored in the capacitor (C) and in the inductor (L) transfers backwards and forwards between them at resonance.

At resonance $X_L = X_C$

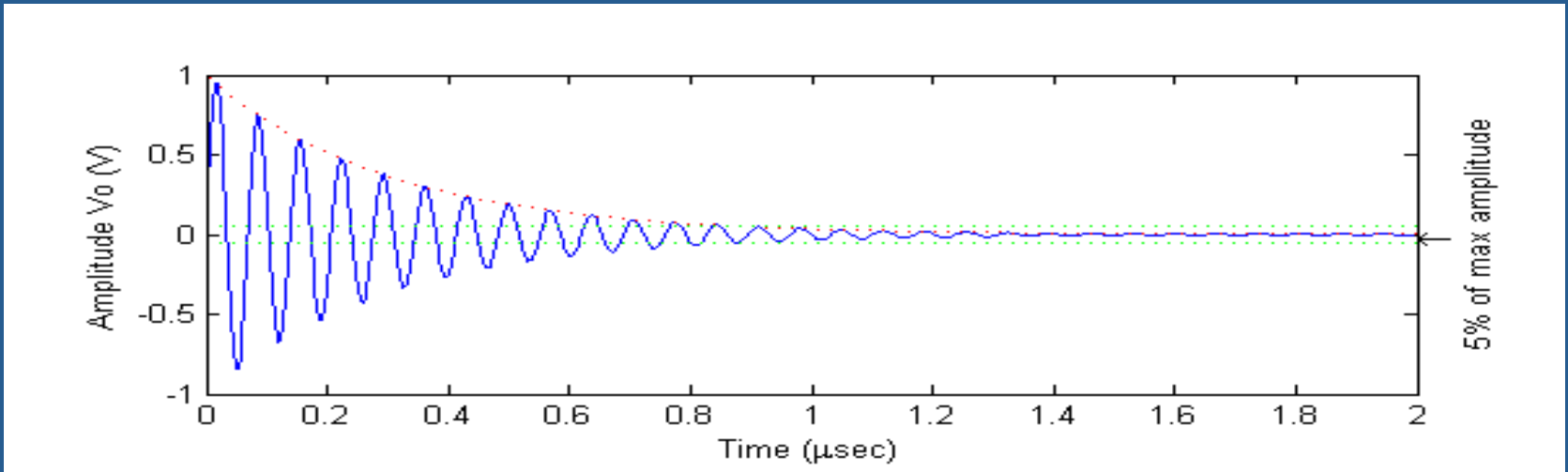
This happens at a fixed or *resonant frequency.*

The actual value of C and the actual value of L determine this resonant frequency.

If the value of L and C are the same in the series and the parallel tuned circuit then the resonant frequency will be the same for both circuits. Varying L or C will vary the resonant frequency accordingly.

Increasing L or C lowers the resonant frequency.

“Ringing” At The Resonant Frequency

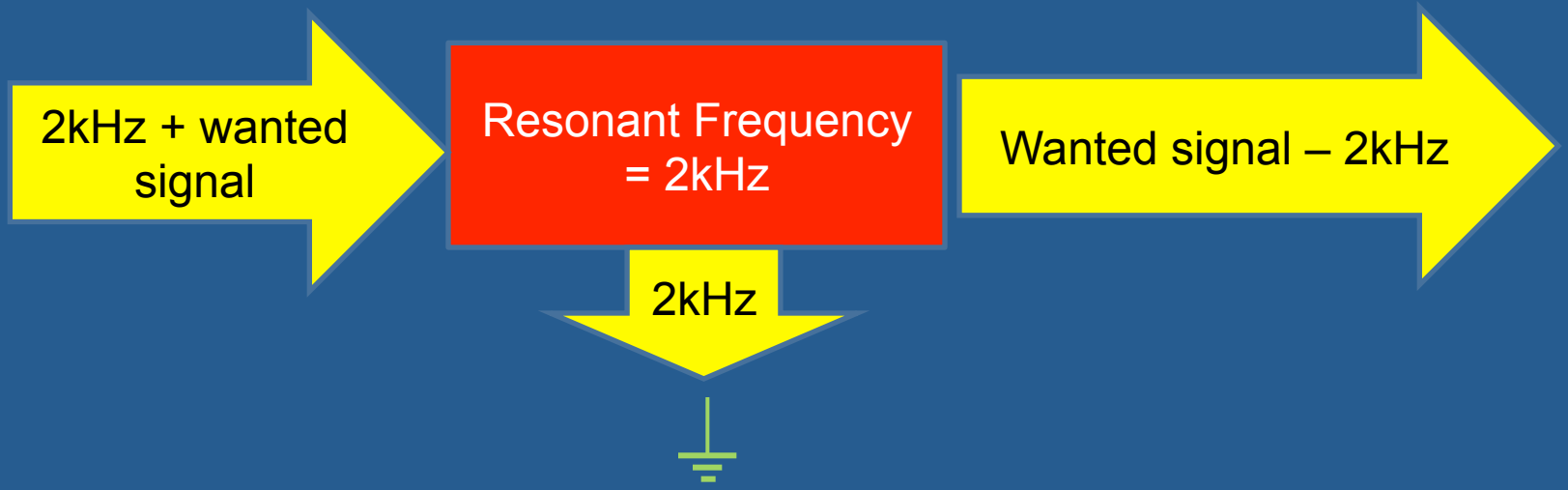


A pulse applied to a circuit containing L and C will “ring” at its resonant frequency. The amount of resistance in the circuit determines the rate of decay of the ringing.

Uses Of Tuned Circuits

In radio work there are many uses for the tuned circuit and the property of resonance.

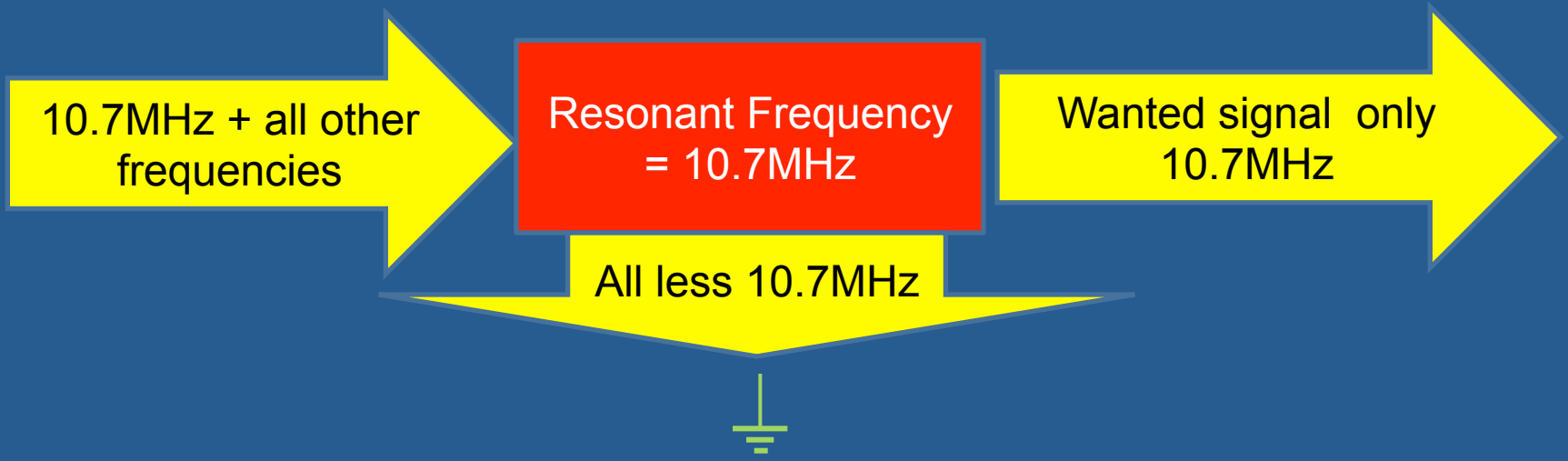
(a): Suppose that we have a 2kHz whistle on an audio signal. If we can construct a resonant circuit that behaves like a short-circuit only at 2kHz then we could shunt the whistle to ground (ie eliminate it) whilst allowing all the wanted frequencies to pass.



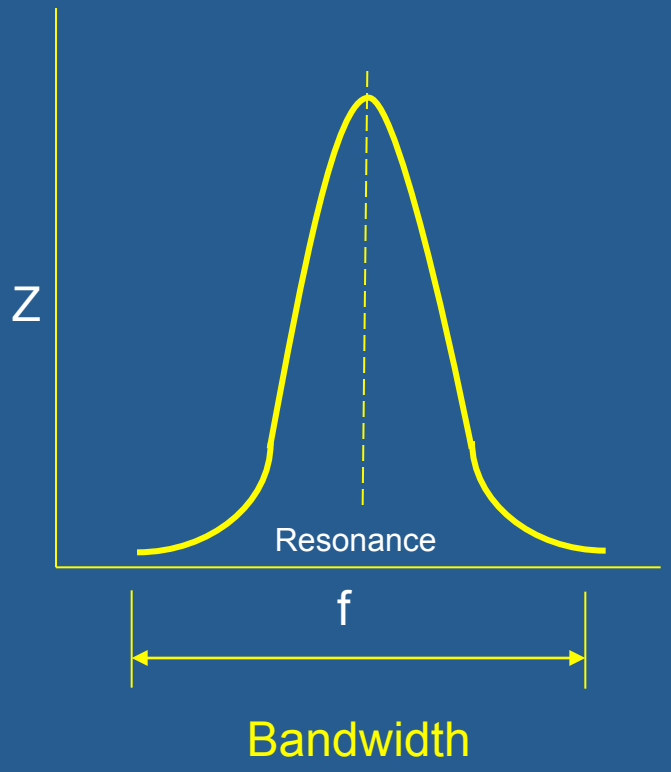
Use Of Tuned Circuits

(b): We can similarly construct a rejector circuit which will reject every frequency except the wanted one.

Suppose we want to reject all frequencies except 10.7MHz. We would make a circuit that looks like a short circuit to earth at every frequency except 10.7MHz.



Selectivity of the Tuned Circuit



A resonant circuit has its maximum response at the resonant frequency where $X_L = X_C$

As the frequency moves either side of the resonant frequency the response of the circuit falls away.

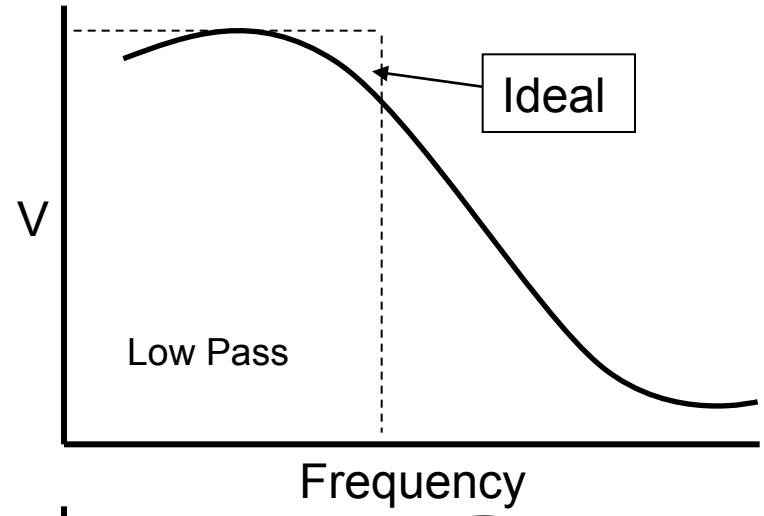
The selectivity of a tuned circuit is the ability to pick out a wanted signal from all others.

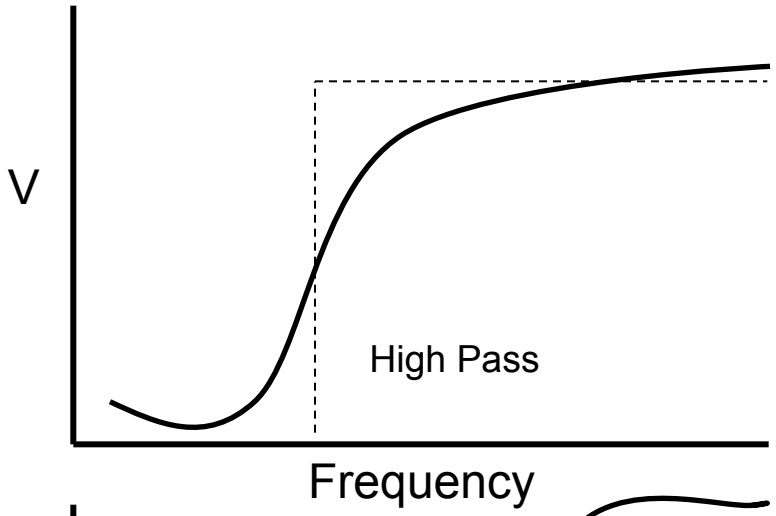
Q is the ratio of the Impedance of the circuit to the Resistance of the circuit at resonance.

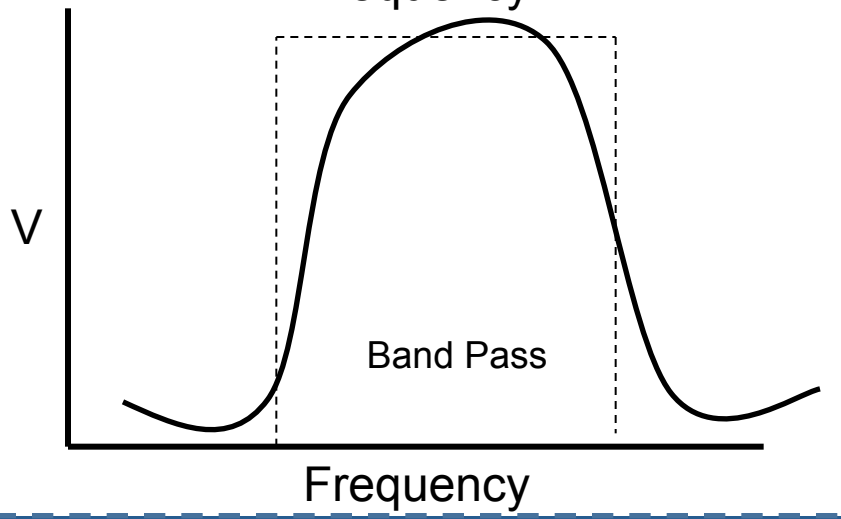
The Q factor of a tuned circuit is an indication of the selectivity of the tuned circuit.

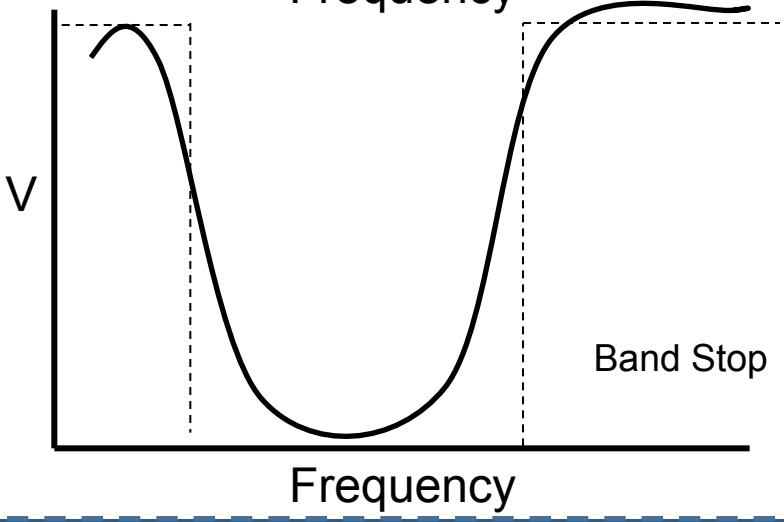
The higher the Q the more selective the circuit.

Low Pass, High Pass, Band Pass and Band Stop (Notch Filters)









2I Semiconductor Devices

Conductors, Insulators and Semiconductors

These terms apply to how easily electrical charge can move, or not be able move, through a material.

The flow of electrical charge (electrons) is what constitutes a current in a material. The bigger the flow – the bigger the magnitude of the current.

Conductors have a crystal lattice structure. This contains a lot of “free electrons” which can drift around at random between the atoms which are rigidly held. Electrons all move in one direction to form a current flow.

Insulators also have a crystal lattice structure - but no free electrons. Insulators are thus unable to support the flow of electrons – there just aren’t any to flow.

A semiconductor isn’t quite a metal nor an insulator. It is made to be somewhere in between. Its conduction profile can be controlled to be almost as good as a metal or as poor as a conductor. (VERY useful!)

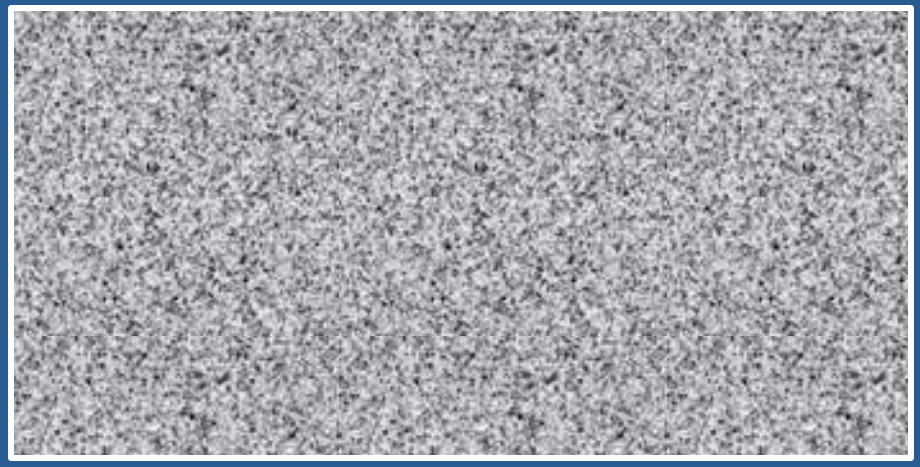
Flow Of Current In A Conductor.

In a conductor the flow of current is due to the uniform motion of electrons effected by a potential gradient caused by an applied voltage across the conductor.

In a conductor the metallic crystal lattice contains free electrons which can move easily through the lattice when a voltage gradient (potential difference) exists across it.

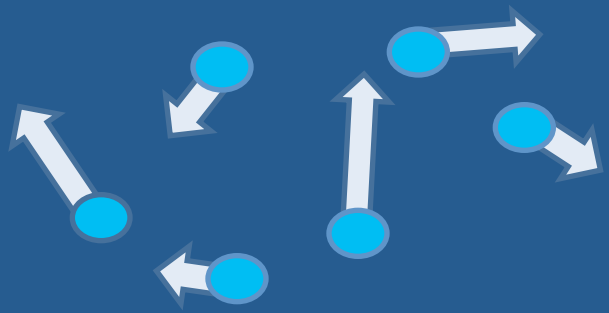
Note: Thinking of electrons rolling down a gradient in the same way that balls roll down a hill is a useful model for visualising what is happening. The steeper the gradient the more and faster the balls roll. However, be aware that the electrons actually move up the electrical gradient towards the positive (anode). The actual direction doesn't matter provided you keep a consistent model in your head. The confusion comes when you randomly switch between the models in your head! Choose a model and direction and stick with it.

Conductor: Random Electron Motions

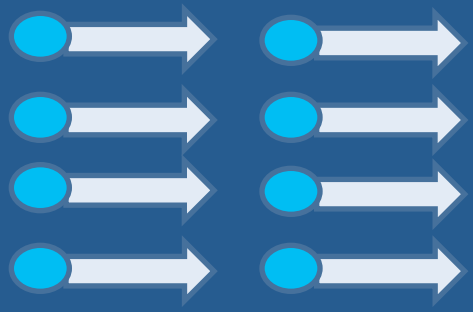


CONDUCTOR:

The conductor has lots of free electrons within the atomic lattice. These will move easily under an applied voltage and constitute a current.



With no applied voltage the electrons in the conductor move in random directions with random speeds. The net effect is no resultant electrical current is produced.



With an applied voltage the electrons in the conductor move along the potential gradient in the same direction and with the same speed. The net effect is an electrical current flows within the conductor

Insulators

In an insulator the crystal lattice contains very few free electrons. There are thus correspondingly fewer charge carriers to constitute a current flow. Even a very large potential (thousands or millions of volts) cannot cause a significant current flow.





Conductor

Conductors and Insulators

Conductors	Insulators
Copper	Wood
Aluminium	Glass
Gold	Ceramic
Silver	Plastic
Brass	Pure Water*
Carbon	
Salt Water*	

** Water is not a good conductor in its pure state. Dissolved salts make it a better conductor. (Wet hands and sweat will be a sufficiently good conductor to allow a harmful current to flow and cause burns to the skin with a significant applied voltage.)*

Wet insulators may also conduct across their surface and may even "flash over" if the voltage is high enough.

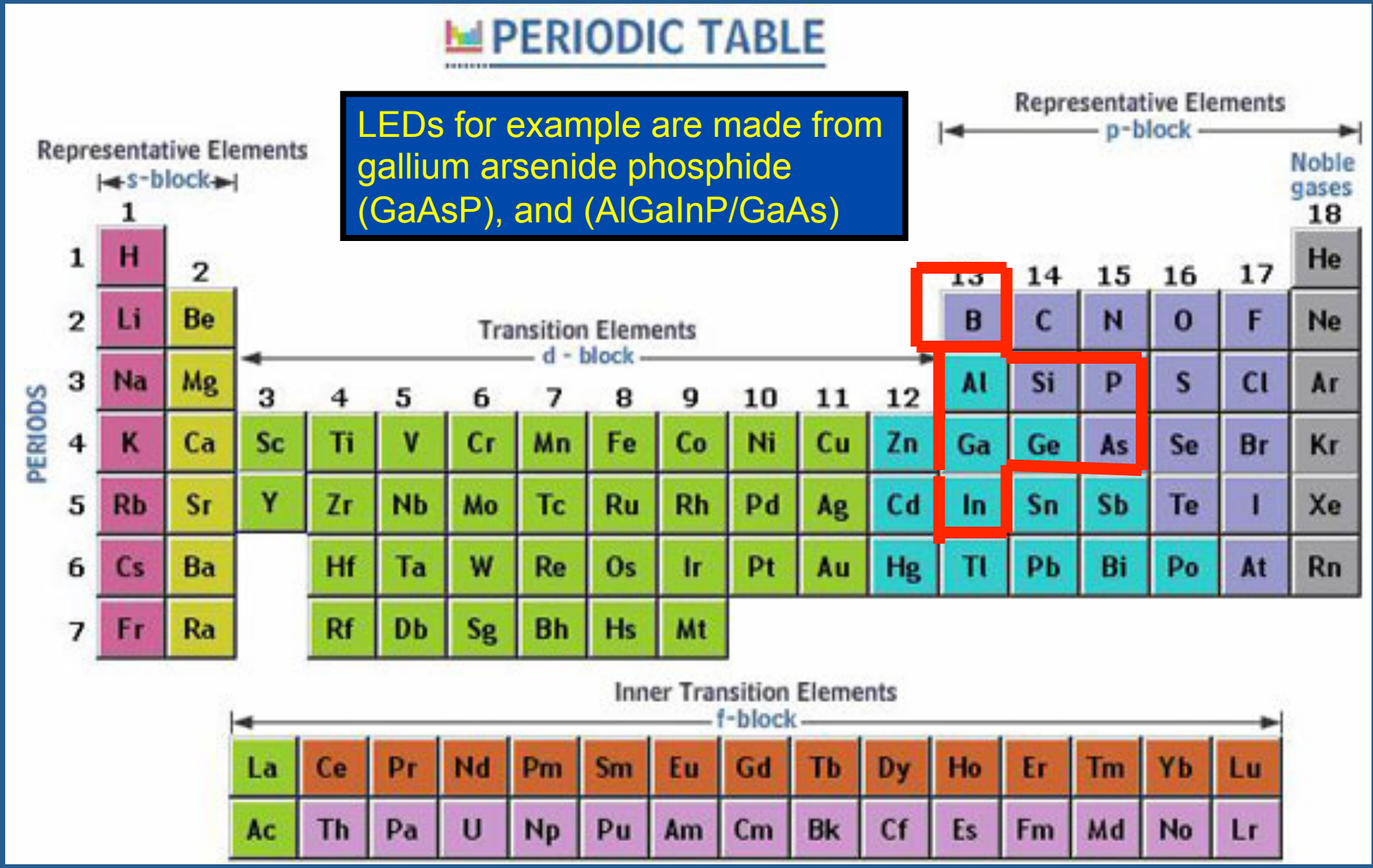
Semiconductors

Semiconductors are materials which are designed to have certain characteristics. These characteristics come from chemical doping in small amounts of the original, pure material.

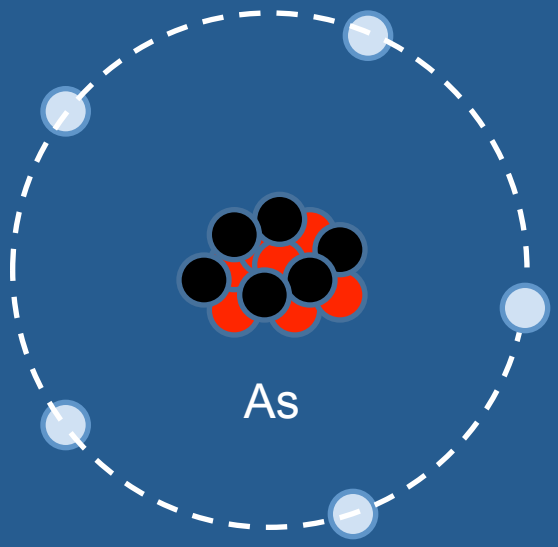
Silicon is the commonest material used to make semiconductors. (Silicon is the main element in sand – an insulator.) For semiconductor devices the silicon has to be in its purest form. By melting impure silicon in a crucible and then introducing a “seed crystal” of pure silicon a single, continuous crystal of high purity can be continuously pulled from the molten material leaving the impurities behind.

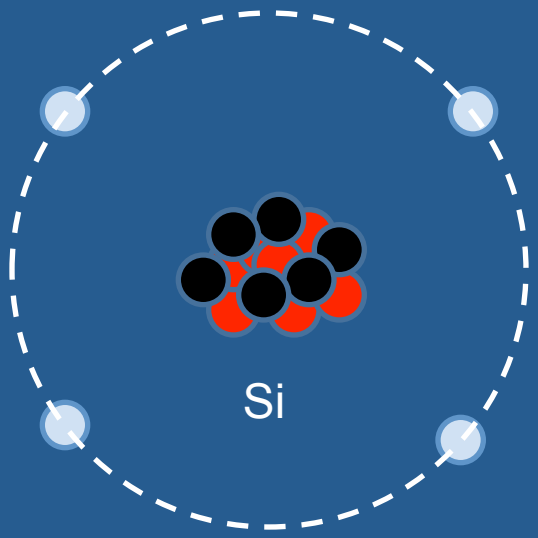
This crystal can be sliced and diced into suitable pieces and then chemically treated (doped) to change it from an insulator into a semiconductor by the addition of other elements under very controlled clean-room conditions.

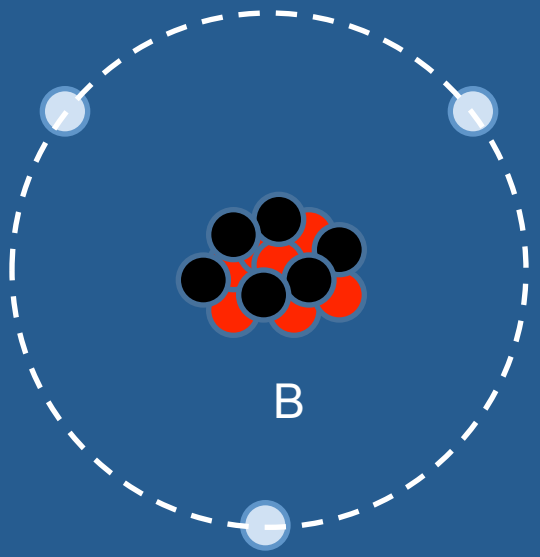
Common Semiconductor Materials



n-Type and p-Type Silicon







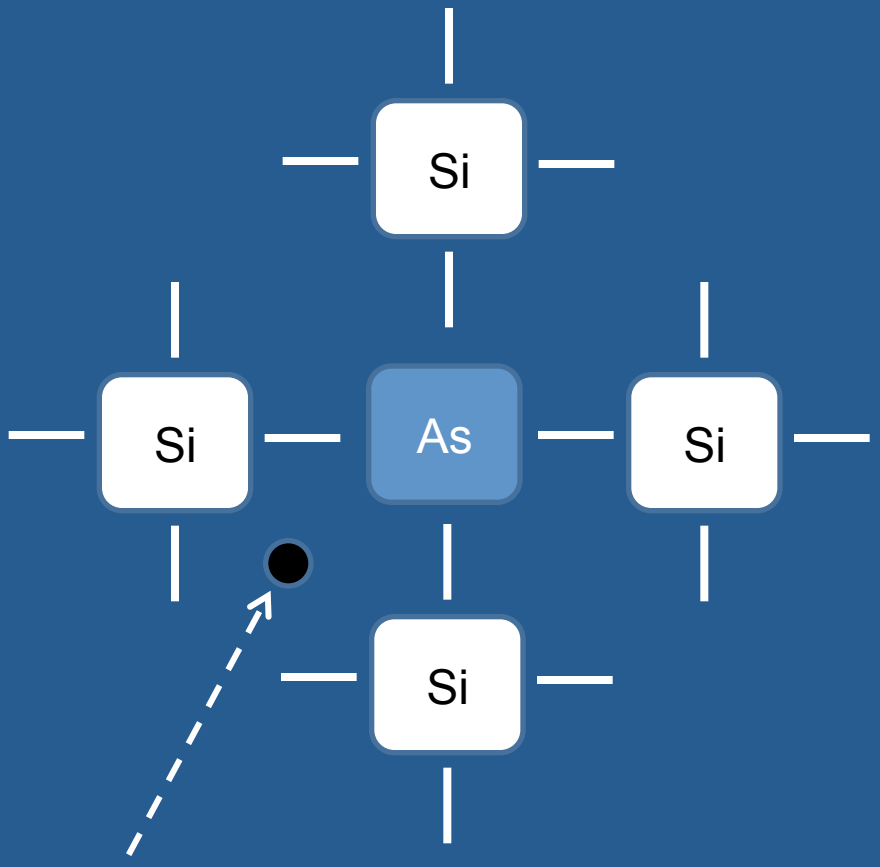
ARSENIC
5 electrons in its outer shell

SILICON
4 electrons in its outer shell

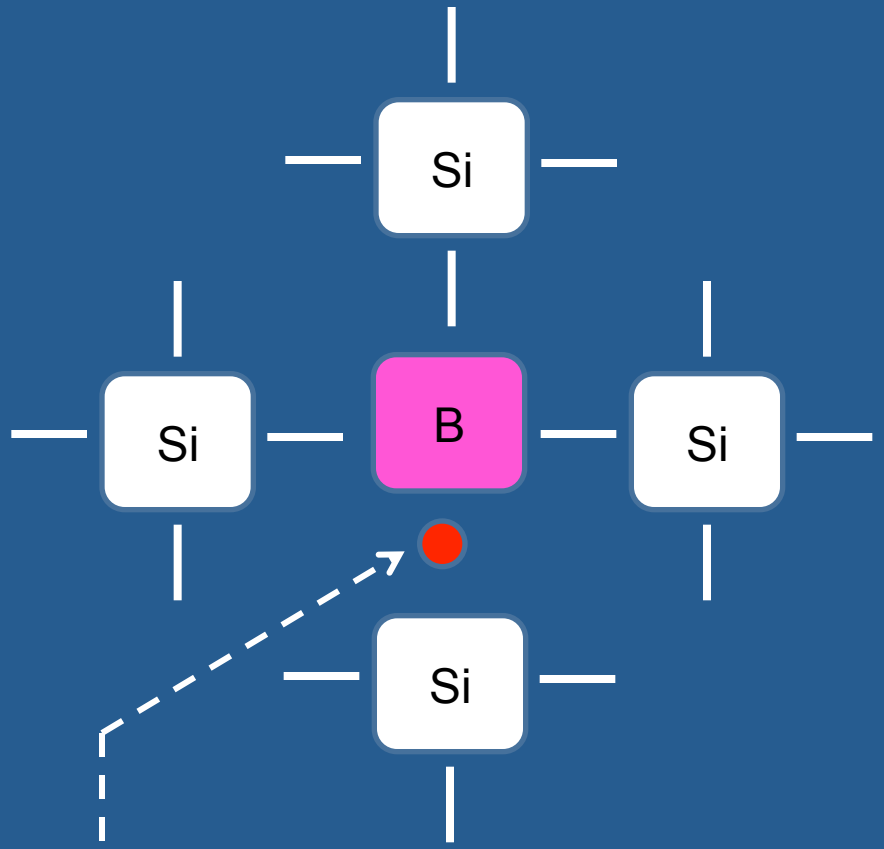
BORON
3 electrons in its outer shell

Arsenic, Silicon and Boron are adjacent to each other in the Periodic Table. In the crystal lattice of Silicon you can replace a Silicon atom with one of Arsenic or one of Boron as they will fit comfortably within the space .

Doping of Silicon

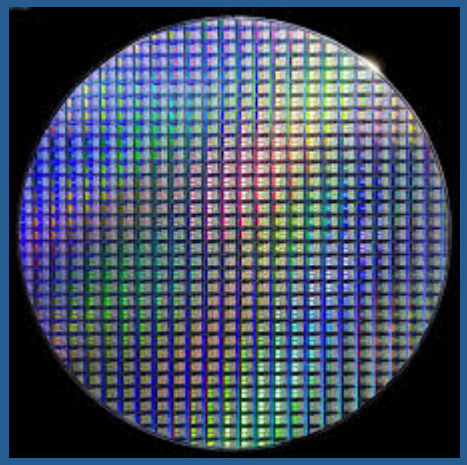


Extra electron donated by the Arsenic giving n-type Silicon. The Silicon lattice only needs four electrons so this one is “spare”



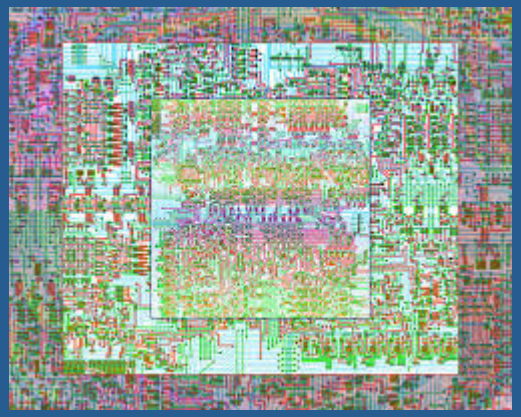
Missing electron or “hole” in the Silicon lattice giving p-type Silicon. (Because Boron only contributes three electrons and Silicon is looking for four electrons. The hole acts like a positive electron and can move about the lattice in a mirror-image way)

Integrated Circuits

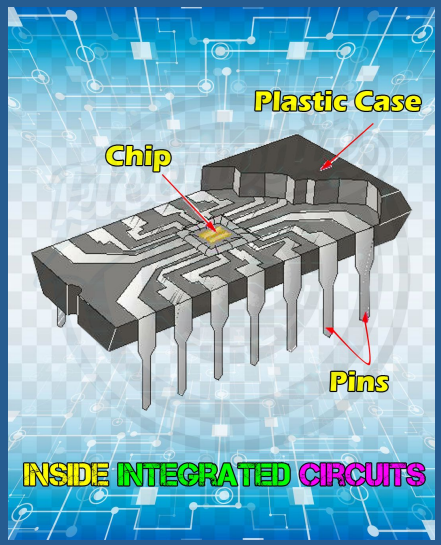


Wafer





All components are fabricated onto the chip



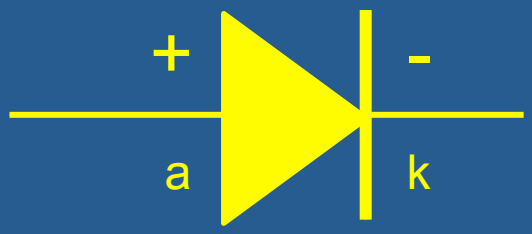
The Diode

Although there are many different variants of the diode they all share a common characteristic. They will conduct when forward biased. They will block (not conduct) when reverse biased. (This assumes the reverse bias is a moderate value of voltage and below the zener or breakdown value.)

For Silicon diodes the forward bias is typically about 600mV.

For LEDs the forward bias needed can be about 2 Volts

The Semiconductor Diode

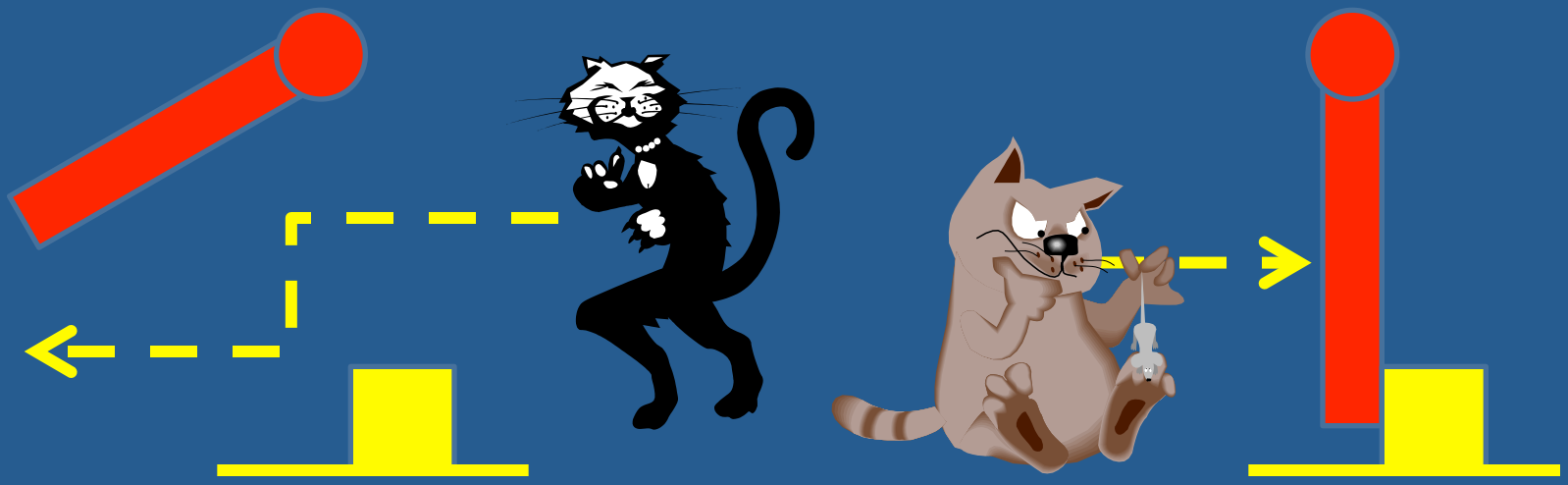


a: anode; k: cathode

When conducting (ie forward biased) a silicon, semiconductor diode has a forward voltage drop of about 600mV across it. It will maintain this voltage drop across its specified current range. (More or less!). This means that it will not start to conduct until at least 600mV is applied across it and the anode is positive with respect to the cathode by this amount.

When the diode is reverse biased (ie anode negative with respect to the cathode) it will not conduct and exhibits a very high resistance to current flow.

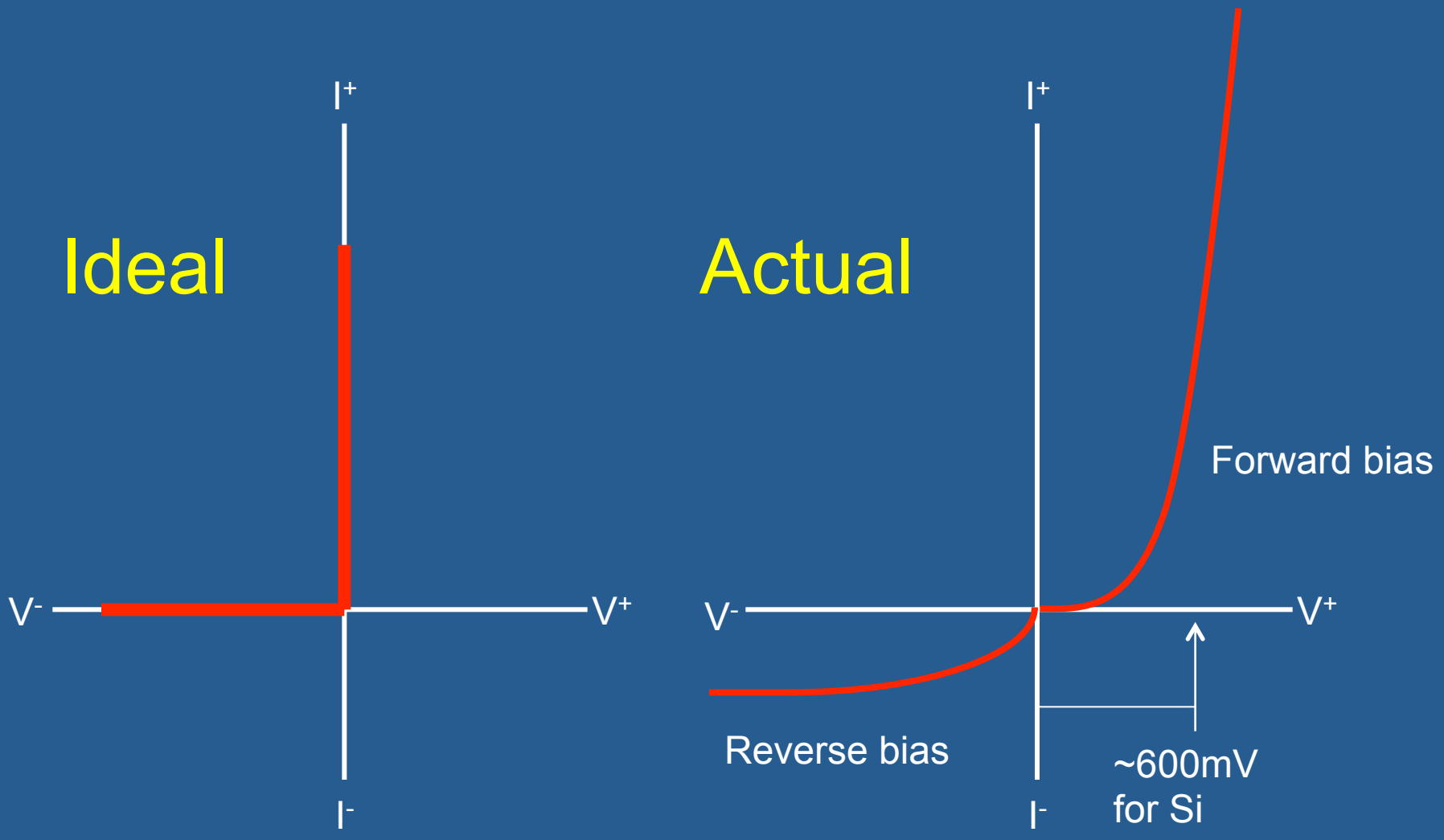
Conduction – The Cat Flap Analogy



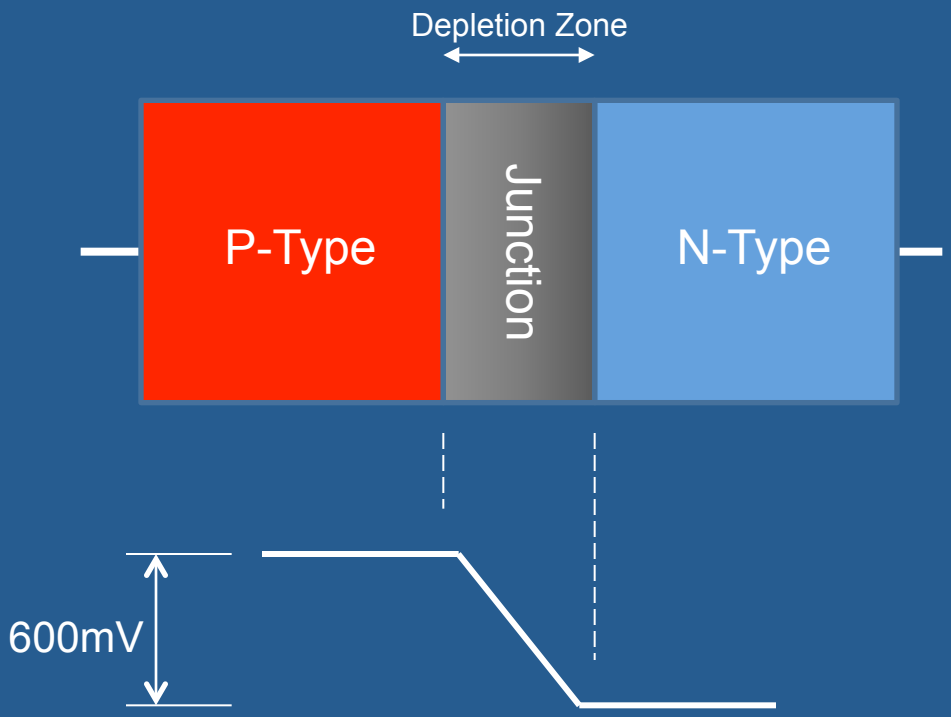
Forward biased

Reverse biased

The P-N Junction I – V Characteristic



The Semiconductor Junction Diode

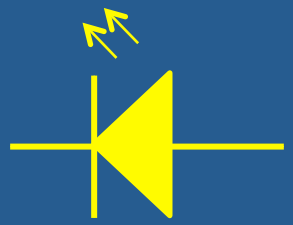


At the junction the electrons from the n-type Silicon and the holes from the p-type Silicon recombine. This forms a depletion zone where there are no free charge carriers.

The effect of the junction and the depletion zone is to create a potential gradient across the junction of about 600mV in Silicon

Forward biasing the diode enables injected charge carriers to overcome the junction potential. Reverse biasing the diode extends the depletion zone and increases the height of the potential barrier. This gives the diode a very high effective resistance and turns it off.

The Light Emitting Diode (LED)



The led is a semiconductor diode. It shares the same basic characteristics of semiconductor diodes. (anode, cathode, forward conduction , etc)

However, when forward biased, it will emit light. (leds can also be obtained that emit infra red or ultra violet. Their output is in or near the visible part of the spectrum.)

Unlike rectifier diodes a light emitting diode is more “electrically fragile”. They cannot tolerate excessive reverse bias and are relatively easy to destroy if you don’t take care of them.

Leds are thus usually supplied only with dc. They are also protected by a series resistor to limit the forward bias current.

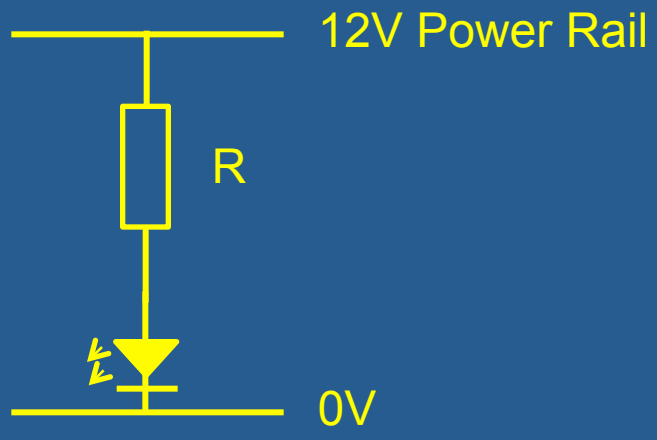
LED Biasing Example

You want to use an led as a “Power On” indicator. The supply is 12 Volts dc.

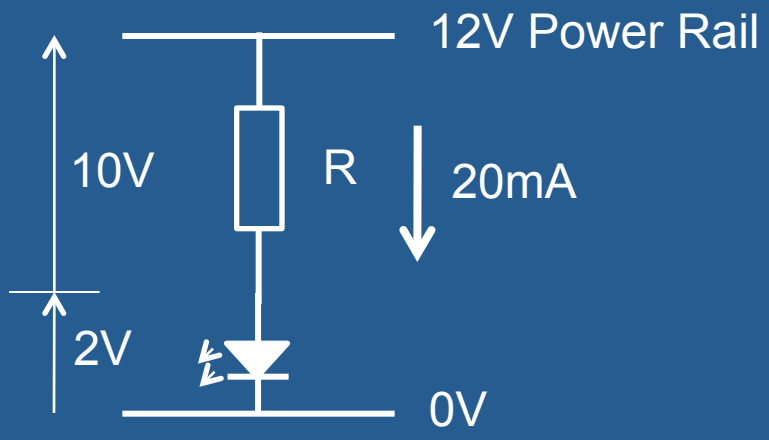
The supplier’s data sheet shows an led with the following characteristics:

Forward Voltage Drop is 2 Volts at a current of 20mA.

What value of protection resistor (R) do you need?



LED Biasing Example



1. When conducting the led develops 2 Volts across it.

2. This leaves (12 – 2) Volts to be dropped across the protection resistor R

3. From Ohms law you know that V = I x R.

So: 10 Volts = (0.02 x R) Volts
R = (10 / 0.02) Ohms
R = 500Ω

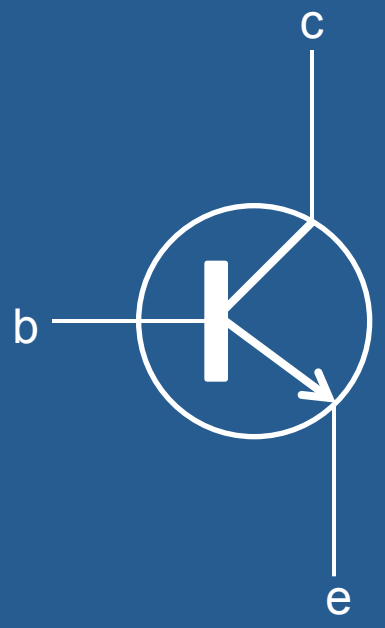
The nearest preferred sizes are 470Ω or 560Ω.

Probably choose 560Ω

The Bipolar, NPN Transistor

The transistor is a three-terminal, semiconductor device. It can be made to operate in two ways:

- As a solid-state switch;
- As an amplifier.

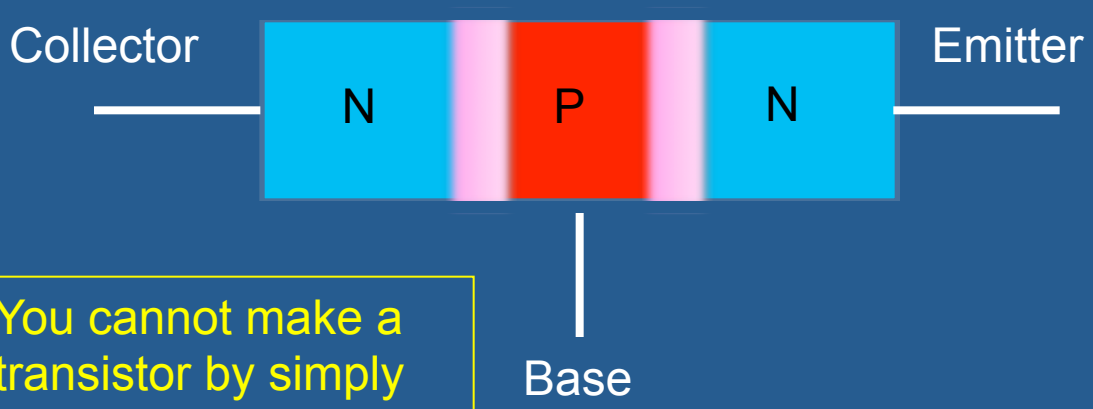


The device terminals are called:

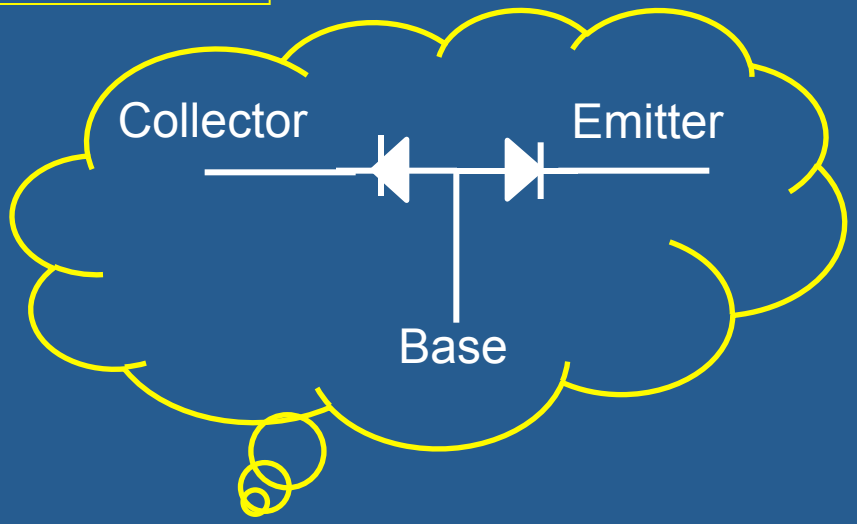
- The Collector; (c)
- The Base; (b)
- The Emitter (e)

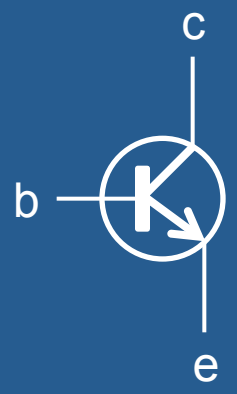
The base terminal is used to control the flow of current through the device.

Simple Model

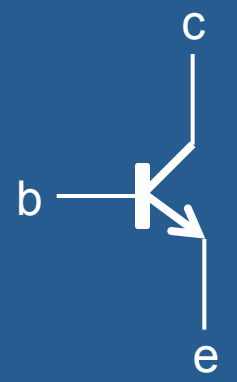


You cannot make a transistor by simply connecting two, diodes back-to-back!





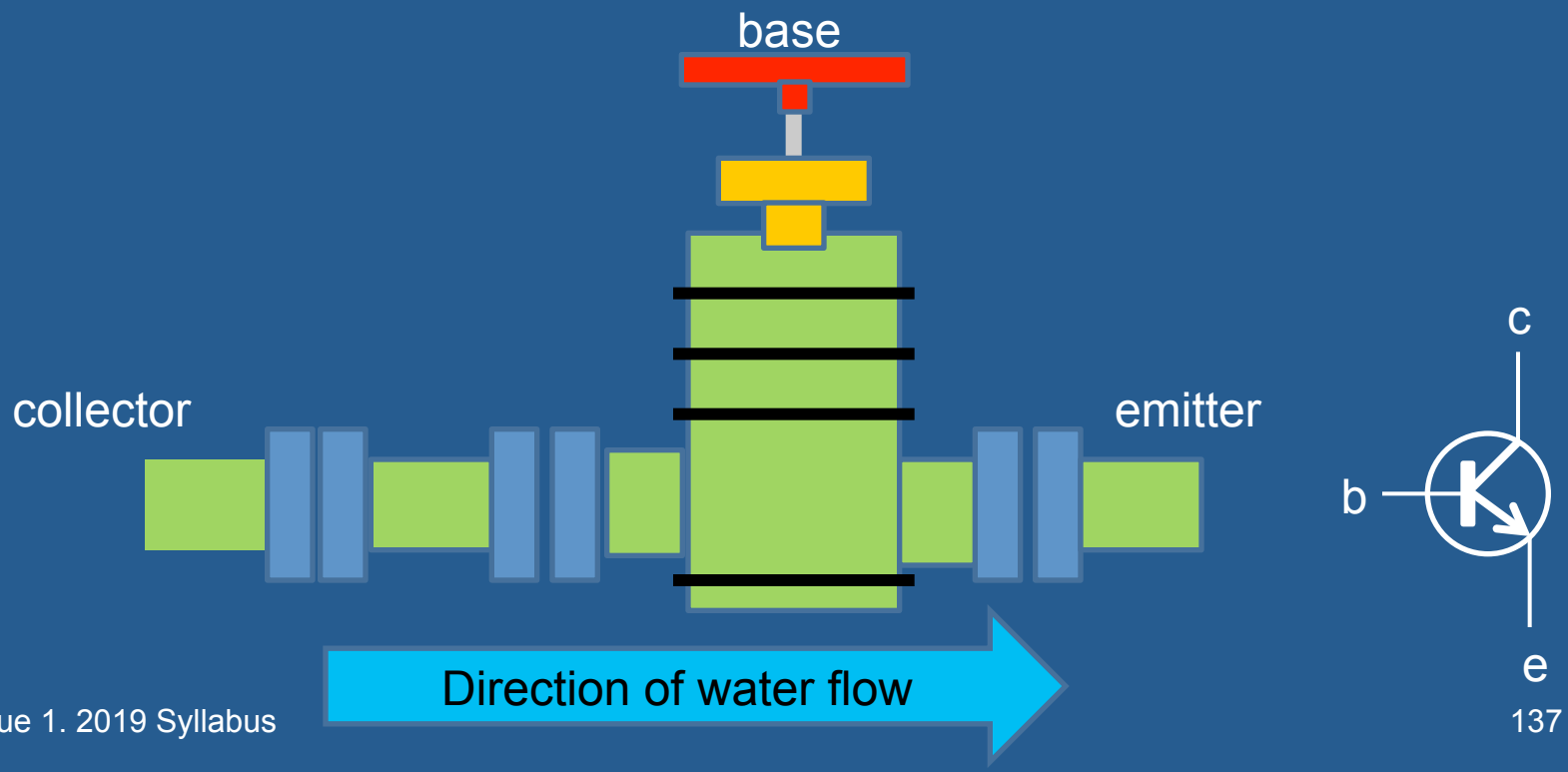
Circuit Symbols



NPN Transistor: Mechanical Analogy

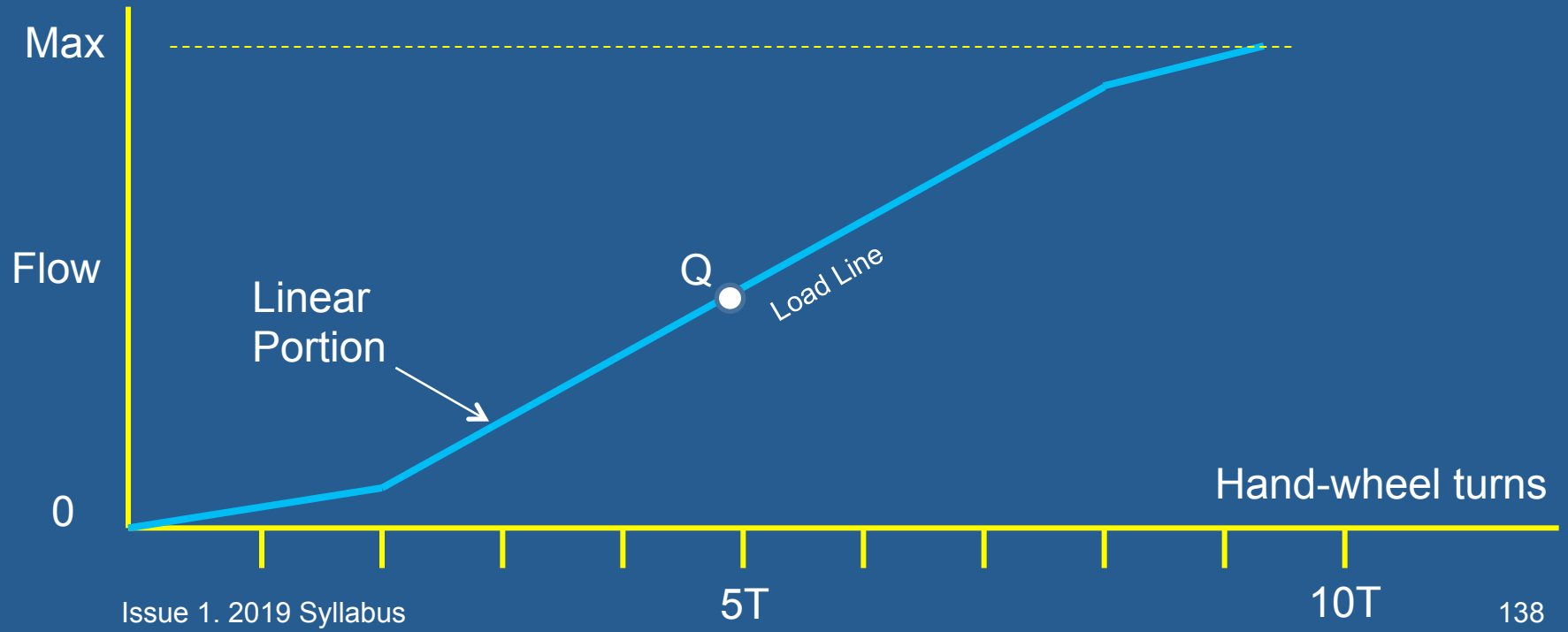
A water valve provides a reasonable analogy to how the transistor operates. By varying the opening of the valve you control the flow through it. A very small amount of effort on the valve's hand-wheel can control a large flow of water.

A small injection of current into the transistor base will control a relatively large flow of current between the collector and the emitter. Rapidly opening the valve to full on is like a switch. Gradually opening the valve progressively increases the flow.



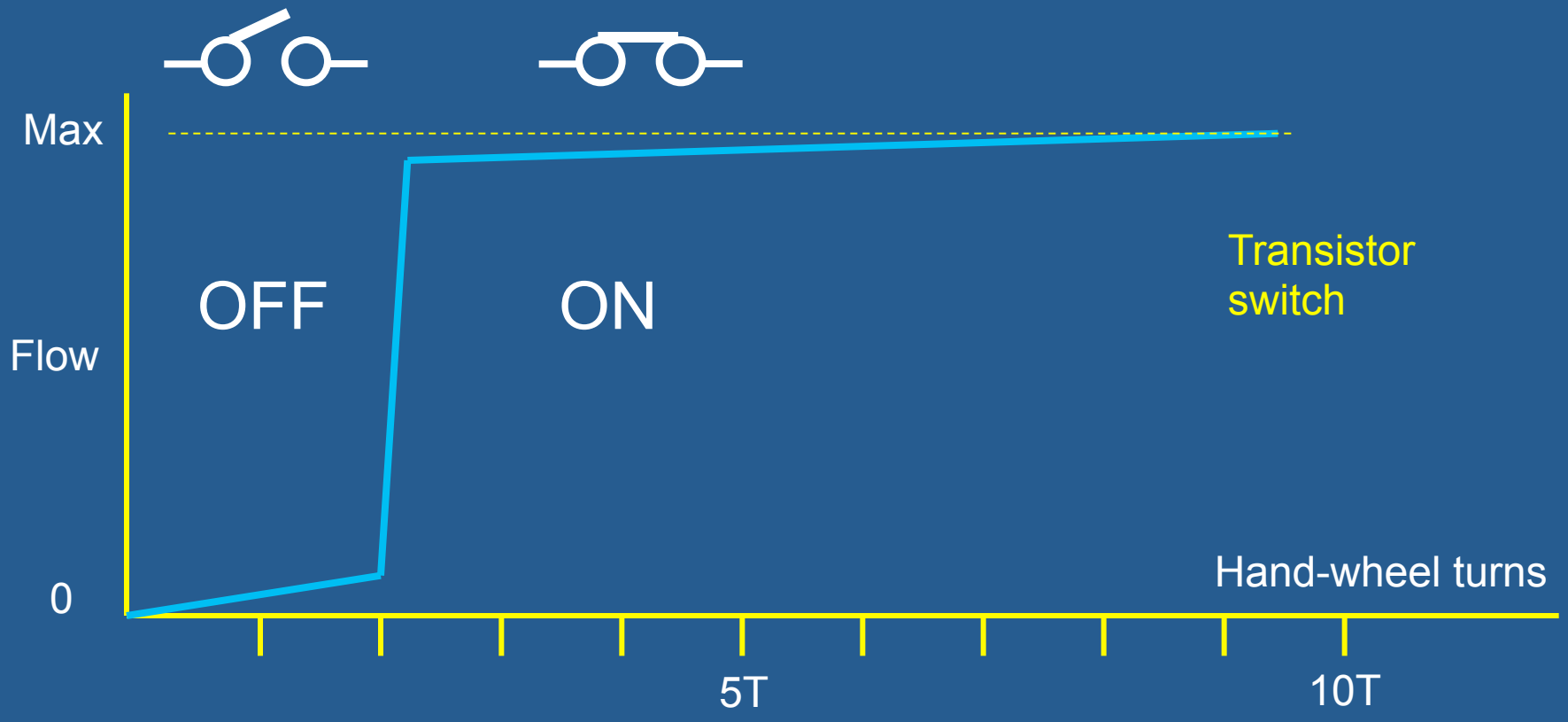
Mechanical Analogy Continued

Let's say that the valve hand-wheel has 10 turns from fully closed to fully open. The first couple of turns serve to lift the valve off its seat so the flow is only a bit of a trickle by the time you get to 2 turns open. Turns 2 to 8 allow the water flow to increase linearly. Turns 8 to 10 on the hand-wheel have little further effect on the volume of water going through the valve. With the valve wheel open 5 turns (Point Q) turning the wheel in either direction will vary the water flow linearly through the valve.



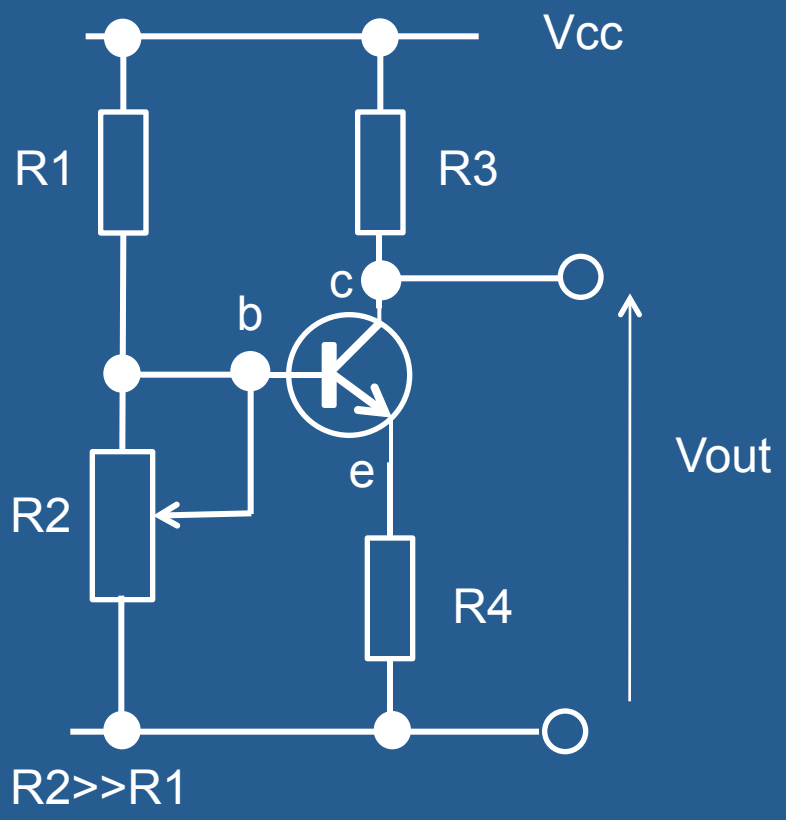
Transistor Switch - Mechanical Analogy

Suppose now that our water valve develops “a fault.” Instead of a smooth transition between turns 2 to 8 the valve now jumps to fully open once you reach 2 turns, The transfer characteristic will now look as follows. It now has the characteristic of a switch. It is either fully off or fully on. Once you are past 2 turns the valve avalanches on.



NPN Transistor Switch

The transistor can also be made to operate as a switch.

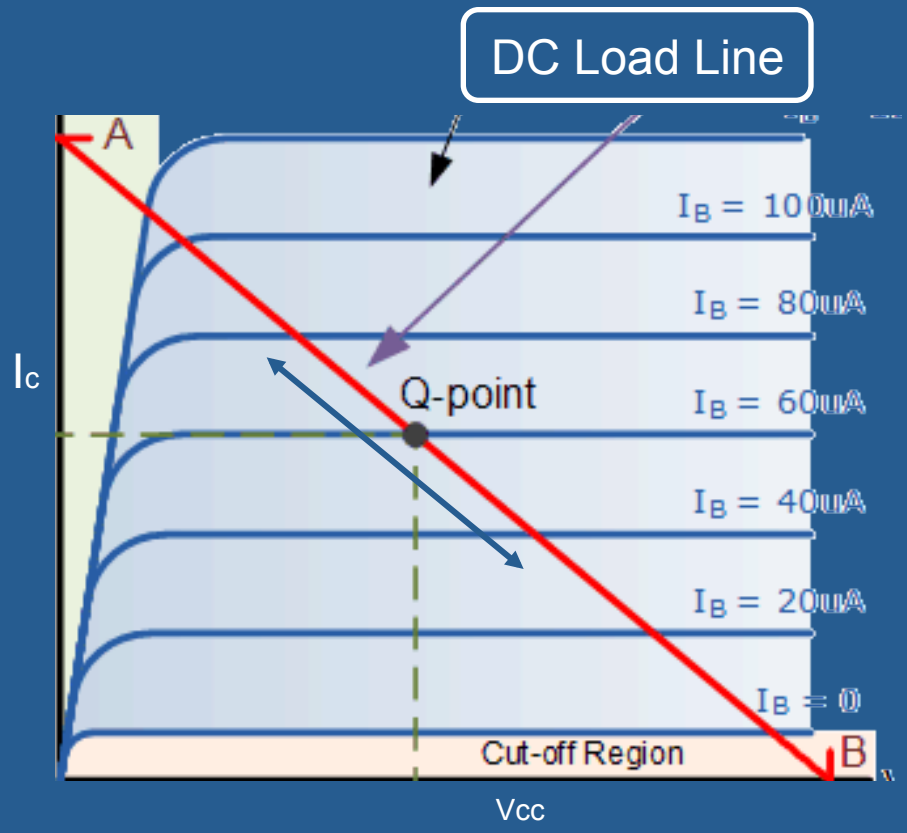


R2 is a variable resistor. By varying the value of R2 the voltage at the base of the transistor can be varied between 0 Volts and the voltage present at the junction of R1 and R2.

As the base voltage moves closer to Vcc the base current and hence the collector current will increase.

Eventually the collector current becomes so large (relatively) that the transistor “saturates” and no further increase in collector current occurs with an increase in base voltage. The transistor is now turned fully on and the collector voltage is low.

Transistor Operating Curve



When operating the transistor as an amplifier you design its quiescent point to be at Q

.

(This is like being at Turn 5 of the hand wheel where the valve can progressively open or close in a linear way as the hand wheel is turned.)

As the input signal varies the base current varies in sympathy. The output of the transistor (collector current) varies linearly along the load line producing an amplified signal at the collector.

Collector Current = Base Current x Current Gain Factor (β)

Transistor Current Gain β

Bipolar transistors are current-operated devices.

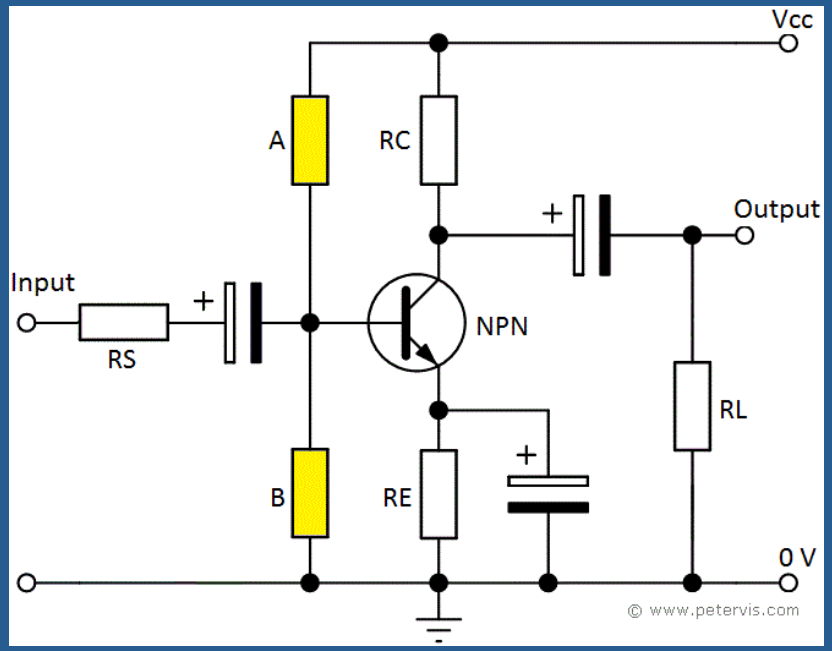
A very useful measure of the amplifying capability or current gain is the ratio:

Increase in Base Current : Increase in Collector Current

$$\frac{I_{collector}}{I_{base}} = \beta$$

β is also described by the term h_{FE}

Common Emitter Amplifier Bias Network



Resistors A and B form a potential divider. This fixes the base voltage Vb at some level above ground.

ie. $Vcc \times [R_B / (R_A + R_B)]$

Success depends upon the value of Vb being reasonably constant. The values of R_A and R_B should not be so high that the potential of the base is affected to a substantial degree by changes in the base current.

In other words the current flowing through them when the base is disconnected should be at least several times the base current Ib. However, you don't want these resistors to be too low and waste a lot of power.

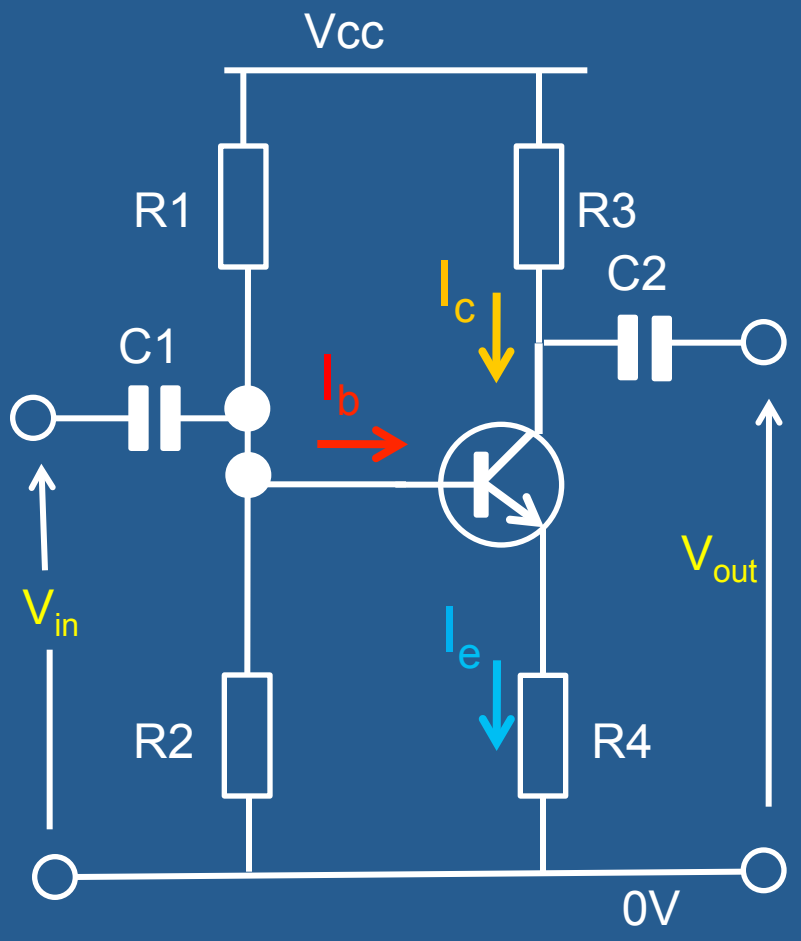
RC limits the collector current. RE is the emitter resistor. It is usually a low value. If the collector current increases too much the voltage drop across RE will also increase. This will reduce the voltage across the base – emitter of the transistor. This reduces the drive and reduces the collector current. RE helps to stabilize the bias voltages.

NPN Transistor Common Emitter Amplifier

V_{in} is the input to the amplifier. The base of the transistor sits at a DC voltage defined by the potential divider R1 and R2.

Capacitor C1 blocks this DC voltage from getting back to the signal source.

The operating point of the transistor (Q) places it half way up its curve on the linear portion. R3 and R4 are used to set the collector current and the operating point. The transistor has a current gain. (β). Any small change in the base current going into the device is amplified by this value β. The collector current will be an amplified version of the base current (signal input) and appears across R3. The amplified signal is taken out via C2 (blocking capacitor).



$$I_e = I_c + I_b$$

$$I_c = \beta \times I_b$$

2J Cells and Power Supplies

Cells in Parallel and Series

BE CAREFUL! *When connecting cells in parallel or series and when dealing with cells that can deliver significant currents (eg NiCads, Lithium and Lead Acid types),*

DO NOT:

- *Mix cell types;*

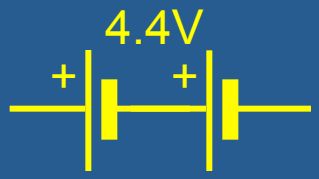
- *Parallel connect cells of different emfs;*

- *Reverse the polarity of any cell in the battery.*

Cells in Series



A single, lead-acid cell has an emf of 2.2 Volts when fully charged.



Two, lead-acid cells when connected in series have a combined emf of 4.4 Volts across them.

Two or more cells connected in series form a battery.



Six, lead acid cells in series form a battery (*sometimes called an accumulator*) of 13.2 Volts. This is a standard car battery voltage. *(Strangely, this is always wrongly described as a 12 Volt battery!)*

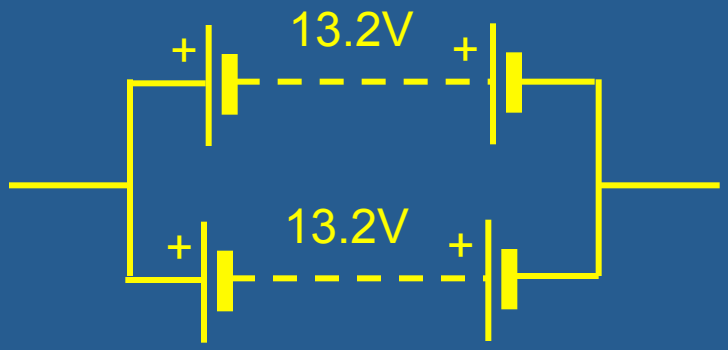
Cells in Series

Cells in series connect positive to negative (head to tail).

The final battery voltage is the sum of the individual emfs of the constituent cells.

The *total circuit* current flows through each cell in the series battery when the battery is connected to an external circuit.

Cells in Parallel



Connecting batteries in parallel is done to increase the stored energy.

If you really must connect two or more high capacity batteries in parallel BE VERY CAREFUL.

*DO YOU **REALLY** NEED TO DO IT?*

Two 13.2 Volt batteries connected in parallel will produce a battery with a terminal emf of 13.2 Volts.

However the total current which the combination of the two batteries can provide is twice the current that one of the pair can provide. (Similarly total charge).

Each of the batteries above will provide half of the total current when an external circuit is connected. (This assumes that both component batteries are absolutely identical.)

Primary and Secondary Cells.

Cells store charge in the form of chemical energy.

Primary cells, once depleted, cannot be recharged.

Secondary cells, once depleted, can be recharged. Connecting the depleted battery to a suitable charger will reverse the chemical process by supplying charge back into the battery.

The process is not 100% efficient. You have to put back more charge than you took out to restore the battery to fully charged. This additional charge is to compensate for losses within the cells.

Battery Ratings

Lead Acid batteries are normally rated at *"The 10 hour rate".* This is their capacity when going from full charge to a fully discharged state at a constant rate of current delivery for a period of 10 hours.

(Note: Fully discharged is not when the terminal voltage is 0 Volts!)

The recharging rate should not normally exceed the 10 hour rate as well.

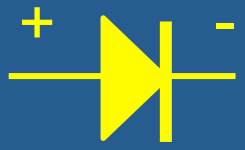
For example:

A 20Ahr (Ampere Hour) battery has a 10 hour rating of being able to deliver a current of 2 Amps for 10 hours. You would recharge it at 2 Amps.

A 50Ahr battery could deliver 5 Amps for 10 hours.

In theory a 50Ahr battery would also deliver 50 Amps for 1 hour as well. (Or any other combination giving a product of 50Ahr) However, in practice, losses and chemistry do not allow this.

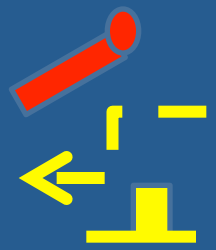
Simple Rectification Of AC: (The Half-Wave Rectifier)



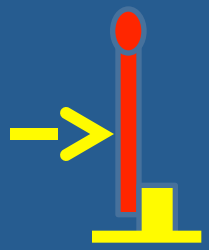
Forward Bias



Reverse Bias

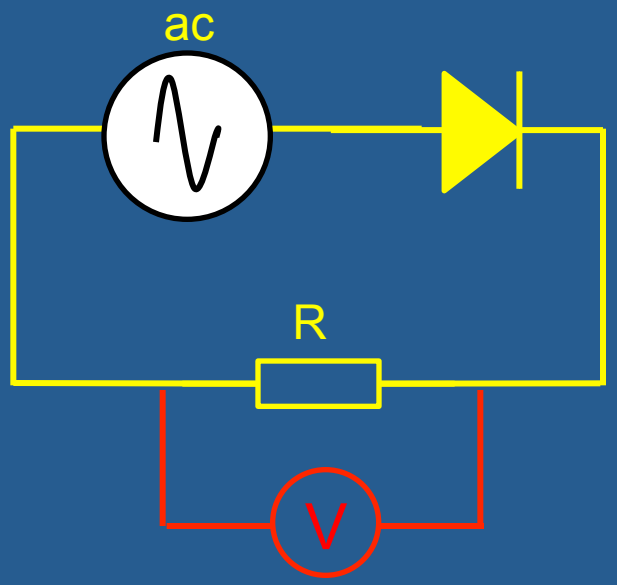


Forward biased



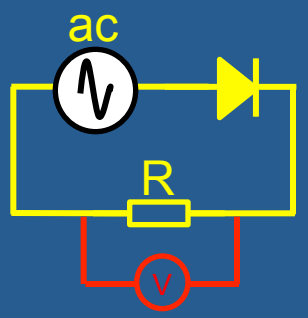
Reverse biased

A reminder about forward and reverse biasing. The diode will only conduct in one direction. That is when its anode is about 600mV positive with respect to its cathode.



The above, simple circuit shows an ac generator connected to a diode and a series resistance. The ac voltage swings about the 0 Volts going alternately positive and negative. This will forward and reverse bias the diode in sympathy with the ac voltage. The voltage is read by a voltmeter.

Half-Wave Rectification



Voltage across resistor R

+V

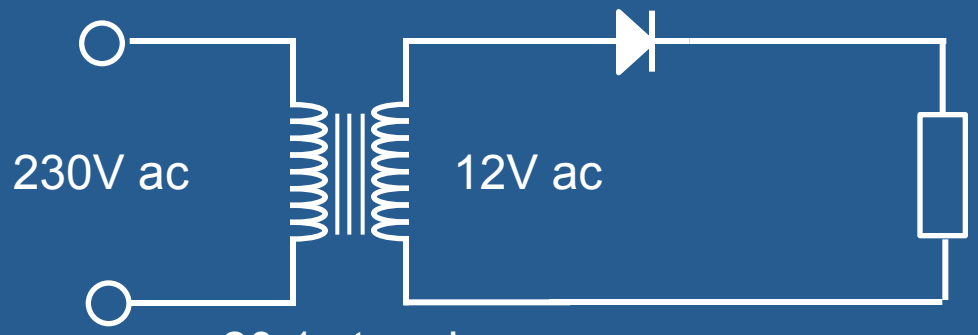
0V

-V

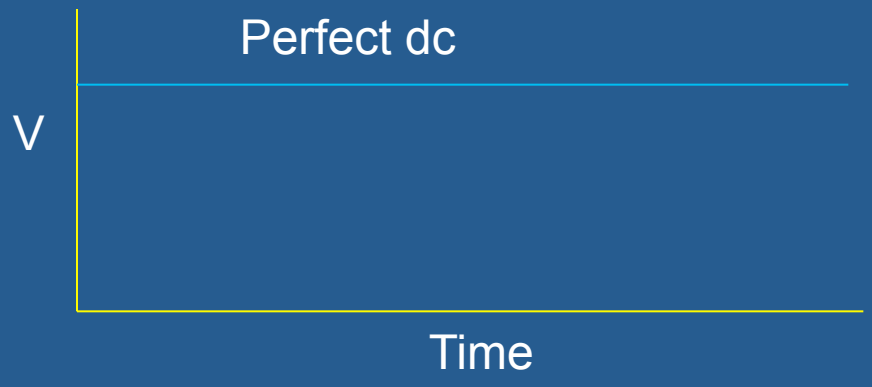
When reverse biased the diode blocks the flow of current.

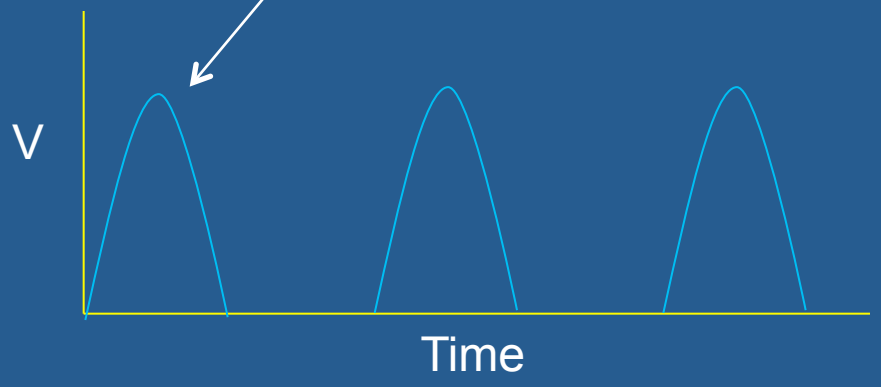
Time

Transformer + Diode Rectification



A single rectifier diode will produce pulsed dc in the load. This is fine for non-critical loads such as battery charging.





So how do you achieve a perfect dc output?

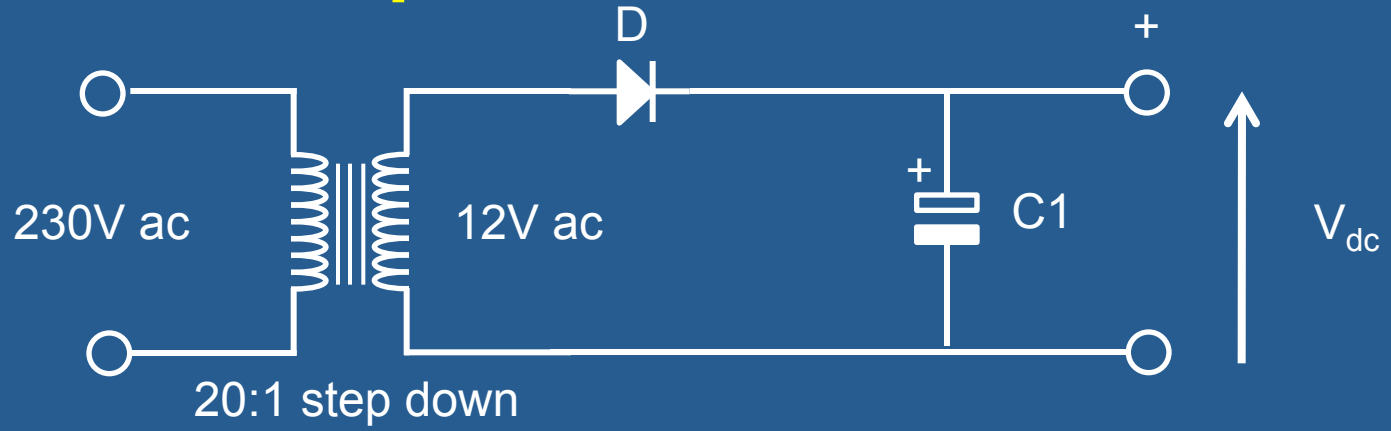
Smoothed dc Output

What we need is an electrical “flywheel”. This would store energy during a pulse and release it to the circuit when the diode was not conducting.

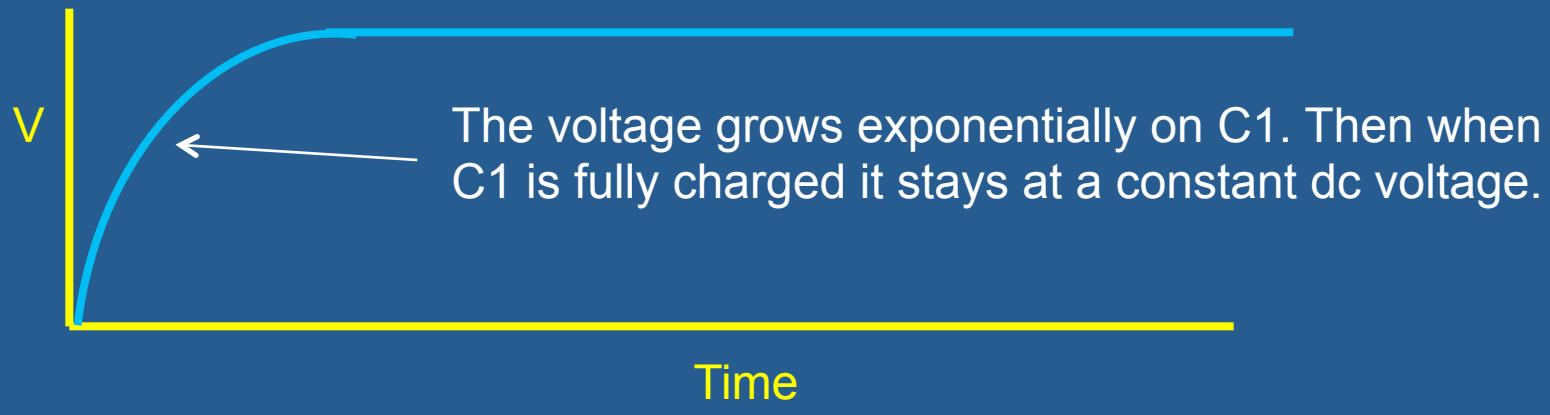
If it helps to visualise this then think of stored electrical charge like water in a cistern and the pulses like a tap filling that cistern - but turning on and off in a regular, pulsed way. You could arrange a supply of water out from the cistern that would be a continuous, steady flow. The store of water in the cistern would smooth out the pulsed flow from the tap,

The device for doing this electrically is known as a *reservoir capacitor*. This will store and release charge to give a smoother output which isn’t heavily pulsed. (This is exactly similar to a water reservoir which stores and releases water over time to maintain a steady supply.)

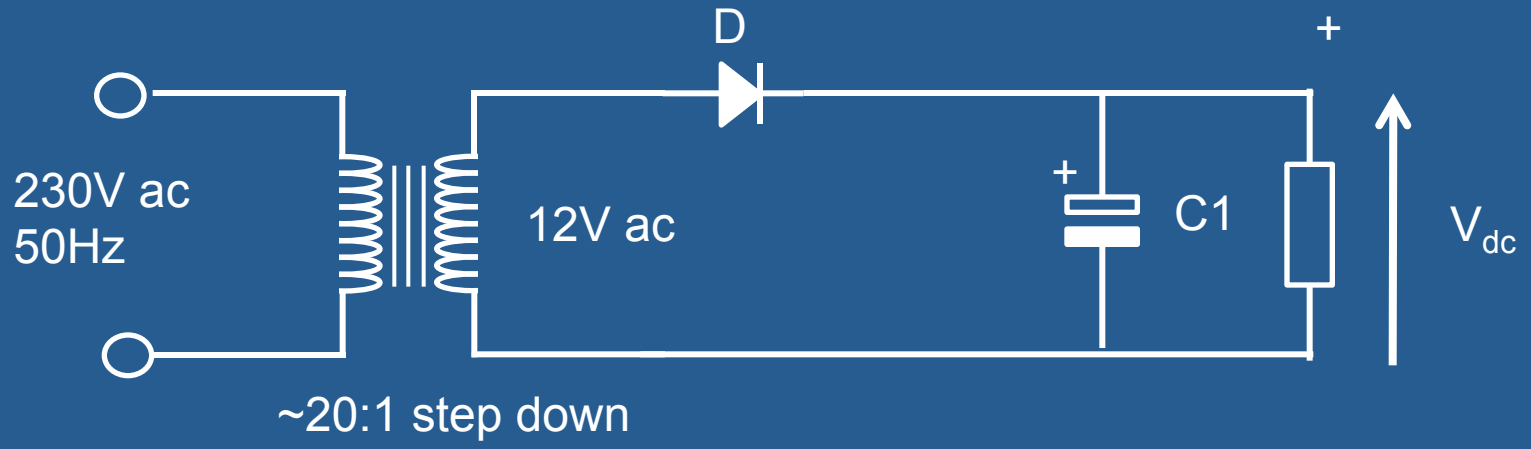
Reservoir Capacitor – No Load Condition

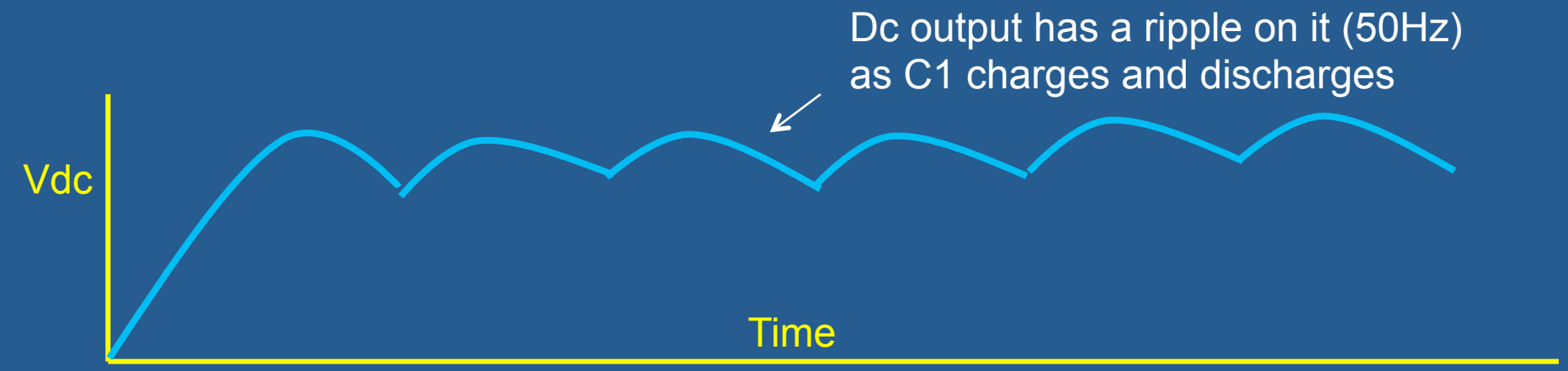


C1 is a large value, reservoir capacitor. (Typically this would be an electrolytic capacitor of several thousand microfarads.) When there is no load across the output the dc waveform will resemble the diagram below when the circuit is energised.



Reservoir Capacitor – Load Conditions





This time there is a load to be supplied with current. To do this during the period that the diode is not conducting C1 has to give up some of its charge to the load. Its terminal voltage will fall as it loses charge. (Water level in the cistern). A bigger reservoir capacitor will produce less ripple. (There is a limit though.)

Full-Wave Rectification

In the previous examples we “threw away” half of the ac waveform. (The negative going half). There is nothing “wrong” with this half of the wave – it’s simply reverses its polarity.

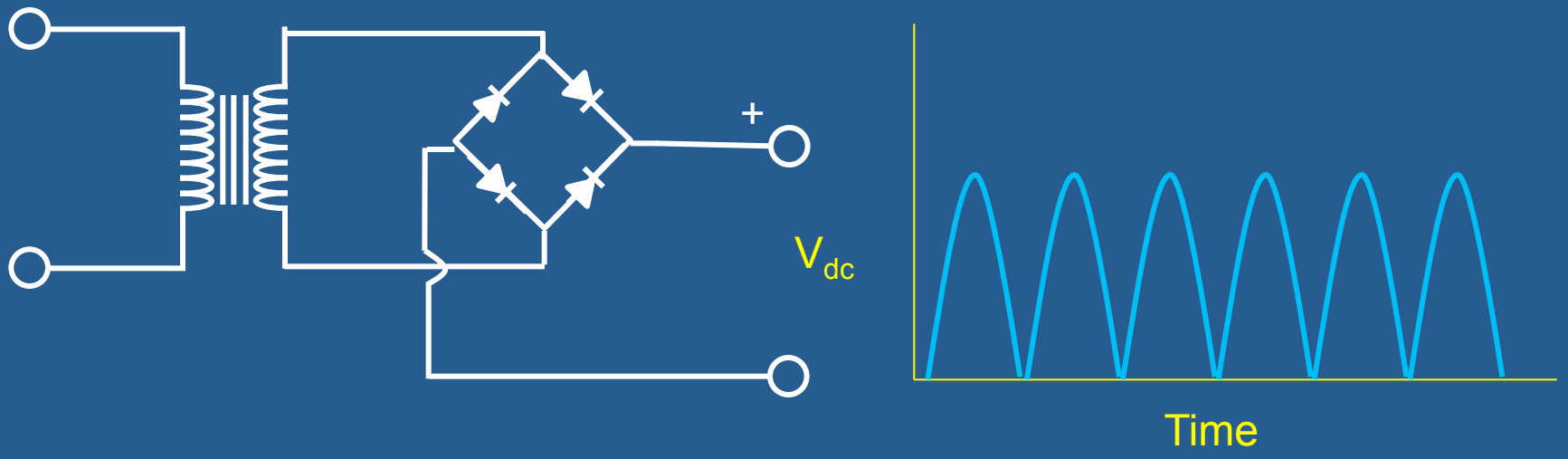
This is obviously inefficient.

A rectification process that used both the positive going and the negative going half cycles would be an efficient process.

It would also not place such demands on the reservoir capacitor, In a system that used both half cycles the reservoir capacitor would be charged at twice the frequency. This would halve the time it is discharging so that as a consequence its terminal voltage would not drop as much.

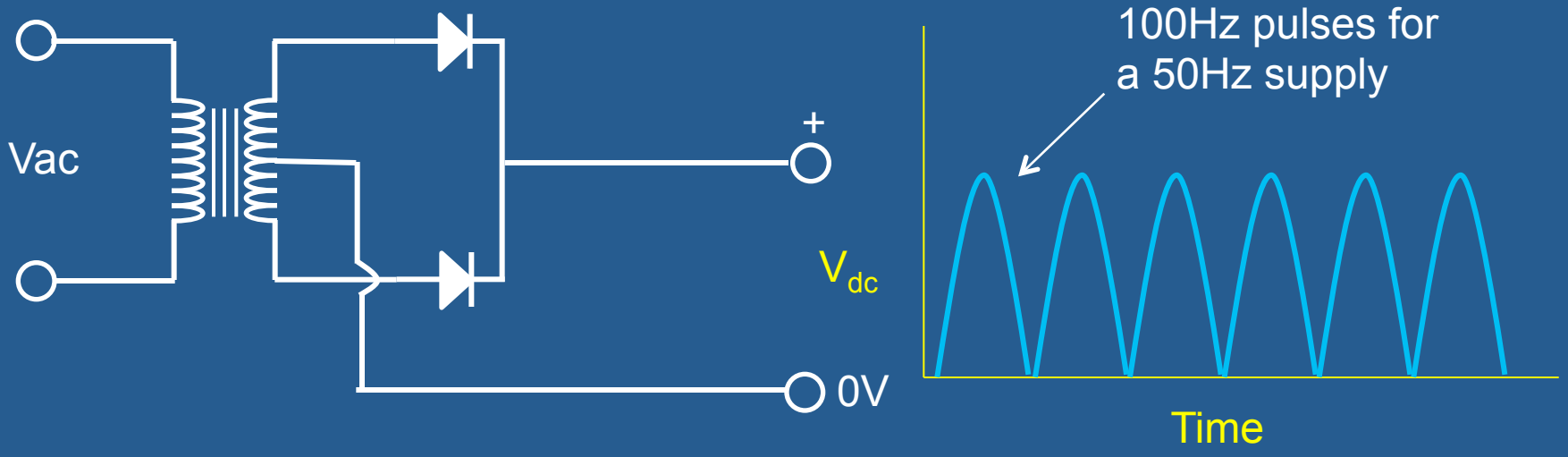
The Full-Wave Rectifier: The Bridge

The first arrangement is known as a bridge rectifier. It comprises four diodes. Usually these come as a single, encapsulated component.



The diodes steer the pulses to the output terminals of the bridge to allow the negative half of the wave to be used.

Full-Wave: Bi-Phase



The output waveform is the same as the bridge rectifier waveform. Although it only uses two diodes the transformer now has two, secondary windings.

The point at which the two windings are connected forms the 0V line.

Placing a reservoir capacitor across the output will eliminate the pulses to a greater or lesser extent depending upon the load conditions. The depth of the ripple voltage is determined by how much current the load draws.

Linear and Switched Mode Power Supplies

The term *linear power supply* implies that the power supply is regulated to provide the correct voltage at the output. Sometimes the sensing of the voltage may be accomplished at the output terminals, or on some occasions it may be achieved directly at the load.

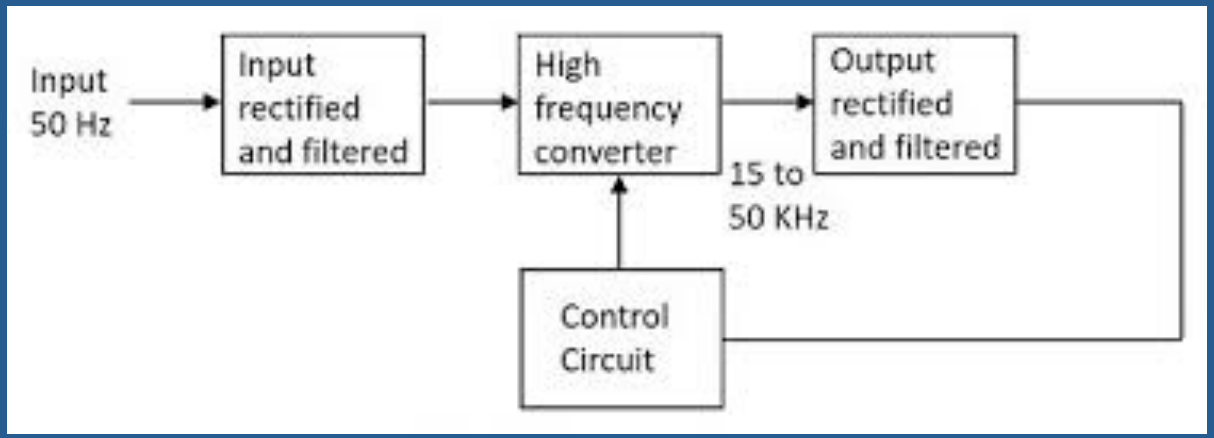
A linear power supply typically uses a large transformer to drop the voltage from an AC line to a much lower AC voltage, and then uses a series of rectifier circuitry and filtering process to produce a very clean DC voltage. The disadvantages are weight, size, and low efficiency.

Linear and Switched Mode Power Supplies

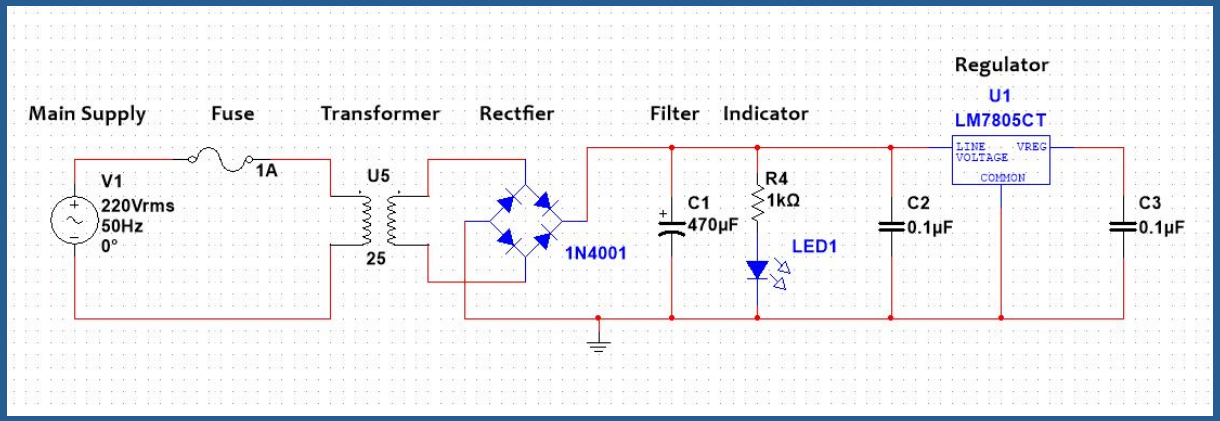
Like other power supplies, a Switched Mode Power Supply (SMPS) transfers power from a DC or AC source to DC loads, such as a personal computer or a Transceiver while converting voltage and current characteristics. Unlike a linear power supply, the pass transistor of a switching-mode supply continually switches between low-dissipation, full-on and full-off states, and spends very little time in the high dissipation transitions, which minimizes wasted energy. A hypothetical ideal switched-mode power supply dissipates no power. Voltage regulation is achieved by varying the ratio of on-to-off time (also known as *duty cycles*)

The switching frequency may be several kilohertz.

Linear & SMPS Block Diagrams



SMPS



Linear

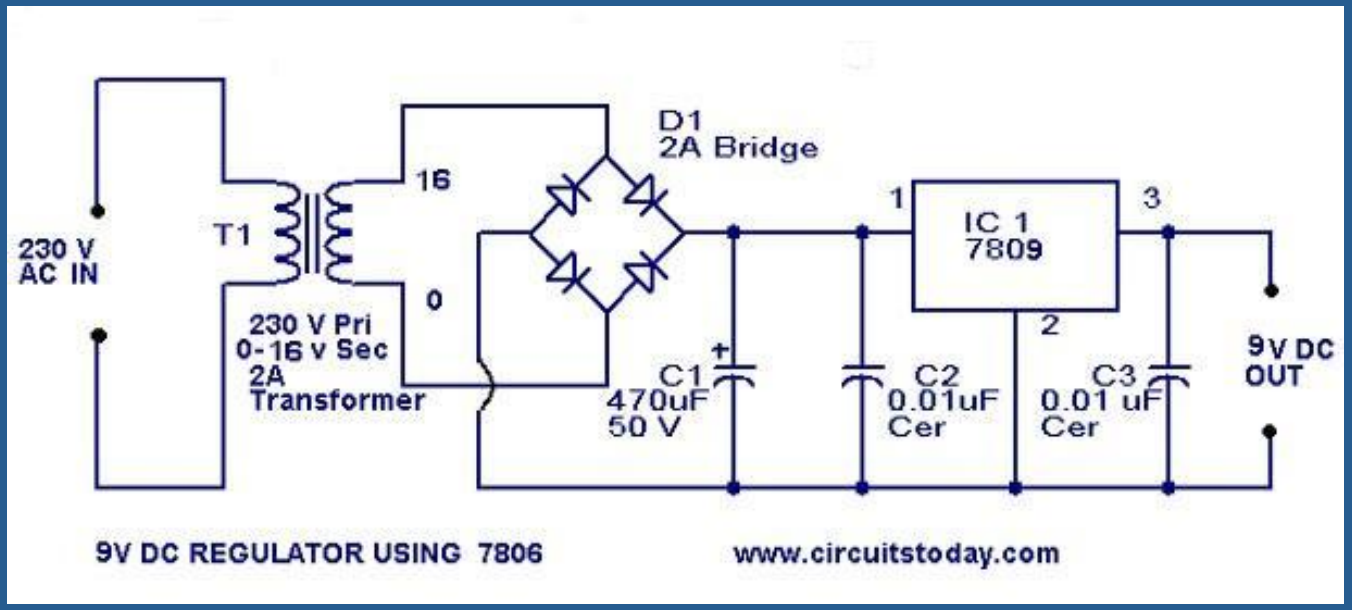
In a linear power supply the regulator has a continuous voltage drop across it.

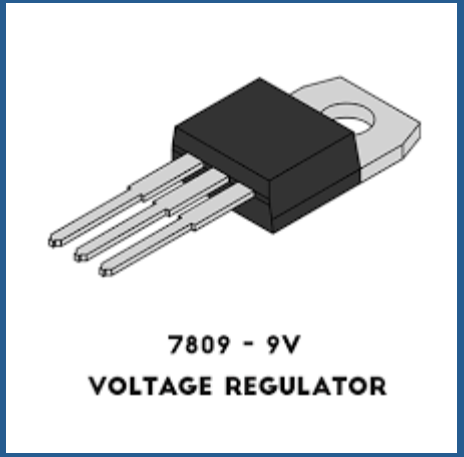
As the current increases the power dissipated by the series pass regulator increases.

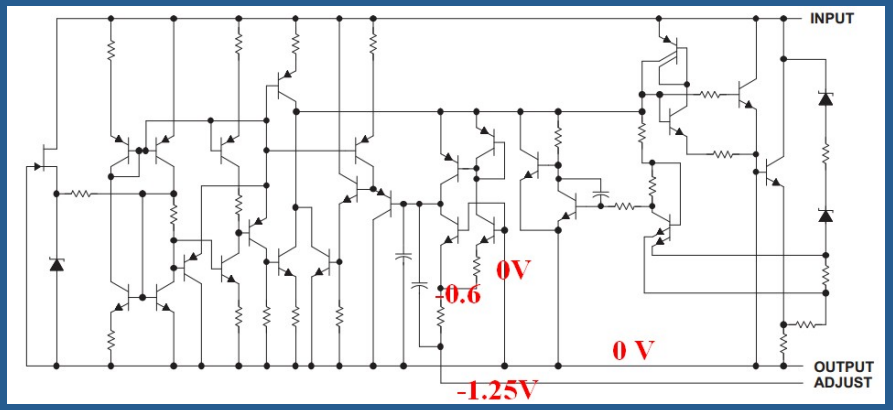
This means that the efficiency of the PSU is reduced.

SMPS can be >95% efficient. Linears are typically around 60%

Linear Power Supply LM78XX Series



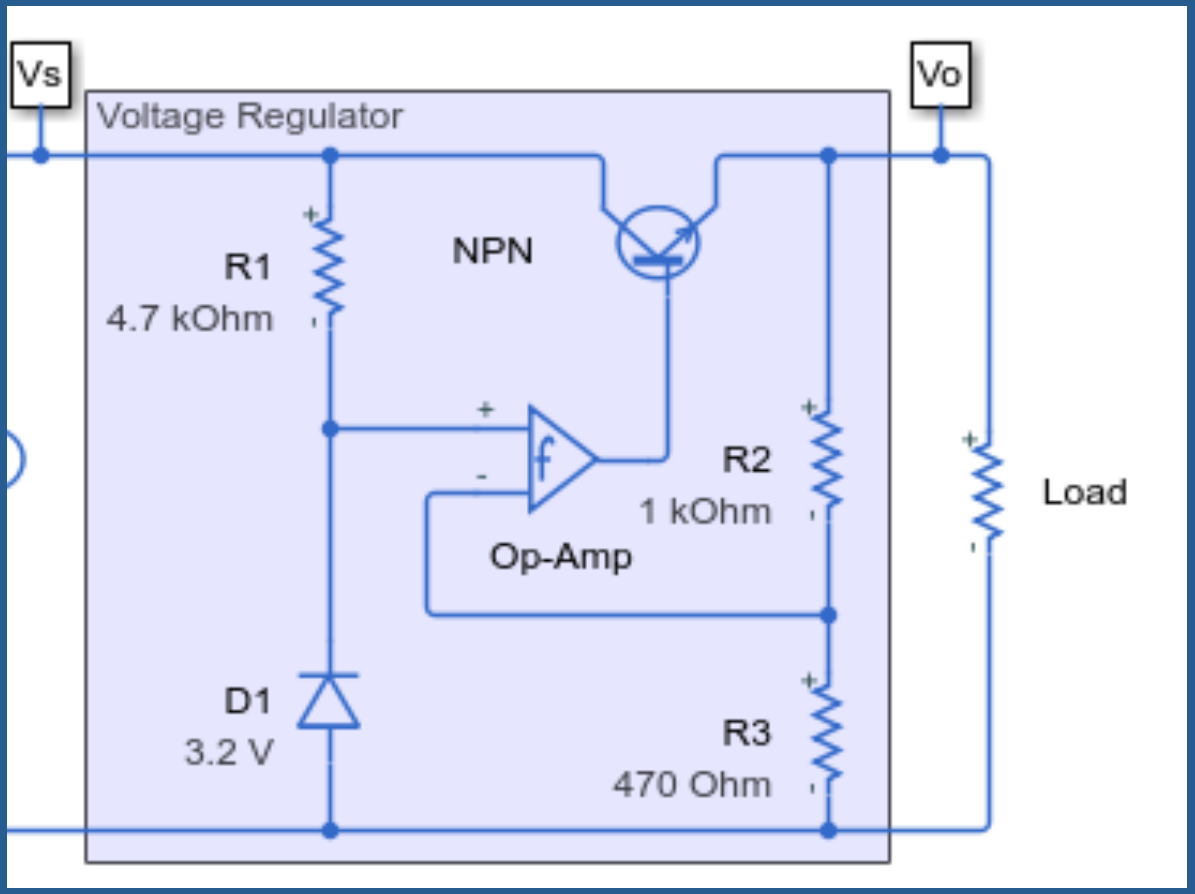




LM78XX Internal Circuit

There are a range of fixed output regulators in the LM78XX range all rated at 1A. Using an integrated circuit gives you lots of advantages over building a regulator from discrete components. These include:
Reliability, accuracy, thermal tracking, short circuit protection, size, cost, versatility.

Discrete Component Simple Linear PSU



The OP Amp is an error amplifier.

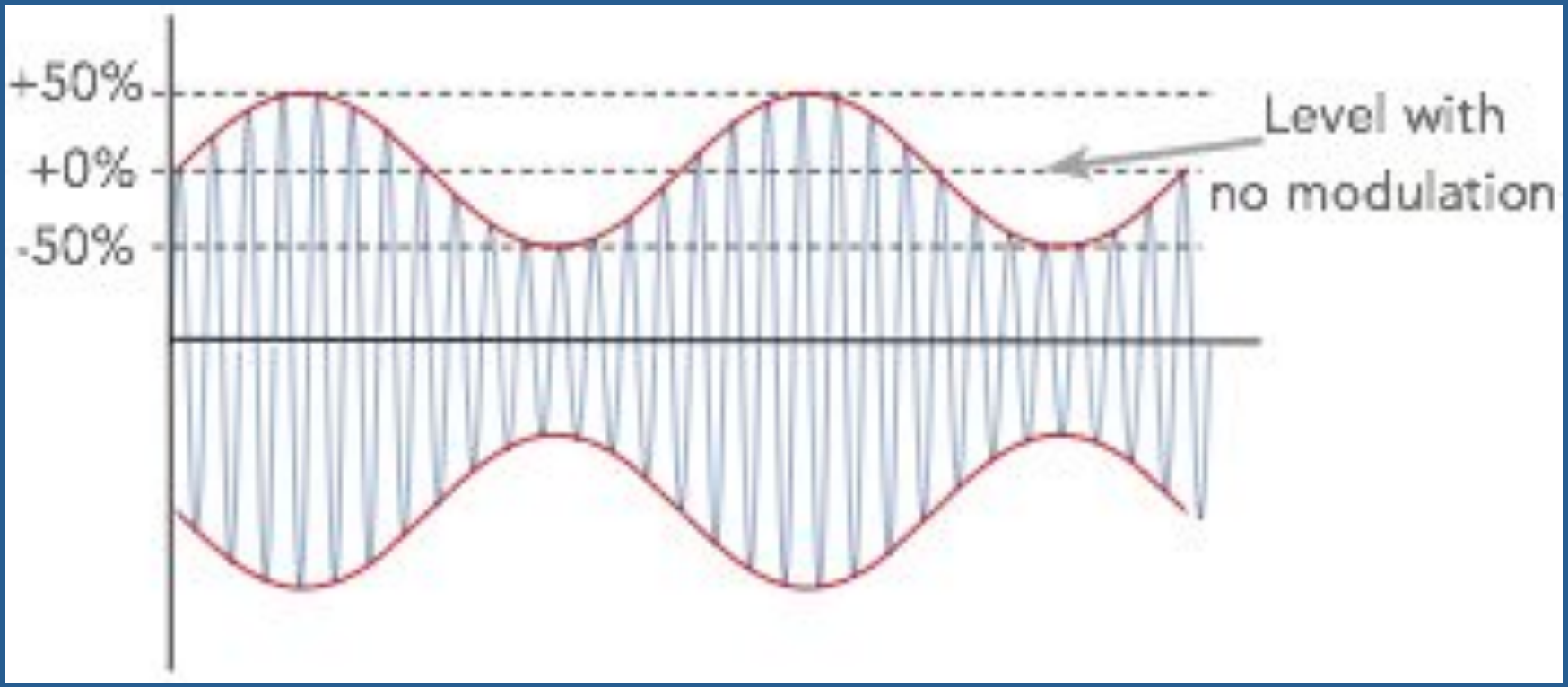
It detects changes in the output voltage and compares them to a fixed reference generated by D1.

If the output voltage starts to drop the error amplifier changes the drive current to the series pass npn transistor to maintain the output voltage at the set level.

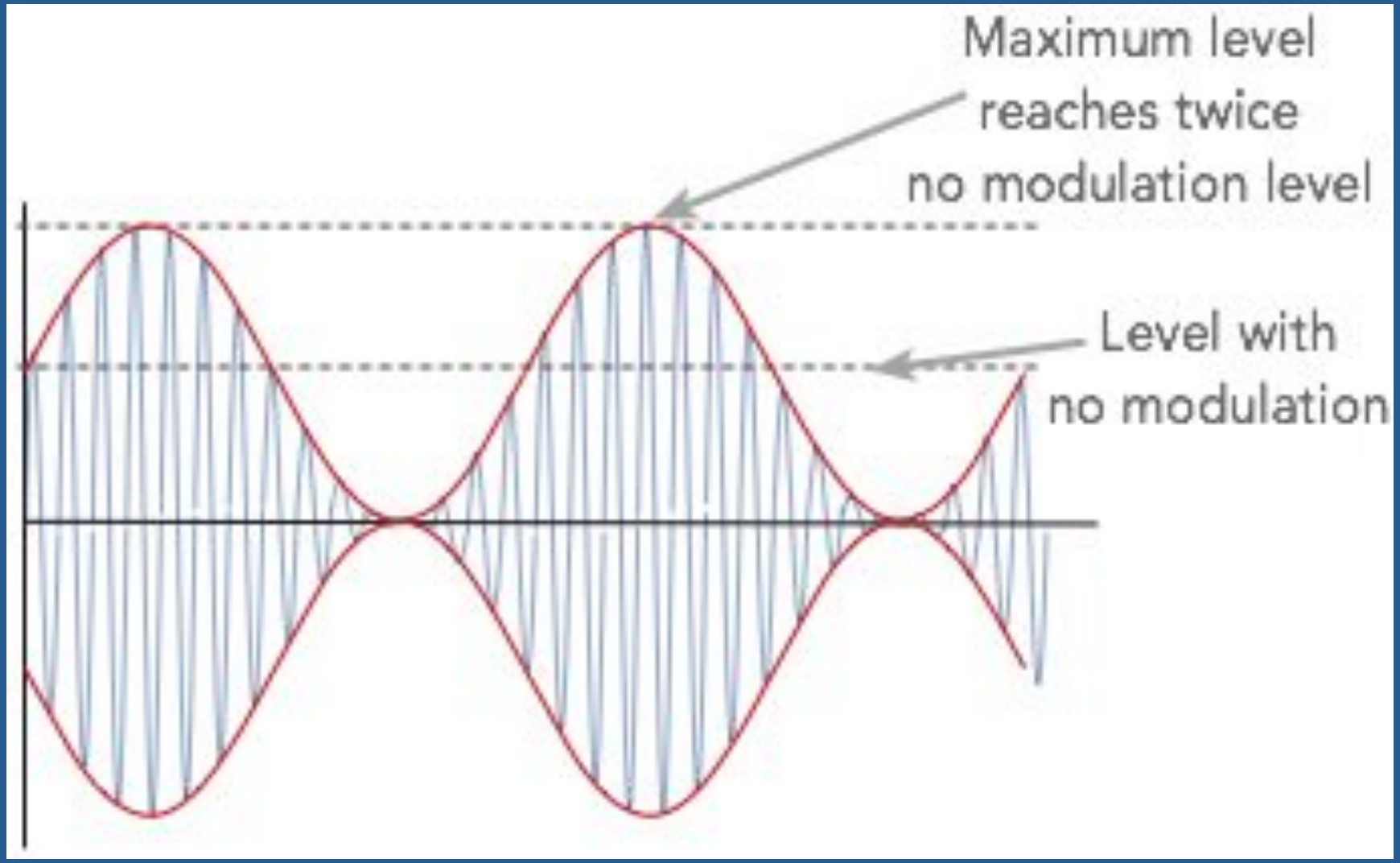
Section 3 Transmitters and Receivers

3A Transmitter Concepts

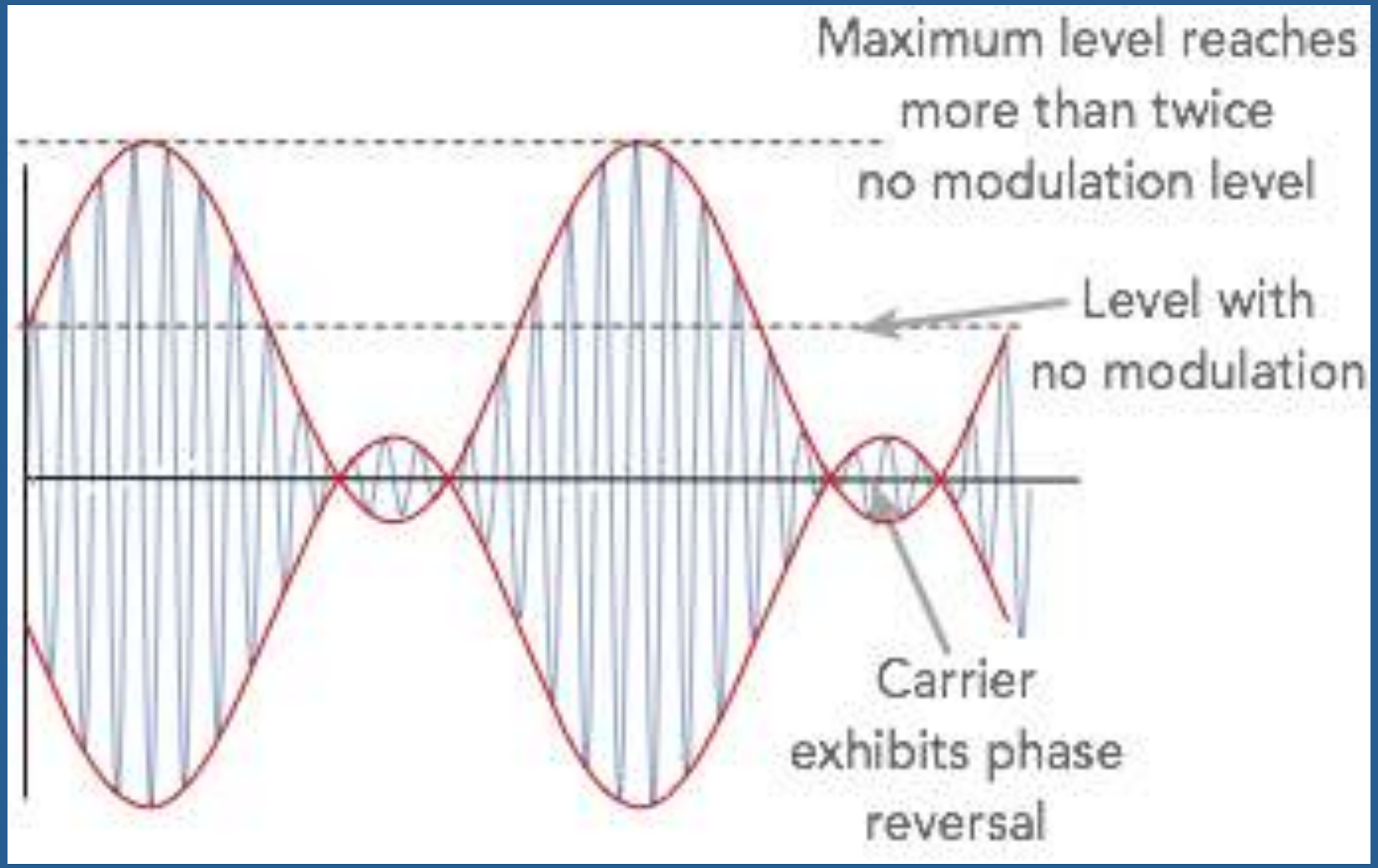
Depth of Modulation



100% Modulated Carrier



Levels In Excess of 100% Modulation



In other words the amplitude modulation index describes the amount by which the modulated carrier envelope varies about the static level.

This can be expressed in mathematical terms as below:

Modulation Index m = M/A

Where:

A = the carrier amplitude.

M = the modulation amplitude and is the peak change in the RF amplitude from its un-modulated value.

As with other modulation indices, the modulation index for **amplitude modulation**, AM, indicates the amount by which the modulated carrier varies around its static un-modulated level. When expressed as a percentage it is the same as the depth of modulation. In other words it can be expressed as: m=M/A.

Using the equation above you can see that a modulation index of 0.75 means that the signal will increase by a factor of 0.75 and decrease to 0.25 of its original level.

Peak Deviation (FM)

What is peak deviation?

When dealing with FM you will come across the term Peak Deviation which means the *MAXIMUM* amount by which the frequency of the signal may deviate from the carrier frequency. Deviation is the frequency change from the carrier frequency both above the carrier frequency and below.

FM Frequency Deviation WBFM and NBFM

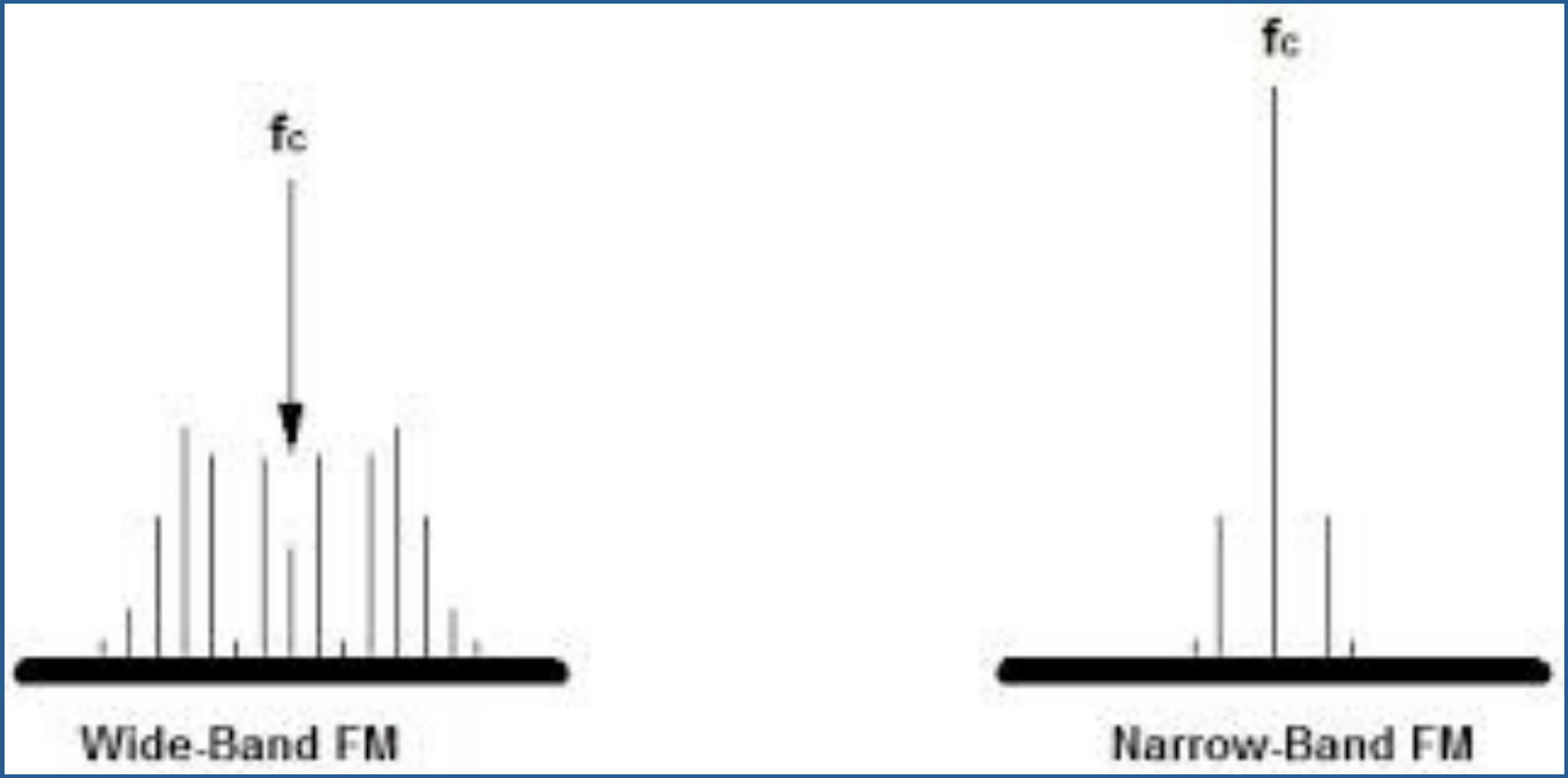
Frequency deviation in an FM radio is used to describe the maximum frequency difference between an FM modulated signal and the nominal carrier frequency.

Wide band FM (WBFM) and Narrow band FM (NBFM) describe the amount of deviation given to an FM carrier.

For voice communication NBFM is sufficient. For broadcasting music in high fidelity you need to use WBFM

The **modulation index** of **FM** is defined as the ratio of the frequency deviation of the carrier to the frequency of the modulating signal.

WBFM and NBFM Spectra



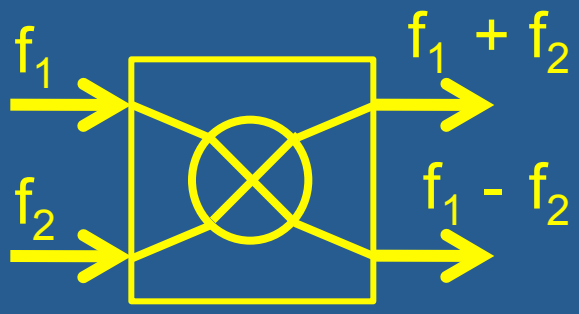
Mixers

A key process within the radio is the transfer of information at audio frequency onto an RF carrier. Another key process is the changing of one frequency to another with the retention of the carried information from one to the other.

This process is carried out in a circuit called a mixer.

When two frequencies are mixed together two further frequencies are produced at the output of the mixer.

Suppose that we have two frequencies f_1 and f_2. Further let's say that f_1 is 1MHz and f_2 is 50MHz



(50MHz + 1MHz) = 51MHz

(50MHz - 1MHz) = 49MHz

AM Modulation And Sidebands

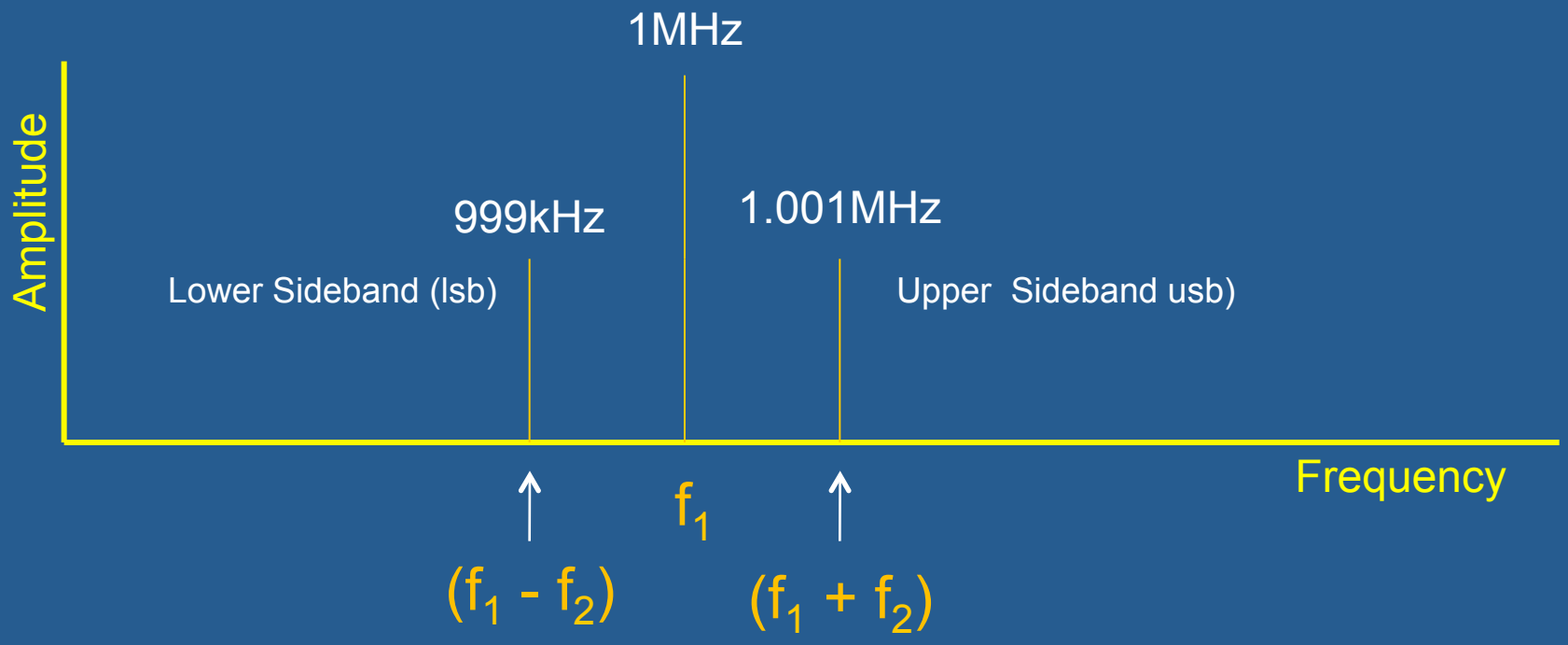
When one of the two input frequencies is an audio frequency and the other is a radio frequency then the resulting two frequencies (f_1 +/- f_2) are known as sidebands.

The output (f_1 + f_2) is the Upper Sideband (usb)

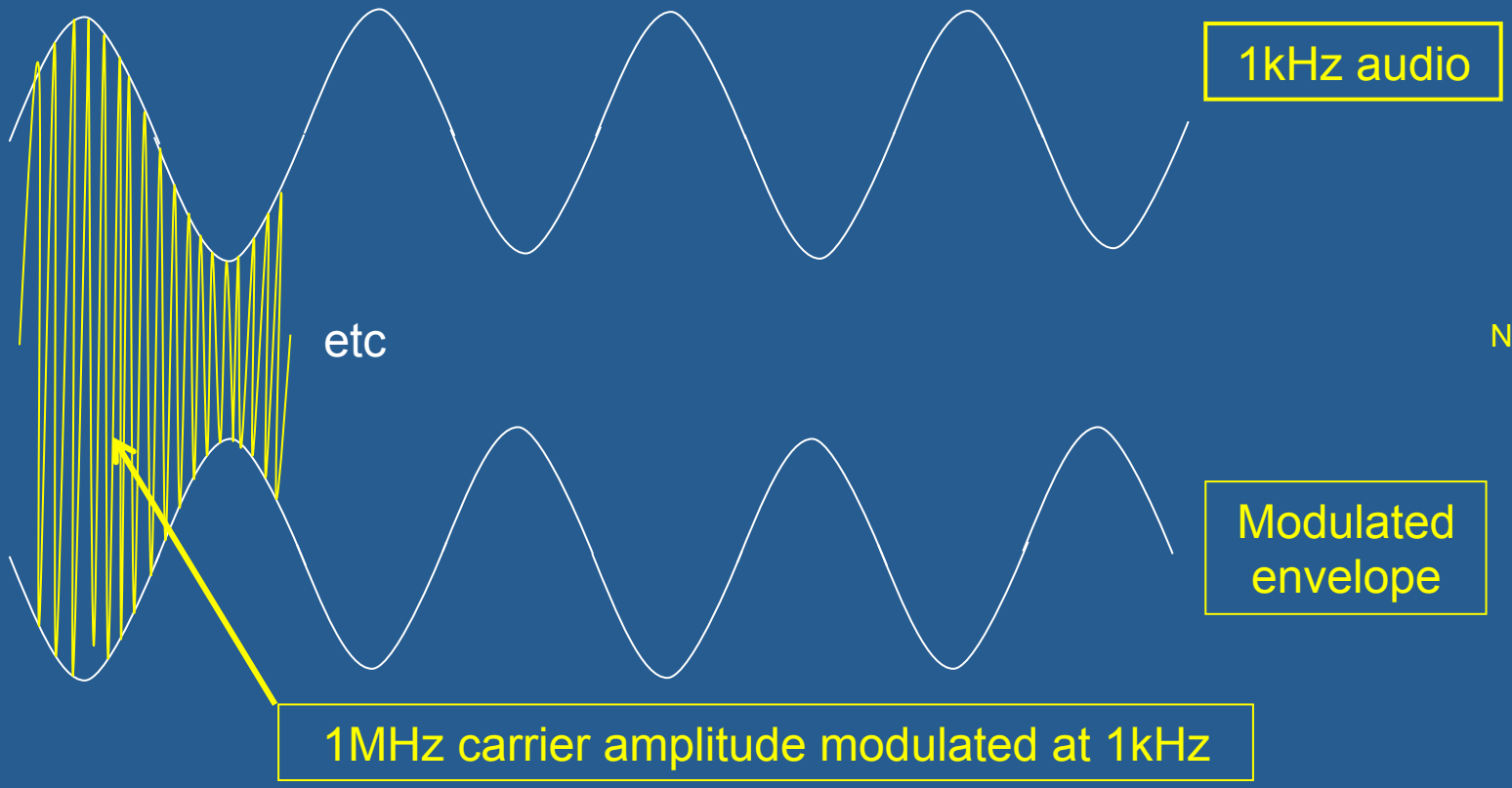
The output (f_1 - f_2) is the Lower Sideband (lsb)

The next slide shows the frequency spectrum for a carrier of 1MHz and an audio signal of 1 kHz.

Spectrum Of 1MHz (f_1) and 1kHz (f_2)

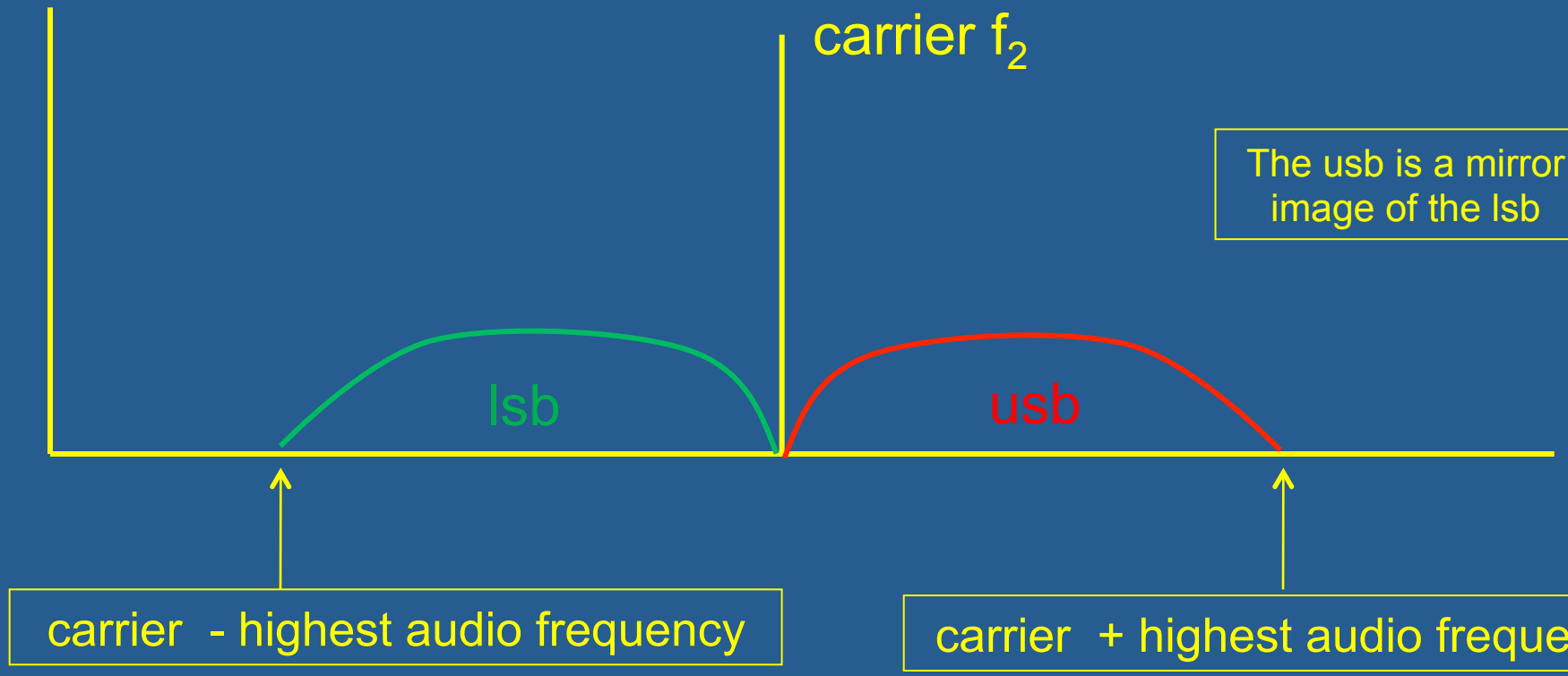


Time Domain of 1MHz and 1kHz



The amplitude of the modulated 1MHz RF carrier is varying at a rate of 1kHz

AM Modulation, Sidebands and Speech



Where the modulating frequency is a continuous band of frequencies (eg speech) then the sidebands (f_2 +/- f_1) are also a continuous band mirroring the speech.

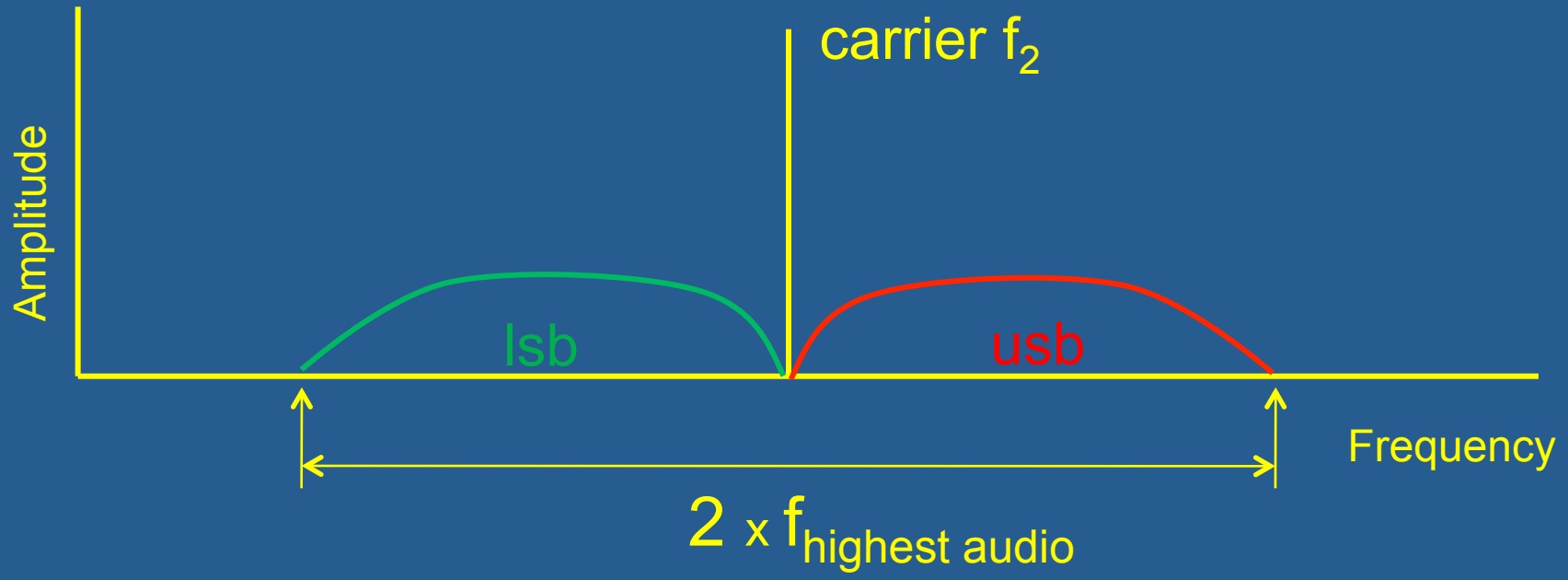
Single Sideband Suppressed Carier (SSB)

In radio communications, single-sideband modulation (SSB) or single-sideband suppressed-carrier modulation (SSB-SC) is a type of modulation used to transmit information, such as an audio signal, by radio waves.

A refinement of amplitude modulation, it uses transmitter power and bandwidth more efficiently. Amplitude modulation produces an output signal the bandwidth of which is twice the maximum frequency of the original baseband signal.

Single-sideband modulation avoids this bandwidth increase, and the power wasted on a carrier, at the cost of increased device complexity and more difficult tuning at the receiver.

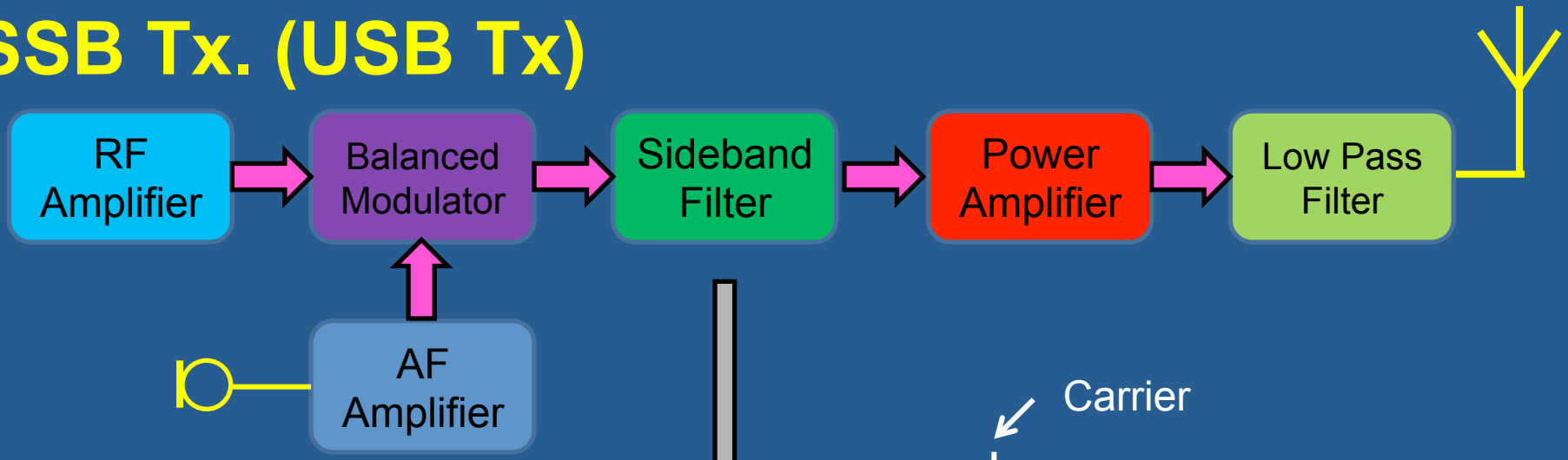
Single Sideband



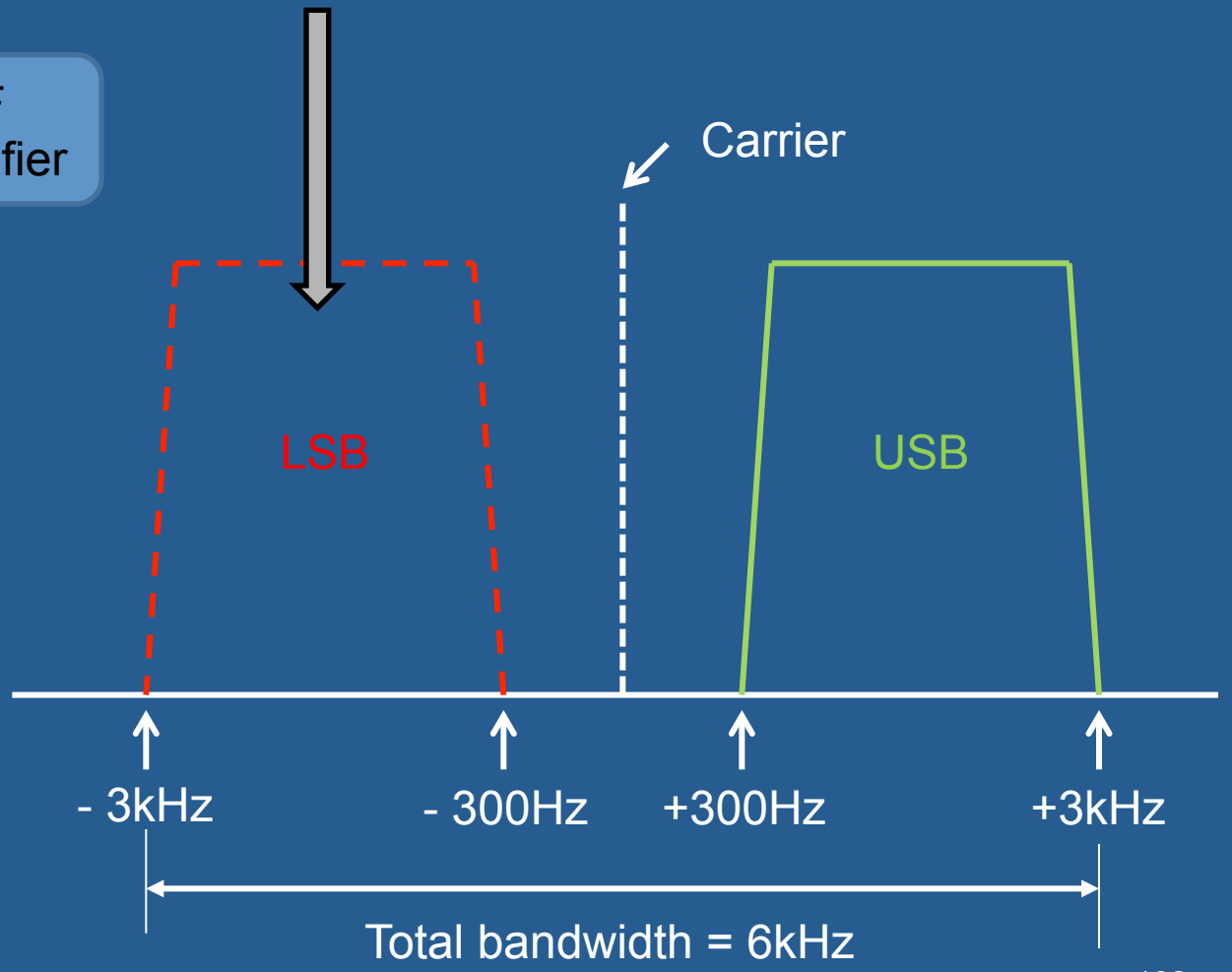
Both sidebands (upper and lower) carry identical information – but each is the mirror image of the other. The carrier wave itself carries no information. Its purpose is to fix the position of the sidebands on the frequency spectrum. If the highest audio frequency is f_h then the AM signal occupies a bandwidth of twice the highest audio frequency.

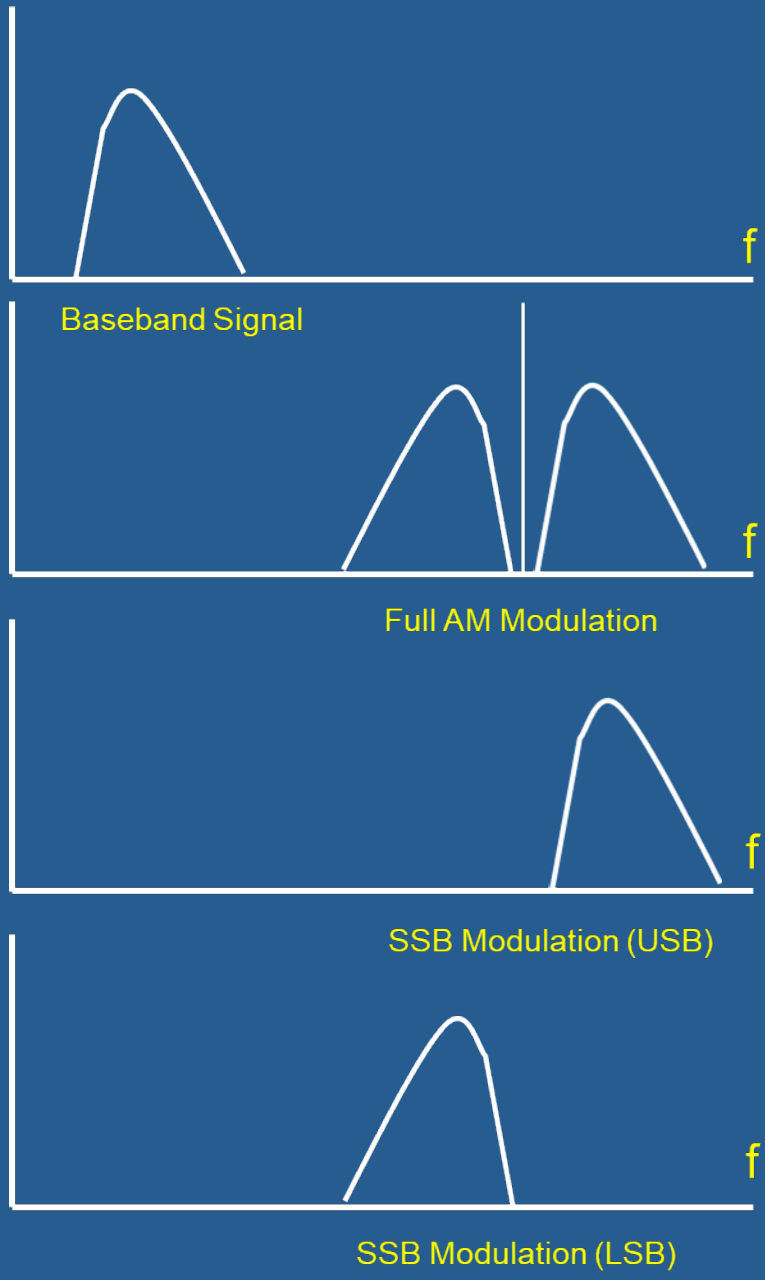
eg. f_h is 3kHz. The bandwidth (bw) is thus 2 x 3kHz = 6kHz

SSB Tx. (USB Tx)



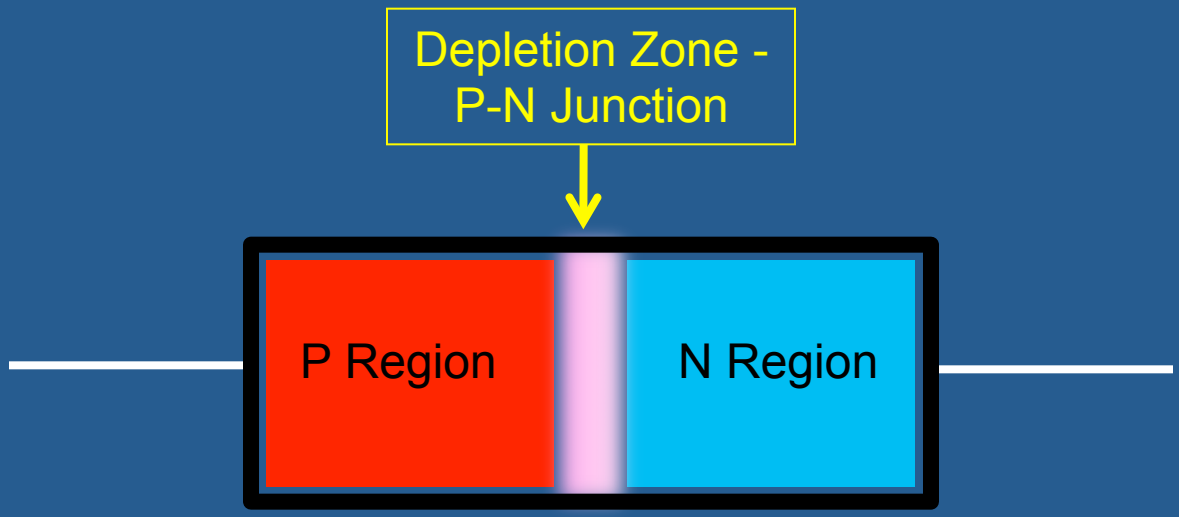
By removing the "mirror image" sideband and the reference carrier you halve the RF bandwidth for an audio signal – thus increasing the capacity of the allocated frequency block for signals by a factor of two. All the Tx power can go into the remaining sideband alone.





- *AM uses less bandwidth than FM*
- *SSB uses less bandwidth than AM*
- *CW uses less bandwidth than SSB.*
- *Digital modes may use less bandwidth than any of the above*

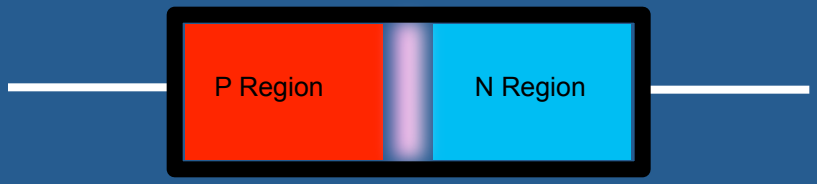
Variable Capacitance Diode (Varicap)



The unique feature of the diode is the junction or depletion zone. Here the two, doped regions merge. The N-type – with its excess of electrons and the P-type with its excess of holes. (Removed electrons.) In this area the holes and electrons combine to form a depletion zone with very few free charge carriers - the P-N Junction.

The junction looks like a plate capacitor. The area of the plate is determined by the physical and mechanical construction of the diode. The depletion layer behaves like a variable-width, dielectric filling between the plates. As the depletion layer varies in extent it alters the distance between the plates and hence the capacitance of the junction

Varicap Diode



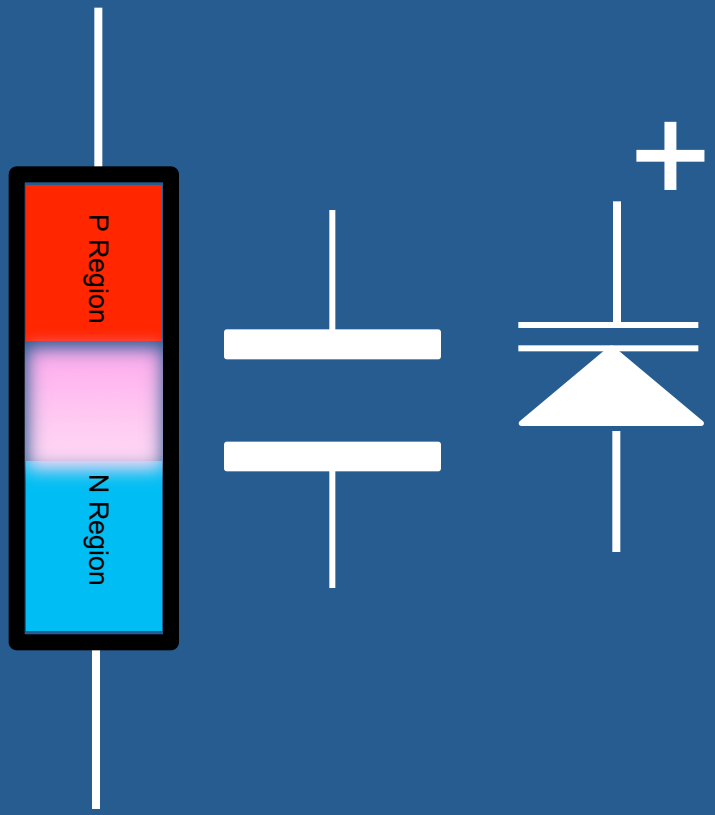
As the diode approaches forward bias the depletion zone shrinks. (This is because you are injecting carriers into the diode from the power supply.) This reduction in the depletion layer causes the diode to start to conduct. When the diode is reverse biased you are increasing the width of the depletion layer. Its resistance rises and it will not conduct. The diode blocks.

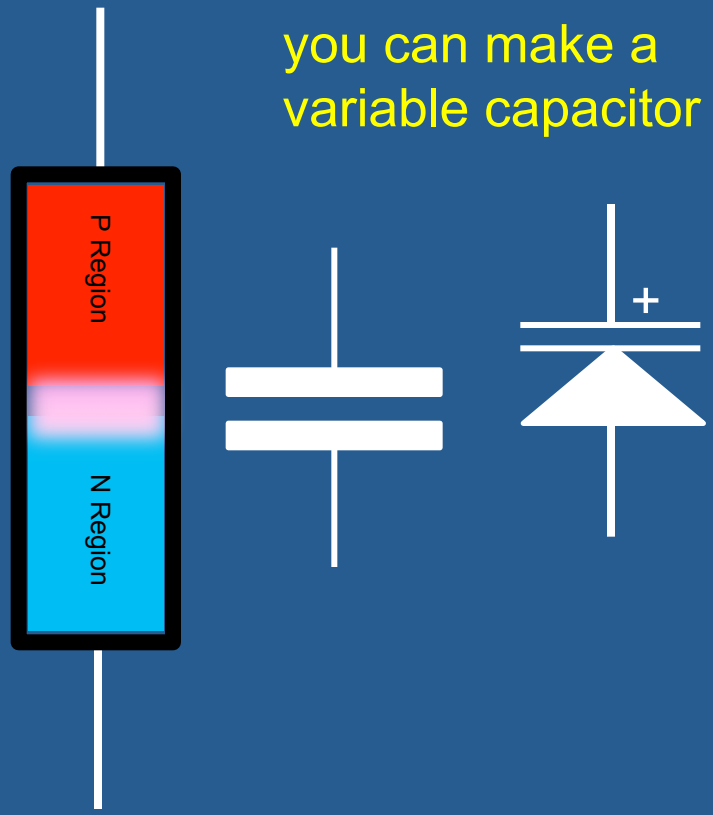
The junction looks like a plate capacitor. The area of the plate is determined by the physical and mechanical construction of the diode. The depletion layer is a variable-width, dielectric filling between the plates. As the depletion layer varies in extent it alters the distance between the plates and hence the capacitance of the junction.

The more you reverse bias the diode the further apart the plates become and the capacity will fall. Conversely, the nearer the diode comes to conduction the closer are the plates and the higher the capacity.

Varicap Diode: Bias Effect

Thus by varying the reverse bias you can make a variable capacitor

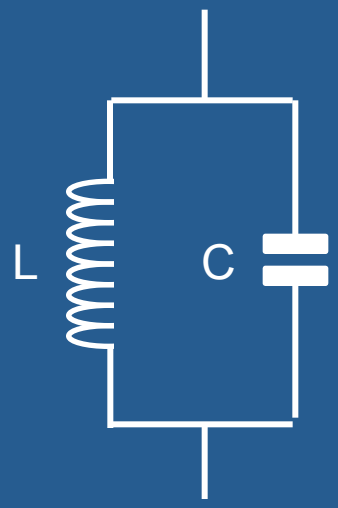




Large reverse bias applied to the diode. Big depletion layer and small capacitance

Small reverse bias applied to the diode. Small depletion layer and large capacitance

Transistor Oscillator



A parallel tuned circuit

This combination of a capacitor and an inductor has a natural *resonant frequency.*

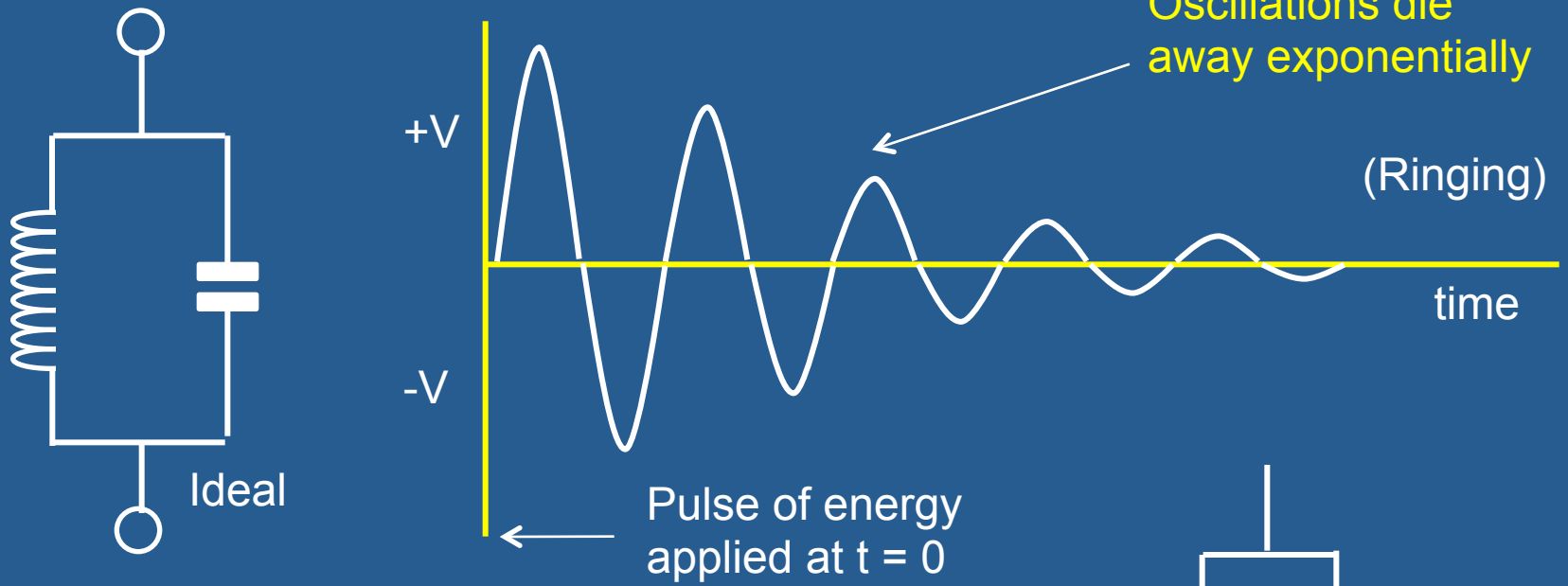
This frequency is determined by the values of L and C.

The equation for calculating the frequency is:

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Where L is in *HENRIES* and C is in *FARADS*

Transistor Oscillator

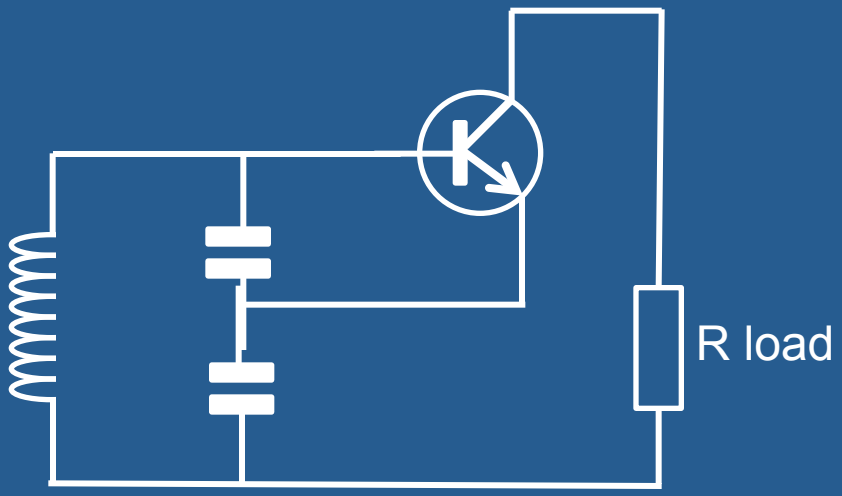


In practice the oscillations (*at the resonant frequency*) die away because the circuit has intrinsic resistance. (coil winding resistance). The energy which was originally stored magnetically in the coil and electro-statically in the capacitor is dissipated as heat in this unavoidable resistance, When winding coils for tuned circuits you should aim to use wire of the lowest, practical resistance.

Transistor Oscillator

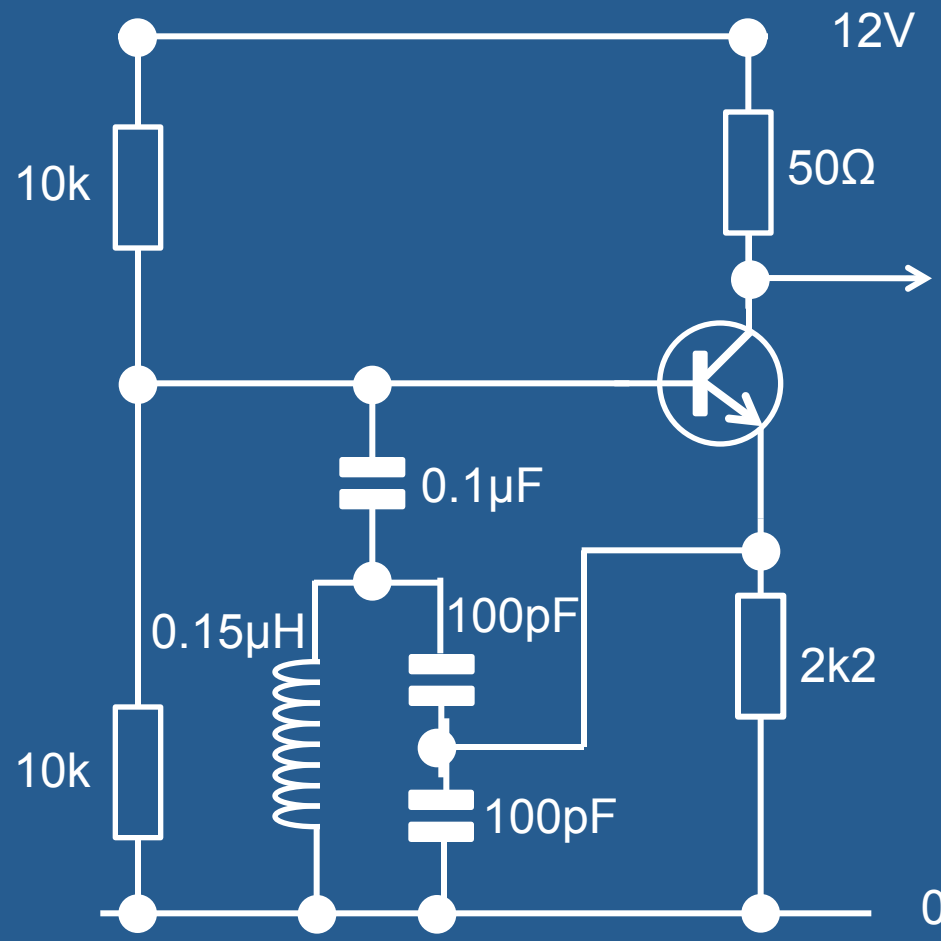
What we need is some means of counteracting this loss of energy through the circuit resistance. If we can do this then we can sustain the oscillations indefinitely. By choosing our values for L and C we can tailor the frequency to produce a practical oscillator.

By using a transistor to provide gain to overcome the losses the tuned circuit will provide the core element of an oscillator.



The transistor makes up for the resistive losses. It provides positive feedback to the tuned circuit to keep it resonating.

Colpitts Oscillator – Practical Circuit



$$f = \sqrt{\frac{0.159}{L1\left\{\frac{C1 \,.\, C2}{C1 + C2}\right\}}}$$

~ 50MHz

Crystal Oscillator

A crystal oscillator makes use of the piezoelectric effect.

The piezoelectric effect is an electro-mechanical property of a crystal. Under an applied voltage the crystal lattice will shift or distort. (Mechanical effect). Conversely a mechanical displacement of the crystal will cause a voltage to appear across opposite faces. (Electrical effect).

Mechanical Displacement  Piezoelectric Voltage

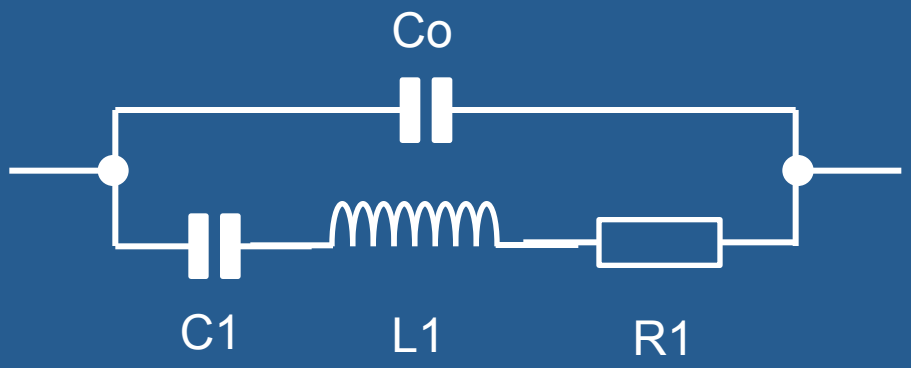
The crystal behaves like a mechanical tuning fork and a tuned circuit

If the crystal (generally quartz) is cut and mounted properly it will oscillate at a precise frequency.

Crystal Oscillator



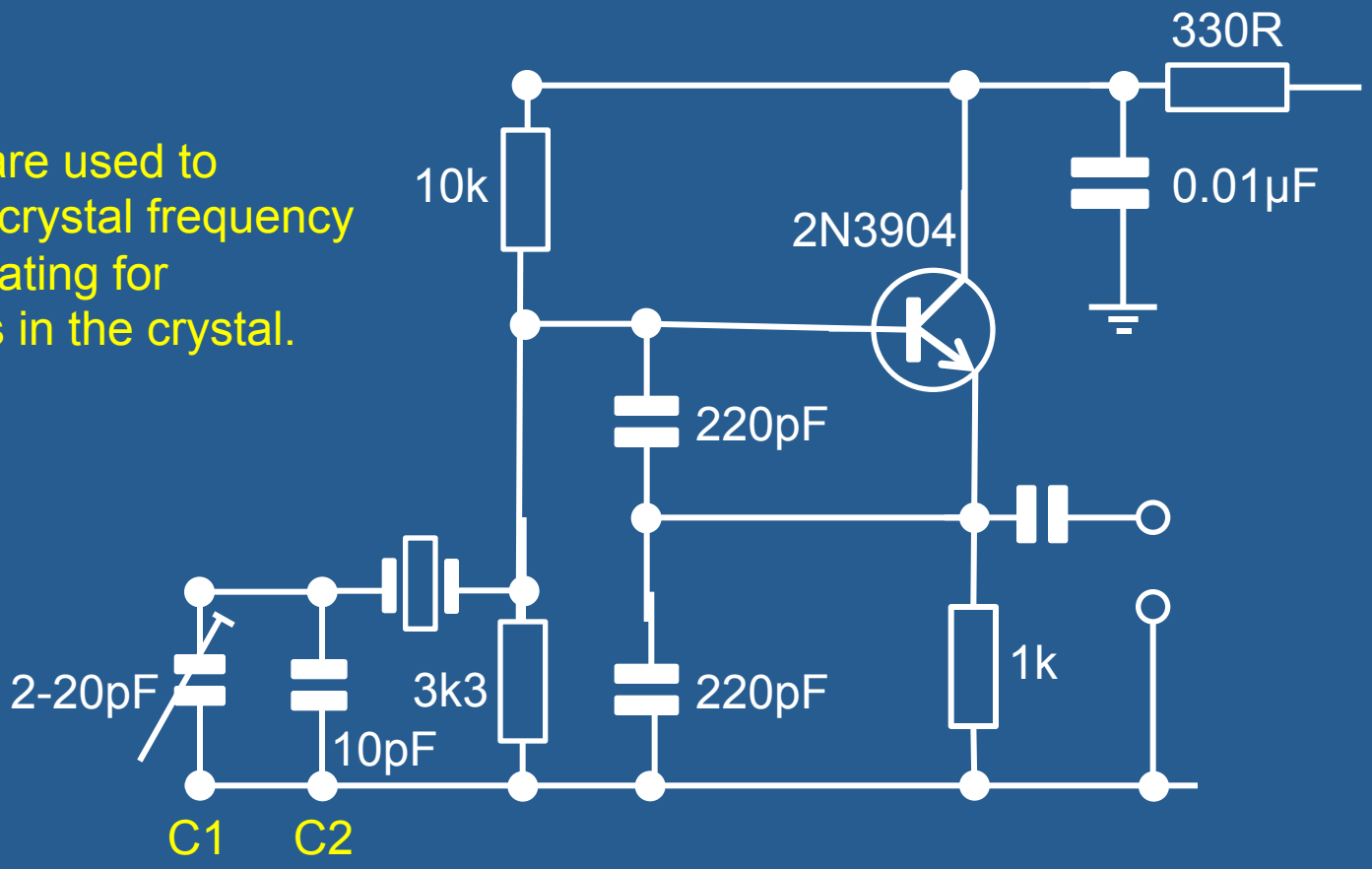
Circuit Symbol



Equivalent circuit of a crystal oscillator.

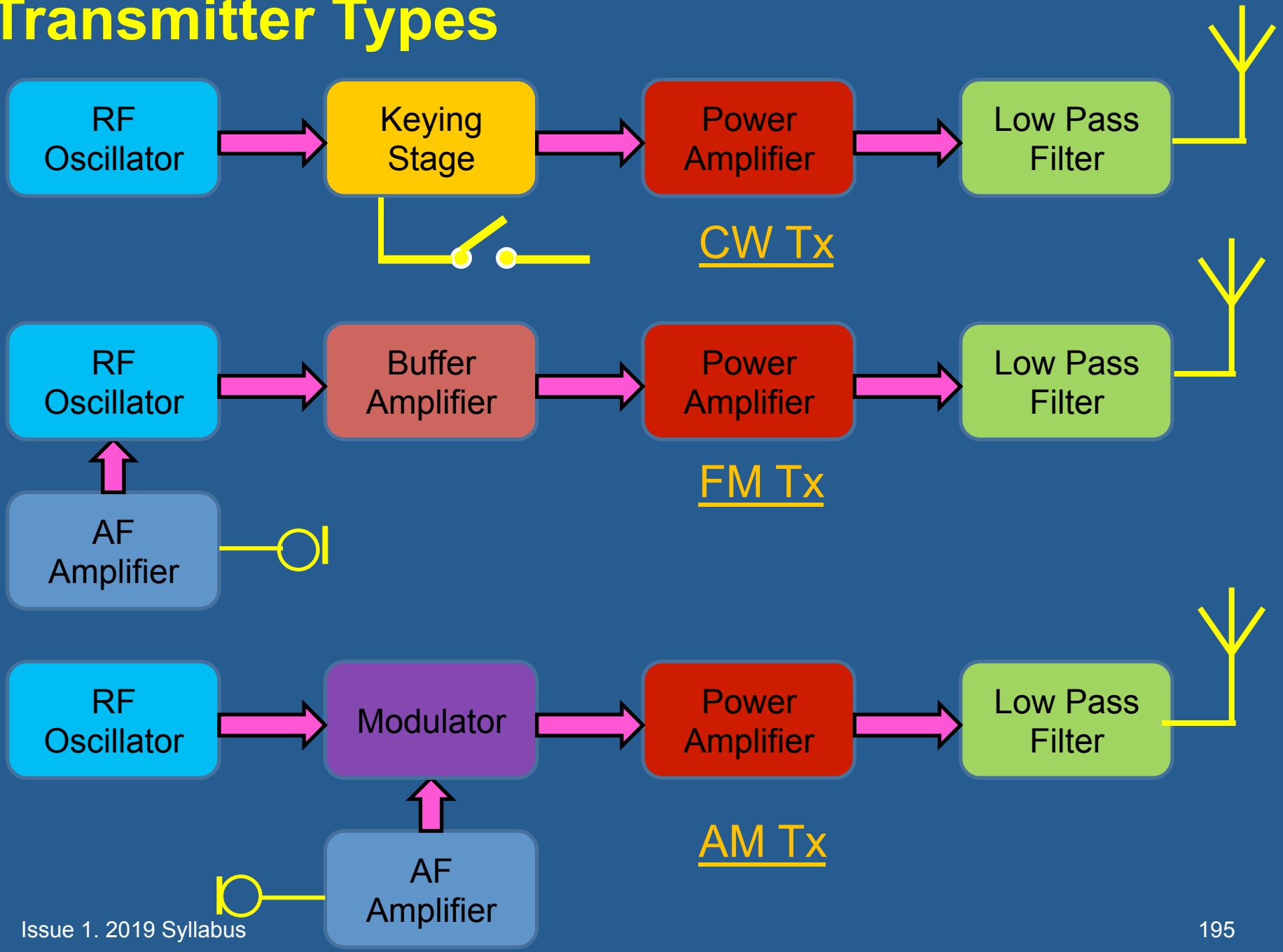
Colpitts Crystal Oscillator

C1 and C2 are used to "nudge" the crystal frequency by compensating for inaccuracies in the crystal.

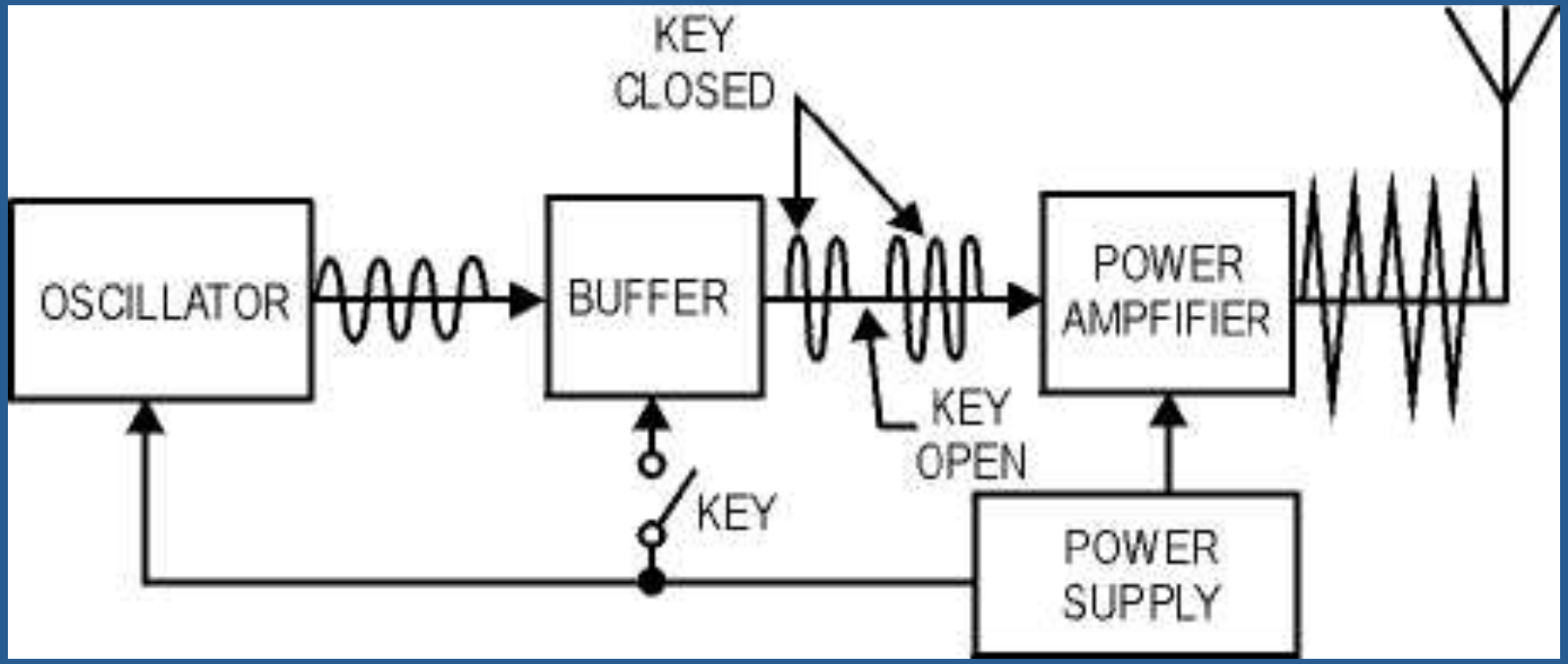


3B Transmitter Architecture

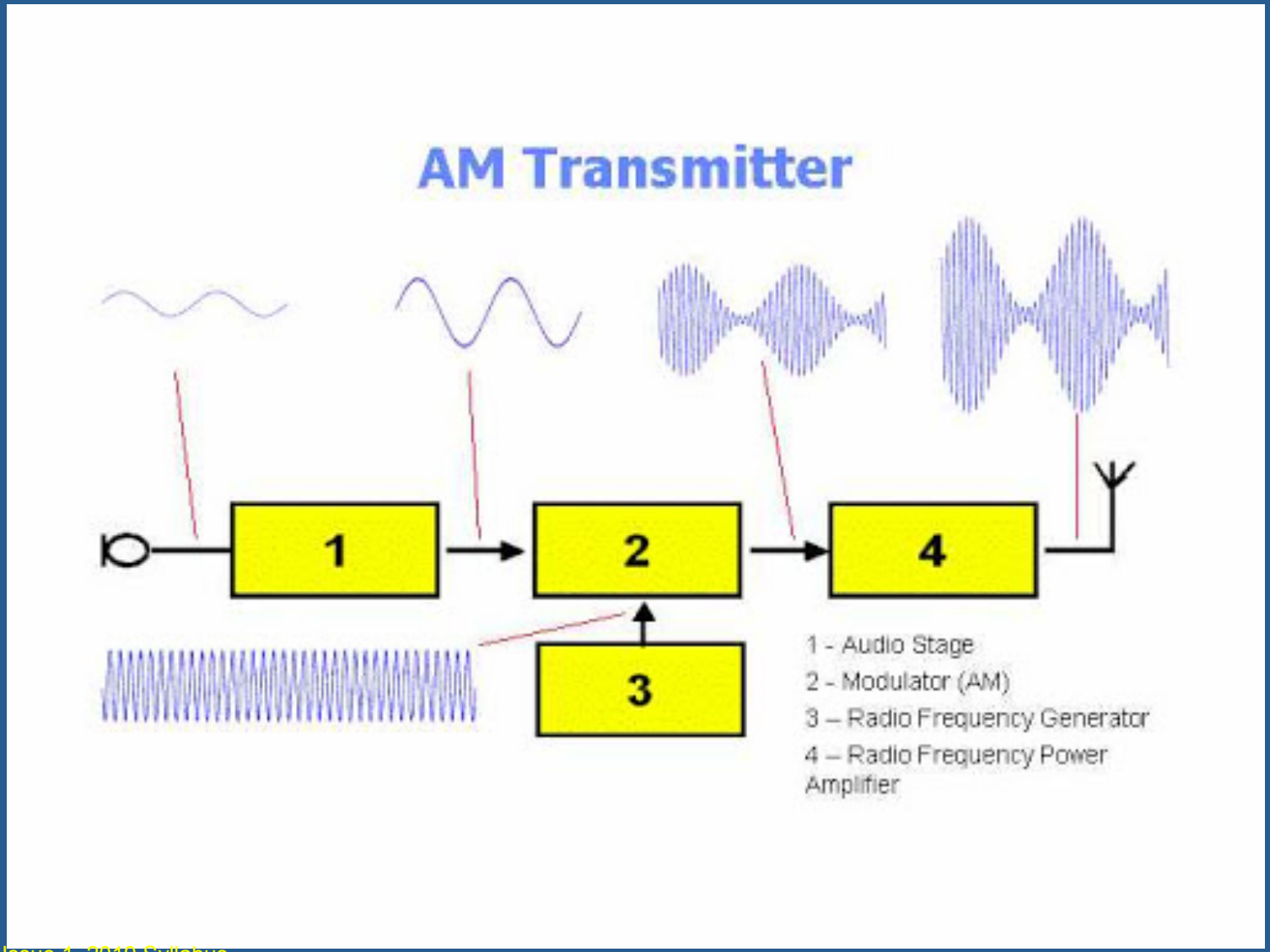
Transmitter Types



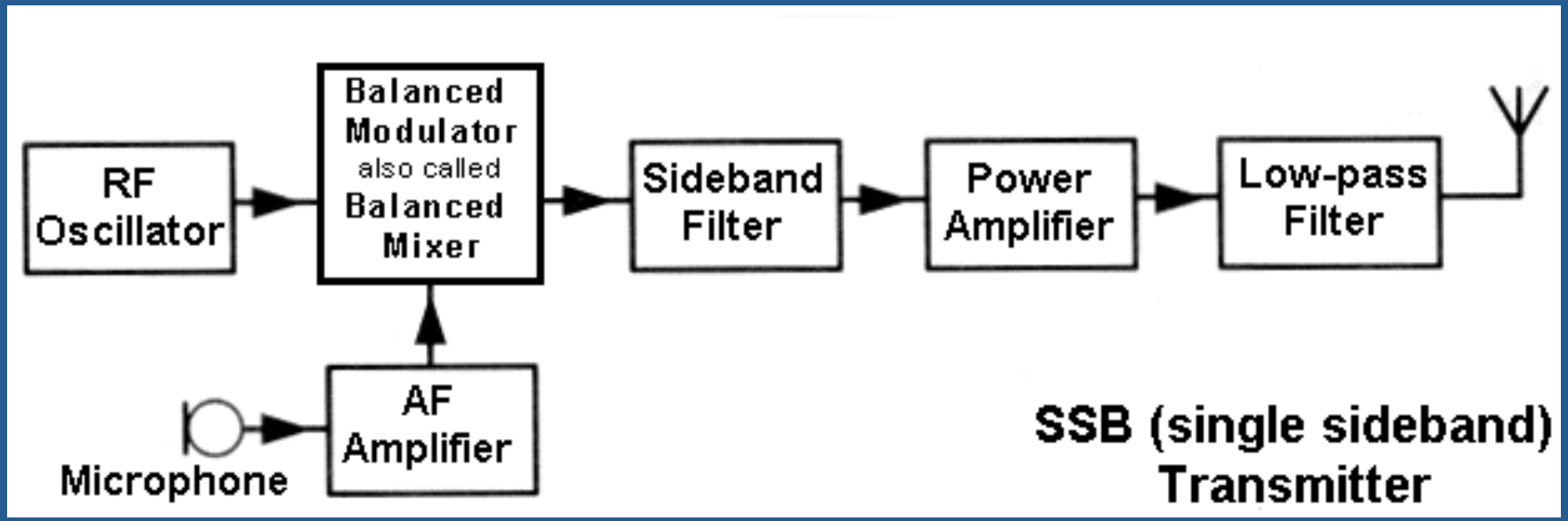
CW Transmitter Block Diagram



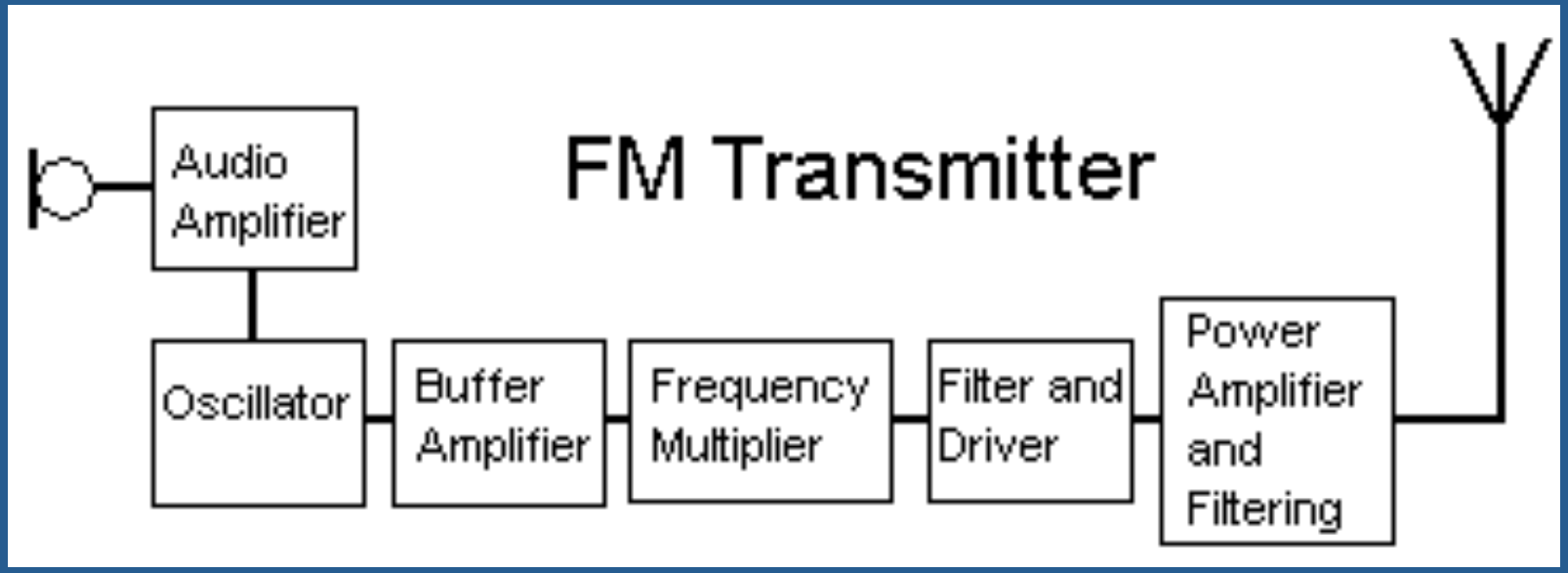
AM Transmitter Block Diagram



SSB Transmitter Block Diagram



FM Transmitter Block Diagram



3C Oscillators

Varicap Diode

Using a Varactor diode modulator is a method of FM generation wherein the carrier frequency is directly varied by the modulating signal. A varactor diode is a semiconductor diode whose junction capacitance varies linearly with applied voltage when the diode is reverse biased.

Relative Merits Of The Crystal And The VFO

Crystal: (Pros)
Easy to set frequency;
Less prone to drifting.

Crystal: (Cons)
Single frequency (with a minimum amount of adjustment);
Crystals can be expensive for non-preferred values;
Standard range values only are generally available. (Non-standard are expensive)

VFO (Pros)
Cheap to build;
Large frequency range is possible.

VFO: (Cons)
Prone to temperature drift;
Need to be calibrated.

The Frequency Of The VFO

The tuned circuit in the VFO determines the frequency of oscillation.

Oscillator Stability: Mechanical

Mechanical Stability: The components in an oscillator have mutual inductance and capacitance. This is an inescapable consequence of their physical size and relative positions. They will mutually couple and interact with each other.

Any mechanical vibrations *(for example tapping the oscillator circuit board or the screened enclosure.)* will set up mechanical vibrations.

Although they are of small amplitude they will cause changes in the mutual inductance and capacitance. These changes will affect the output frequency of the oscillator.

Oscillator Stability: Thermal

Thermal Stability: The component values in an oscillator will change as their temperature changes. As a consequence of this the output frequency of the oscillator will change as well.

The drift in frequency can, to a certain extent, be minimised by placing the oscillator in a temperature-controlled environment or "oven". *(High stability crystal oscillators are often placed in a "crystal oven" which maintains the device at a steady temperature).*

Not all components vary at the same rate or in the same direction (+ / -). By careful design you can match component drifts so that as one drifts upwards in value another drifts downwards. The net effect can be a degree of neutralisation which helps the thermal stability.

Oscillator Stability: Screening

Placing the oscillator circuit in a screened, metal enclosure will help to isolate it from the effects of other circuit elements. These elements may themselves be oscillating and producing local RF. This can couple into the oscillator circuit and cause instability.

Oscillator Stability: Regulated dc Supply

A stable, regulated and constant dc supply is essential for good oscillator stability. Usually the system is supplied by a common, dc rail. This can provide a conduit for all sorts of signals to travel around the system and cause interference.

Any stray signals, coupled to the supply and passed through to the oscillator have the potential to affect the oscillator stability.

Variations in voltage may cause changes in component values and semiconductor characteristics. While these may be only small changes when you are dealing with oscillators in the tens or hundreds of Megahertz a small change can represent a wide swing in RF output frequency.

Drift and Operation Outside Band Limits

An ideal oscillator will not drift and will remain at the set frequency. If it drifts it may cause its RF output to move outside the permitted band. As an extreme example:

Suppose that you are operating at 144.100 MHz and your RF oscillator drifts downwards in frequency by 0.1%. (one part in one thousand).

The new oscillator frequency will be changed by (144.100 x 0.001) MHz.

This will be (144.100 – 0.1441) MHz which equals 143.9559 MHz

This is now outside the 2 metre amateur band.

Digitally-Synthesized Oscillators

Most modern transceivers use RF oscillators the output of which is digitally-synthesised.

Provided that the digital clock driving the synthesiser is stable then any frequency that is synthesised will share the clock stability.

By placing the clock in a crystal oven very high levels of oscillator output stability are achievable.

This is called Direct Digital Synthesis (DDS)

3D Empty

3E Microphone Amplifiers and Modulators

Balanced Modulator

A balanced modulator mixes the audio signal and the radio frequency carrier, but suppresses the carrier, leaving only the sidebands. The output from the balanced modulator is a double sideband suppressed carrier signal and it contains all the information that the AM signal has, but without the carrier.

Single Sideband Filter

In radio communications, single-sideband modulation (SSB) or single-sideband suppressed-carrier modulation (SSB-SC) is a type of modulation used to transmit information, such as an audio signal, by radio waves.

The sideband filter is a band-pass filter that removes the unwanted sideband from the output of the balanced modulator. It passes the wanted sideband to the RF power amplifier. In analogue transmitters this filter is usually a crystal filter.

Single-sideband modulation avoids the bandwidth increase of simple AM and the power wasted on a carrier at the cost of increased device complexity and more difficult tuning at the receiver.

3F RF Power Amplifiers

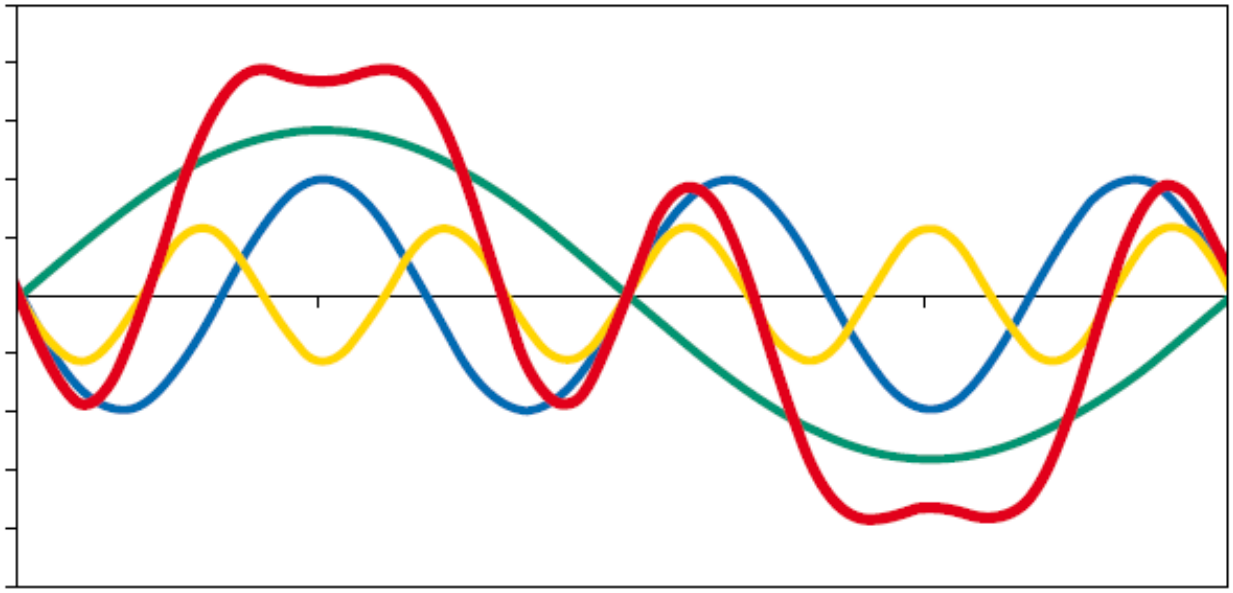
RF Power Amplifier Efficiency

The efficiency of an RF power amplifier can be determined by dividing the RF output power by the DC input power. An RF amplifier is used to take low-power radio frequency signals and convert them to higher power signals. Efficiency is a measure of how much of the input power actually gets converted to output power.

eg. RF output power = 30 Watts
DC Input power = 60 Watts.
$\eta = (30 / 60) = 50\%$

3G Transmitter Interference

Harmonics



Caption:

- nonsinusoidal waveform
- first harmonic (fundamental)
- third harmonic
- fifth harmonic

Harmonics are even or odd multiples of the fundamental frequency. The “purity” of the output sine wave depends upon which harmonics are also present. Transmitters and oscillators produce harmonics. Harmonics can cause out-of-band interference.

The Filter

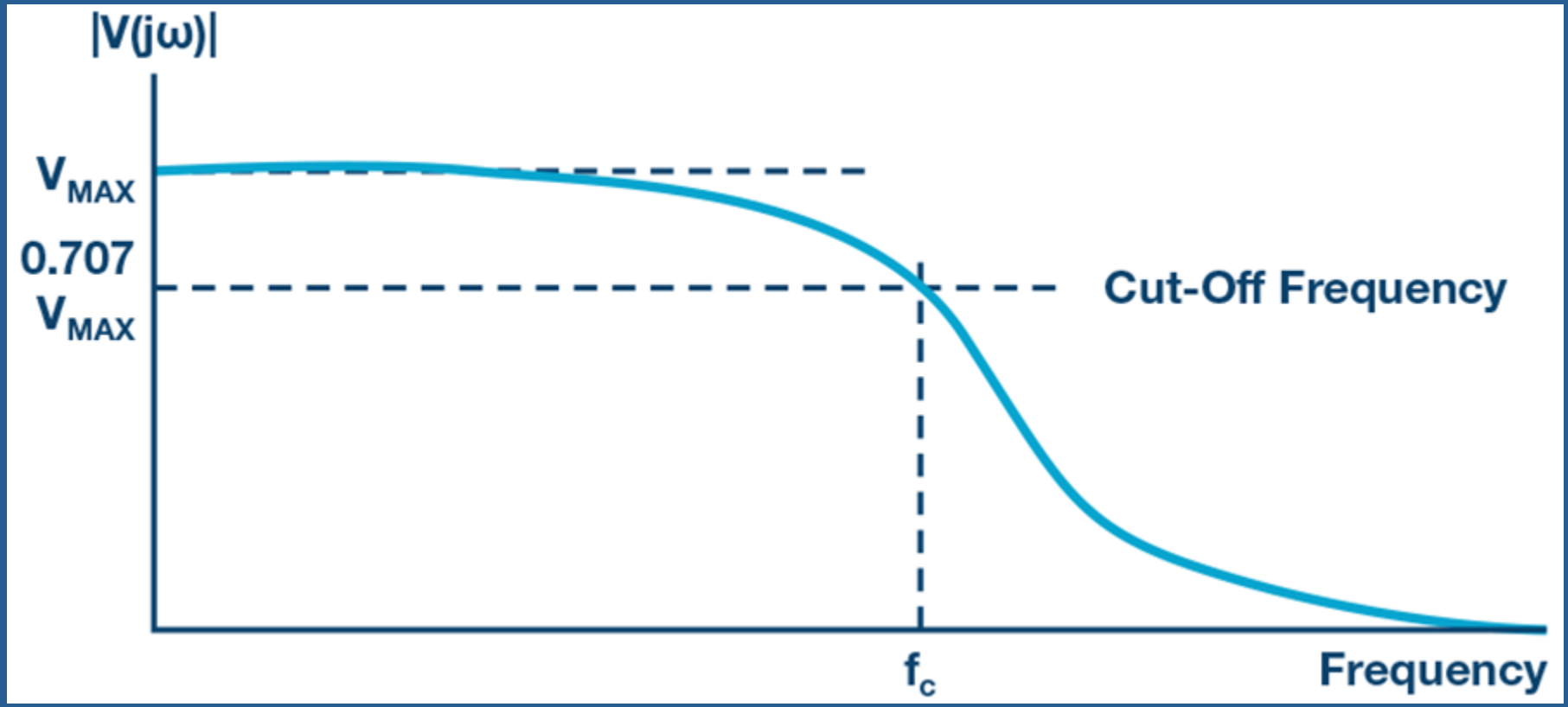
A filter is a device which selectively attenuates unwanted frequencies and allows the wanted frequency, or range of frequencies to pass through.

Filters can be:

- Low pass;
- High pass;
- Band pass;
- Band stop.

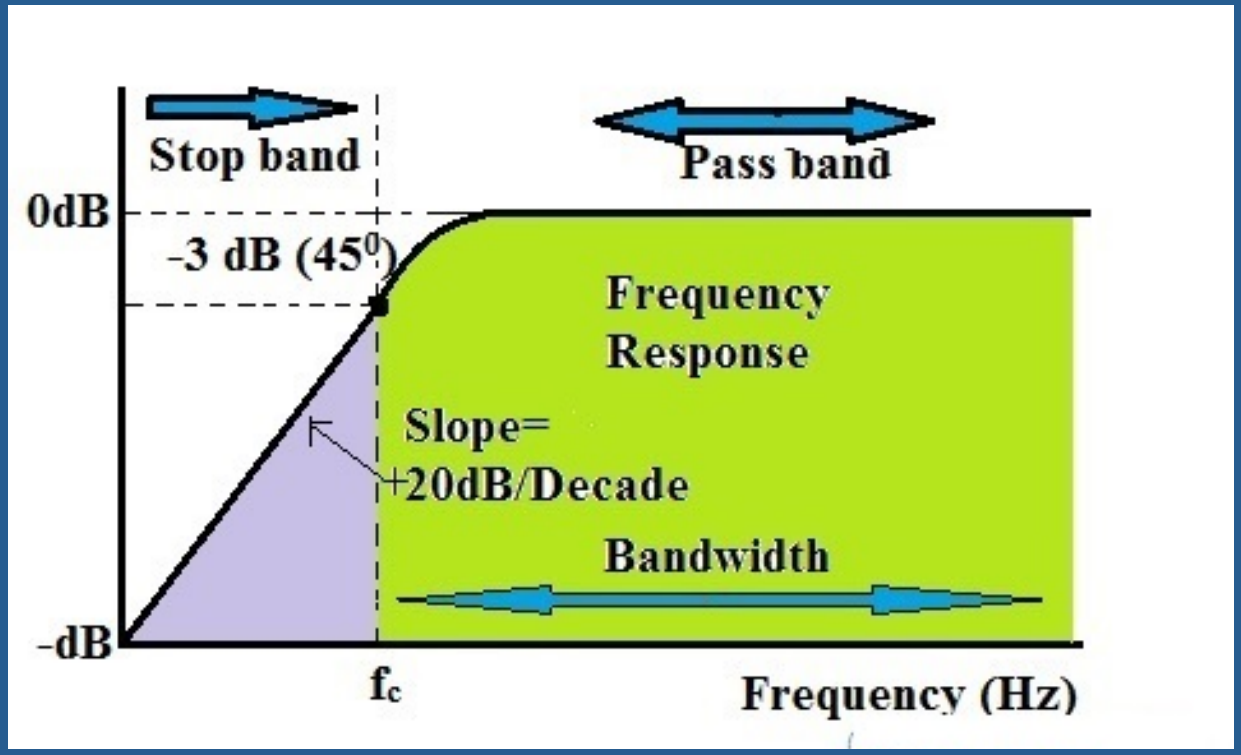
The Low Pass Filter

The Low Pass Filter – the low pass filter only allows low frequency signals from 0Hz to its cut-off frequency, fc point to pass while blocking those any higher.



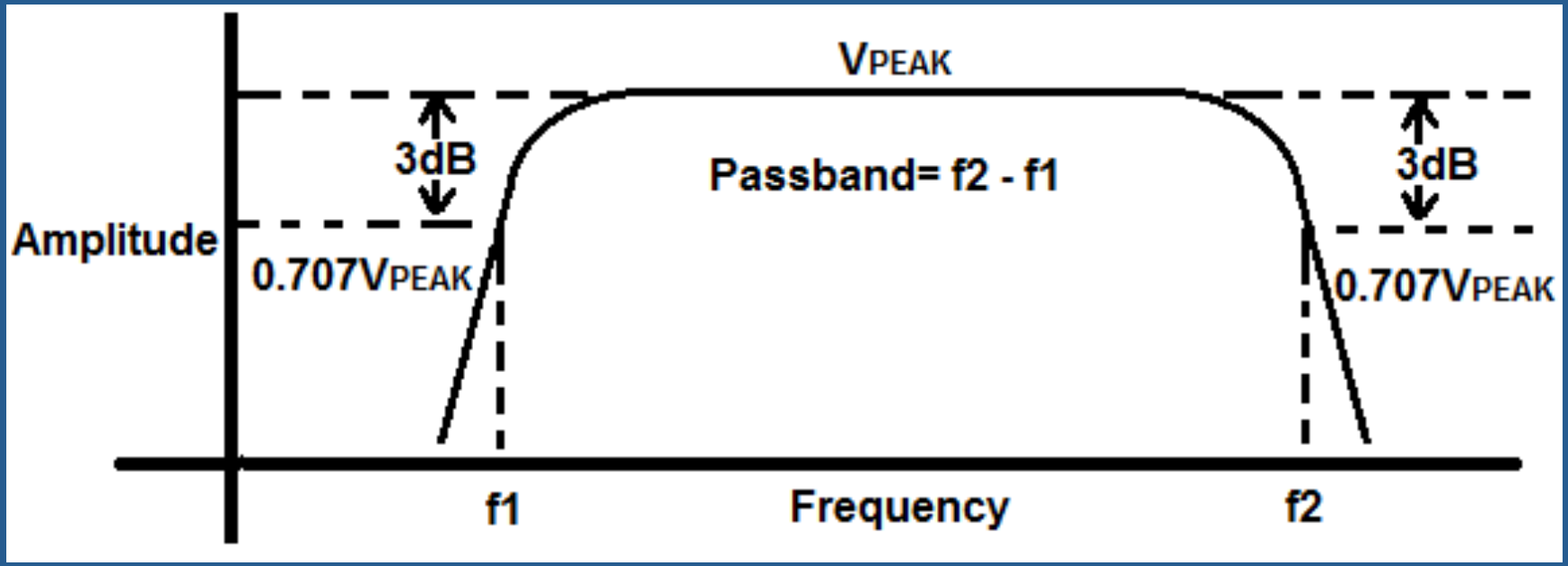
The High Pass Filter

The High Pass Filter – the high pass filter only allows high frequency signals from its cut-off frequency, fc point and higher to infinity to pass through while blocking those any lower.



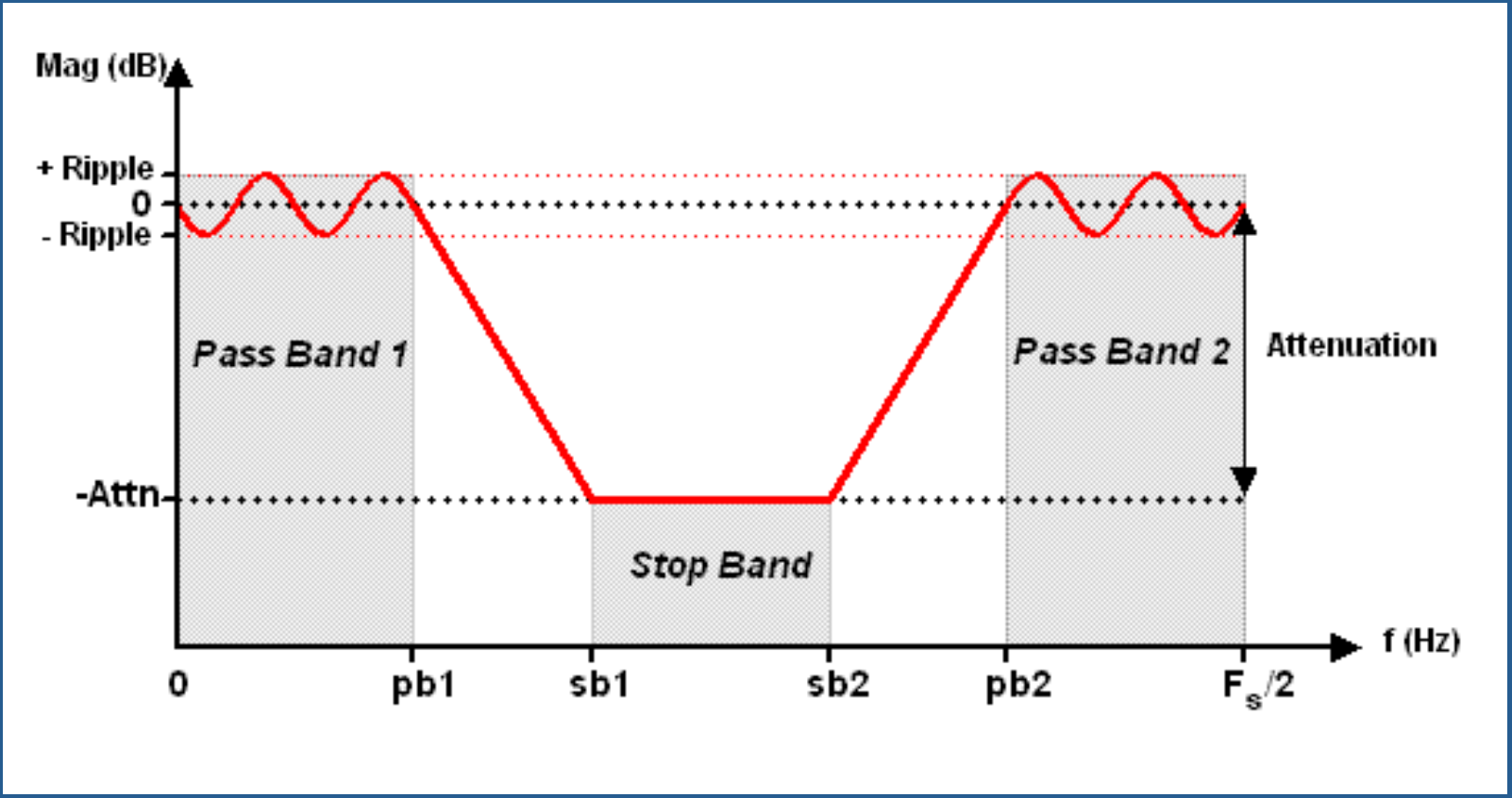
The Band Pass Filter

The Band Pass Filter – the band pass filter allows signals falling within a certain frequency band set up between two points to pass through while blocking both the lower and higher frequencies either side of this frequency band.

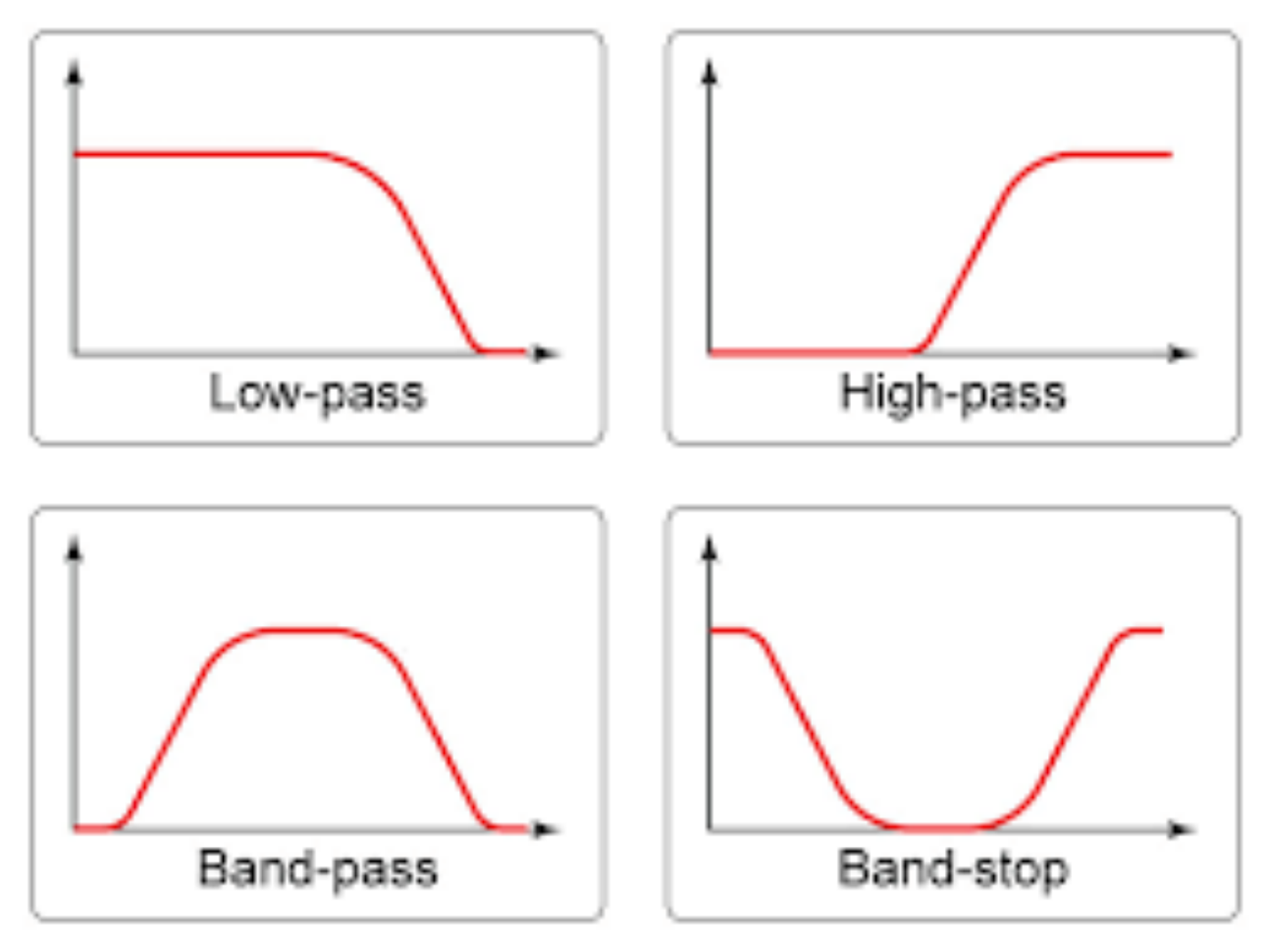


The Band Stop (Notch) Filter

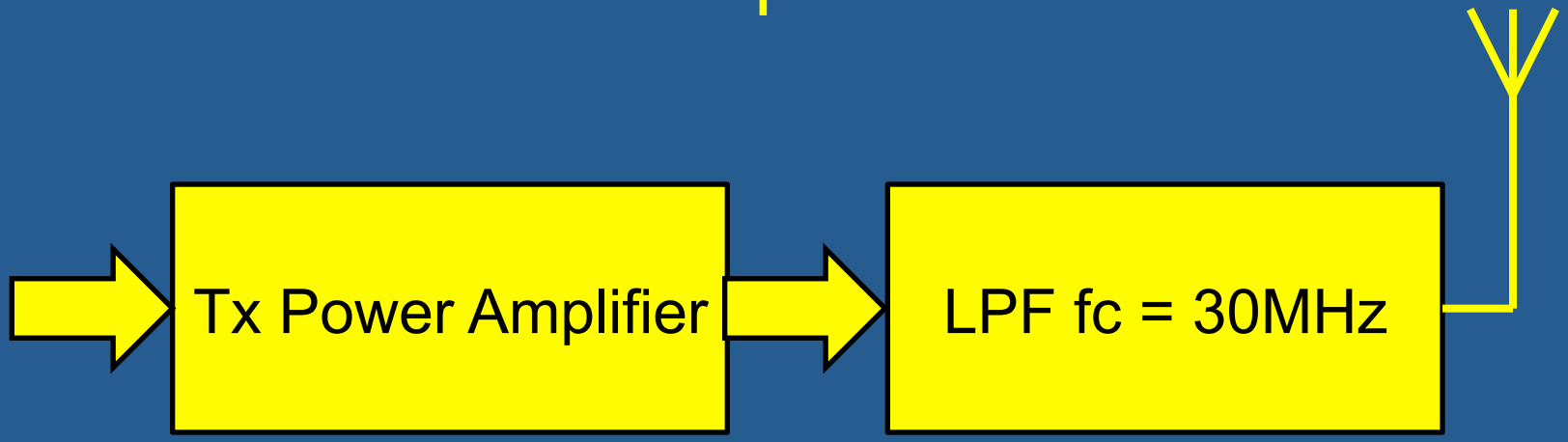
The Band Stop Filter – the band stop filter is reversal to the Band Pass Filter and allows signals passing both the lower and higher frequencies either side of the blocking frequency band.



Filter Profiles



Low Pass Filter Example



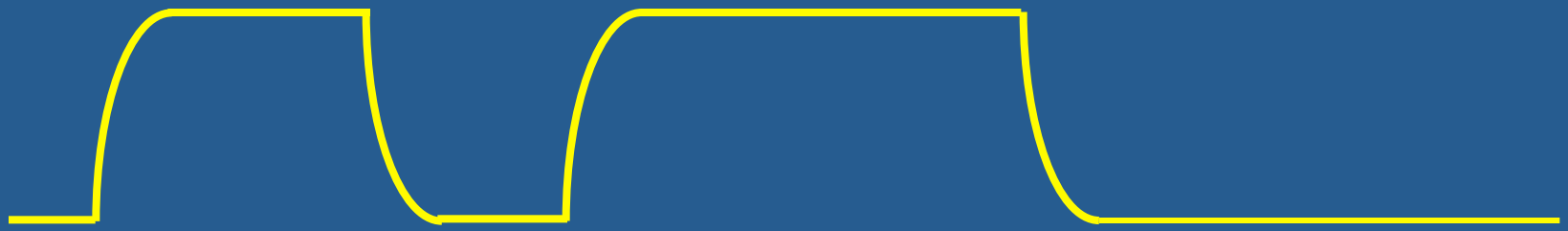
A low pass filter installed after the final RF power amplifier in a transmitter will attenuate frequencies above 30 MHz and reduce the chances of interference at VHF from an harmonically rich HF transmission.

For specific frequencies a band stop filter can attenuate the interfering signal. (A band pass filter could be used to the same effect but allowing only the wanted signal to pass.)

Morse Key Clicks



Waveforms with a fast rise time such as the switching waveform from a Morse key contain a large number of harmonics. These can be effectively eliminated by slowing the rise time in the keying stage.



“Chirp”

"Chirp" is a change in frequency when the transmitter is keyed on (by pressing the Morse key) and keyed off (the release of the Morse key) when the Morse characters are being formed. -Thus the change in frequency would be heard on a receiver at the start and end of each keying stroke.

There are three main causes of chirp :-

Poor design of the transmitter :

- DC Instability caused by poor voltage regulation.
- Pulling

RF Feedback:

- RF Feedback getting back into the frequency determining stage (oscillators).

Eliminating “Chirp”

DC Instability: If the power supply to the oscillator is from the same rail as the PA supply then changes in rail voltage when the transmitter is keyed cause the oscillator to shift frequency a little.

REMEDY Use separate power supplies for the oscillator and PA and ensure that the oscillator supply is well regulated and stabilised.

Pulling This is where the frequency of other stages changes due to the keying of the transmitter.

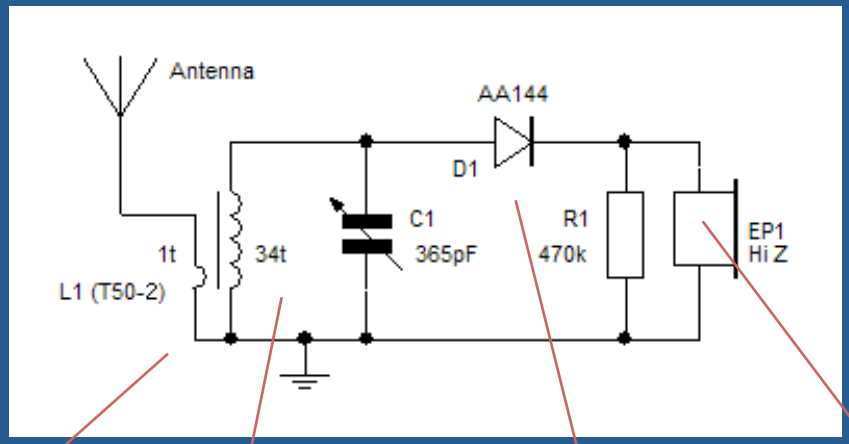
REMEDY Provide better isolation of the oscillator from the other stages .

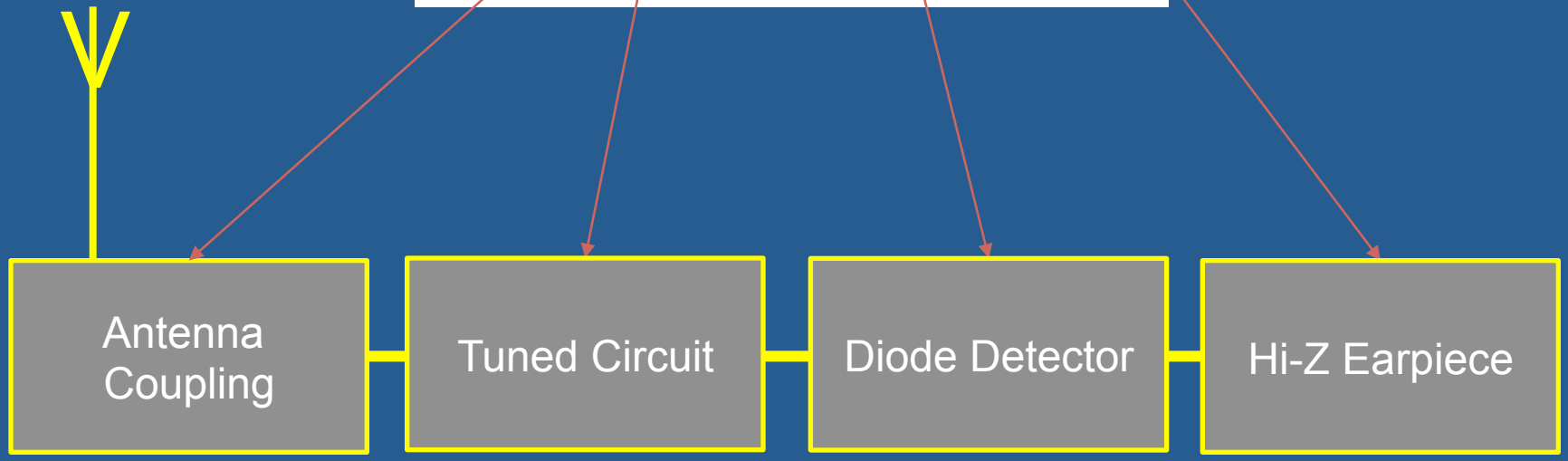
RF Feedback This is where RF energy is finding its way back into the transmitter causing changes in other stages.

REMEDY Pay close attention to screening of leads carrying RF; keep leads as short as possible and properly decouple all supply lines.

3H receiver Concepts

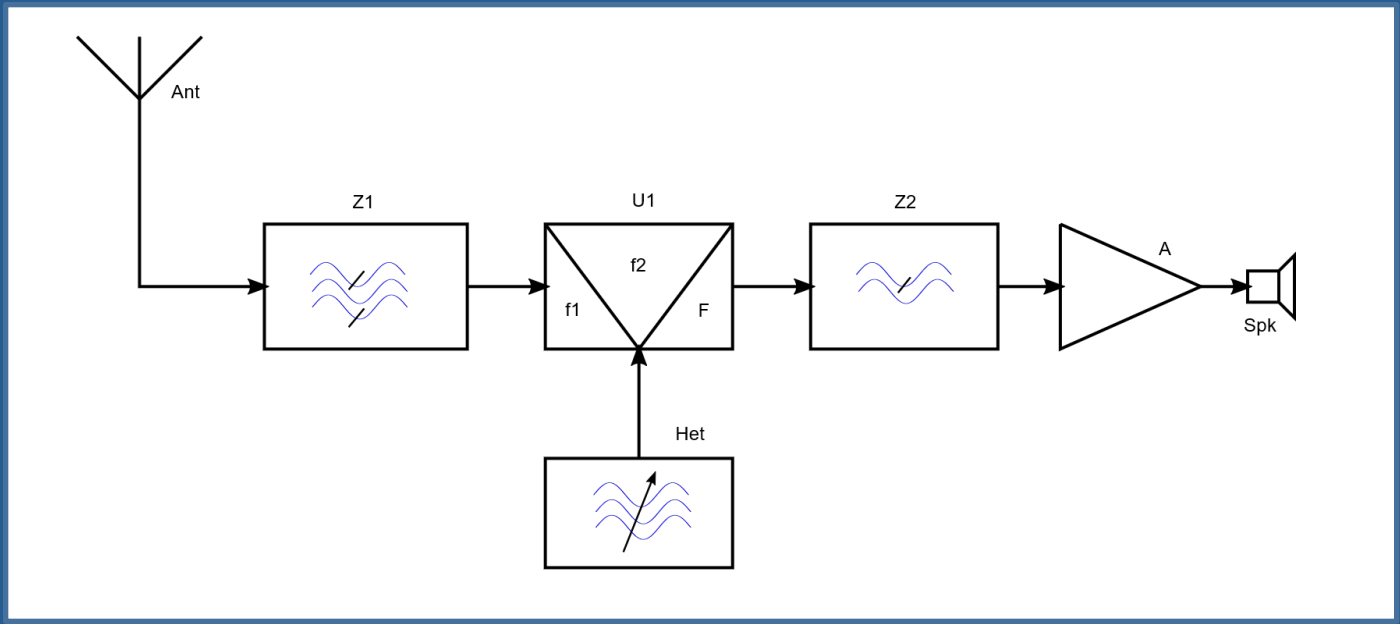
The Crystal Diode Receiver





Direct Conversion Receiver

A direct-conversion receiver (DCR), also known as homodyne, synchrodyne, or zero-IF receiver, is a radio receiver design that demodulates the incoming radio signal using synchronous detection driven by a local oscillator whose frequency is identical to, or very close to the carrier frequency of the intended signal.



Receiver RF Amplifier

The signal received by the antenna has very low power. This signal cannot be demodulated correctly. A low-noise amplifier (LNA) is used at the first stage. An LNA is an electronic amplifier that amplifies a very low-power signal without significantly degrading its signal-to-noise ratio. The RF amplifier increases the power of both the signal and the noise present at its input.

LNAs are designed to minimize additional noise. Designers minimize noise by considering trade-offs that include impedance matching, choosing the amplifier technology (such as low-noise components) and selecting low-noise biasing conditions.

The Demodulator (Detector)

The process of extracting an original message signal from the modulated wave is known as detection or demodulation. The circuit, which demodulates the modulated wave, is known as the demodulator.

The Audio Power Amplifier

The audio signal from the output of the demodulator is at a low level. In order to drive a loudspeaker the audio signal from the demodulator needs to be raised to a level where it can drive a loudspeaker.

The Audio Power Amplifier is the circuit which achieves this.

Sensitivity

The ability of a receiver to respond to very weak signals is known as the receiver sensitivity.

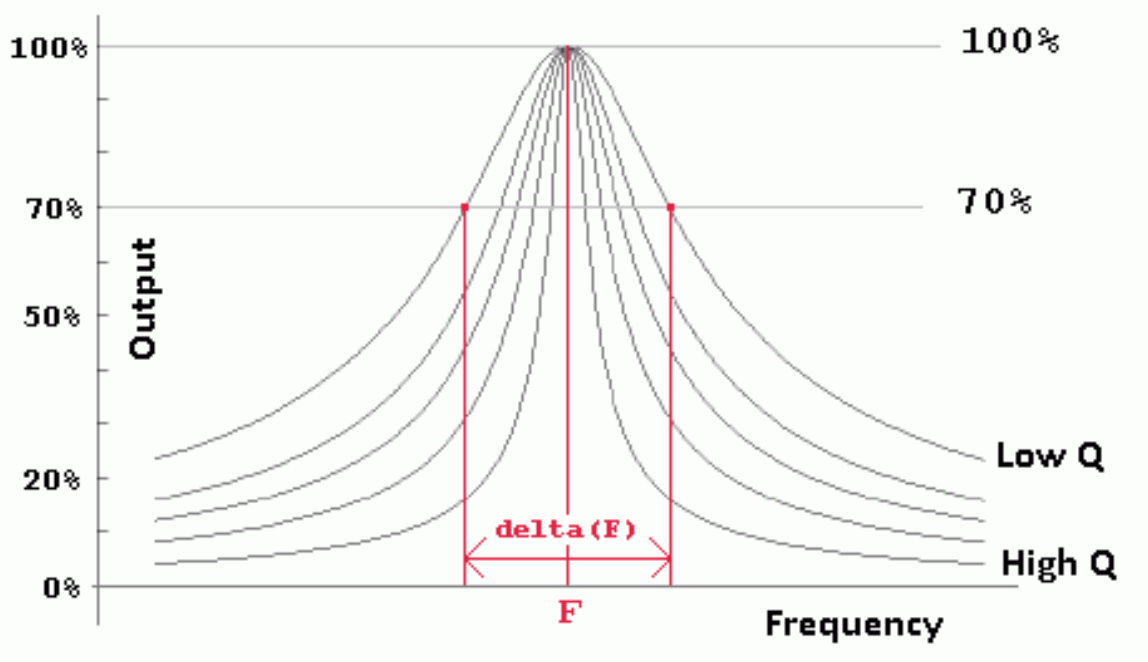
Weak signals may induce less than 1 microvolt at the antenna.

Conversely very strong signals at the antenna can overwhelm the RF stages and cause distortion on the signal.

Selectivity

The ability of a receiver to differentiate a wanted signal and reject other, close by, signals is known as the receiver's selectivity.

Limitations of Tuned Circuits



High Q tuned circuits respond to a narrow range of frequencies giving a sharp narrow peak in the graph above.
Low Q tuned circuits respond to a wider range of frequencies giving a lower and broader peak in the graph above.
A receiver with a higher Q tuned circuit will be more selective. It will be better at receiving the wanted signal and rejecting signals on adjacent channels.
Q = F / delta(F).

3I Superheterodyne Concepts

The Advantages of the Superheterodyne

The superheterodyne receiver converts the high frequency incoming radio frequency to a lower, intermediate (IF) frequency. *(There may be several stages of frequency reduction and a corresponding number of IFs).*

All the signal processing takes place at the lower, intermediate frequencies. *(Devices operating at lower frequencies are cheaper to produce than devices operating at higher frequencies).*

It is easier to filter the IF signal than the RF signal.

It has better sensitivity compared to direct conversion.

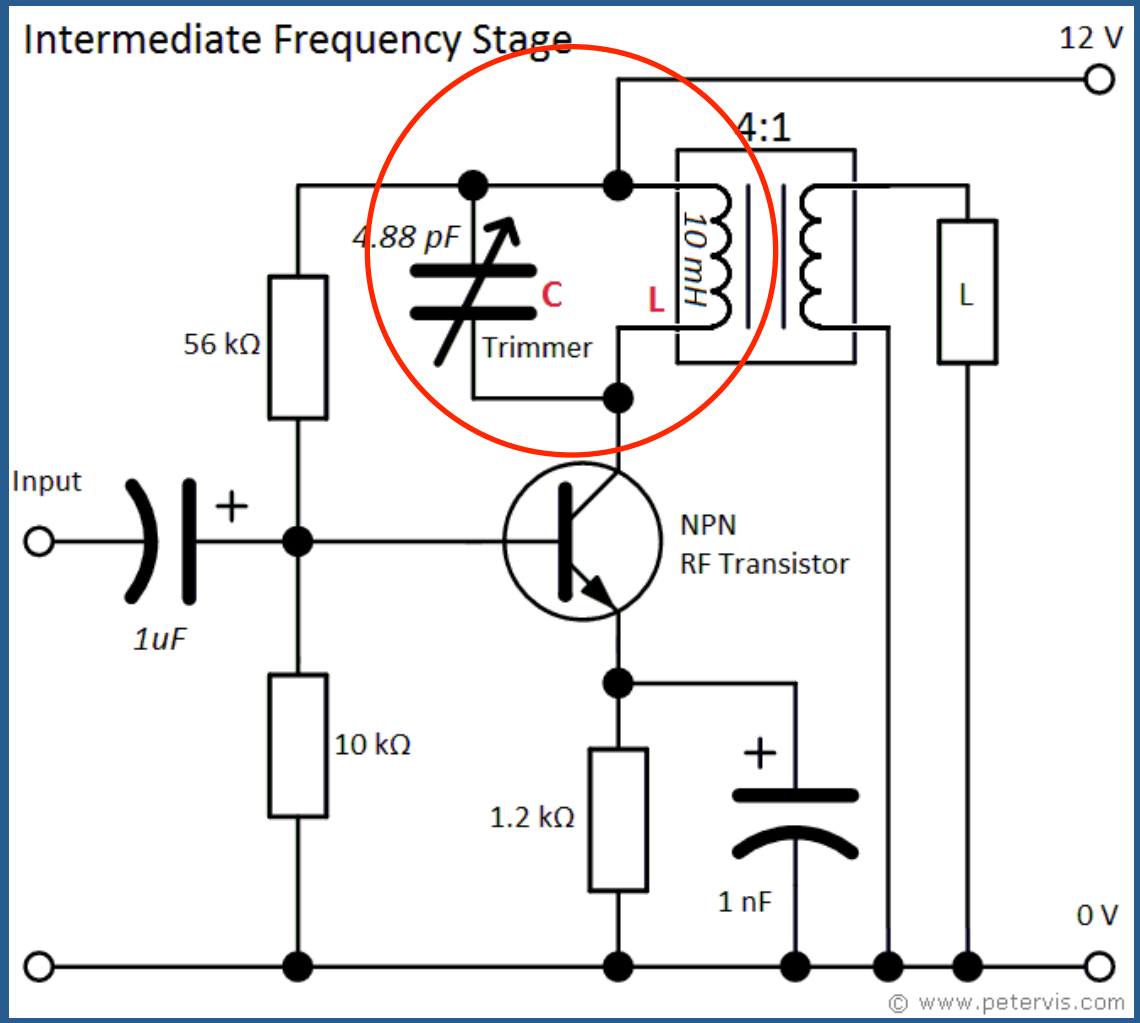
The Heterodyne receiver uses a single frequency conversion and a super heterodyne receiver uses double conversion.

Selecting The Signal in A Superheterodyne

In a superheterodyne receiver the wanted signal is selected by means of tuned circuits.

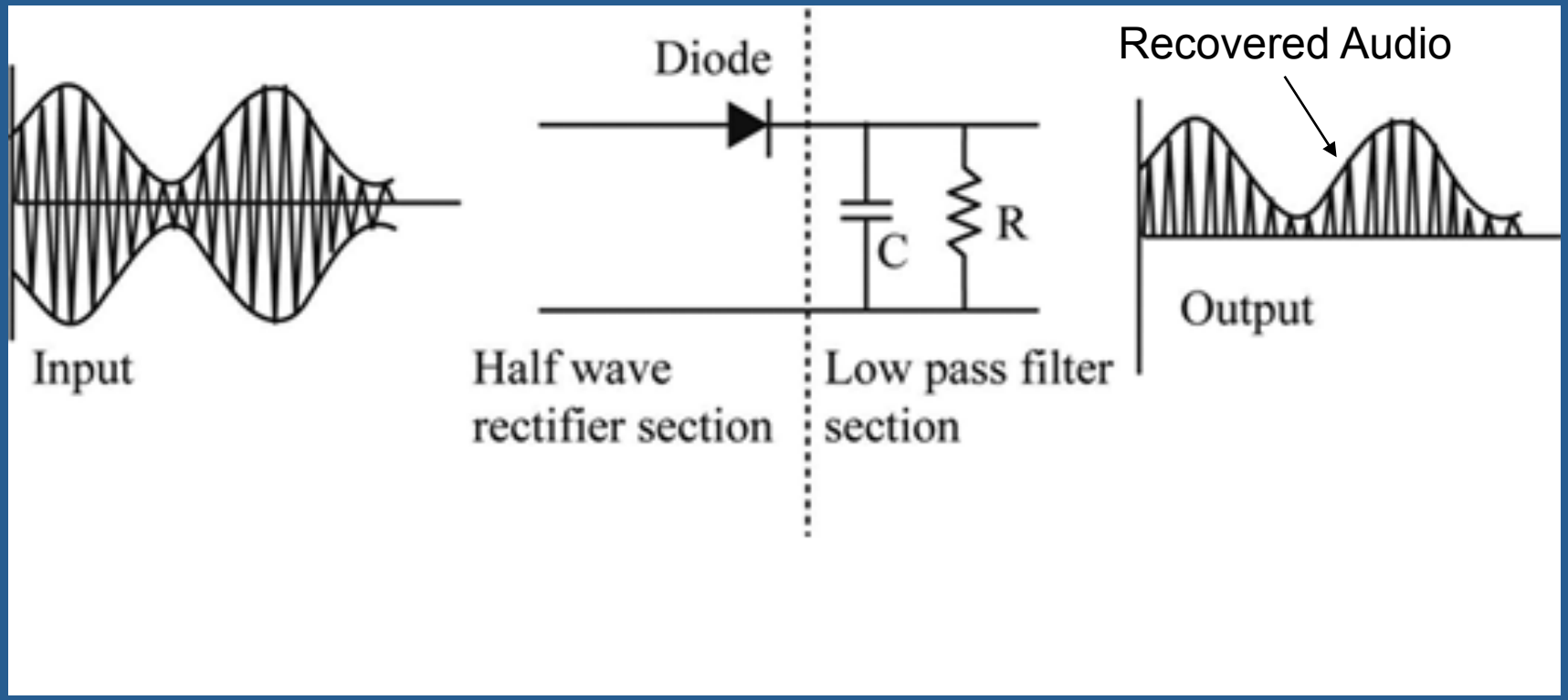
In particular having a fixed IF makes the design of selector circuits simpler.

IF Amplifier Tuned Circuit

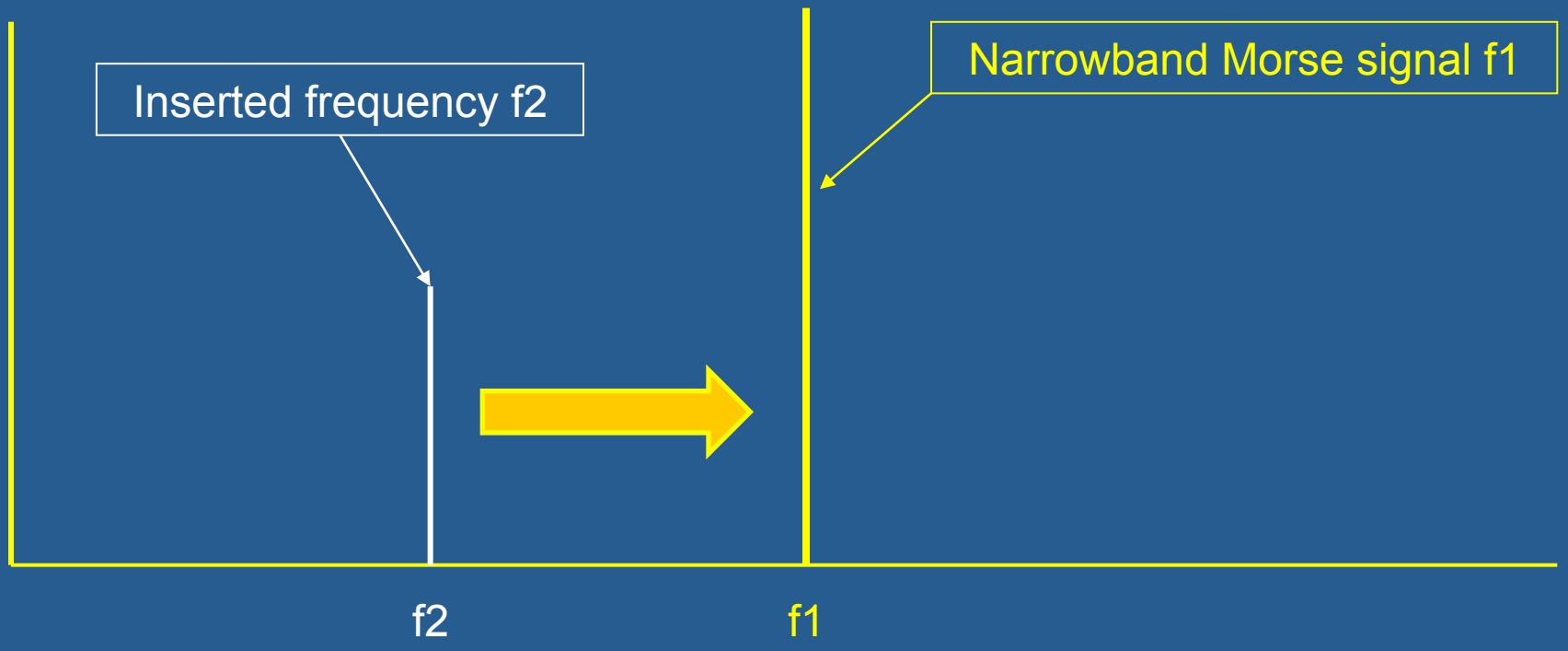


3K Demodulation

Diode Detection



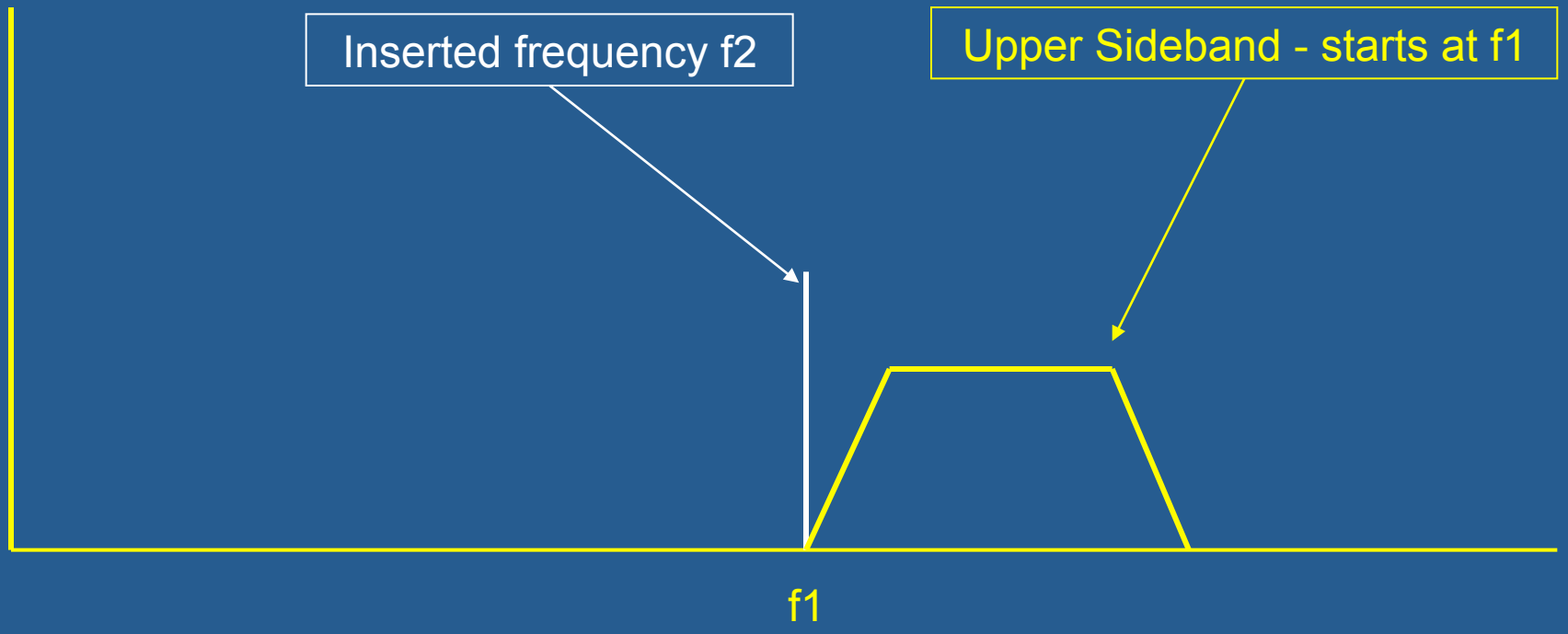
The Beat Frequency Oscillator (BFO)



If you mix a signal of frequency f2 with the wanted signal f1 as you move f2 closer to f1 the difference in frequency (f1-f2) reduces. Eventually the difference will be audible. This means that each time a Morse character is sent at f1 you hear it as (f1-f2).

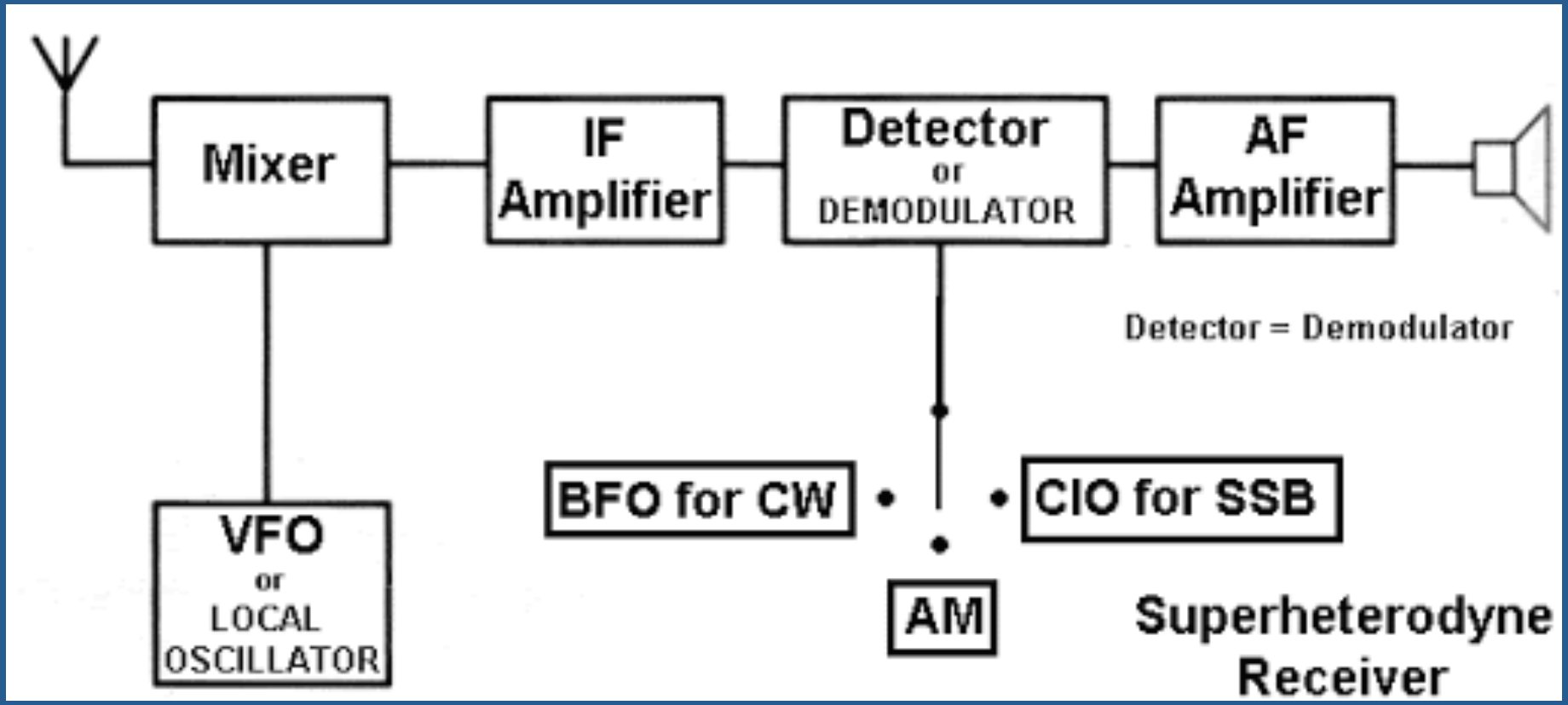
This is the operation of the Beat Frequency Oscillator (BFO)

The Carrier Insertion Oscillator (CIO)



If you mix an inserted frequency f2 at the start of the sideband frequency such that it is the same as the original, suppressed carrier f1 then when it mixes with the sideband frequencies they will produce clear audio. If f2 differs from f1 then the sideband audio changes frequency by the difference between f2 and f1.

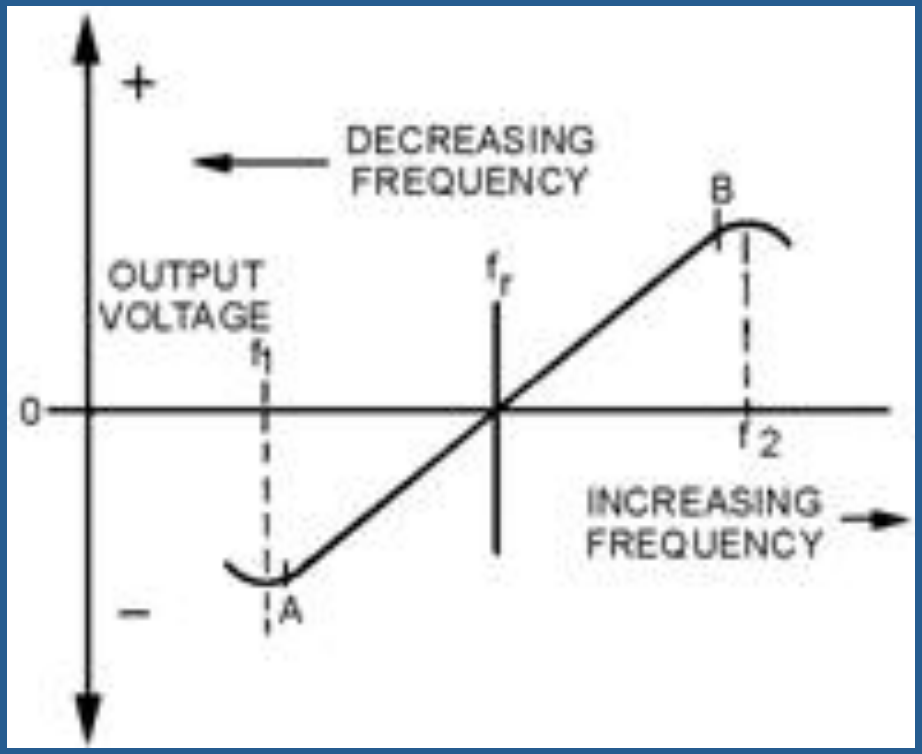
This is the operation of the Carrier Insertion Oscillator (BFO)



In a superheterodyne receiver the inserted frequencies (BFO or CIO) can be at the intermediate frequency rather than the original frequency.

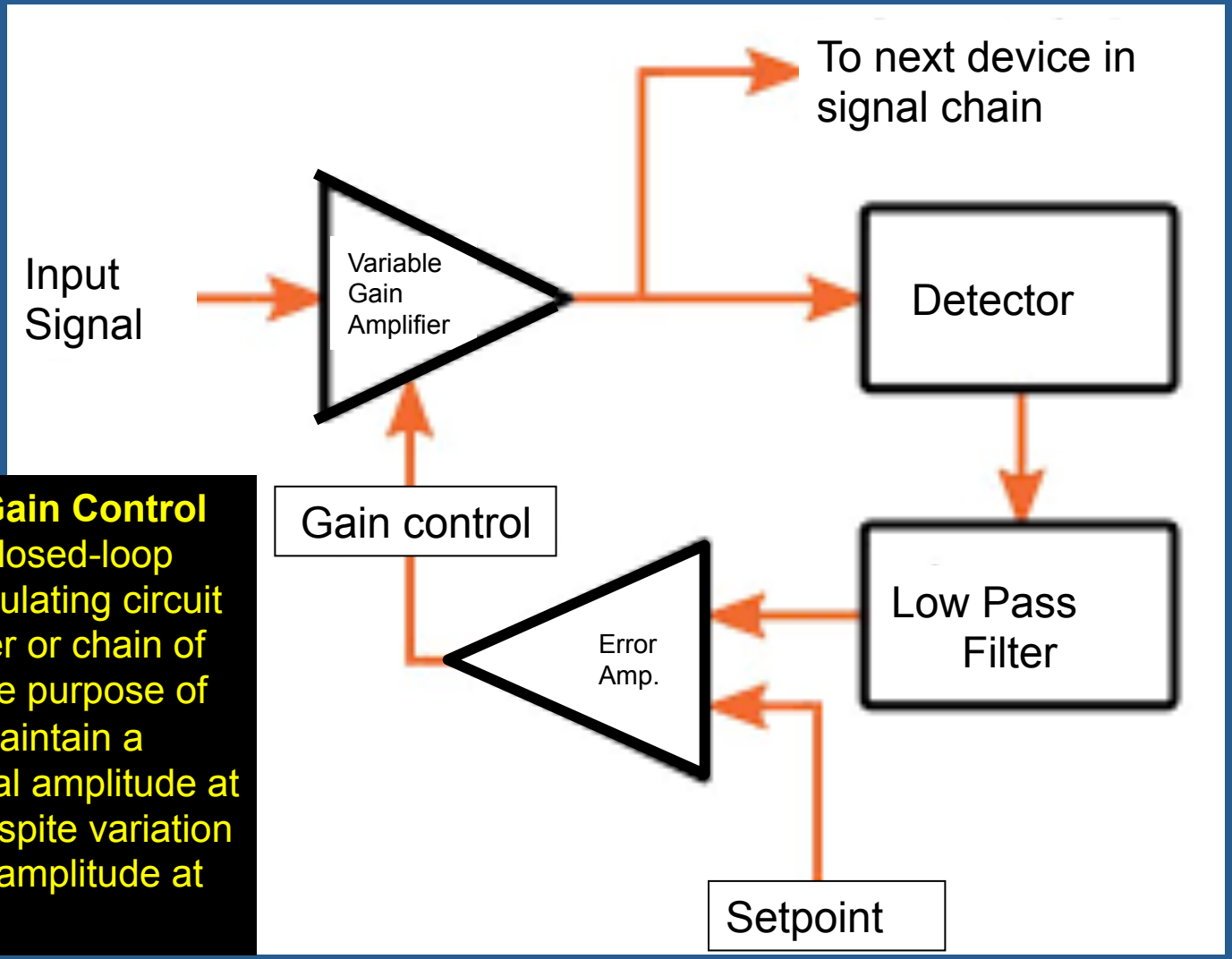
FM Discriminator

In order to be able to demodulate FM it is necessary for the radio receiver to convert the frequency variations into voltage variations - it is a frequency to voltage converter. When the carrier frequency deviates to the lower end of the frequency range over which it deviates a lower voltage may be produced, then as it deviates higher in frequency, a higher voltage is produced.



3L Automatic Gain Control (AGC)

Automatic Gain Control



Automatic Gain Control (AGC), is a closed-loop feedback regulating circuit in an amplifier or chain of amplifiers, the purpose of which is to maintain a suitable signal amplitude at its output, despite variation of the signal amplitude at the input.

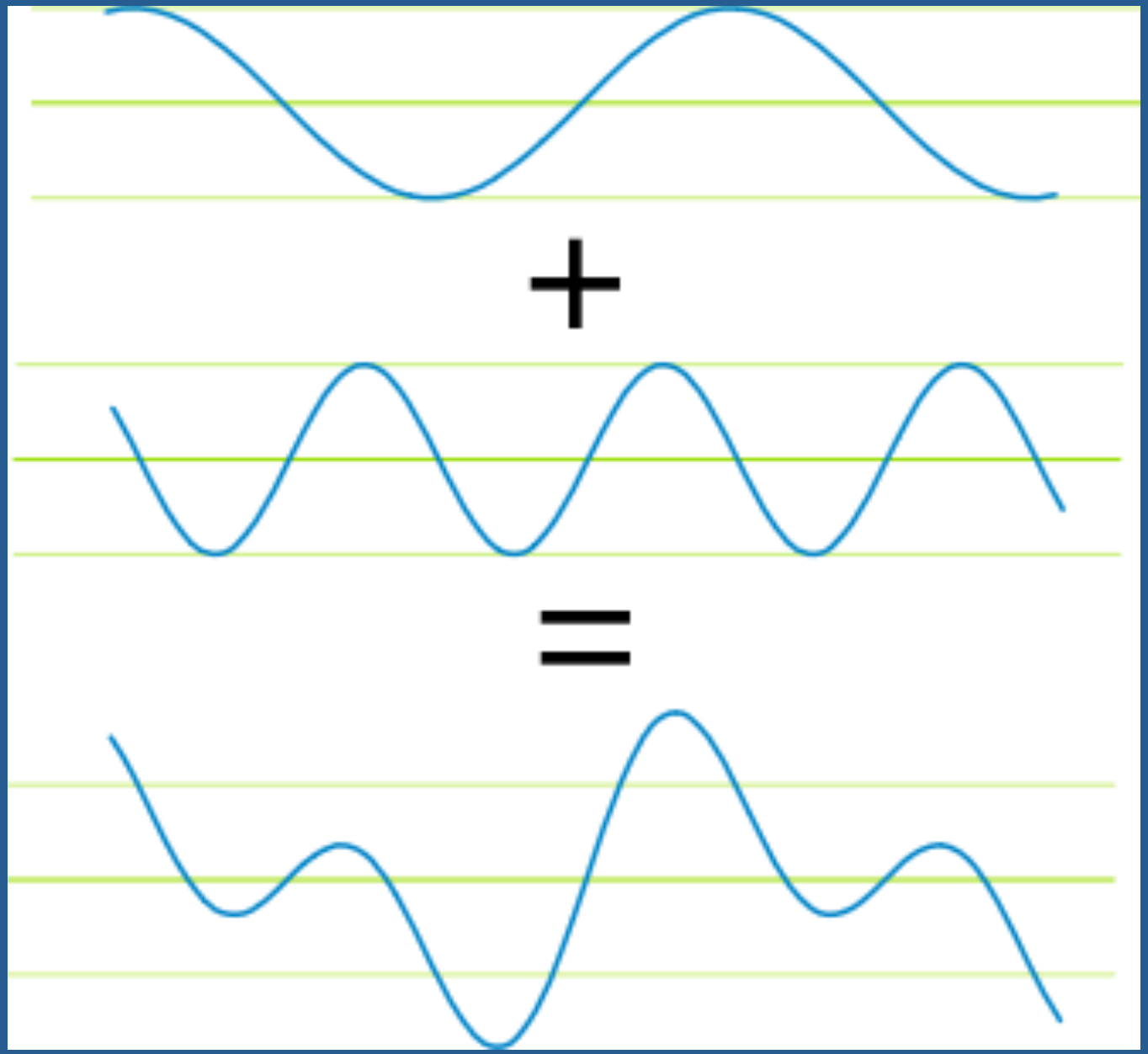
3M SDR Transmitters & Receivers

The Fourier Transform

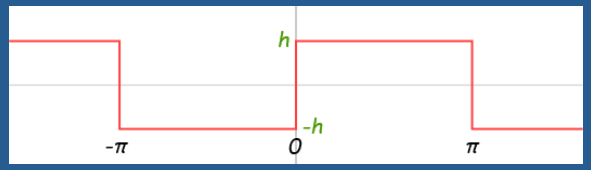
You can add sine and cosine waves to form other wave shapes. If you add sufficient waves of different – but related – frequencies in a series you can produce any wave shape.

The Fourier Transform breaks down a wave shape into these constituent frequencies.

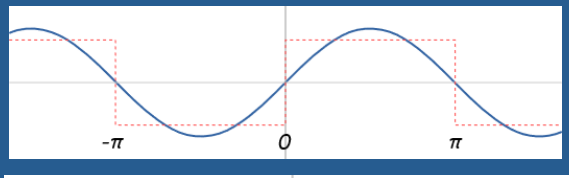
This allows you to move between the Time Domain (what you see) and the Frequency Domain (the frequencies comprising the wave).



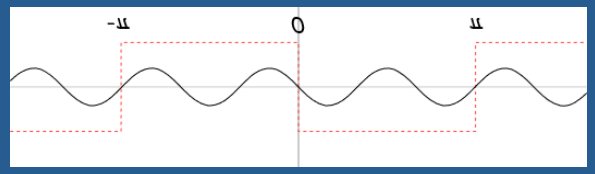
How to make a square wave from a series of sine waves.



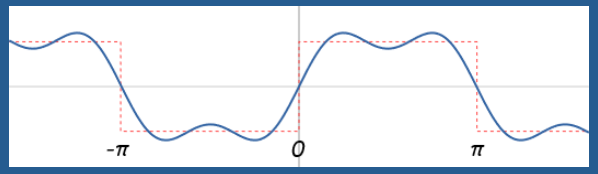
Start with sin(x):



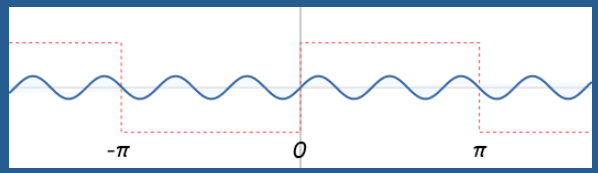
Then take sin(3x)/3:



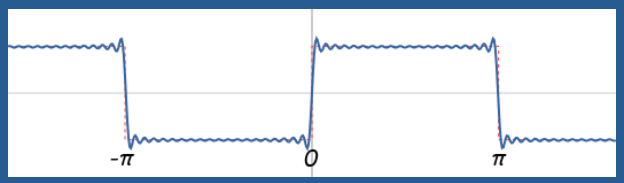
And add it to make sin(x)+sin(3x)/3:



Now take sin(5x)/5:



Add it also, to make sin(x)+sin(3x)/3+sin(5x)/5:



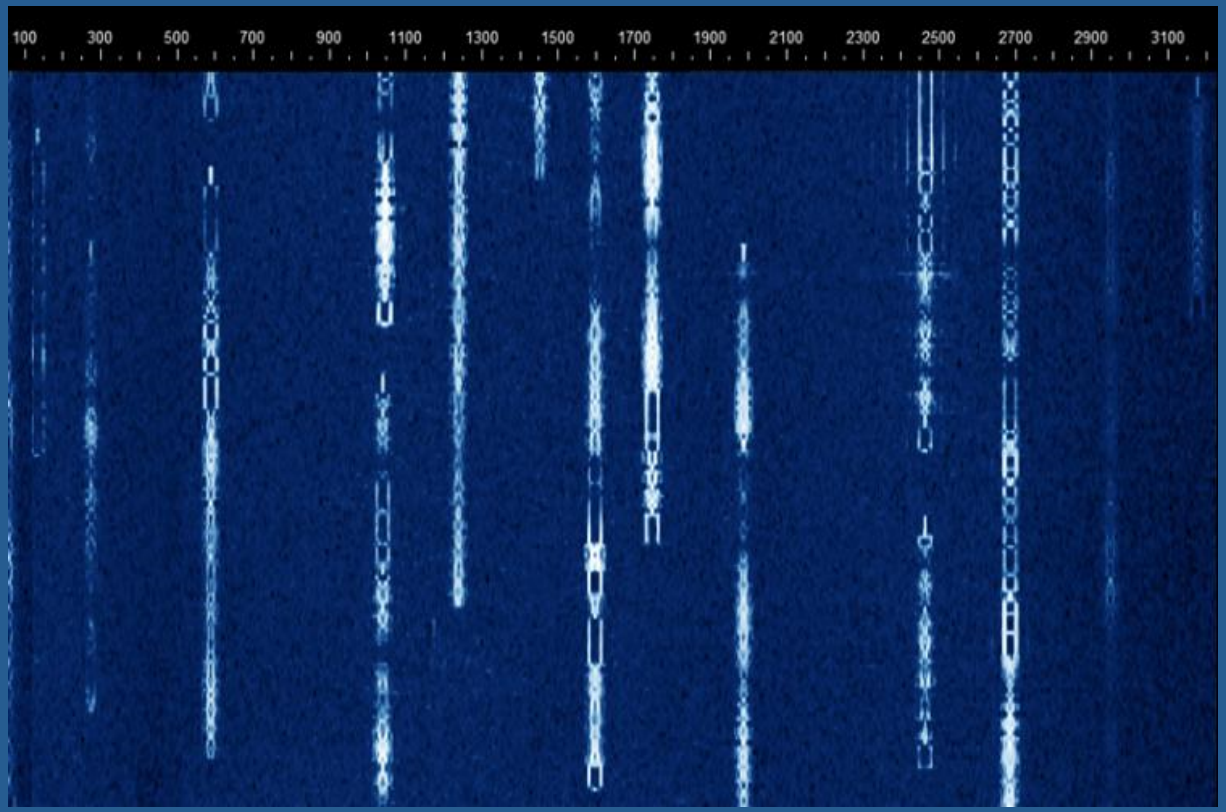
Using 100 sine terms gives a very good square wave. An infinite number of terms will give a perfect square wave.

The SDR Software

The SDR software breaks down the signal into its component frequencies by means of the Fourier Transform. This allows the software to operate on each of the frequencies to process the signal in the desired way.

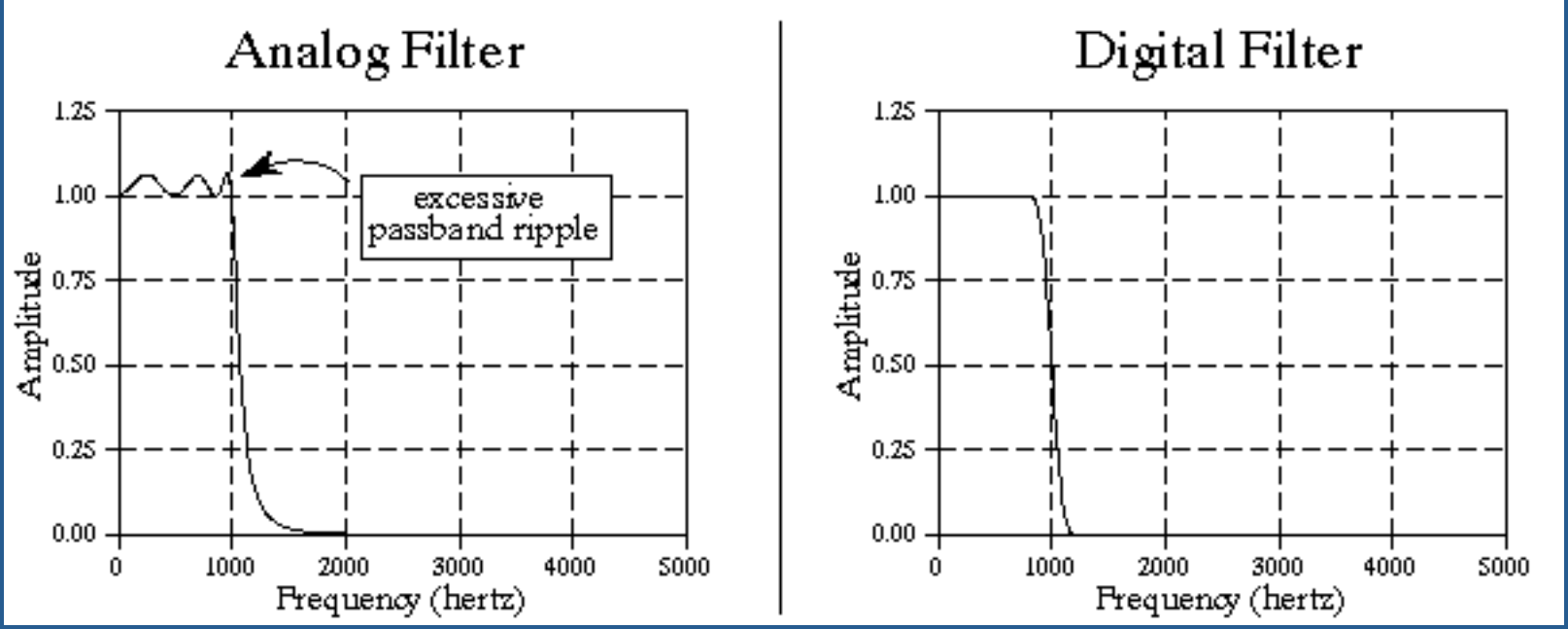
The Forier Transform can also be used to generate a Waterfall display – sometimes called a spectrogram.

It displays the different signals in a passband, The display constantly moves downwards giving the impression of a slowly moving waterfall.



Pictured in the image above is a number of signal traces. It shows the frequency range where PSK31 is used, The signals are very narrow (only a few tens of Hz wide each), but it could easily cover a much larger frequency range "zoomed out" and still look basically the same. Here, black and dark blue is basically background noise, and bright white represents a very strong signal. We can also see that the station around 2450 Hz into the receiver passband appears to have insufficient sideband suppression (notice the additional, weaker signals centred on the main signal frequency). ARRL K2NCC

Digital Filters



Digital filters are used for two general purposes:

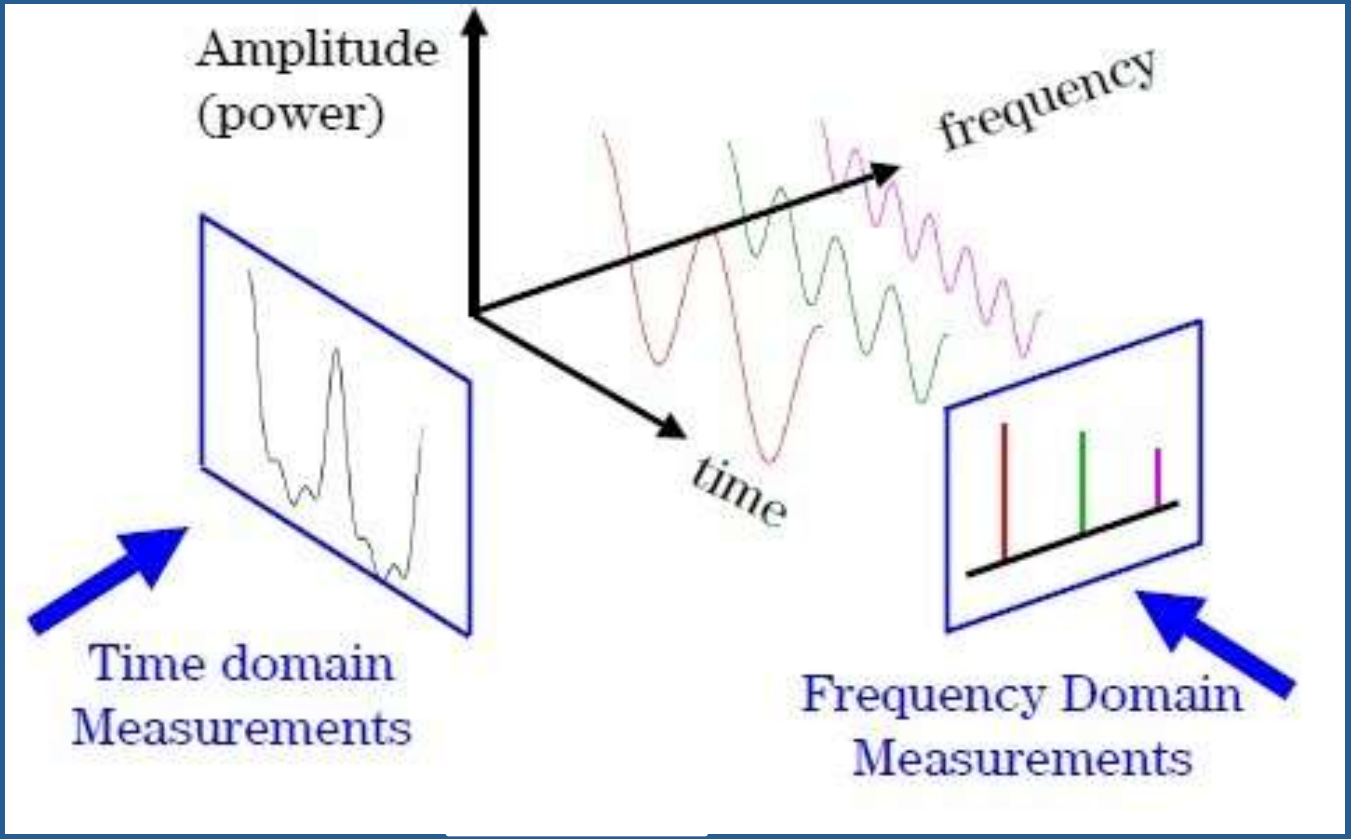
(1) separation of signals that have been combined;
(2) restoration of signals that have been distorted in some way.

Analog (electronic) filters can be used for these same tasks; however, digital filters can achieve far superior results – particularly their selectivity.

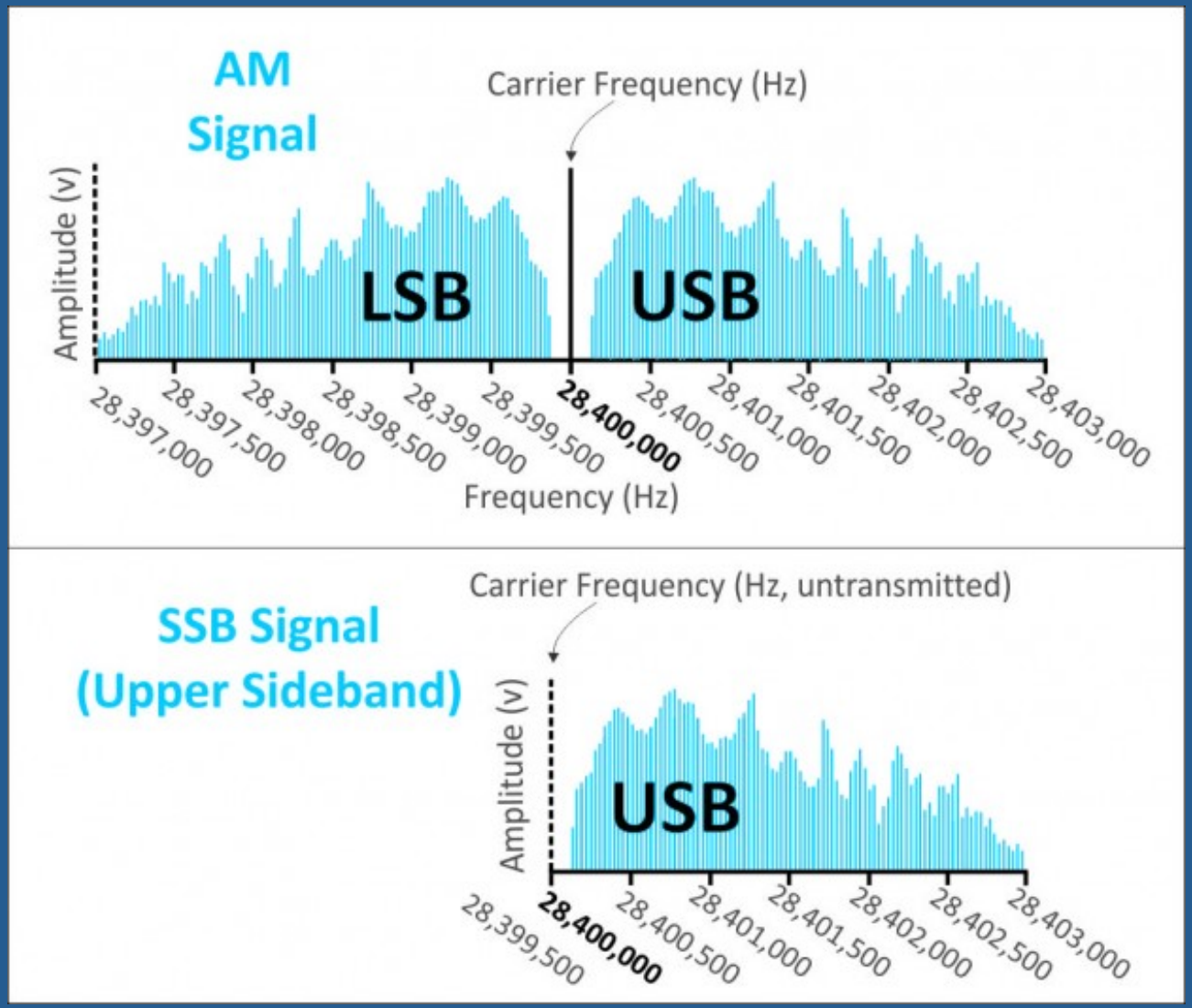
Time Domain and Frequency Domain

You can display a signal in one of two ways.

1. You can show how it varies with time - eg an oscilloscope;
2. You can show what frequencies it contains – eg a spectrum analyser

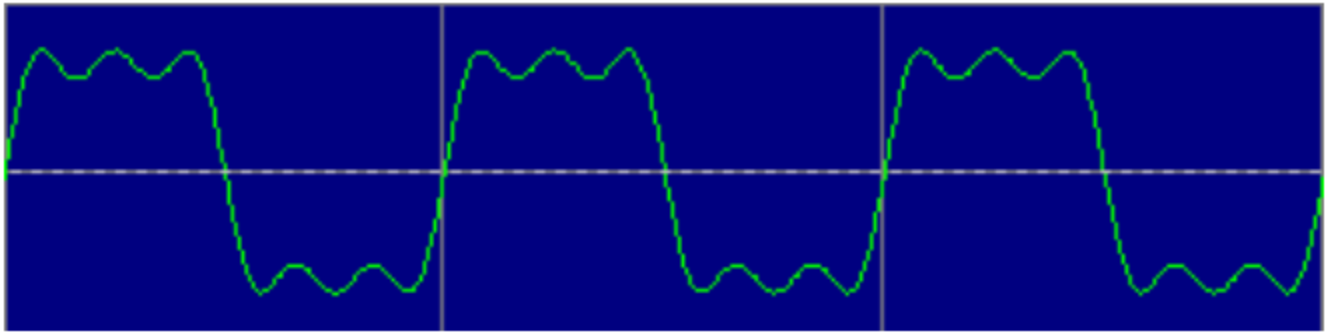


Sideband Signals – Frequency Domain



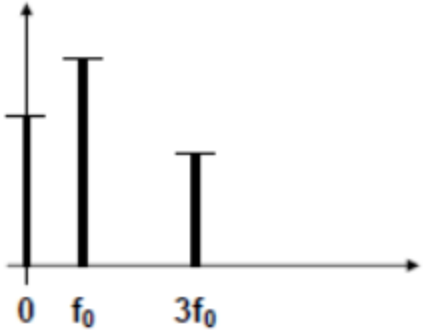
Harmonic Display in The Frequency Domain

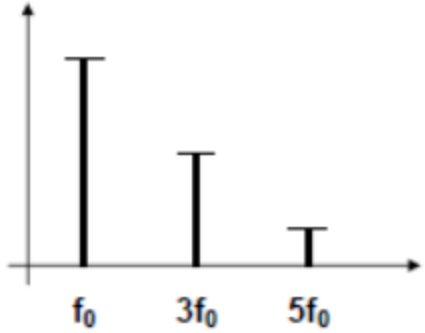
The signal's period is $T=10^{-3}$ [s].

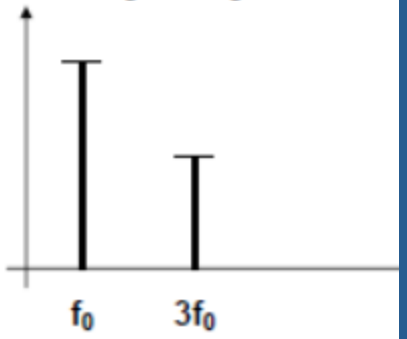


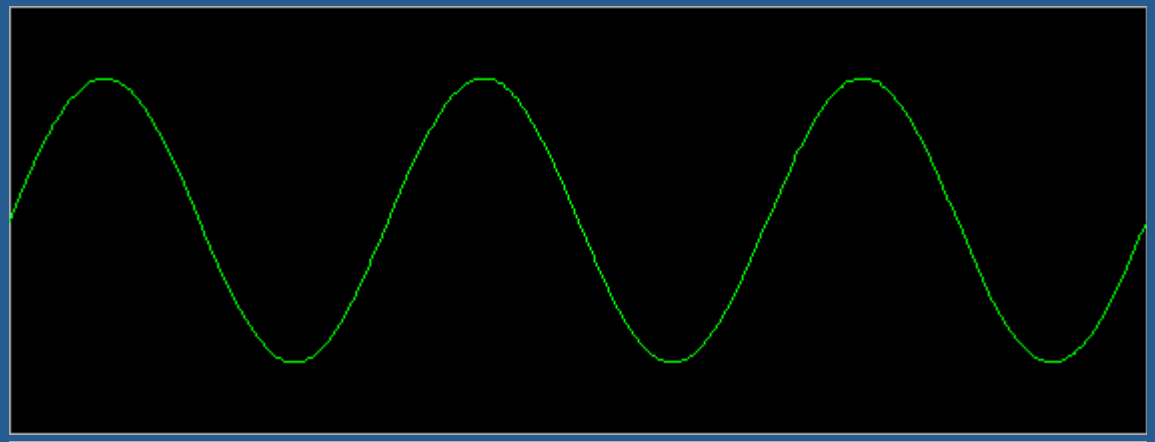
a) What is the bandwidth of the above signal?

b) Which of the following is (the most likely) frequency domain representation of the given signal?

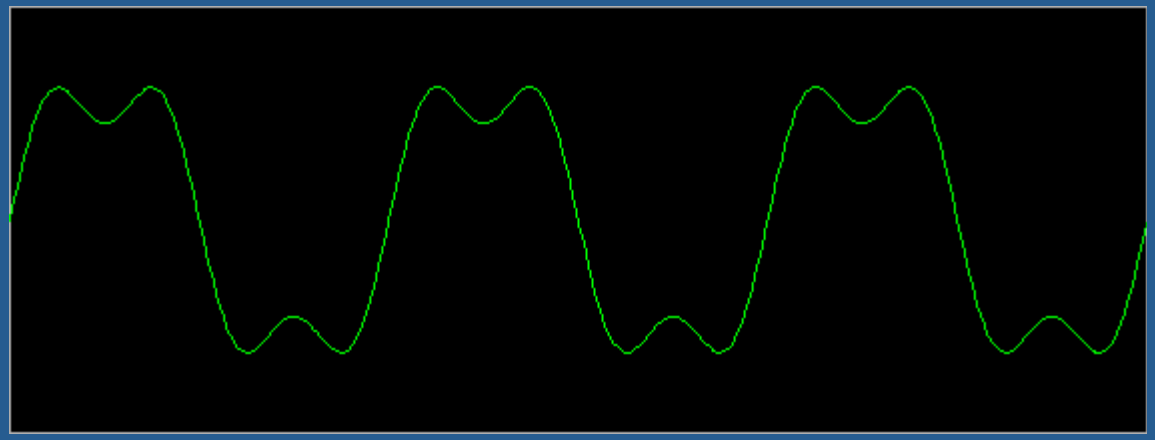




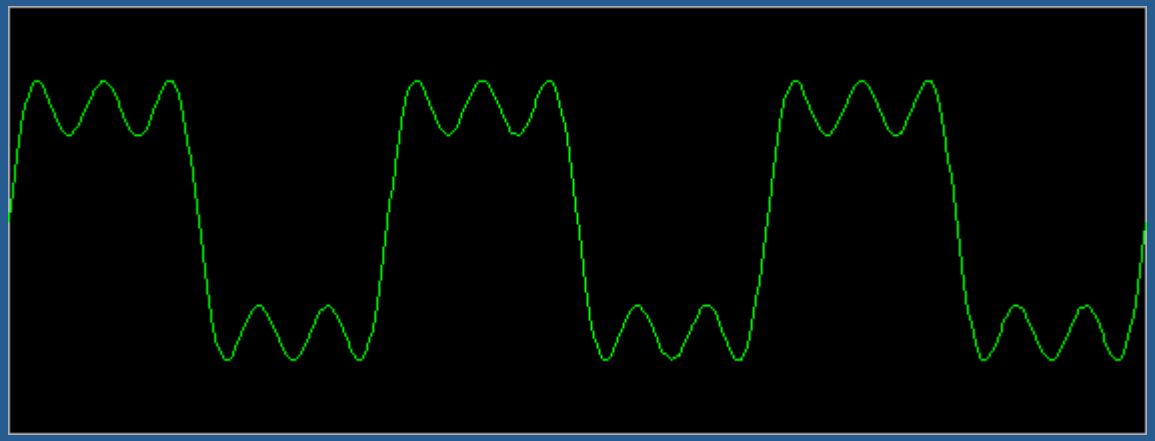




f_0 is the fundamental signal frequency of 1kHz (1ms period) if it had no harmonics it would look like this:



Add $3f_0$ (3kHz) with the same phase but 30% amplitude, and you get this: *Notice how the humps go up and down at 3kHz.*



Finally, add $5f_0$ (5kHz) at 30% amplitude. *Notice how the humps go up and down at 5kHz.*

BW = (5 - 1) kHz = 4kHz

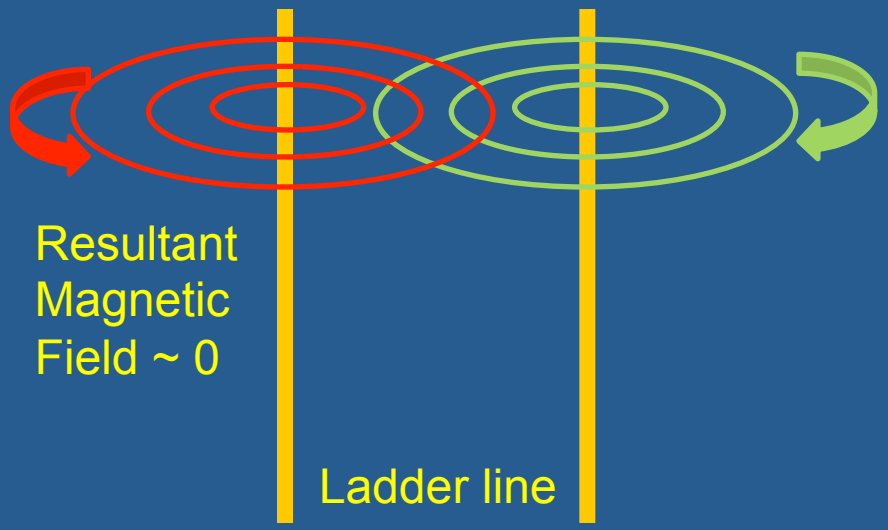
Section 4 Feeders and Antennas

4A Feeders

The Antenna And Its Feeder

- The antenna is the biggest single factor governing the effectiveness of your station in making contacts.
- A well-matched antenna will radiate effectively.
- An expensive, state-of-the-art transceiver cannot work well if it is connected to a poor antenna.
- *"Lots of wire as high as you can"* is good advice.
- Positioning the antenna is usually a compromise.
- A bit of advance planning pays dividends here!

Balanced Feeder: Equal and Opposite Currents



Antenna feed currents and resultant magnetic fields are equal an opposite.
No radiation from feeder

Two RF conducting surfaces

With balanced feeder there are two, equal and opposite currents. The resultant magnetic field is zero and the feeder does not radiate.

However, if it passes near to metallic objects (eg guttering) this can cause an imbalance in the feeder currents. The resultant magnetic field is no longer zero and radiation can occur.

Balanced feeder such as ladder line should always be kept well away from conducting items.

Rectangular Waveguide

At microwave frequencies rectangular waveguide is often used.

The physical dimensions of the waveguide are critical.

The waveguide has to have its larger dimension > ($\lambda/2$) to support propagation of the wave in the guide.

The Decibel

These are a convenient way of showing *RATIOS of POWER.*

You need to know the following to understand how decibels are used.

$10^0 = 1$; $10^1 = 10$; $10^2 = 100$; $10^3 = 1{,}000$; etc

You don't have to use whole numbers as the index. For example:

$10^{0.3} = 2$; $10^{0.6} = 4$; $10^{0.9} = 8$;

The ratio (Power Level 1) to (Power Level 2) expressed in decibels is:

$$\left(\frac{P_2}{P_1}\right) \text{dB} = 10 \log_{10} \left(\frac{P_2}{P_1}\right)$$

For example: P_1 = 10W and P_2 = 40W.
What is the power gain in dB?

$$\frac{40}{10} \text{dB} = 10 \log_{10} \frac{40}{10}$$

$$= 10 \log_{10} 4$$

$$= 10 \times 0.6$$

$$= 6\text{dB}$$

Know These db Power Ratios!

0db = 1
3db = 2
6db = 4
9 db = 8
10db = 10
20db = 100
26db = 400
30db = 1000

A minus sign in front of the db

(-db)

means a loss.

Feeder Characteristic Impedance

In amateur radio the characteristic impedance of coaxial cable used is usually 50Ω.

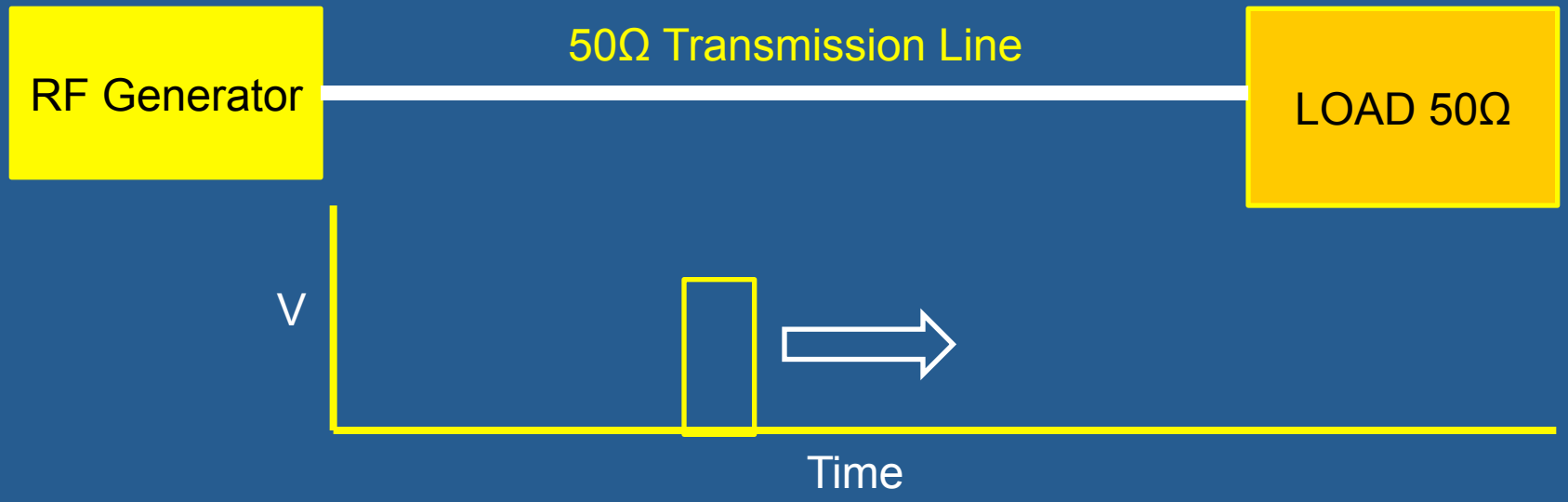
For tv and satellite a 75Ω coaxial cable is used.

The characteristic impedance is a function of the separation distance between the inner and outer conductors.

Twin wire feeder comes in values between 75Ω and 600Ω

A correctly-terminated feeder is one which is terminated in a resistance equal to the characteristic impedance of the feeder.

Why The Characteristic Impedance Is Important



Imagine a pulse of current leaving a transmitter and travelling down a transmission line towards the load. On leaving the transmitter the current pulse has no "knowledge" of the load until it arrives there. So how does the transmitter "know" the magnitude of the pulse that it has to deliver to the transmission line?

This magnitude is determined by the characteristic impedance of the transmission line. If the transmission line is correctly terminated in its characteristic impedance the magnitude of the current pulse will be exactly right to be dissipated in the load. If the load is not equal to the characteristic impedance the current pulse will not "match" and reflections will occur. The characteristic impedance is also known as the surge impedance.

Feeder Loss

Twin wire feeder usually has a much lower loss than coaxial feeder. (db/metre).

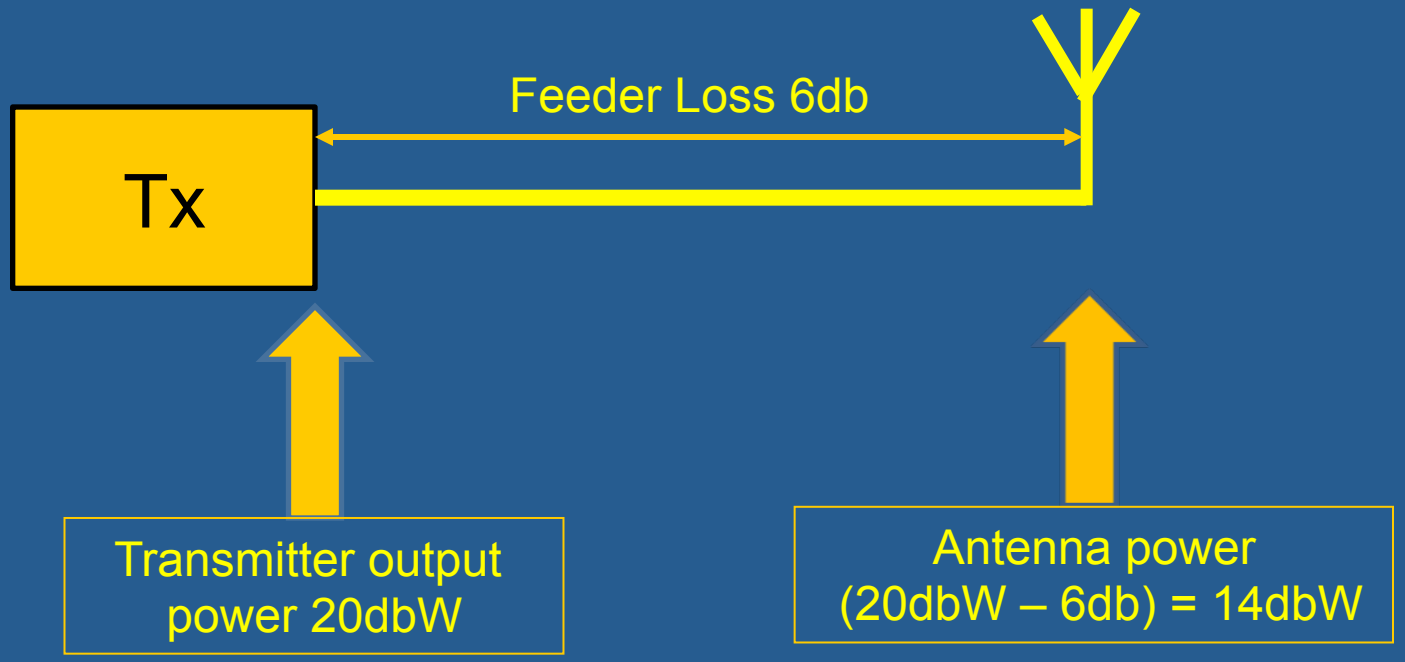
Feeder loss is measured in decibels.

The loss in decibels is:

$$10\log_{10}\ (\text{Power Out} / \text{Power In})$$

Performance data for coaxial cable will state the loss in (db/10metres) at given frequencies. *The higher the frequency the greater the loss.*

Power Generated, Feeder Loss and Power Delivered to the Antenna



20dbW = 100W; 6db is a factor of 4, 14dbW is 25W [100 = 4 x 25]

4B Baluns

The Balun (1)

Coaxial feeder is “unbalanced” with respect to earth. This means that one side of the cable is connected to earth. In this instance the braid or outer.

Balanced feeder is not connected to earth. The currents on both wires vary symmetrically about the zero reference.

A dipole is a balanced antenna. Neither side is connected to earth.

If you try to use an unbalanced feeder to feed a balanced load you can experience problems with out-of-balance currents travelling down the braid. These will radiate and cause distortion on your signal when they get into the transmitter.

The Balun (2)

To overcome this issue you need to insert a BALUN (**bal**anced to **un**balanced).

The balun works to *choke off* the out-of-balance currents getting onto the outer surface of the coaxial feeder at the load.

By winding the feeder around a ferrite ring or winding coils onto a ferrite you can create a high impedance to these out-of-balance currents. This reduces their magnitude and hence their ill effects.

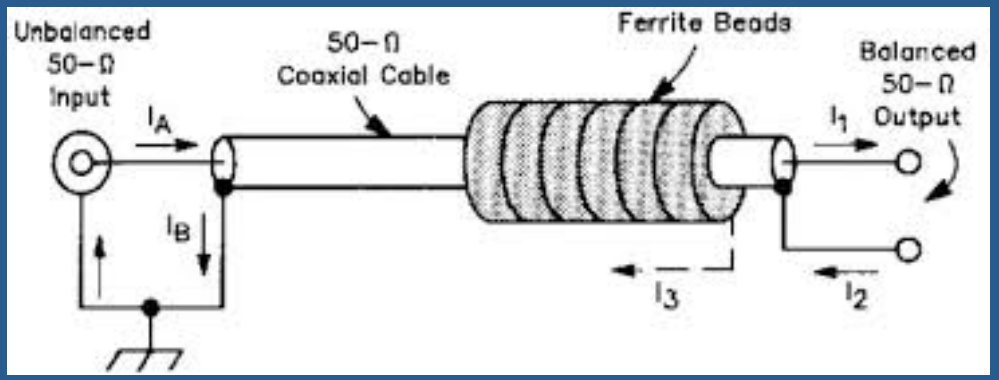
Ideally you should use a balanced feeder for HF dipoles. This is not always practicable – hence the need for the balun.

Types of Choke Balun











4C Antenna Concepts

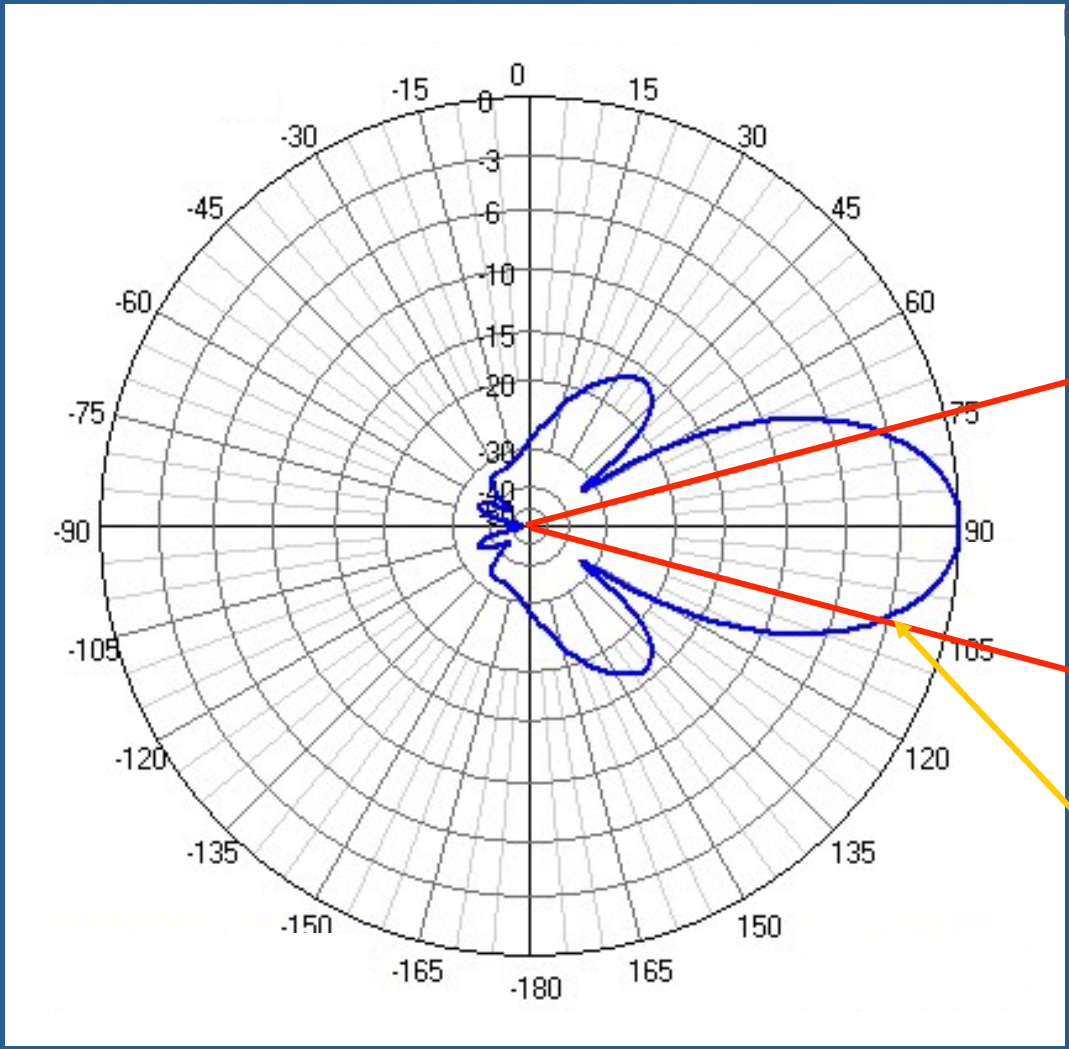
Front to Back Ratio (F/B Ratio)

The Front to Back Ratio (F/B Ratio) of an antenna is the ratio of power radiated in the front/main radiation lobe and the power radiated in the opposite direction (180 degrees from the main beam).

$$\text{Front to Back Ratio} = \frac{\text{Forward Power (F)}}{\text{Backward Power (B)}}$$

This ratio tells you the extent of backward radiation and is normally expressed in dB. This parameter is important in circumstances where interference or coverage in the reverse direction needs to be minimized.

Antenna Beamwidth



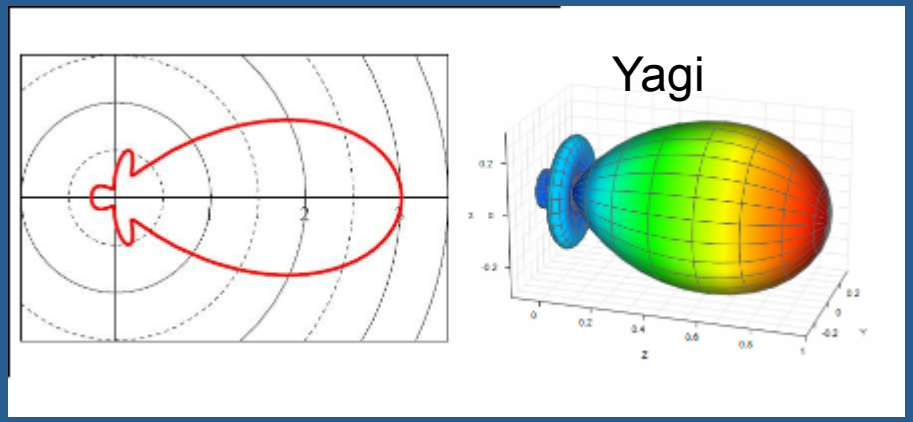
In a radio antenna pattern, the half power beam width is the angle between the half-power (-3 dB) points of the main lobe, when referenced to the peak effective radiated power of the main lobe.

15 + 15 degrees = 30 degrees

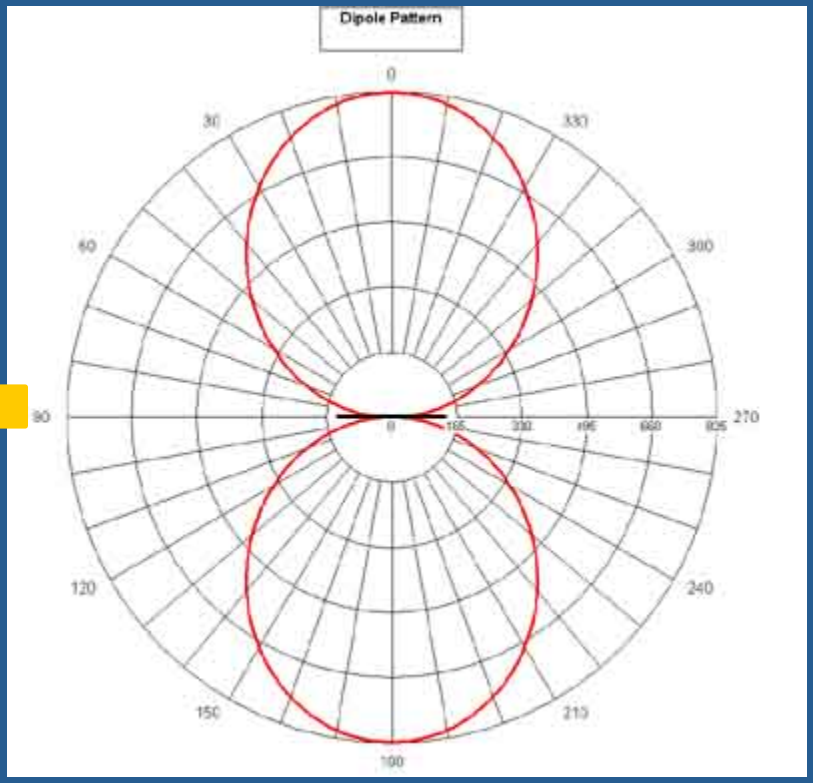
Beamwidth is usually but not always expressed in degrees and for the horizontal plane.

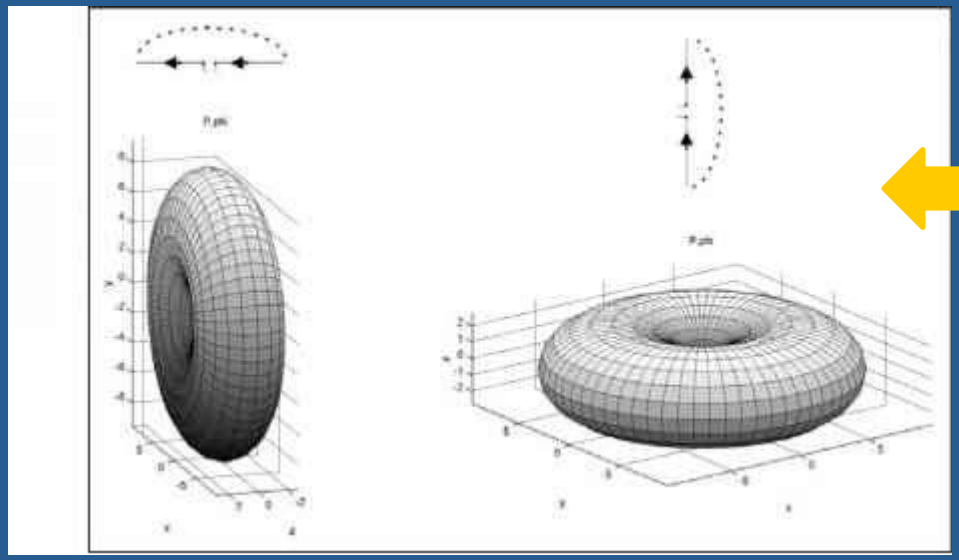
-3dB contour

The Antenna Radiation Pattern is 3D

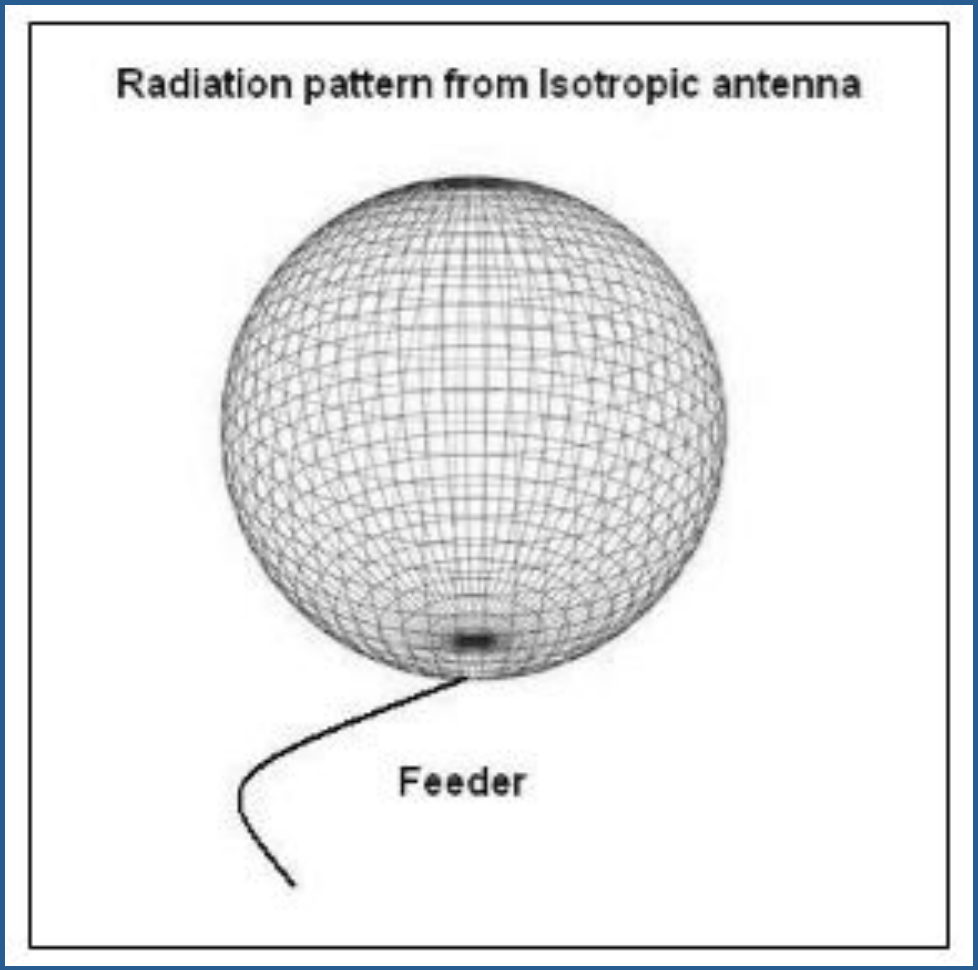


Half Wave Dipole





Isotropic Radiator



An isotropic antenna is a theoretical type of antenna that radiates equally in all directions.

The Effective Isotropic Radiated Power (EIRP) is based on an isotropic radiator and is expressed in dBi

Gain of a Dipole Antenna over An Isotropic Radiator

In its optimum direction a dipole antenna exhibits a gain of:

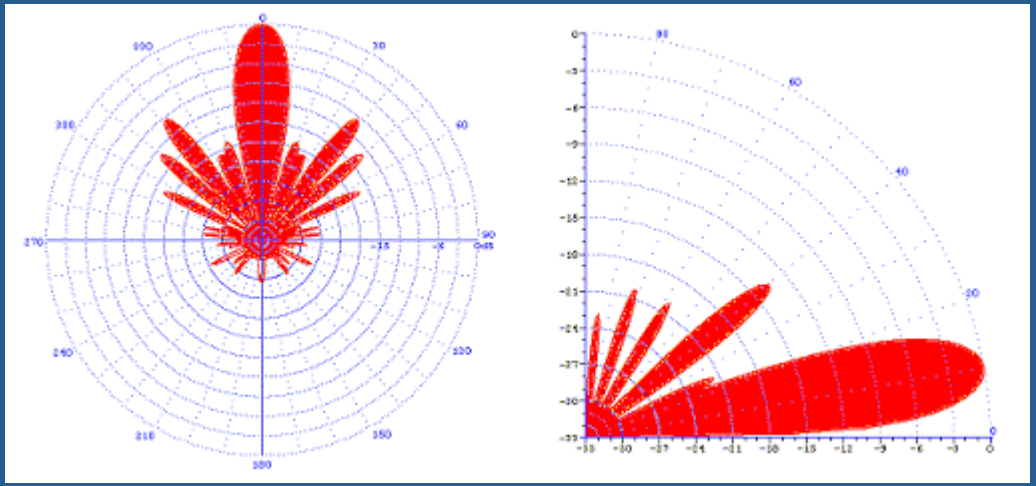
2.15dBi

This equates to: x1.6

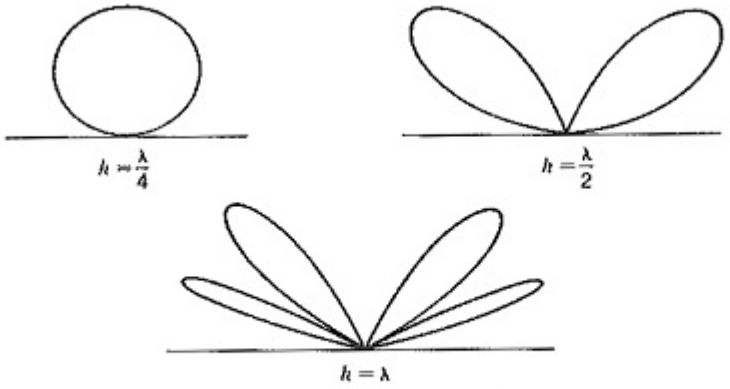
Angle of Radiation

The angle that the radiation leaves the antenna is known as *the angle of radiation.*

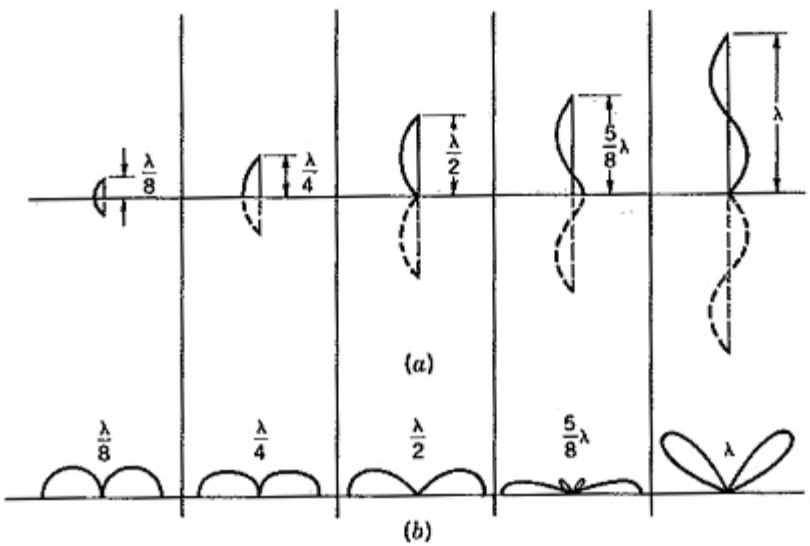
Long distance work (dx) requires a low angle of radiation of the main lobe.



The Effect of Ground on the Angle of Radiation



Ungrounded half-wave dipole



Vertical, grounded antenna.
(a) Heights and current distribution,
(b) radiation pattern

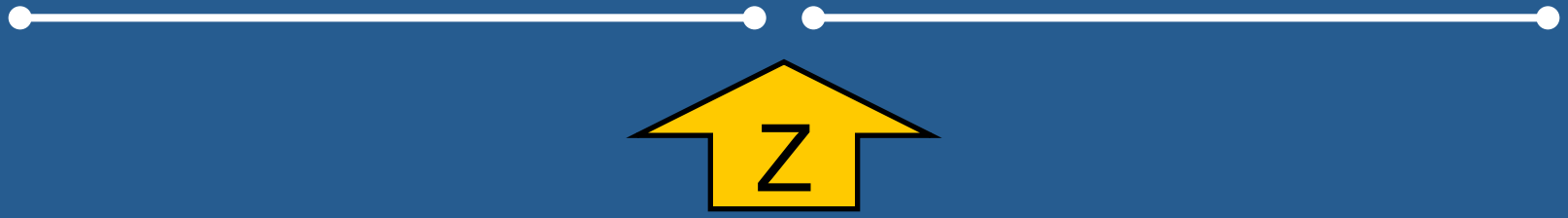
Near Vertical Incident Skywave (NVIS)

Near vertical incidence skywave, or NVIS, is an HF skywave radio-wave propagation path that provides usable signals in the distances range 0–650 km. It is used for military communications and broadcasting, especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter.

There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

By placing the antenna – eg a dipole - close to the ground (~0.15λ) most of the radiation will be directed upwards. This is the opposite to where you want a low angle of take-off to meet the ionosphere at a low angle and maximise the distance where the first refracted wave returns to the Earth.

Antenna Feed Point Impedance

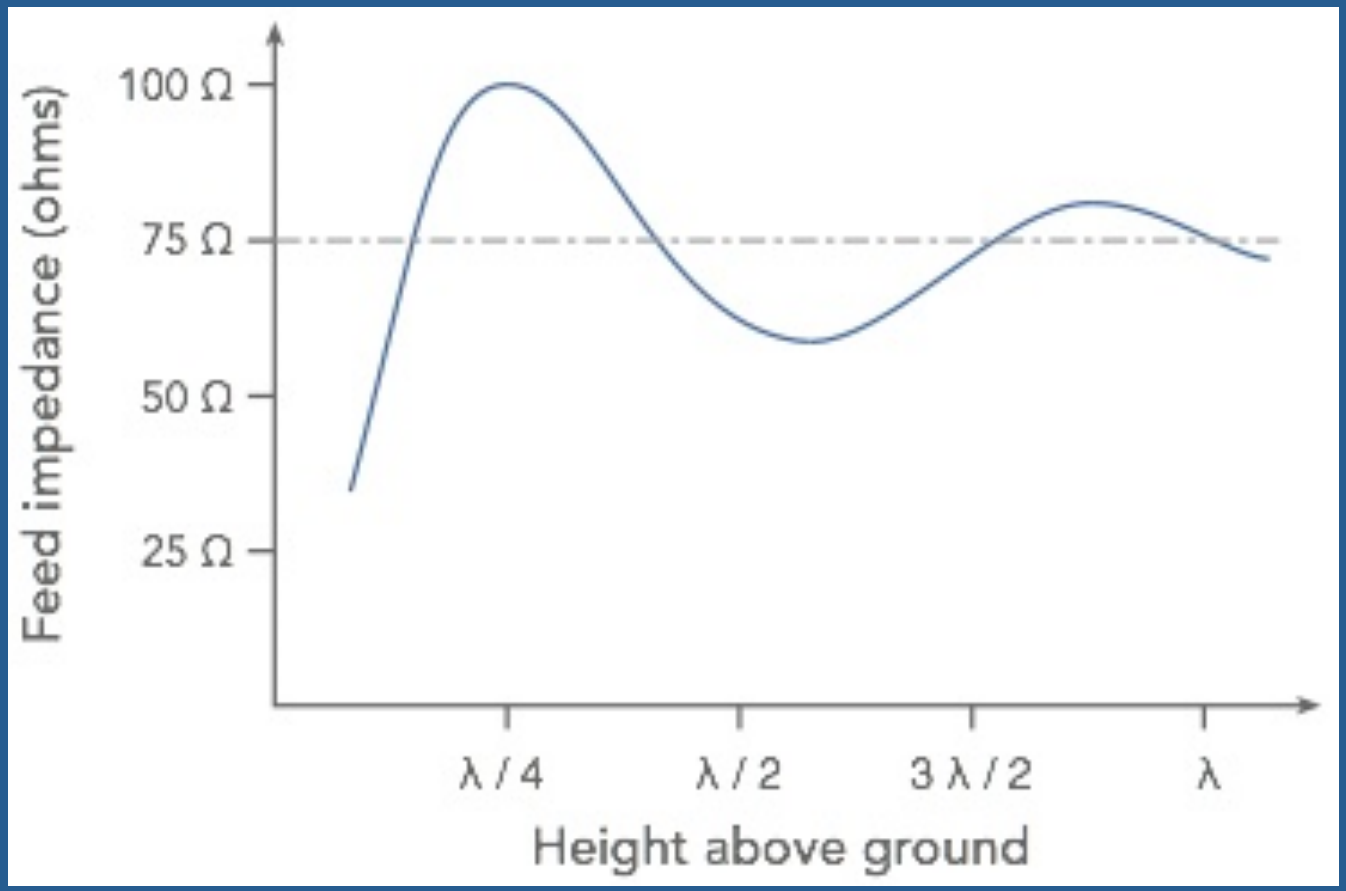


The antenna feed point impedance (Z) is what you “see” when you look into the feed point of the antenna. The antenna’s feed point impedance is a function of:

Its height above the ground;
The physical size of the antenna;
The frequency that you apply to it.

The current flowing into the antenna is a function of the feed point impedance and the applied voltage.

Effect of Height Above Ground



An antenna will only present the correct feed point impedance when it is fed with the frequency for which it was designed.

As the height above ground varies so does the antenna feed point impedance Z. Above 1λ over the ground Z is about 75Ω. At practical heights (eg for an 80m dipole) Z = ~50Ω

4D Types of Antenna

Two Types of HF Antenna

- There are two, common types of HF antenna:

Centre-fed

(Hertzian types – or balanced antenna)

End-fed

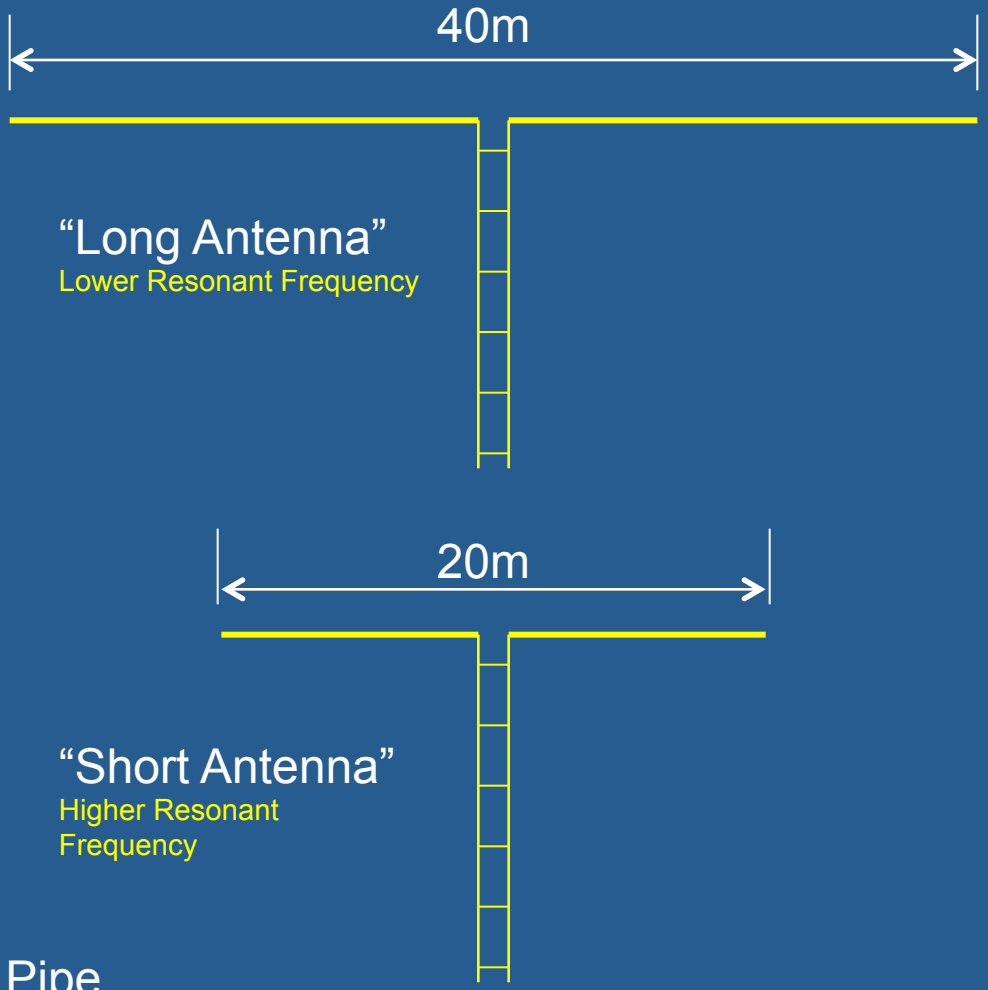
(Marconi types – or unbalanced antenna)

Antenna Resonance

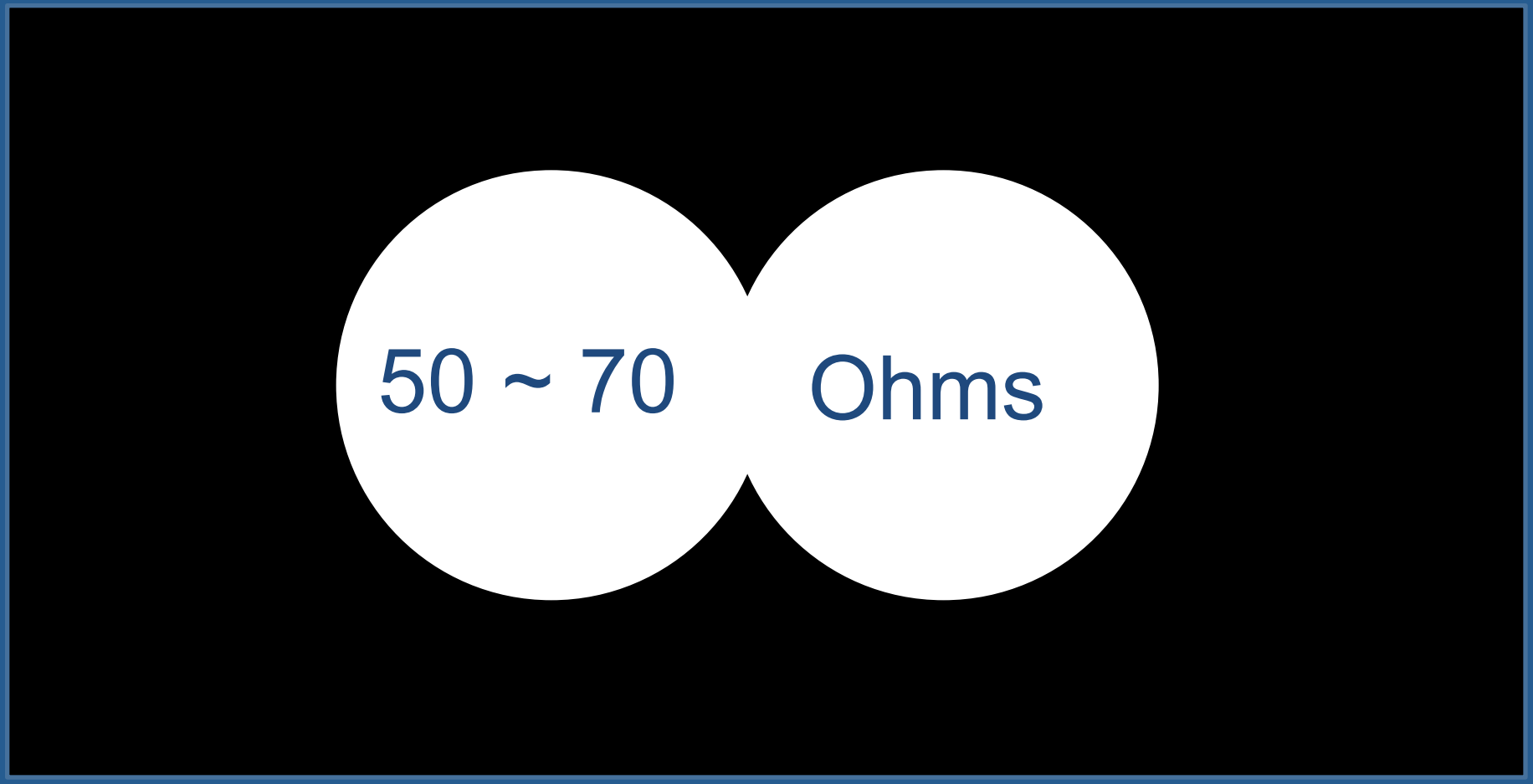


Long Pipe
Low frequency

Short Pipe
High frequency



What The Transmitter "Wants to See" When It Looks Into The Feeder Towards The Antenna



This rarely happens with "real antennas"

What The Transmitter "Actually Sees"

A perfectly resonant antenna



An antenna that is physically longer than the resonant length at the applied frequency. *(ie the wavelength at the applied frequency is shorter than the resonant wavelength of the antenna.)*

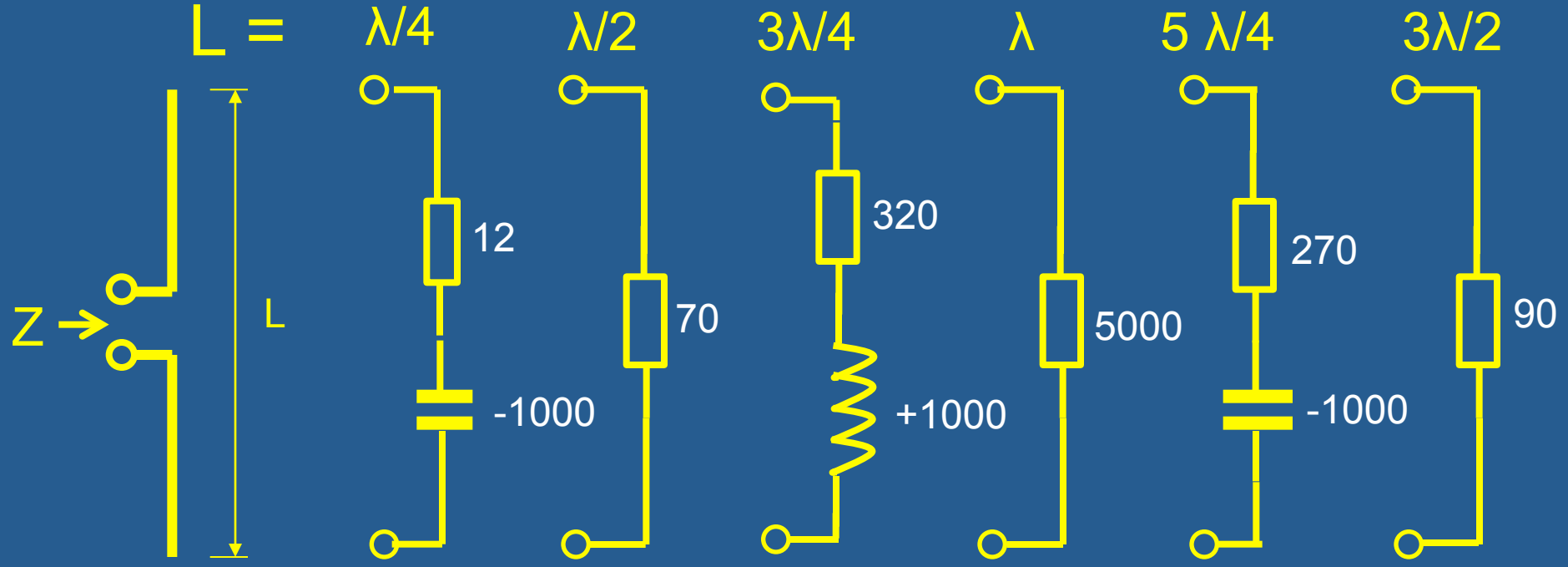


An antenna that is physically shorter than the resonant length at the applied frequency. *(ie the wavelength at the applied frequency is longer than the resonant wavelength of the antenna.)*



What The Transmitter Actually Sees (Z) At Various Antenna Lengths (λ Multiples)

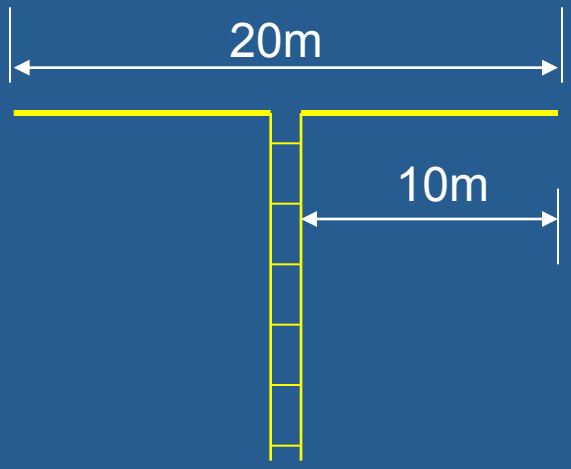
Note: λ is the wavelength of the applied frequency onto the antenna (eg 80 metres at 3.75MHz). So, for a wire dipole antenna to resonate at 80 metres (3.75MHz) it will be 40m long overall (λ/2 or half a wavelength at 3.75MHz). As the applied frequency varies the antenna length measured in terms of wavelengths at the applied frequency will also vary. The antenna therefore becomes electrically longer or shorter.



The Dipole Resonant Length (Recap)

A simple, HF, wire dipole resonates at the frequency at which it is half a wavelength long . (λ/2)
(Remember this!)

So to be resonant at 7.5MHz (say) - which is equivalent to a wavelength of 40 metres – a dipole needs to be 20 m long overall and thus comprises two, equal lengths of wire - each 10 metres long.



A resonant dipole antenna has a radiation resistance of around 50 Ohms to 70 Ohms

The Amateur Bands

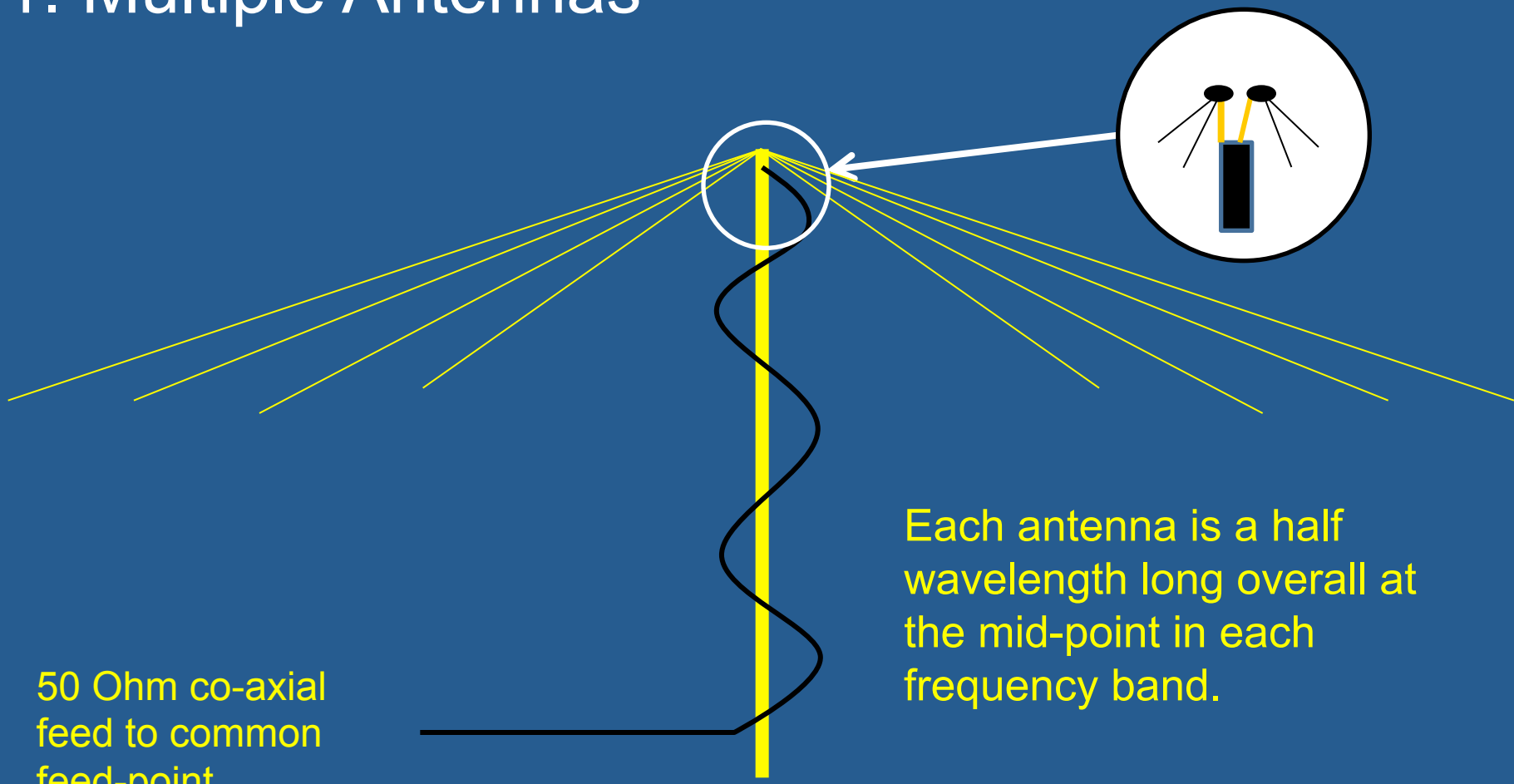
The HF Amateur Bands you want to use are:

Band	Frequency	~Wavelength metres
80 metres	3.50MHz to 3.80MHz	85.7 to 100
40 metres	7.00MHz to 7.20MHz	42.8 to 41.6
30 metres	10.10MHz to 10.15MHz	29.7 to 29.6
20 metres	14.00MHz to 14.35MHz	21.4 to 20.9
17 metres	18.068MHz to 18.168MHz	16.6 to 16.5
15 metres	21.00MHz to 21.45MHz	14.3 to 14.0
12 metres	24.89MHz to 24.99MHz	12.1 to 12.0
10 metres	28.00MHz to 29.70MHz	10.7 to 10.1

There is obviously no single, dipole antenna that is resonant at every frequency. So what do we do…..?

And The Solutions Are…….

1. Multiple Antennas

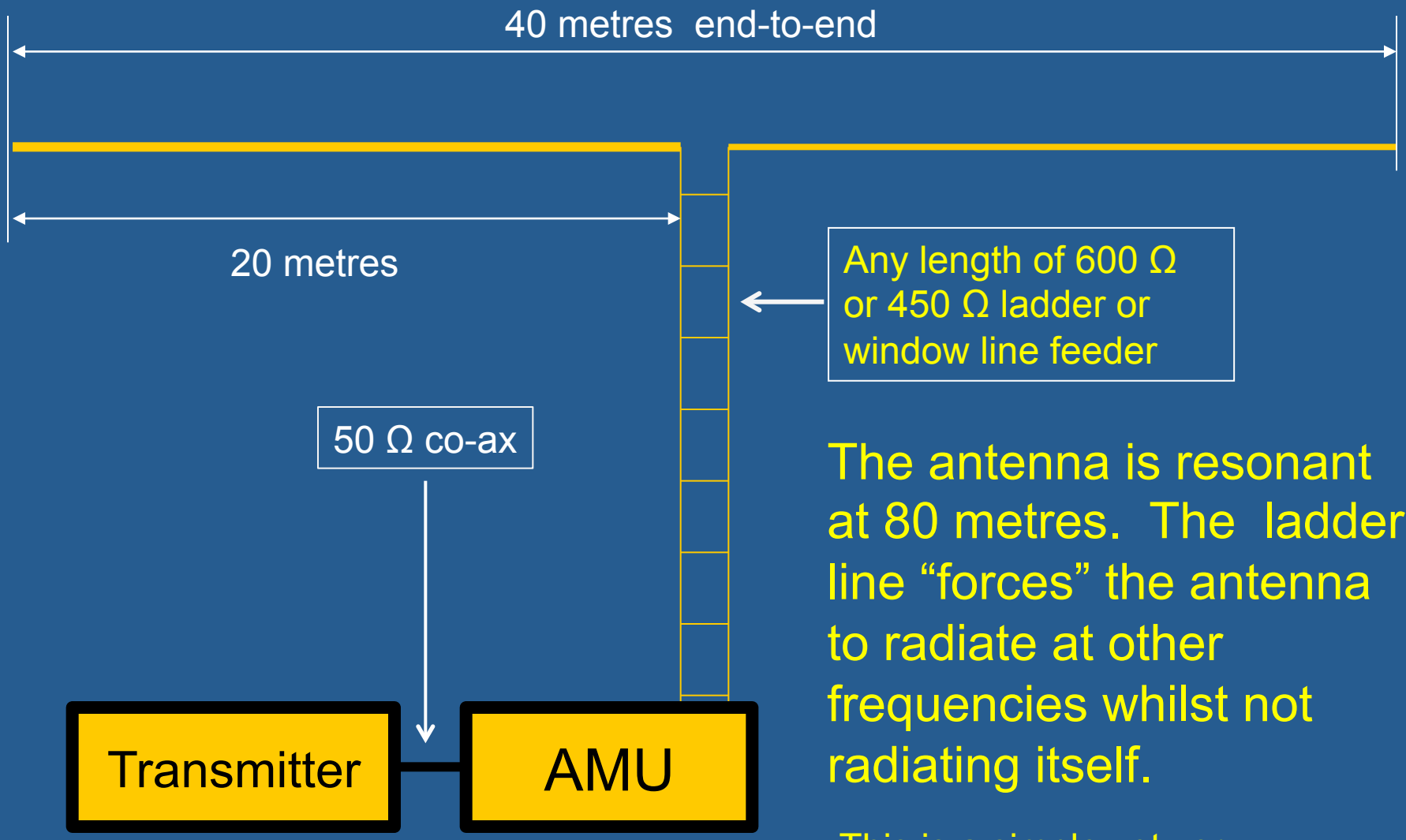


Each antenna is a half wavelength long overall at the mid-point in each frequency band.

50 Ohm co-axial feed to common feed-point

There is inevitably some interaction between the dipoles so setting up can be a bit tricky. You need quite a bit of space as well.

2. The HF Doublet Antenna

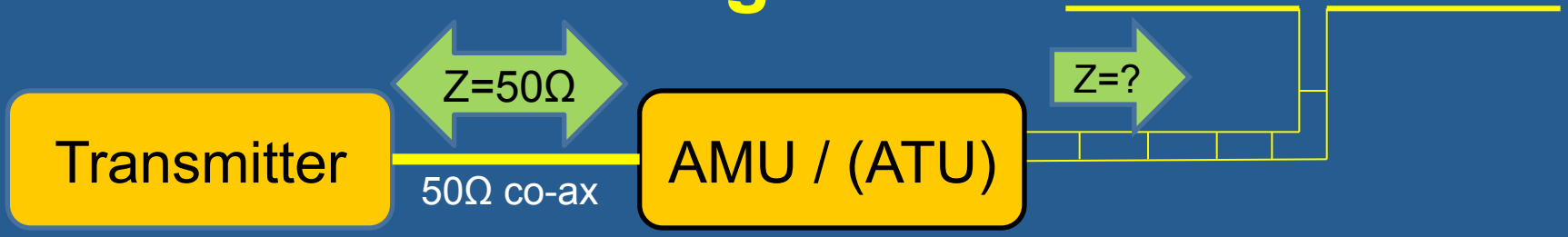


AMU: Antenna Matching (Tuning) Unit

The antenna is resonant at 80 metres. The ladder line "forces" the antenna to radiate at other frequencies whilst not radiating itself.

This is a simple yet very effective antenna

The Antenna Matching Unit



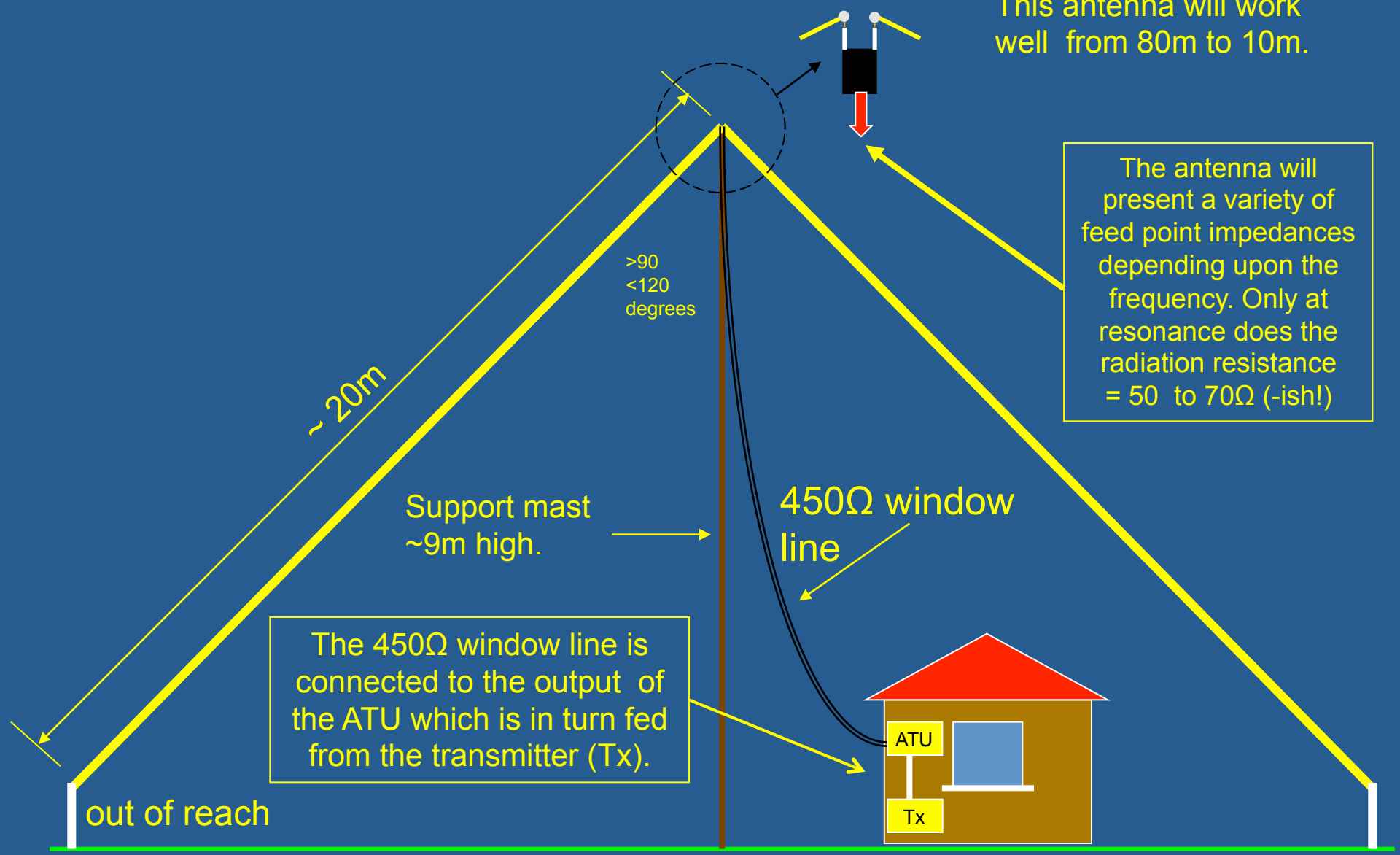
As we have seen the antenna does not present a constant impedance as you move away from its resonant frequency. The transmitter, however, only operates correctly into loads which are around the 50Ω value.

The AMU (usually called an Antenna Tuning Unit ATU) is placed between the transmitter and the antenna. It provides an impedance transformation (change) which transforms (changes) the various antenna impedances back to 50Ω for the output of the transmitter. You can thus use 50Ω co-axial cable at this point.

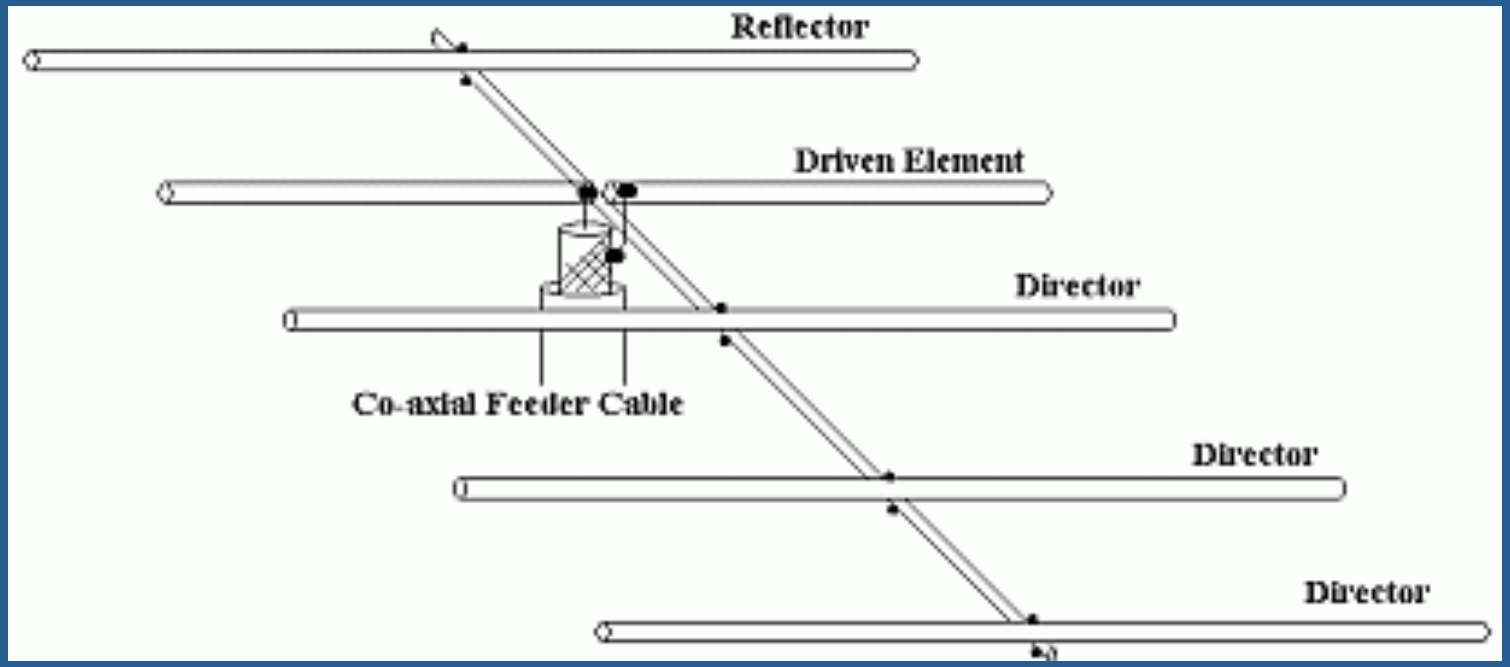
The ATU contains inductance and capacitance. These are adjusted so that there is no reflected power (current) on the outer braid of the co-ax.

THE ATU DOES NOT CHANGE THE ACTUAL IMPEDANCE OR RESONANT FREQUENCY AT THE ANTENNA - IT ONLY TRANSFORMS THEM FOR THE TRANSMITTER.

Inverted Vee Doublet



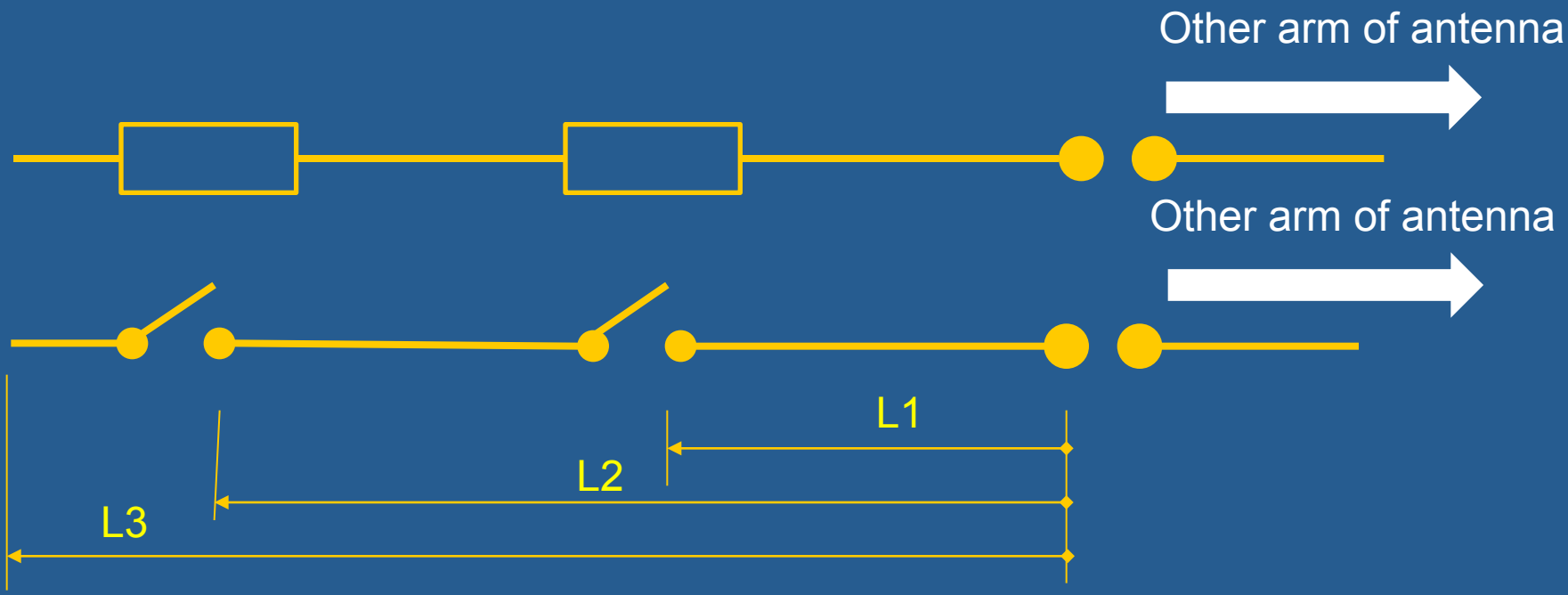
The Yagi Antenna



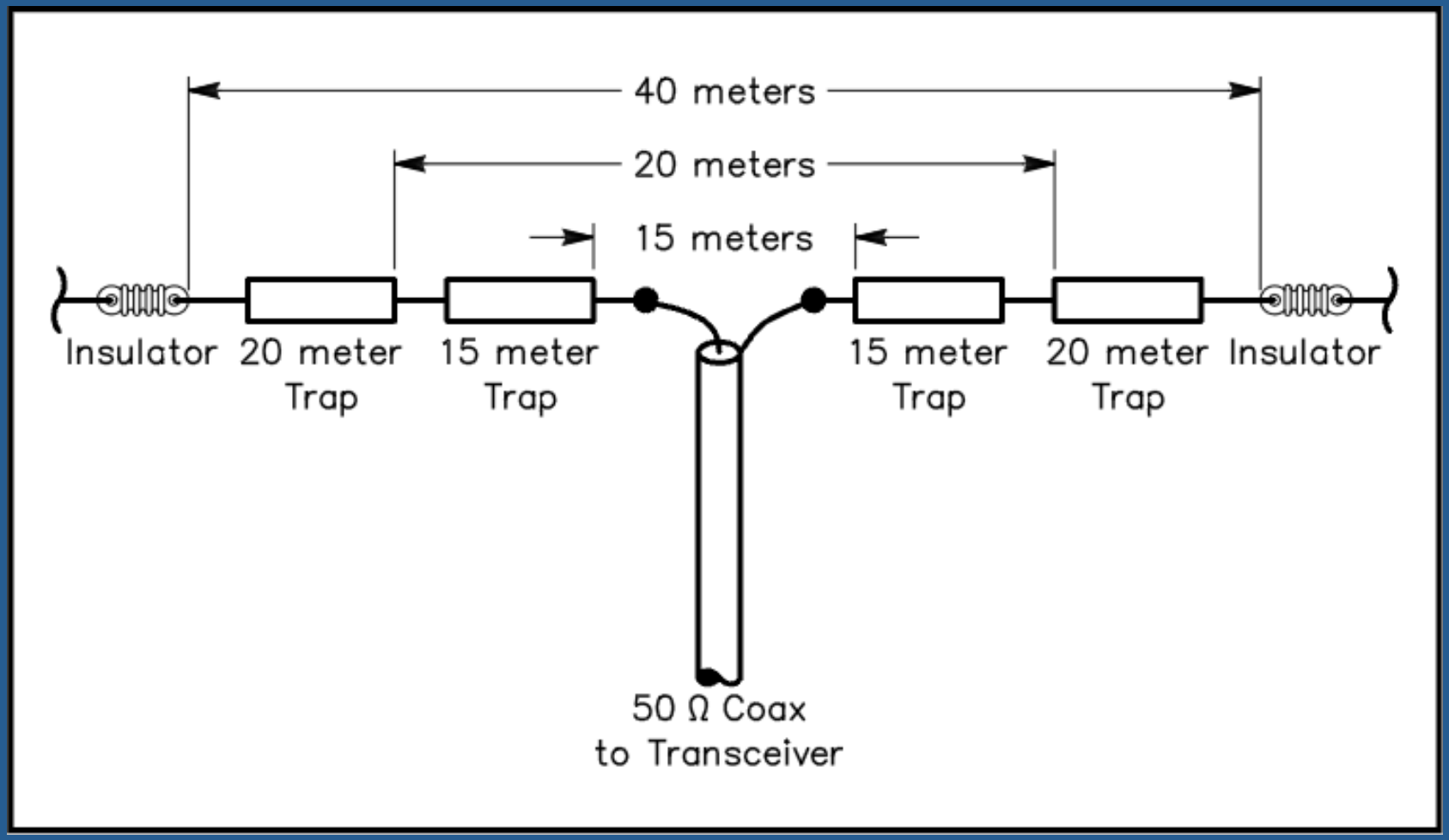
A yagi antenna comprises a reflector, a driven element and one or more directors. The reflector is about 5% longer than the driven element. The first director is about 5% shorter than the driven element. Each subsequent reflector may also be shorter than its preceding one.

The Antenna Trap

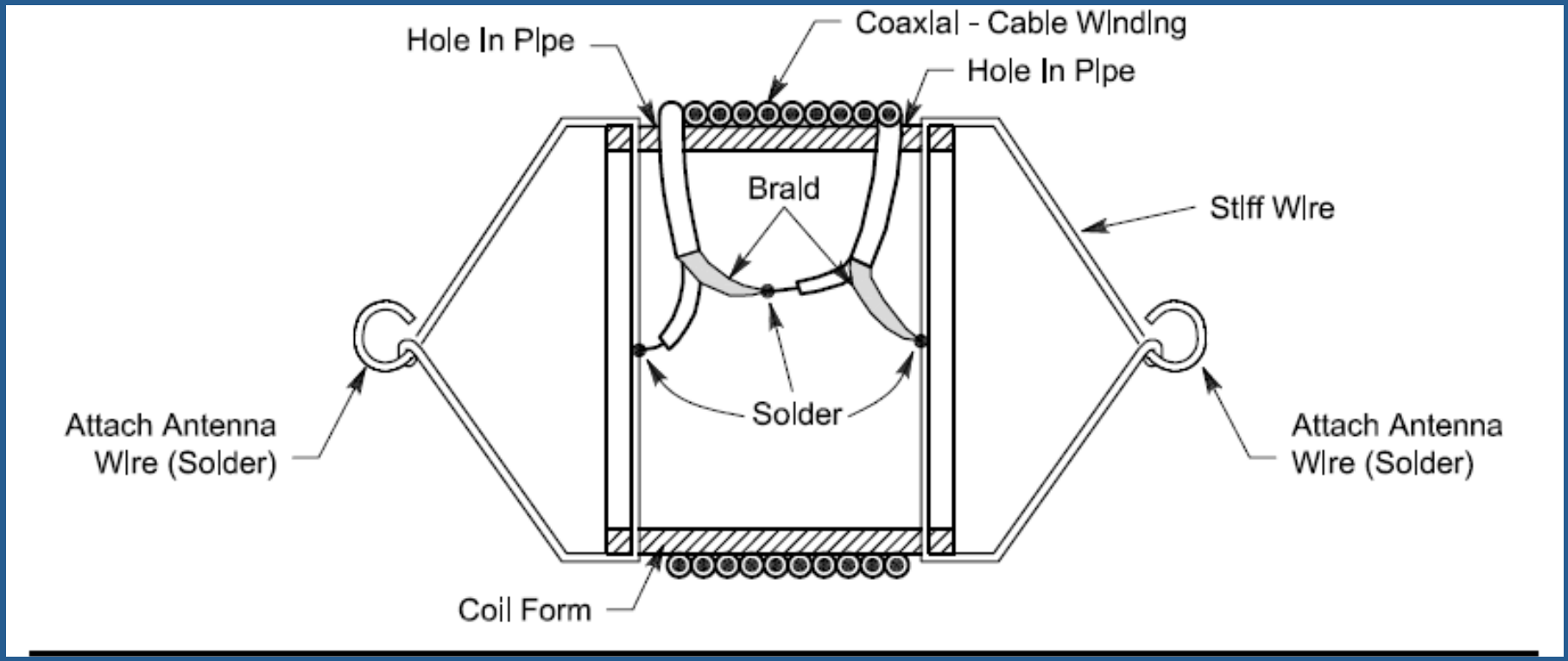
The antenna trap is a parallel, tuned circuit inserted into each arm of a dipole. A parallel tuned circuit displays a high impedance at resonance. By inserting traps you can effectively switch in and out sections of the antenna when you apply the correct frequency. This effectively makes the antenna be the resonant (physical) length for that frequency.



Practical Example



Traps Using Co-Axial Cable



An open-circuit length of co-axial cable is effectively a tubular capacitor.

By sizing the coil correctly the inductance of the coil and the capacitance of the coaxial cable makes the parallel resonant circuit for the trap. (You can of course wind the coil conventionally and add a discrete capacitor.)

Trapped Yagi



4E Standing Waves

Voltage Standing Wave Ratio: VSWR

As its name suggests the VSWR will comprise two numbers showing a comparative size relationship one to the other. For example: 3 : 1 or 1 : 1 etc.

The ratio is always positive and cannot be less than 1 : 1.

It is a property of transmission lines – in our case antenna feeders such as coaxial cable , ladder or window line.

The VSWR on the feeder is a measure of how well the antenna feed-point impedance (load) matches the characteristic impedance of the feeder to which it is attached.

For example: A coaxial cable of 50Ω characteristic impedance will perfectly match an antenna with a feed-point impedance of 50Ω and produce a VSWR of 1 : 1 on the co-axial feeder.

Efficient Transfer of RF Power From The Transmitter (Source) To The Antenna (Load)

When you transmit the transmitter generates RF energy in the form of RF voltage and current. The feeder transports that energy to the antenna load where it is radiated as electromagnetic waves.

You want a system where ideally 100% of the RF energy generated by the transmitter appears at the load and is radiated as electromagnetic energy (radio waves) without any losses en route.

In the real world this never happens because there will always be losses in the transmission system due to cable resistance and the insertion losses from equipment such as the Antenna Tuning Unit.

These losses are only a few percent at worst. However, something can occur at the load to drastically limit the radiation efficiency.

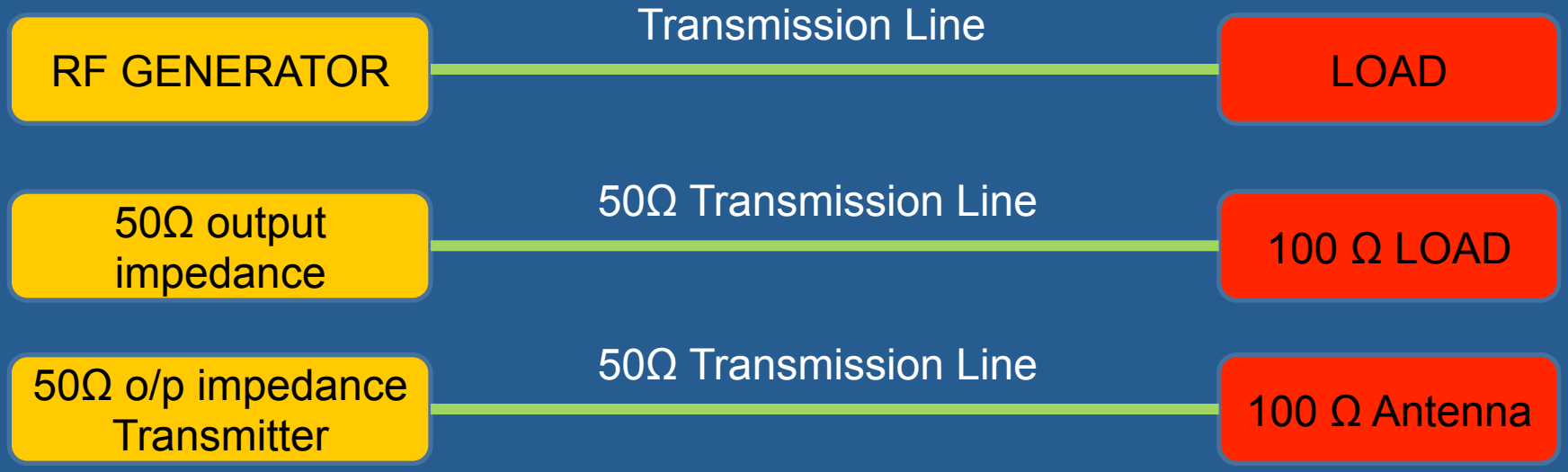
Matched Load



The above represents a perfectly-matched system. The output impedance of the source, the characteristic impedance of the coaxial cable and the load impedance are all identical.

Under these conditions all of the energy generated by the transmitter will be transported to the load where all of it will be radiated.

Mis-Matched Load



The above represents a mis-matched system. The output impedance of the source and the characteristic impedance of the coaxial cable are matched BUT the load impedance is a MIS-MATCH.

Under these conditions NOT all of the energy generated by the transmitter will be radiated by the load.

Some of the energy will be REFLECTED back by the load towards the Transmitter along the transmission line.

Generation of Standing Waves

As the reflected energy travels back down the transmission line it encounters energy which is still travelling towards the load. This energy is in the form of voltage and current waves.

These waves interfere with each other to create standing waves of both current and voltage on the feeder cable. These standing waves do not travel along the cable but create high and low voltage points at regular intervals along the cable.

The bigger the mis-match in impedance between the feeder and the load the bigger the value of these standing waves.

The ratio of the mis-matched impedances is numerically equal to the:

VOLTAGE (or CURRENT) STANDING WAVE RATIO

So for a 50Ω coaxial cable feeding a 100Ω load the VSWR will be (100 / 50) or 2 : 1

The magnitude of the standing wave will be twice that of the travelling wave taking the energy to the load. With a VSWR of 15:1 or 20:1 (say) the standing wave voltage can be many hundreds of volts or thousands of volts – enough to destroy the feeder.

Protecting The Transmitter

Transmitters are designed to output RF energy – not to absorb it. Reflected energy arriving back at the transmitter will cause damage in the output stage. Modern transmitters will start to shut down if the VSWR that they see on their feeder gets above 1.5 : 1 or so.

The Antenna Matching Unit, as we have seen, sits between the transmitter and its load. It provides a match to the 50Ω cable linking the ATU and the Transmitter. The transmitter thus sees 50Ω.

On the antenna side of the ATU there is still a mis-match. There will be circulating currents in the ATU and standing waves on the antenna feeder. The antenna radiates but not the entire output of the transmitter.

Recap of Key Points

This Section contained a lot of information. Here are the key points we covered:

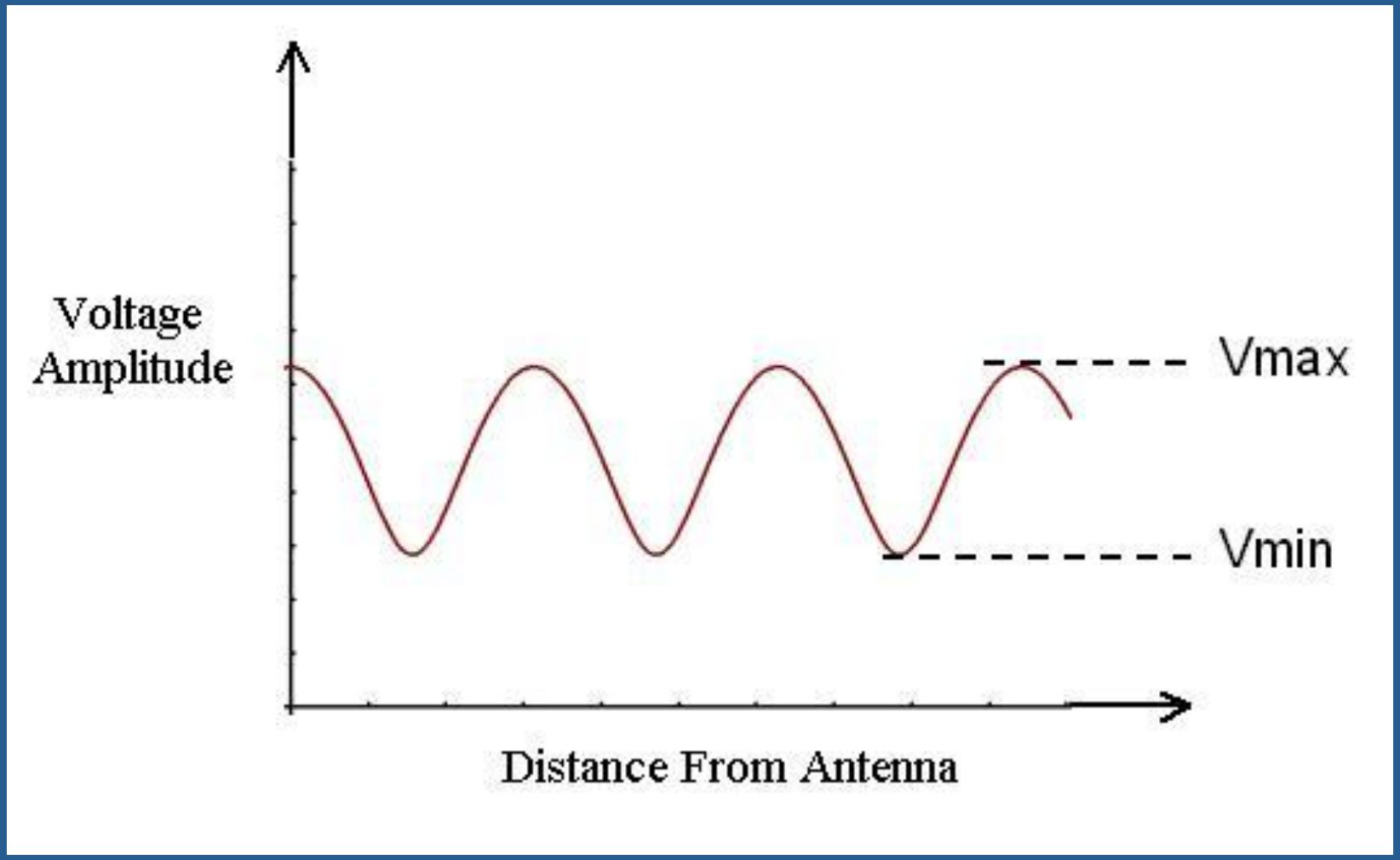
1. Ladder Line is a BALANCED FEEDER. Co-axial Cable is an UNBALANCED FEEDER.
2. If feeding a BALANCED ANTENNA (dipole) with co-axial cable outside of its RESONANT FREQUENCY you must use a BALUN to prevent imbalance currents on the outer braid.
3. A dipole has an overall length of HALF A WAVELENGTH at resonance.
4. At its resonant frequency a dipole antenna has a RADIATION RESISTANCE of 72Ω in theory. Its environment modifies this to around 50Ω to 72Ω. (ish!)
5. Amateur transmitters have an OUTPUT IMPEDANCE of 50Ω. They need to operate into antenna loads around this figure if they are to avoid damage.
6. An ATU MATCHES the antenna impedance to the transmitter's output impedance.
7. Any termination of a feeder that is not equal to the characteristic impedance of the feeder will give rise to VOLTAGE STANDING WAVES on the feeder through REFLECTION of power from the mismatched termination.
8. The level of termination mismatch is expressed as a VOLTAGE STANDING WAVE RATIO (VSWR) where a VSWR of 1:1 represents a perfect match.
9. A DUMMY LOAD is a perfect termination for a feed line that absorbs all the power it receives without reflecting or radiating it to allow for transmitter adjustment.

Reflection Coefficient Γ (Gamma) *(Not in the Syllabus)*

The reflection coefficient Γ is a measure of how much power is reflected by the load. The VSWR derives from the reflection coefficient Γ.

$$VSWR = \frac{1+|\Gamma|}{1-|\Gamma|}$$

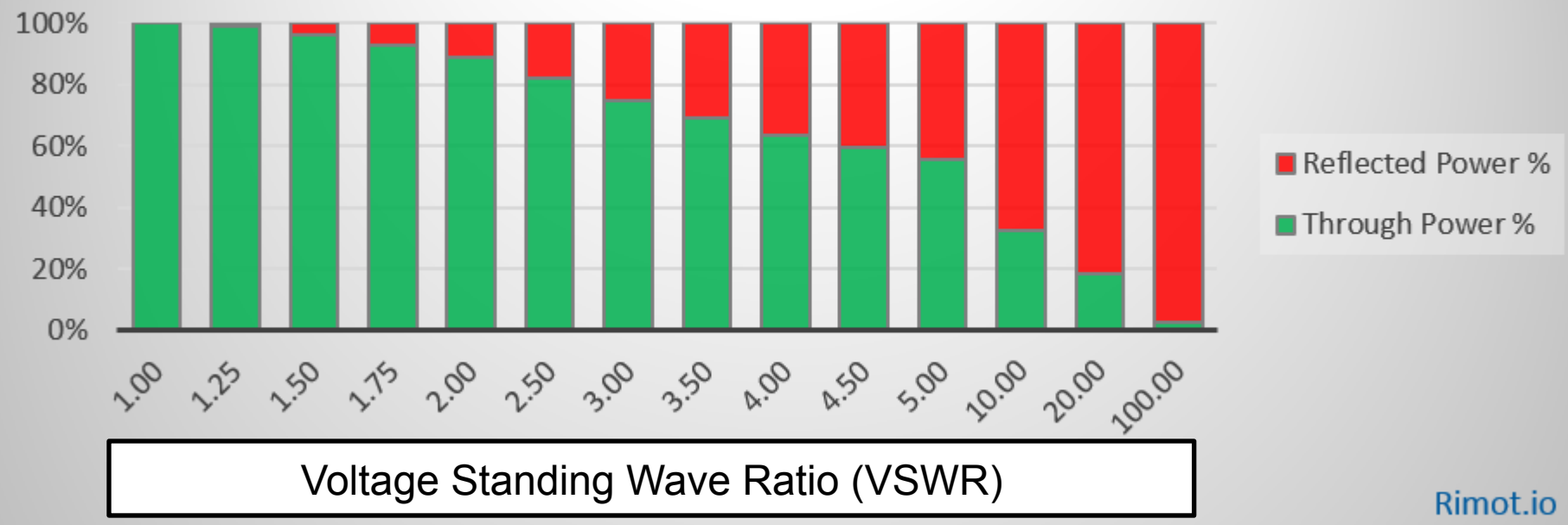
The VSWR is always a real and positive number for antennas. The smaller the VSWR, the better is the antenna matched to the transmission line and the more power is delivered to the antenna. The minimum VSWR is 1 : 1. In this instance no power is reflected from the antenna which is ideal.



VSWR is determined from the voltage measured along a transmission line leading to an antenna. VSWR is the ratio of the peak amplitude of a standing wave to the minimum amplitude of a standing wave.

VSWR	Γ	Reflected Power (%)	Reflected Power (dB)
1.0	0.000	0.00	-Infinity
1.5	0.200	4.0	-14.0
2.0	0.333	11.1	-9.55
2.5	0.429	18.4	-7.36
3.0	0.500	25.0	-6.00
3.5	0.556	30.9	-5.10
4.0	0.600	36.0	-4.44
5.0	0.667	44.0	-3.52
6.0	0.714	51.0	-2.92
7.0	0.750	56.3	-2.50
8.0	0.778	60.5	-2.18
9.0	0.800	64.0	-1.94
10.0	0.818	66.9	-1.74
15.0	0.875	76.6	-1.16
20.0	0.905	81.9	-0.87
50.0	0.961	92.3	-0.35

The Higher The VSWR – The Less Power Radiated From The Antenna



Measuring the VSWR:

Gives a good measure of the overall health of the antenna system;

Can highlight degraded system performance – coverage, voice quality, data throughput, etc.;

Helps avoid damage and failure to transmitters and repeaters from high VSWR;

Indicates if the system is performing as designed and intended;

Γ

In the table, a VSWR of 4 has 36% of power delivered by the receiver reflected from the antenna (64% of the power is delivered to the antenna). Note that a reflected power of 0 dB indicates all of the power is reflected (100%), whereas -10 dB indicates 10% of the power is reflected. If all the power is reflected, the VSWR would be infinite.

Note that VSWR is a highly non-linear function of the reflection coefficient Γ. That is, there is very little difference in reflected power when the VSWR increases from 9 to 10; however there is an 11% change in reflected power when the VSWR changes from 1 to 2.

4F Antenna Matching Units

Matched Load

The transmitter is designed to work into a 50Ω load. This will allow the maximum power transfer.

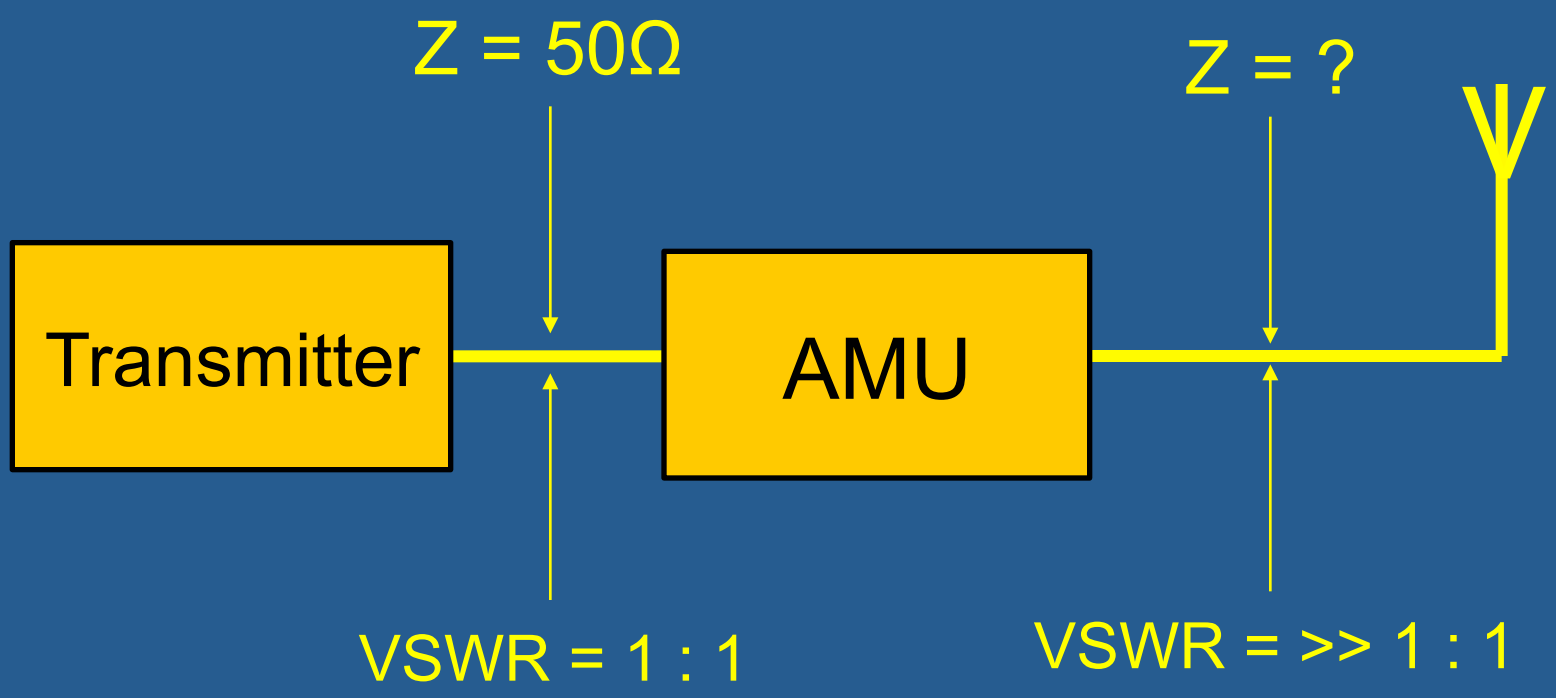
Any other impedance will be a mismatch and reflect power.

The transmitter needs to be protected against excessive mismatch. This is achieved by placing an Antenna Matching Unit (AMU) between the transmitter and the antenna.

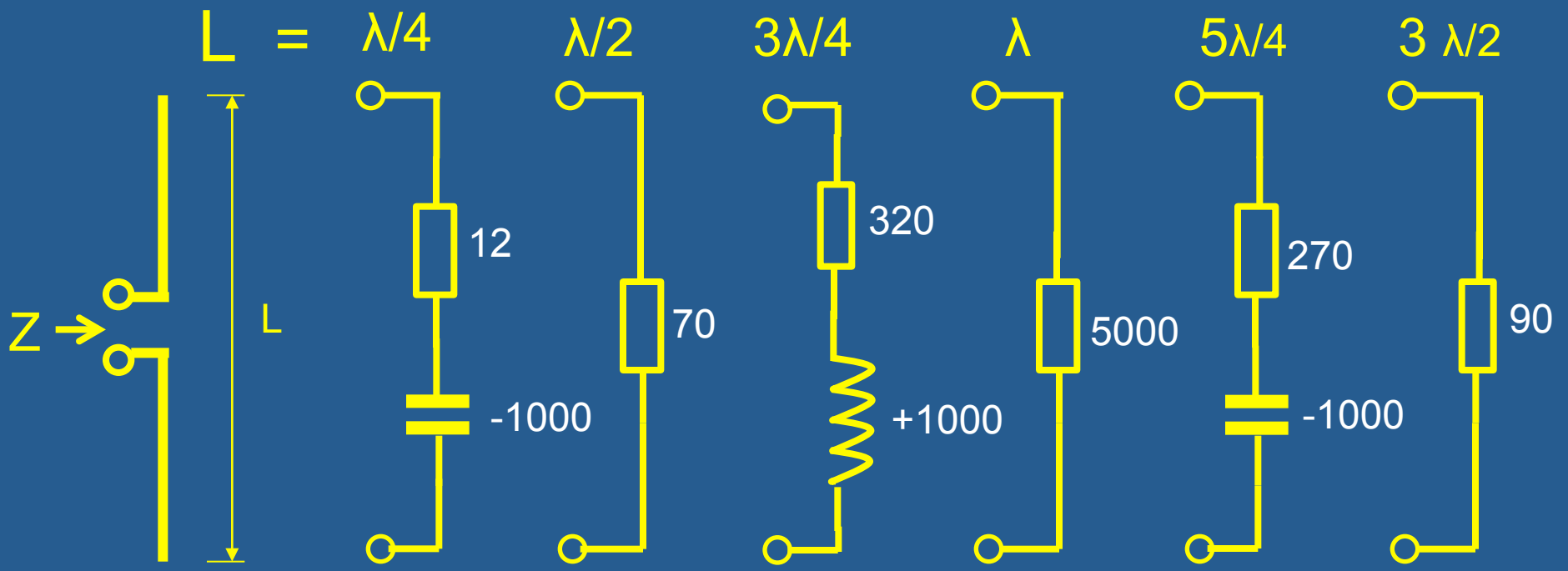
The AMU, *when correctly adjusted*, changes the impedance presented to the transmitter to 50Ω.

When located at the Transmitter the AMU does not *tune* the feeder or the antenna to resonance. It *does not* change the impedance of the antenna.

The AMU in Use



What The ATU Does



It can transform the above impedances:

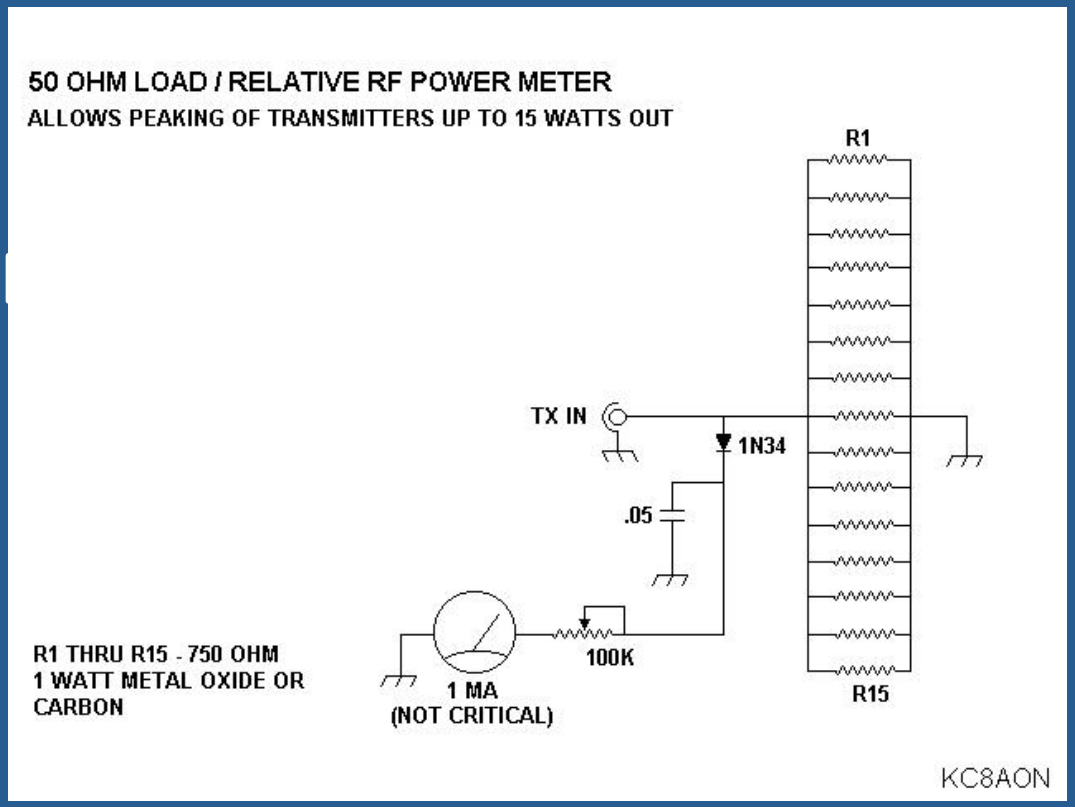


Into the load the transmitter "sees"

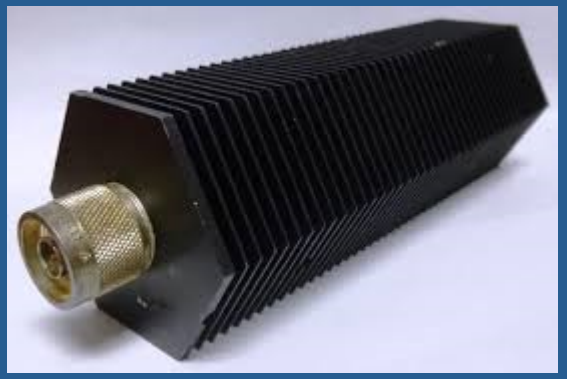
4G The Dummy Load

Dummy Load

The dummy load is a non inductive resistor that can absorb the output power of the transmitter. It is especially useful in allowing transmitter adjustments without radiating a signal. (eg setting the microphone gain.)







4H Plugs and Sockets

RF Plugs and Sockets

Plugs and sockets allow the joining of transmission lines to transmitters, receivers and antennas. The ideal plug or socket would have an identical impedance characteristic to the transmission line into which it is inserted. *(eg. It would look like an integral length of 50Ω coaxial cable at all frequencies and would not cause any reflections.)*

In practice this is impossible. However some RF plugs and sockets come close to achieving this. Others are not so good – particularly as the frequency increases.

N-type, SMA, SMB and BNC plugs and sockets are good up to at least 500MHz. PL259 types are poor above 30MHz.

You can use RCA phono plugs and sockets for QRP

Common RF Connectors









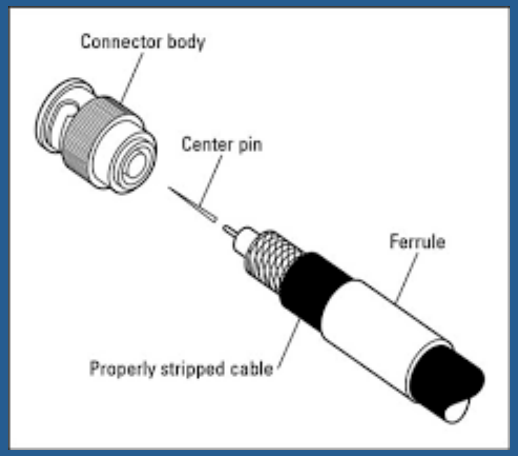








Joining Coaxial Cable



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x



x



x

Correctly connected means screen and inner conductor continuity through any plug and socket.

The purpose of an RF connector is to make a connexion with an RF cable and a piece of equipment or to join a cable to another cable.

A good RF connector would be “invisible” to the signal as it transits through the connector. In other words the connector should not introduce any loss or reflection into the transmission path.

It should display a constant impedance (50Ω) over its specified frequency range.

You need to be very careful with any soldering or mechanical forming of the cable and plug to maintain this characteristic.

It isn’t just a plug – it’s an integral part of the transmission line.

Section 5 Propagation

5A Radio Propagation – Key Concepts

Electro-Magnetic Wave

Electromagnetic waves are transverse waves. Their vibrations, or oscillations, are changes in electrical and magnetic fields at right angles to the direction of wave travel.

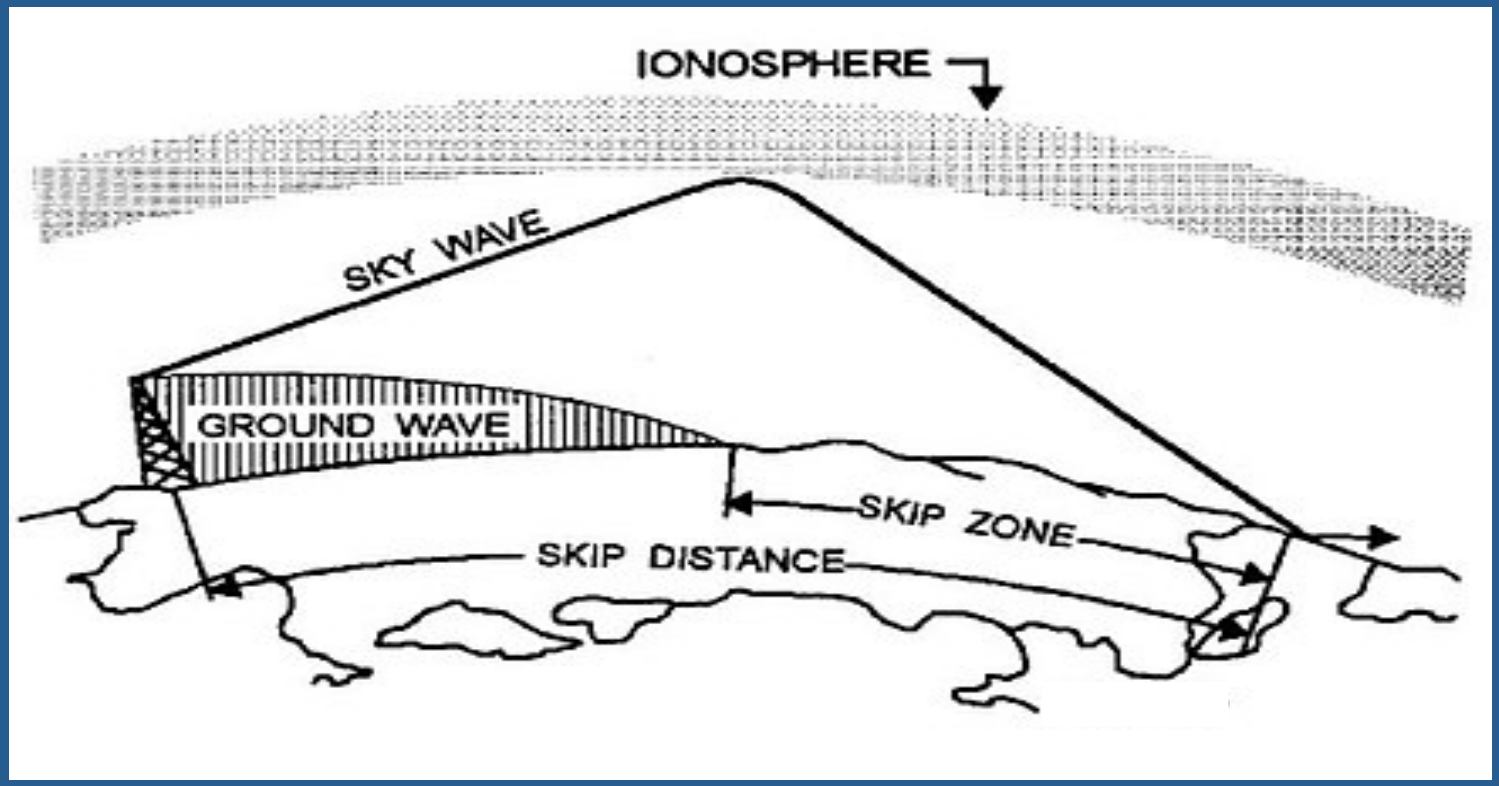
All electromagnetic waves:

- transfer energy as radiation from the source of the waves to an absorber;
- can travel through a vacuum such as in space;
- travel at the same speed through a vacuum or the air.

Electromagnetic waves such as visible light travel at 300,000,000 (3×10^8) metres per second (m/s) through a vacuum.

Some types of electromagnetic waves, such as radio waves, microwaves, infrared waves, visible light and ultraviolet waves, can be reflected and refracted. Refraction is caused by differences in the velocity of waves travelling through different substances.

Ground Wave, Sky Wave, Skip Zone and Skip Distance.



The ground wave in particular has a very limited range due to absorption by obstructions

Tropospheric Wave Propagation

Tropospheric propagation describes electromagnetic propagation in relation to the troposphere. The signal from a VHF or UHF radio transmitter extends to just beyond the optical horizon, at which point signals start to rapidly reduce in strength. In this "deep fringe" reception area during certain conditions, weak signals normally masked by noise increase in signal strength to allow good reception. Such conditions are related to the current state of the troposphere.

Tropospheric propagated signals travel in the part of the atmosphere adjacent to the surface and extending to some 7,620 m. Such signals are thus directly affected by weather conditions extending over some hundreds of miles. During very settled, warm anticyclonic weather (i.e., high pressure), usually weak signals from distant transmitters improve in strength.

Trpospheric Ducting at VHF and UHF

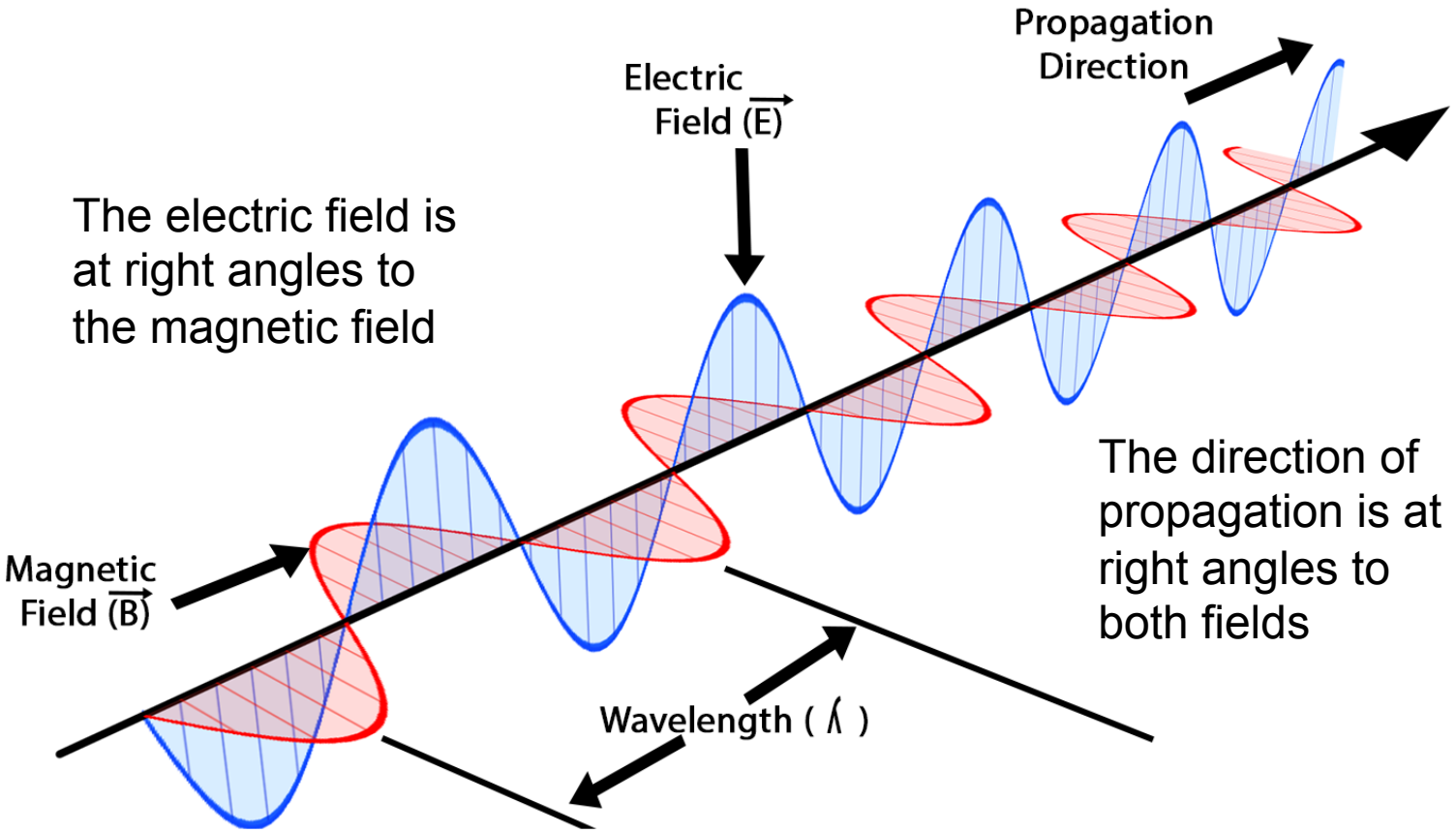
Tropospheric ducting is a type of radio propagation that tends to happen during periods of stable, anticyclonic weather. In this propagation method, when the signal encounters a rise in temperature in the atmosphere instead of the normal decrease (known as a temperature inversion), the higher refractive index of the atmosphere there will cause the signal to be bent.

Tropospheric ducting affects all frequencies, and signals enhanced this way tend to travel up to1,300 km (though some people have received "tropo" beyond 1,600 km, while with tropospheric-bending, stable signals with good signal strength from 800+ km away are not uncommon when the refractive index of the atmosphere is fairly high.

The Electro-Magnetic Wave

Radio waves can be reflected and refracted

The wave propagates at the speed of light

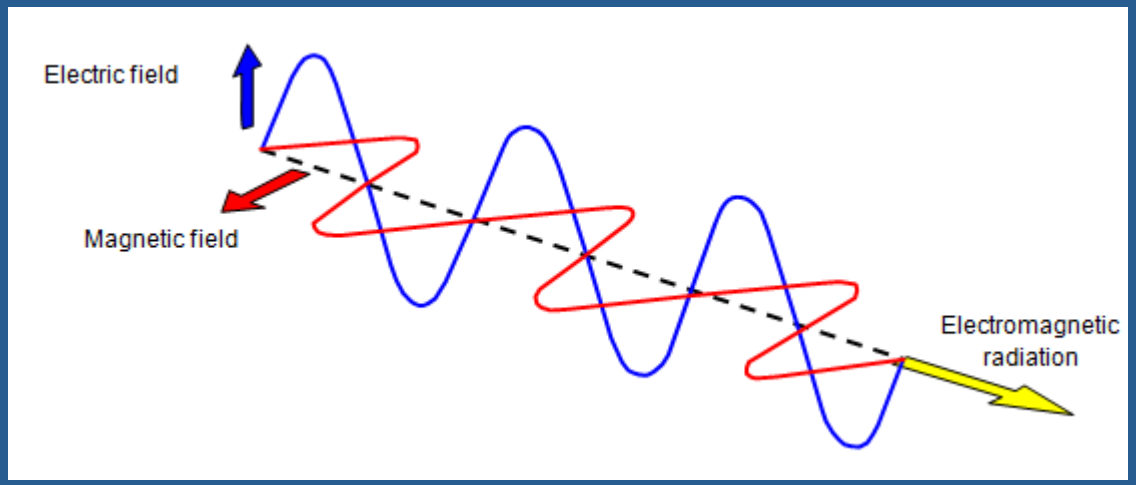


The electric field is at right angles to the magnetic field

The direction of propagation is at right angles to both fields

Plane of Polarisation of the Electric Field

The "polarization" of electromagnetic waves refers to the direction of the electric field with respect to the Earth's surface.



Horizontal Dipole = Horizontally Polarised

Vertical Antenna = Vertically Polarised

5B The Ionosphere

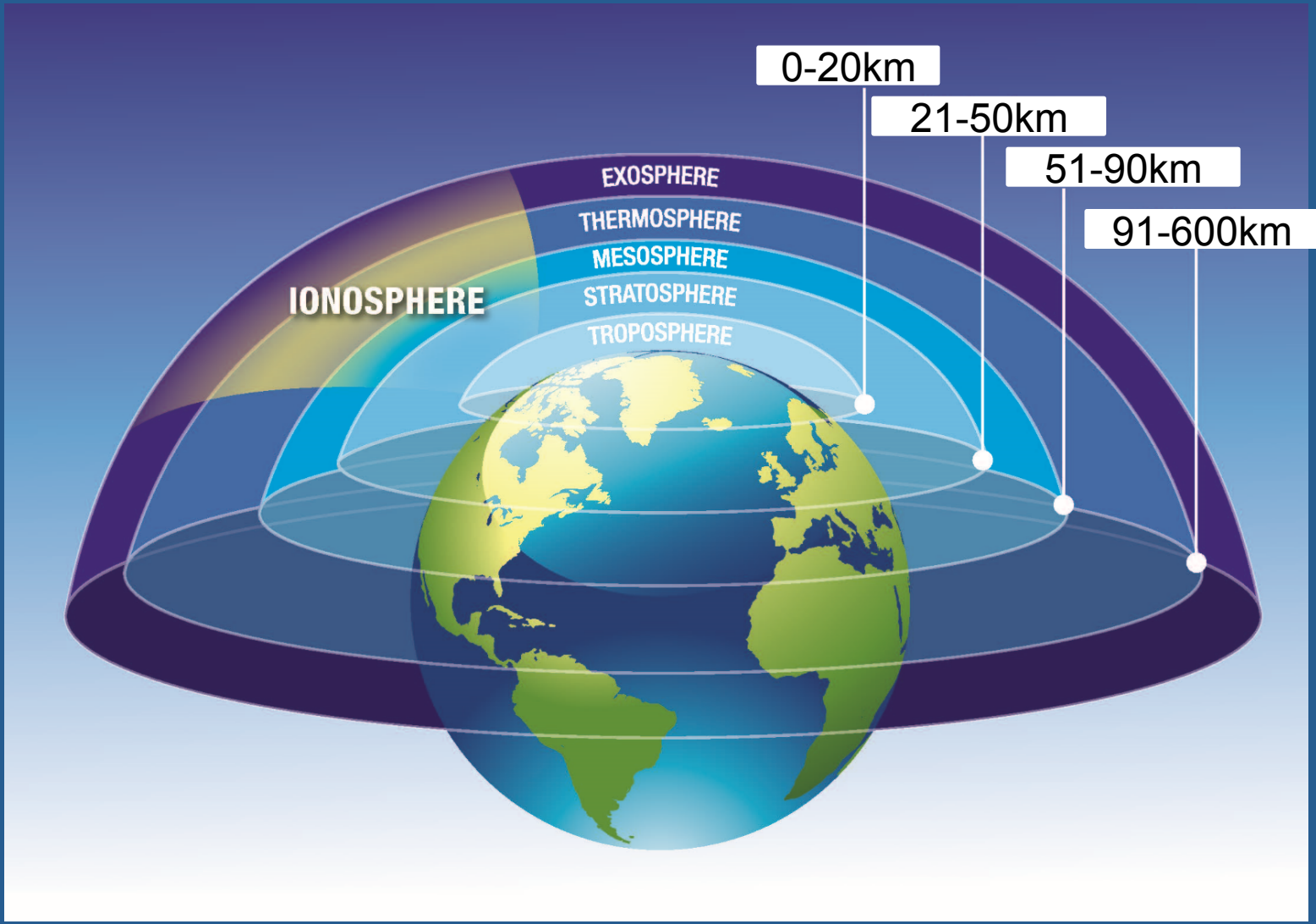
The Ionosphere

The ionosphere comprises layers of ionised gases. The ionosphere starts at the edge of space and varies in height between about 90kms and 500kms above the surface of the Earth

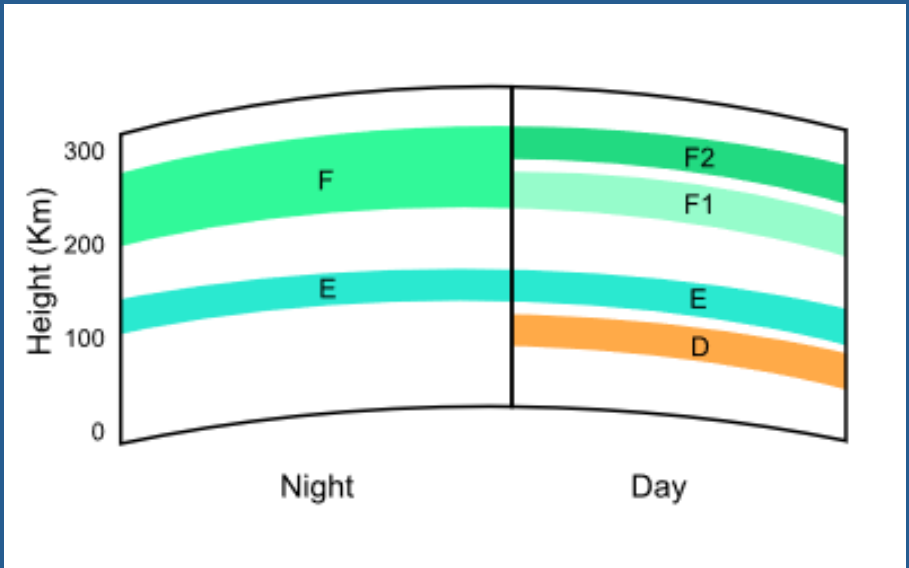
Solar activity – solar flares and the solar wind – create the ionosphere. In particular ultra-violet radiation associated with increased sunspot and their associated solar flare activity is the main cause of the ionisation.

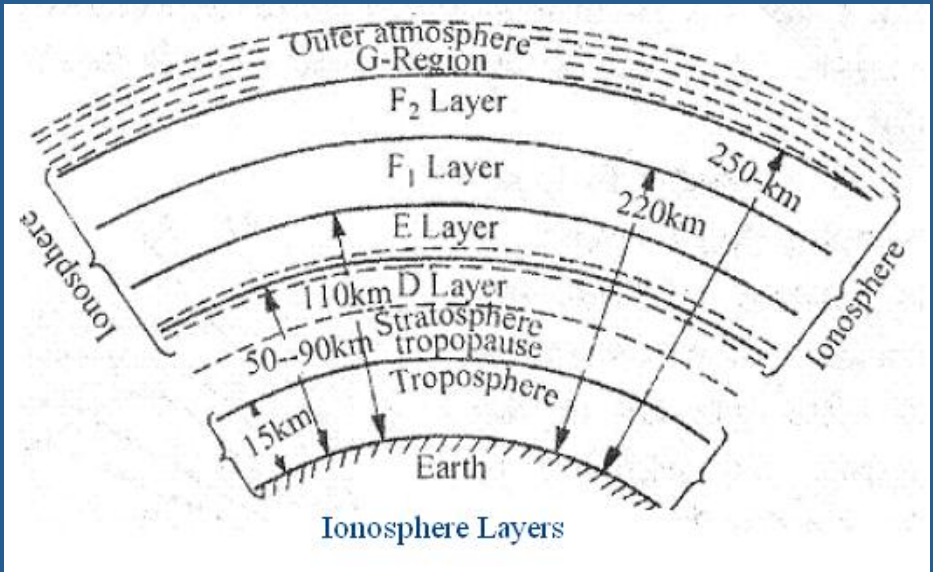
The UV radiation knocks electrons from the gas atoms to form the charged ionospheric layers. Ionised atoms in the rarefied higher layers take longer to recombine and thus ionisation here lasts longer after sunset.

The Layers of the Atmosphere



Levels of The Ionosphere





The ionosphere comprises four, distinct, daylight layers. These are:

- The D layer 60 to 90 kms above the Earth;
- The E layer 90 to 150 kms above the Earth;
- The F1 layer;
- The F2 layer.

} 150 to >500 kms above the Earth

At night the D level disappears through recombination, the E layer weakens and the F1 and F2 layers recombine to form a single F layer.

The Degree of Ionisation

The degree of ionisation is determined by several factors. Some of these are solar and some are due to the season or time of day. They include:

- The level of solar activity (CMEs, sunspots, flares, solar wind);
- The position of the 11-year current sunspot cycle;
- The season of the year;
- The time of day.

The sunspot number gives a good indication of solar activity. The sunspot number is a daily count of visible sunspots. Generally the higher the sunspot number the greater is the degree of ionisation and the better the chance of enhanced propagation at HF.

The maximum Useable Frequency (MUF)

This is the highest frequency that will be refracted. The MUF is determined by radio-sounding the ionosphere. This is done several times each day.

References:

http://www.spacew.com/www/realtime.php

http://www.sws.bom.gov.au/Educational/5/2/2

The gov.au site is particular informative. It has an excellent explanation about the ionosphere.

The F2 layer

The F2 layer permits long distance communication at HF.

Radio waves refract at this layer and, depending upon their angle of incidence, will return to the Earth up to 4000kms away.

A reflection from the ocean surface and a subsequent refraction will gain an additional 4000kms.

Multiple refractions and reflections allow an HF signal to propagate worldwide under good conditions.

The F2 layer combines with the lower F1 layer at night to form a single F layer.

Fading of the Signal

Fading is a radio propagation anomaly caused by partial cancellation of a radio signal by itself. The signal arrives at the receiver by two different paths, and at least one of the paths is changing (lengthening or shortening).

This typically happens in the early evening or early morning as the various layers in the ionosphere move, separate, and combine. The two paths can both be skywave or one can be the groundwave.

Long Path and Short Path Routes

If you wanted to work a North American station on 20m using an HF beam (Yagi) you would point your antenna to the Northwest. This would be the most direct route – the short path - in terms of distance and ionospheric "hops".

Your contact would point his/her beam on a reciprocal bearing towards the Southeast for the same reason.

However, the long path which goes the other way around the Earth is sometimes the better route. (ie. You point Southeast and your contact points Northwest.)

Even though the geographical distance is much greater the signal propagation may be superior.

There are noticeable delays and signal fluttering on long path routes.

D Layer Absorption and Lowest Useable Frequency (LUF)

The D layer, which is the lowest layer of the ionosphere, tends to absorb the lower HF frequencies.

As the lowest layer the density of the gases is much higher than the F layer gases. This allows the ions to recombine quickly when the sun sets. Thus the D layer disappears at night.

The lowest HF frequency that can pass through the D layer without suffering excessive absorption is known as the Lowest Useable Frequency (LUF).

If D layer absorption (LUF) is higher than the MUF than no ionospheric propagation can take place.

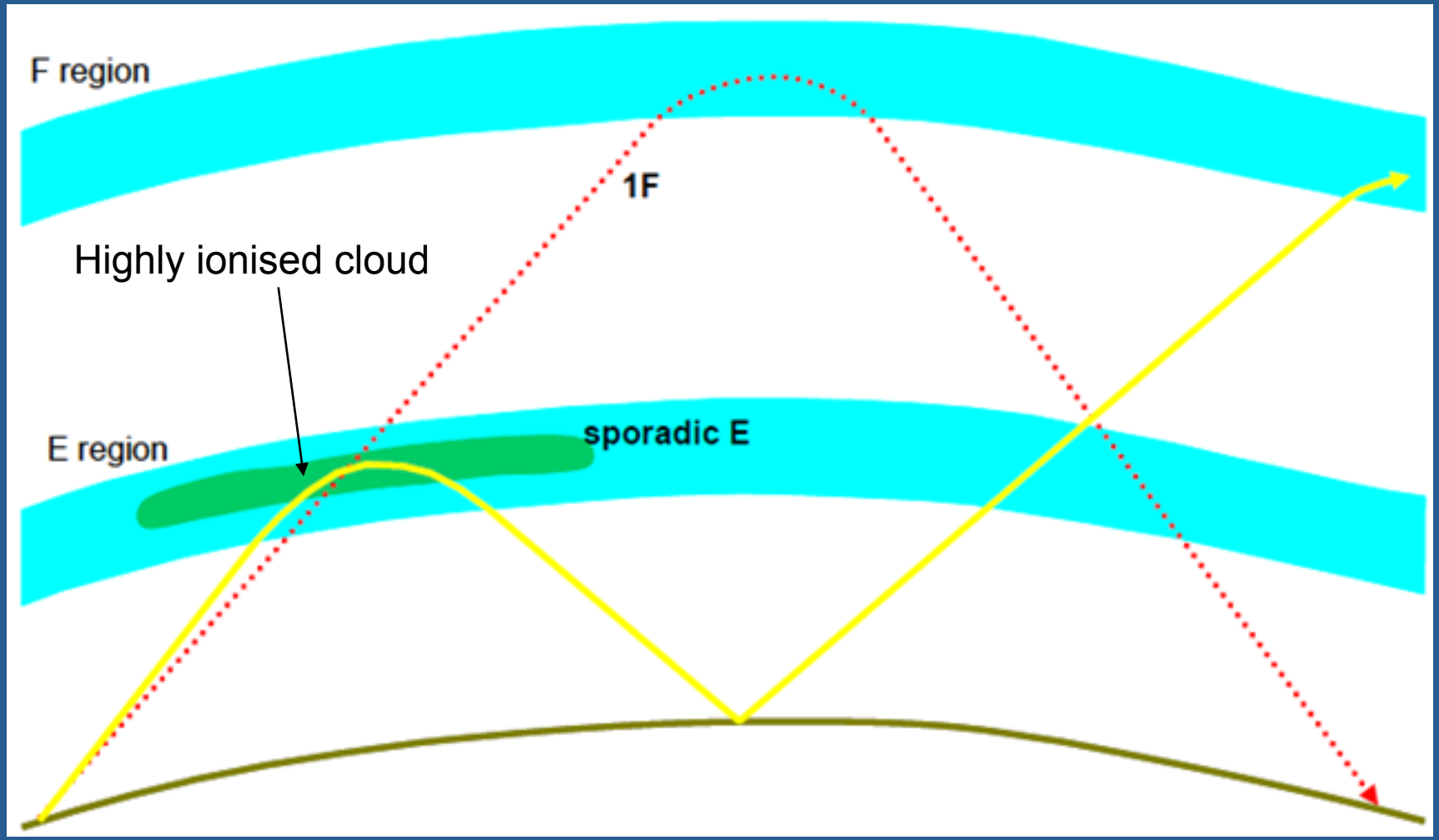
Sporadic E

Sporadic E or E_s is an unusual form of radio propagation using characteristics of the Earth's ionosphere. Whereas most forms of skywave propagation use the normal and cyclic ionization properties of the ionosphere's F region to refract (or "bend") radio signals back toward the Earth's surface, sporadic E propagation refracts signals off smaller "clouds" of unusually ionized atmospheric gas in the lower E region (located at altitudes of approx. 90 to 160 km).

This occasionally allows for long-distance communication at VHF frequencies not usually well-suited to such communication.

Sporadic E refraction can extend down to around 24MHz and cause temporarily enhanced propagation in the 12 and 10m band.

Sporadic E Refraction



The height of the Sporadic E cloud will support a single hop of up to around 2000kms. Multi-hop propagation is also possible.

Classification of Radio Waves: Propagation + Use

Classification	Frequency Range	Wavelength Range	Propagation Characteristics	Typical Uses
Very Low Frequency (VLF)	10kHz – 30 kHz	30,000m–10,000m	Low attenuation at all times of the day and of the year	Long distance point-to-point communication.
Low Frequency (LF)	30kHz – 300kHz	10,000m – 1000m	Propagation at night similar to VLF but slightly less reliable. Daytime ionospheric absorption drops at night.	Long distance point-to-point services, marine navigational aids.
Medium Frequency (MF)	300kHz –3MHz	1000m – 100m	Ground wave by day. Sky wave absorbed in ionosphere by day but not by night.	Broadcasting, marine communications, navigation, harbour telephone etc.
High Frequency (HF)	3MHz–30MHz	100m – 10m	Transmission over considerable distances depends solely on the ionosphere and so varies greatly with time of day, season and frequency.	Moderate and long distance communications of all types.
Very High Frequency (VHF)	30MHz–300MHz	10m – 1m	Substantially straight line propagation similar to light waves. Not affected by or reflected by the ionosphere.	Short distance communication, FM broadcasting, airplane navigation.
Ultra High Frequency (UHF)	300MHz –3GHz	1m - 10 cm	Similar to VHF but some atmospheric absorption.	Short distance communication, television, radar, mobile phones.
Microwaves	3GHz – 30GHz	10 cm – 1 cm	Similar to UHF but with increased atmospheric absorption.	Radar, satellites. Navigation systems.

5C Multipath Propagation at VHF and Above

Multipath Propagation at VHF and Above

At VHF and above signals are subject to multipath propagation.

Objects such as buildings, ships, aircraft and meteor trails can reflect VHF signals.

The receiver may well be subject to several signals arriving from different reflective paths as well as the direct, unreflected, signal.

Aircraft reflection produces a distinctive flutter to the received signal.

Section 6 Electromagnetic Compatability (EMC)

EMC Concepts

All electronic equipment is capable of radiating and absorbing radio frequency energy.

The basic principle of electromagnetic compatibility is that:

"*apparatus should be able to function satisfactorily in its electromagnetic environment and without causing undue electromagnetic disturbance to other apparatus in that environment*"

Immunity

Wires and power supplies are a significant route for interference to both enter and radiate from a device.

Long, trailing wires such as speaker leads and power cables look like antennas.

The addition of filters or chokes to cables and power supplies has a beneficial effect on device immunity.

Typically a ferrite core will be attached to a power or control lead as close as practicable to the device. This provides a high impedance barrier to radio frequency energy. Similarly encasing the device in an earthed metal screen will attenuate radiation.

Transmitters in a Domestic Environment

This is an “unusual” situation insofar as sources of domestic interference are concerned. *(eg an electric drill or sewing machine.)*

High field strengths generated near to the house will induce currents in the house wiring and other antenna “look-alikes”. These currents can then easily enter other equipment. If these have a low immunity to electromagnetic interference (EMI) then problems will arise.

Under these circumstances you will need to take special measures *(eg fit chokes)* to regain control of the interference.

Equipment Immunity

New equipment should meet BSI or CE standards for immunity.
(See Electromagnetic Compatibility Regulations 2016 and Directive 2004/108/EC)

Older equipment probably will not have current levels of specified immunity.

Any equipment that you buy should meet or exceed these standards.

You may have to provide additional protection measures for older equipment.

Poorly installed equipment will also give rise to issues.
(eg solar voltaic inverters.)

6B Sources of Interference and Their Effects

AM, SSB and FM Signals

Any break through of RF signals into audio equipment may give rise to speech like sounds perceptible on the output.

AM and ssb speech transmissions in particular will cause this effect.

An FM speech transmission may cause the audio equipment to become desensitised and / or give rise to a loss or attenuation of a wanted signal either at RF or audio.

Non Radio Sources of Interference

- Arcing thermostats;
- Vehicle ignition systems;
- Electric Motors;
- Computers and peripherals;
- Switch mode power supplies;
- Plasma TVs;
- Very high bit rate digital subscriber line (VDSL) equipment;
- LED lighting;
- Solar photovoltaic (PV) inverters.

These all give rise to various buzzing sounds on analogue radio receivers which can correlate with the nature and use of the interference source (*e.g. bursts of undesirable sounds when a thermostat opens or closes).*

Interference to DAB Radios and Digital TVs

Interference to Digital Audio Broadcasting (DAB) may cause loss of signal (muted audio).

Interference to digital televisions may cause the picture to freeze, appear to pixelate, that is break up into larger squares, become jerky or disappear.

Routes of Entry for EMI

Interference which is directly picked up by an affected device tends to be independent of the transmitted frequency.

TV masthead amplifiers and distribution systems may be broadband devices. Their passband may extend into amateur frequencies.

Such an amplifier seeing a high field strength interfering signal may produce overloading in the amplifier and /or distortion in its load device.

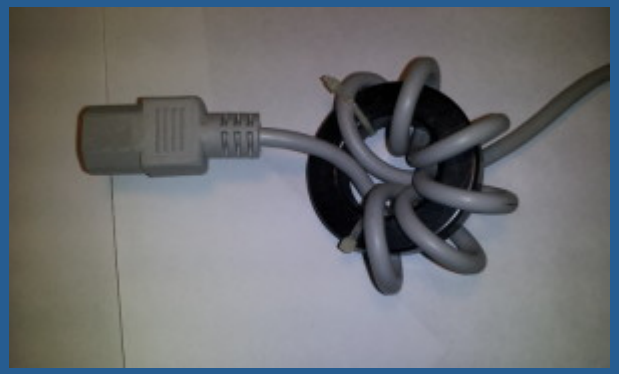
6D Filtering and Remedial Measures

Filters



There are mains filters which you can insert into the supply to an affected device. These will filter out noise and help suppress spikes.

Do not attempt to build one yourself unless you are qualified to do so.



Winding about 6 turns of a mains lead around a suitable ferrite core *(FT240-31 for example)* will suppress interference from the transmitter back through the mains.

Choke Baluns on Downleads etc.





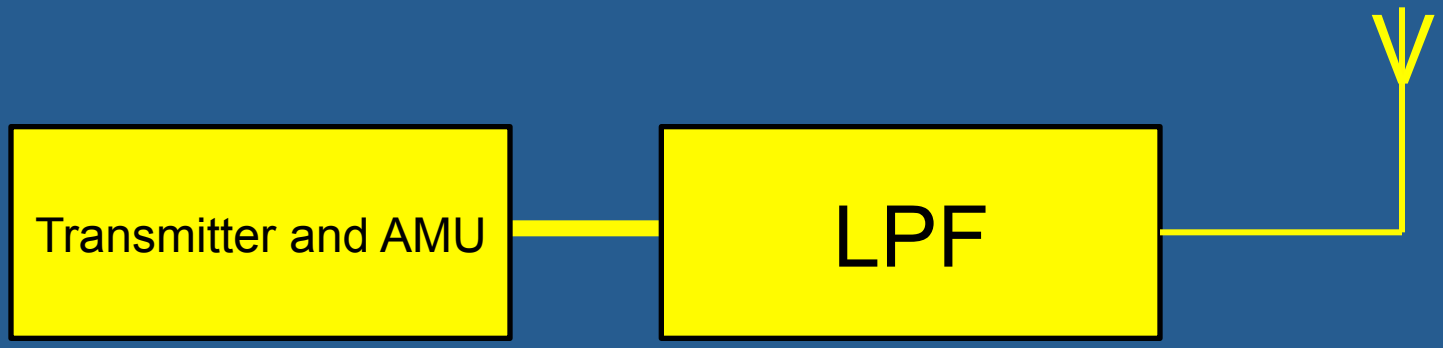


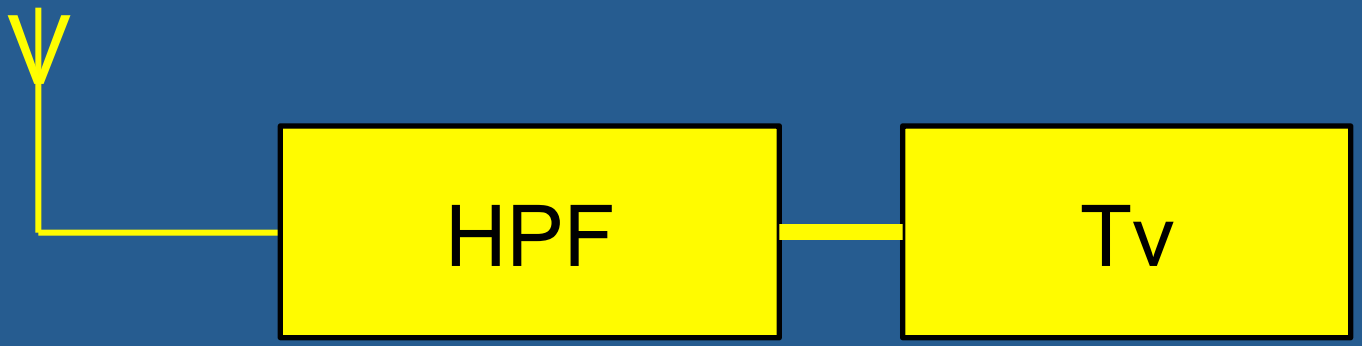




Winding the coaxial feeder around a ferrite core or threading ferrite rings over the cable will choke off common mode currents that can cause interference by pick up in wiring to devices.

Hi Pass and Lo Pass Filters





The use of a suitable filter to remove unwanted emissions will help eliminate EMI

Common Mode Current or Signal

Common mode current is the portion of conductor currents not matched by exactly opposite and equal magnitude currents.

This is the portion of total current responsible for a feedline behaving like a single wire line – and thus radiating a signal.

Common mode current is most commonly caused by improper feedline installation or antenna design.

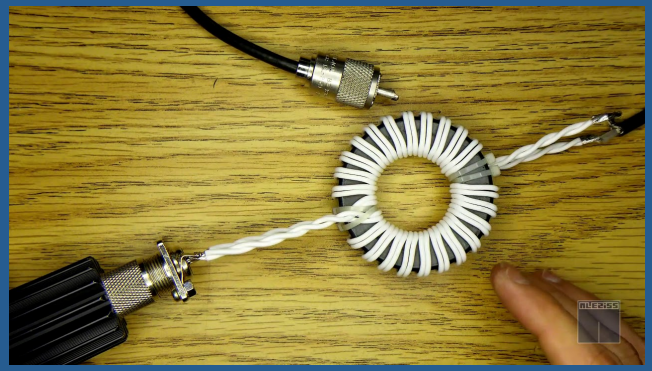
Differential Mode Current or Signal

The differential or normal mode current refers to signals, currents or noise that flow in opposite directions in a pair of lines.

Differential mode currents do not radiate because their magnetic fields are equal and opposite and thus cancel.

Eliminating Common Mode Currents





The skin-effect is operative on a coax-shield at radio-frequencies, so the transmission-line current is on the shield's inside surface and the harmful "common-mode currents" and so-called "antenna-current" are on the shield's outside surface. It is the choke that limits these harmful currents; these currents do cause flux in the core. The ferrite offers a high impedance to these currents and so chokes them off.

Using a General Coverage Receiver to Check for Spurious and Harmonic Emissions



With a short *(300mm)* length of wire as the receiver antenna transmit a low power signal in the 80 metre band. *(For example on 3.6MHz)*

Detect that signal on 3.6MHz on the receiver.

Then tune the receiver to 7.2MHz and listen for the second harmonic.

Then tune to 10.8MHz and listen for the third harmonic etc.

Use the signal strength meter on the receiver to get an idea of any output.

Using a Dummy Load to Detect Interference



Transmit into a dummy load. Check for signs of interference in previously affected equipment.

If the interference persists it is probably mains-borne from the transmitter.

If the interference has disappeared it was probably pick up from the antenna.

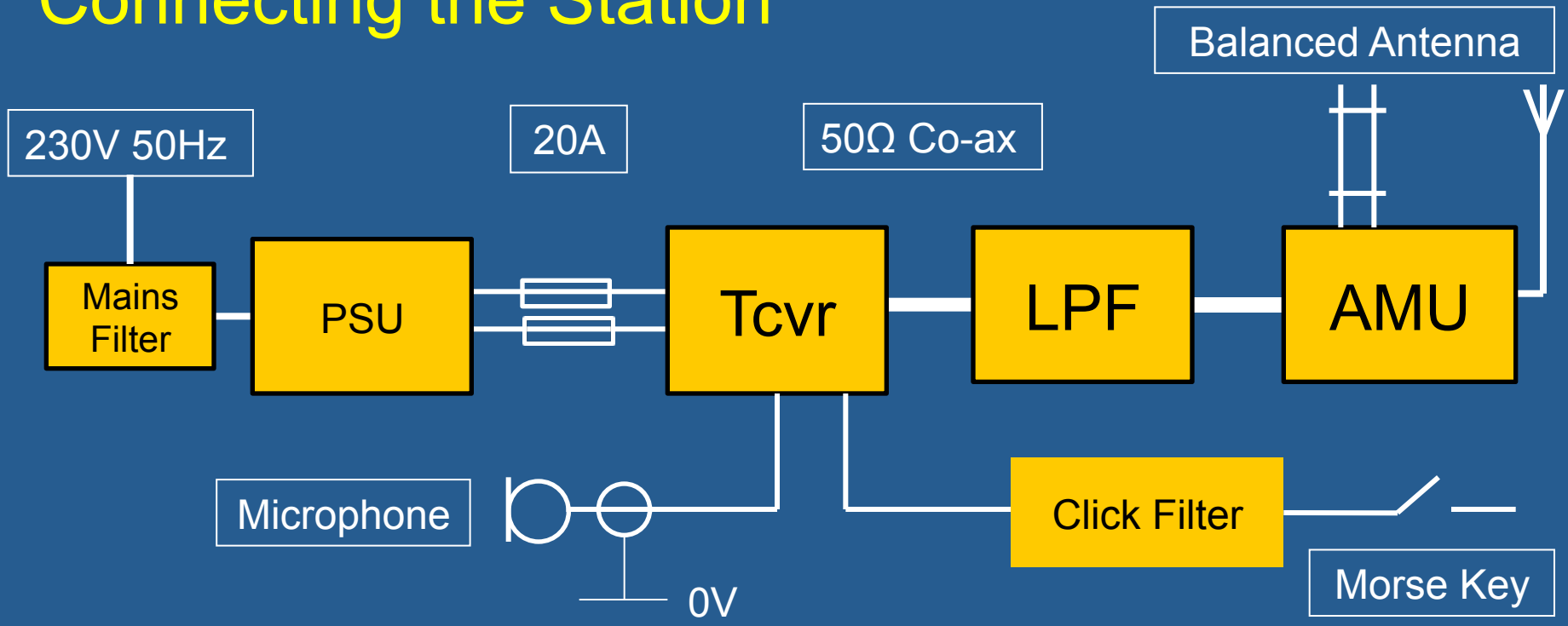
Repeat the test after remedial work to check that you have fixed all the sources - it could have been both.

EMC: Recap

- EMC - Electro-Magnetic Compatibility
- Station Design For EMC
- RF Earth Connection
- Choice of Antenna Type
  - *Dipole / Balanced System (Best for no TV interference)*
  - *Long Wire / End-Fed Wires System (Worst for TV interference)*
- Choice of transmission Mode
  - *FM Best for no TV interference*
  - *SSB/AM Worst for TV interference*
  - *CW may cause TV interference*
  - *PSK31 should be benign*
- Fit Filters where needed
  - *Transmitter- (Low pass)*
  - *Receivers - TV Radio (High pass)*
  - *HiFi / PC Speakers – Ferrite rings*
- Mobile Installations Issues
- Social Issues
  - *Diplomacy at all times*
  - *Log book*
  - *RSGB EMC committee may help*
  - *Ofcom's assistance (£50+)*
- Your local radio club
  - *Ask - and someone may have the answer – as they may have experienced it all before.*

6E Station Design and Antenna Placement

Connecting the Station



Use the best quality coaxial cable and plugs. A balanced antenna is preferable to an end-fed near the house. A LPF will attenuate harmonics. An AMU will also help attenuate harmonics depending upon the design. A key click filter will prevent fast rise time edges on CW.

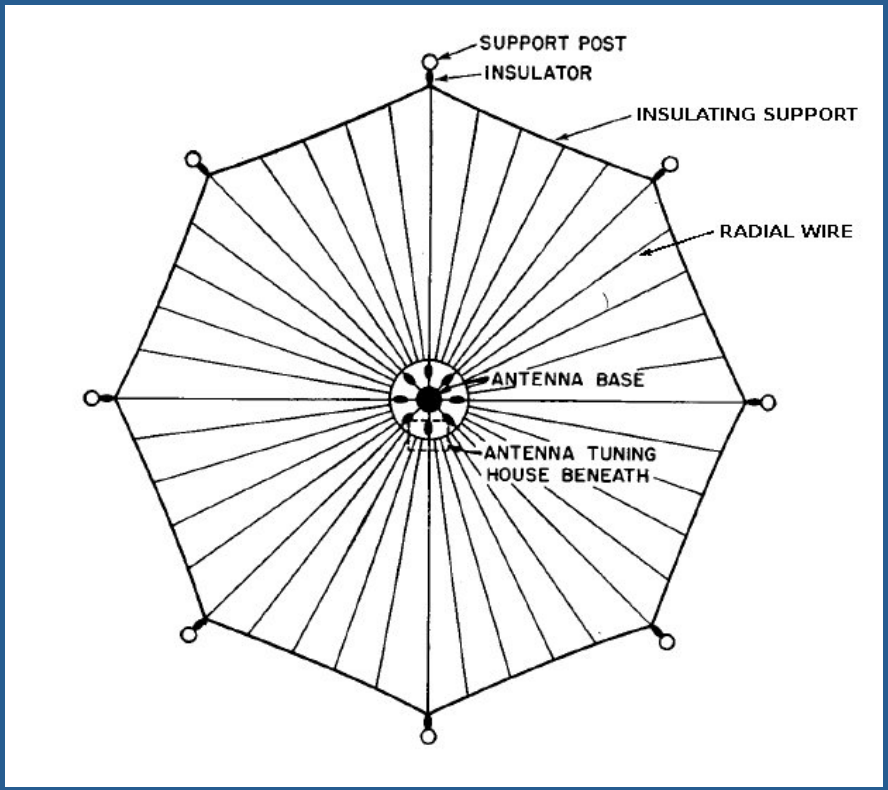
A Good RF Earth

For most amateur installations a good RF earth is very difficult to achieve. A good RF earth presents a low impedance to return ground currents at the operating frequencies. Salt water is a good RF earth.

Simply placing a metal spike in the ground will not produce a good RF earth.

For an HF vertical antenna *at least* 2 radials *at least* as long as the antenna is high is the barest minimum. 20 or more approaches something satisfactory. Commercial practice is to have around 120 radials at the base of an antenna.

An earth stake will, however, help drain static charge from an antenna.







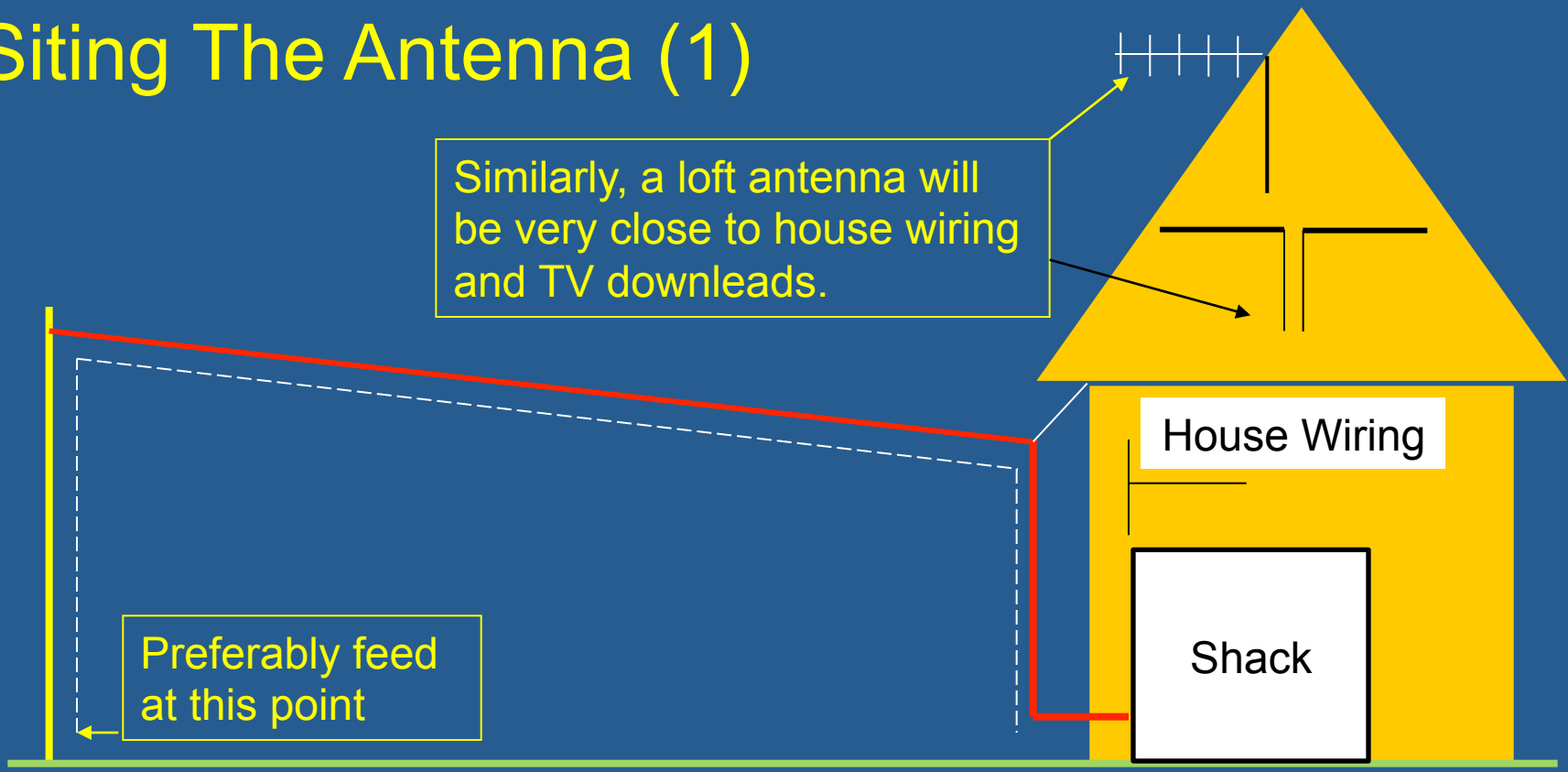


Ground Plane

Grindavik VLF Transmitter NRK 37.5kHz



Siting The Antenna (1)



An end-fed random wire antenna is very likely to couple in with the house wiring. The maximum current in the antenna is at the house-end of the antenna. Moving the feed point to the distant end will be a big improvement.

Siting The Antenna (2)

Bear in mind where the maximum field strength is with your antenna. Keep this furthest from any sources of wiring or cabling which could route the signal to a sensitive device.

With dipoles the maximum field strength will be at right angles to the direction of the antenna. If you have the room to optimise the orientation of the antenna – do so.

Generally keep the antenna as far from houses as possible.

With a Yagi antenna you may get problems when it points directly at a TV antenna and the signal strength overwhelms the TV amplifier – even though the signal may be several hundred megahertz away from the TV band.

6F Mobile Installations

In-Vehicle Wiring

When routing RF cables and mobile radio DC power leads within vehicles they should not be routed in parallel with the vehicle wiring loom and they should not be run near electronic control units.

Radio frequency energy can cause interference to vehicle electronic circuits, including audio systems, navigation systems, remote locking, alarms and engine fuel management systems particularly when operating equipment with an RF output of 10W or more.

Mobile antenna location can affect the radiation field strength within the vehicle; e.g. wing or boot mounted antennas are likely to produce higher exposures than roof mounted antennas. (Shielding).

Section 7 Operating Practices & Procedures

7A Good Operating Practice

Common Prefixes

You should know a range of common prefixes. These include:
EI(Eire),
EA(Spain)
CT(Portugal)
F(France),
D(Germany)
I(Italy),
JA(Japan),
ON(Belgium)
PA(Netherlands),
VE(Canada),
VK(Australia),
W(USA),
ZL(New Zealand).

Contests and Awards

There are awards available for achievements which include: working continents, countries, islands, prefixes, locator squares and that variations may include certain frequency bands or low power.

Amateur radio contests require the exchange of information such as signal report, serial number and location.

Contests often have sections for different bands, power levels and modes.

7B Band Plans

Band Plans

Band plans are produced by the IARU. (International Amateur Radio Union).

The band plans state that:

- No SSB operation should take place in the 10MHz (30m) band;

- No contests shall be organised in the 5MHz (60m),10MHz (30m), 18MHz (17m) and 24MHz (12m), bands;

- Transmissions on satellite frequencies should be avoided for terrestrial contacts.

Notes

The 5MHz (60m) band is NOT available to Intermediate Licence holders.

Questions on beacon and satellite frequencies will be limited to the 14MHz (20m) and 144MHz (2m) bands and a copy of the relevant Band Plans will be provided.

The Band Plan supplied for examination purposes will be a typical plan and need not be one in current use.

The Reference Booklet containing the examination plan is available on the RSGB web site.

7E Codes and Abbrieviations

Common Codes and Abbrieviations

You need to know these common “Q” codes and the reason for the use of “Q” codes.

QRM,
QRN,
QRO,
QRP,
QTH.

QRT,
QSB,
QSL,
QSO,
QSY,

7F Digital Interfaces

Digital Interfaces

Several types of transmissions can be generated and received with the use of a personal computer and a suitable interface.

Minimal distortion can be obtained by careful adjustments between the DAC interface and the transmitter.

Other programs running on the PC that is handling the transmitter or receiver audio may cause interference e.g. warning beeps and alerts.


SignaLink™ USB
TX
RX
DLY
PWR
PTT
Integrated USB Sound Card

7G Satellites

Satellites

Satellites orbit the Earth at heights above 250km.

Most amateur satellites are moving in relation to the Earth and will only be above the horizon at certain times.

The up-link and down-link frequencies are generally in different amateur bands. Details are published by amateur organisations.

The transmitting station must be able to receive both the up-link and down-link signals.

Satellite Reception

Amateur satellites can only be used when they are above the horizon at both the sending and receiving stations.

The movement of the satellite will cause frequency variation, known as Doppler shift, on the received signal, which must be allowed for when selecting operating frequencies.

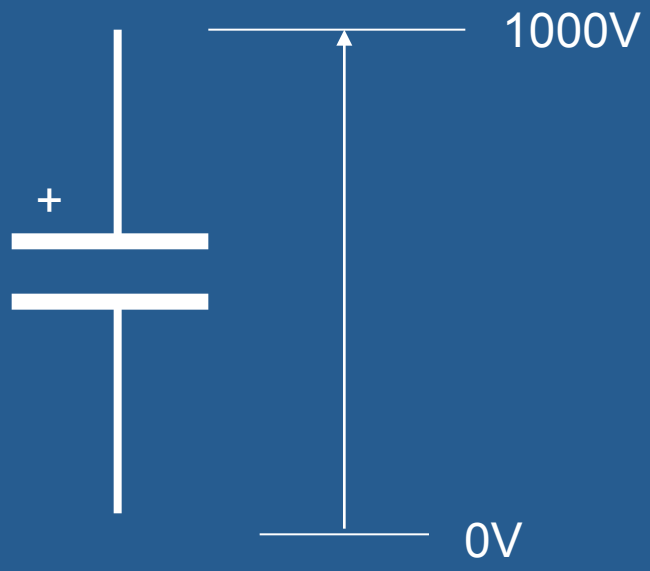
Satellites have a very limited power supply, derived from solar panels.

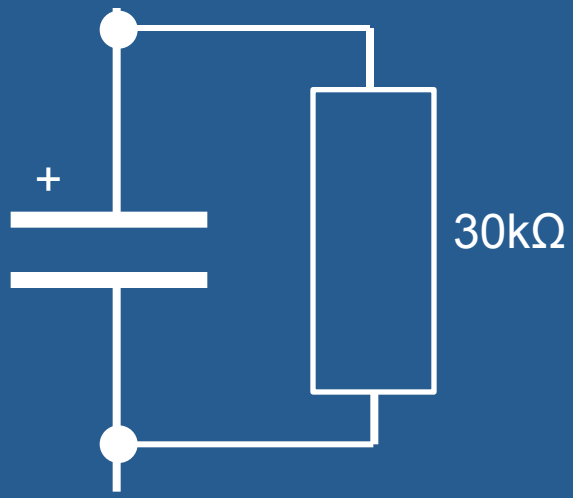
Excessive up-link power may result in wasteful and unfair use of the satellite's power.

Section 8 Safety

8A Electricity

Charge Retention on Capacitors





A high voltage capacitor will retain its charge for a long time when the power supply is turned off. This can be several tens of minutes.

It poses a substantial risk

By connecting a high value "bleed resistor" across the terminals the capacitor can be discharged to a safe level in seconds after the disconnection of the supply.

Always discharge high value, high voltage capacitors before working on equipment.

Exposed Conducting Surfaces

All exposed metal surfaces that could be energised to mains potential must be earthed.

Correct Fusing

Equipment mains fuses may be of a special type, such as quick blow or slow blow to allow for an initial surge of current and the specified type must be fitted.

A fuse must be correctly rated for proper protection, and, in the absence of manufacturer's instructions, you must select an appropriate fuse.

For mains fuses:

$$\text{Current} = (\text{Power}/230)$$

where 230 is the nominal mains voltage

Live Working

In a word - “Don’t”

Working on live equipment is *very dangerous so avoid doing it*.

If working live is the only alternative *(Is it really?)* then take proper precautions:

- The tools are of the correct voltage rating;
- The tools are insulated;
- Only use one hand;
- Do not touch any earthed metal;
- Remove or securely tape rings.

BASICALLY - DO NOT WORK ON LIVE EQUIPMENT!

Storage Batteries

Large capacity batteries that you may use will probably be of the lead-acid type. These will be either “wet” types which contain liquid sulphuric acid as the electrolyte or “sealed – valve regulated” types in which the electrolyte is a gel. Only use the sealed types as these cannot leak electrolyte.

The electrolyte is concentrated sulphuric acid. A fully-charged car battery can easily deliver over 1000A under short-circuit conditions. This can start a fire and / or cause the battery to explode – covering the area with hot electrolyte.

ALWAYS fuse a sealed lead acid cell to limit the current that can be accidentally drawn.

TREAT THESE BATTERIES WITH THE UTMOST RESPECT.

Charging A Sealed Lead Acid Battery

ALWAYS use the correct charger for the battery.

Hydrogen gas is liberated when the battery is charging.

Over-charging can cause the valve to open and allow Hydrogen gas to escape.

ALWAYS charge a battery in a well-ventilated area to avoid the risk of reaching a lower explosive limit concentration of the gas in the compartment.

8B Use Of Tools

Soldering Skills and Safety

During the Practical Weekend we will show you the correct way to solder. These are the salient points:

- Wear eye-protection.
- Solder is molten ~ 250° Celsius – it will burn you if you are careless!
- The soldering iron is used to heat the components *so that they are hot enough to cause the solder to melt*. The solder will flow into and around the joint *only* when all the pieces to be soldered are above the melting point of the solder.
- Solder is an alloy of two or more metals in such proportions as to achieve a “eutectic mix” (lower melting point than any of the constituent metals.)
- Solder in a well-ventilated space and avoid breathing the fumes.
- Place your soldering iron in its stand when not in use.
- A good soldered joint is bright and looks like a “miniature volcano” surrounding the wire. If it’s a “blob” and / or dull then it’s a bad (dry) joint!
- Always use fresh solder if you have to remake a joint.

Good Practice (1)

Screwdrivers, drills, saws and files have the potential to cause deep cuts if you don't use them properly. In particular NEVER use a file without a properly fitting, sound handle. The tang of the file will injure your hand when the file jams – *which it will!*

ALWAYS keep your fingers behind the blade of hand tools.

ALWAYS clamp the workpiece securely. Use a vice or similar device to prevent them slipping or rotating. This is especially important when drilling.

NEVER hold the workpiece in your hand when you drill.

Good Practice (2)

ALWAYS remove the chuck key before using a power drill or similar tool. This will prevent the chuck key being ejected at high speed when the drill starts.

Use a centre punch to initially position the drill point.

A stable, bench-mounted pillar drill is safer to use than a hand-held drill. You can clamp the work piece securely and you have more control over the depth of the cut.

8E Lightning

Lightning Arrestor

You can obtain a limited amount of protection for equipment against the build-up of static charge by fitting gas discharge arrestors, spark gaps and bleed resistors.







If lightning is likely then unplug all your antennas and power supplies.

Don’t touch your installation during a lightning storm.

Section 9 Measurement & Construction

9A Measurements

The Multimeter





The basic multimeter combines a volt – ohm and ammeter in one instrument. More advanced instruments carry other functions such as inductance and capacitance measuring ranges, transistor parameters and frequency measurement.

Selecting The Scale and Range - Basics

Before applying the probes to the circuit check that you have correctly set up the meter for what you want to measure.

1. Select the parameter you wish to measure eg: amps or volts etc.
2. Select the range (full scale reading) of the meter*. If you are unsure what the likely measurement value will be select the highest range first.*
3. Check that you have correctly set the AC or DC switch if measuring current or voltage.
4. If measuring DC then respect the polarity of the meter.
5. VOLTAGE is measured ACROSS a component and CURRENT is measured THROUGH a component. If measuring current then position the meter in-circuit before applying the power to the circuit.

Multi-Meters and Units of Measurement

You are probably going to possess a digital multimeter. The salient points are:

- Start on the highest range first to avoid an overload.
- Disconnect the meter before changing ranges – protects the range change switch from arcing if you are switching on a current range.
- Use a fused meter.
- Check that you are not on the AC range if you get strange readings from a DC circuit!
- Don't use the Ohms (Resistance Scale) on a powered-up circuit.
- Using the Ohms scale on an in-situ component may give a false reading as that component may have others in parallel with it elsewhere in the circuit.
- Don't try and measure voltage with the meter set for current as you will cause a short across the points to which you are connected.
- Observe the correct polarity :

RED + **Black -**

The Multimeter

The multimeter is an essential piece of test gear. It may be either analogue or digital. (Nowadays finding a good analogue multimeter is difficult.)

A basic multimeter will measure Volts/Amps/Ohms. Many offer capacitance and inductance measurement as well as transistor and diode testers.

An ideal multimeter will present an infinite resistance when measuring voltage and zero resistance on its current ranges. This will allow it to make measurements without loading the circuit under investigation.

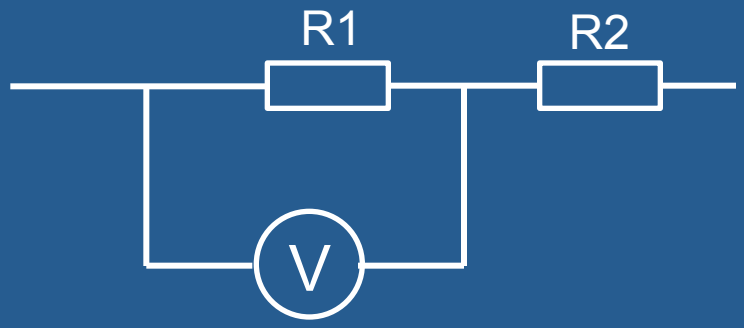
All practical voltmeters fall short of this ideal. However a reasonably priced model will approach these ideals and be more than sufficient for our purposes.

Measuring With The Multimeter

Voltage: This is an *"across variable".* That is the voltage appears *across* a component or circuit. You measure the voltage between two points. The voltmeter goes in parallel with the component or element. Always start with the voltmeter on its highest voltage range. Then select the voltage range which will display the voltage measured to the precision you require within the upper limit of the range. *(It is good practice not to change range with the meter in circuit in case the range change switch shorts momentarily as it commutes round.)*

Current: This is a *"through variable".* You measure the current *through* a circuit element or component. The ammeter goes in series with the component or branch of the circuit being measured. Always start with the highest current range first for the initial measurement. Then reduce the range to the one which will accommodate the reading to the precision you require.

Voltmeter and Ammeter Connection



To measure the voltage *across* R1 the voltmeter is connected *across* the resistor *in parallel* with it.



To measure the current *through* R1 (and R2) the ammeter is connected *in series* with it.

Measuring Ohms

Do not put the ohmeter in the ohms range across a circuit element with the circuit energised. You will damage the meter.

Ideally you should remove the item or element out of circuit completely and discharge any stored voltage before measuring.

Semiconductor devices can give strange readings as they are polarised devices and may be reversed biased by the meter which has a battery in it.

The ohmeter is a voltage source in series with an ammeter. The unknown resistor completes the circuit. The ammeter is calibrated to read ohms instead of amps. (Remember current is linearly related to resistance.)

Analogue Versus Digital Multi-meters

There are pros and cons between the two types. This is similar to that between digital and analogue watches.

Digital (Pros)

- Easy to read;
- Handles reverse polarity easily in the dc ranges;
- Can be auto-ranging to select the optimum range setting.

Digital (Cons)

- Difficult to estimate a percentage change or peak reading at a glance

Ideally have one of each!

Analogue Versus Digital Multi-meters

Analogue (Pros):

- Can see at-a-glance the rough value of a reading by the position of the needle on the scale - ¼, ½, ¾, of the full-scale deflection.
- Small changes are easy to see – especially if you are "peaking up"

Analogue (Cons):

- Easy to misread non-linear scales.
- Does not handle reverses of polarity in the dc ranges.

Importance Of Polarity

Digital Meters: This is generally not a problem with digital meters. The meter will indicate a “negative” symbol to indicate that the meter leads need to be reversed to respect the actual polarity.

Analogue Meters: In an analogue meter the needle only moves from left to right. If the meter is reverse connected then the needle will be pushed against the left-hand end stop. This can lead to the burn out of the armature coil or a bent needle.

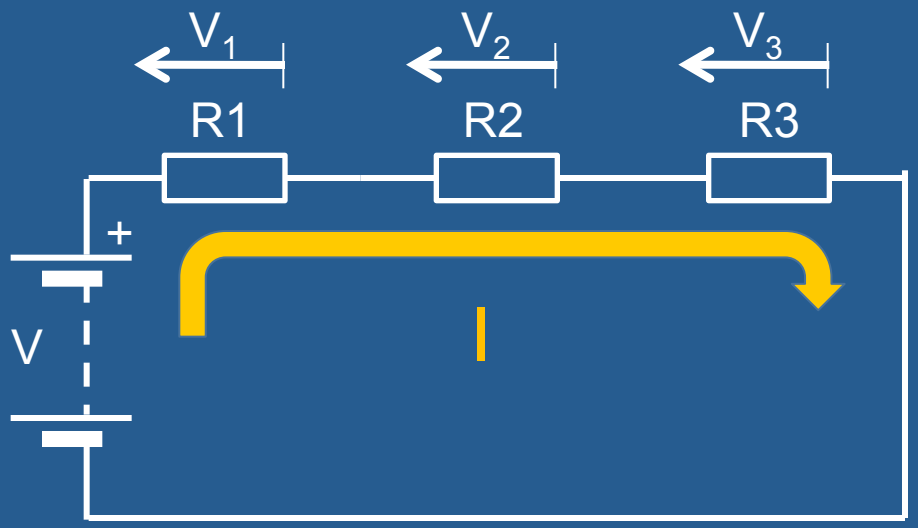
Series And Parallel

Series Circuit: Shares a *common current*.

Parallel Circuit: Shares a *common voltage*.

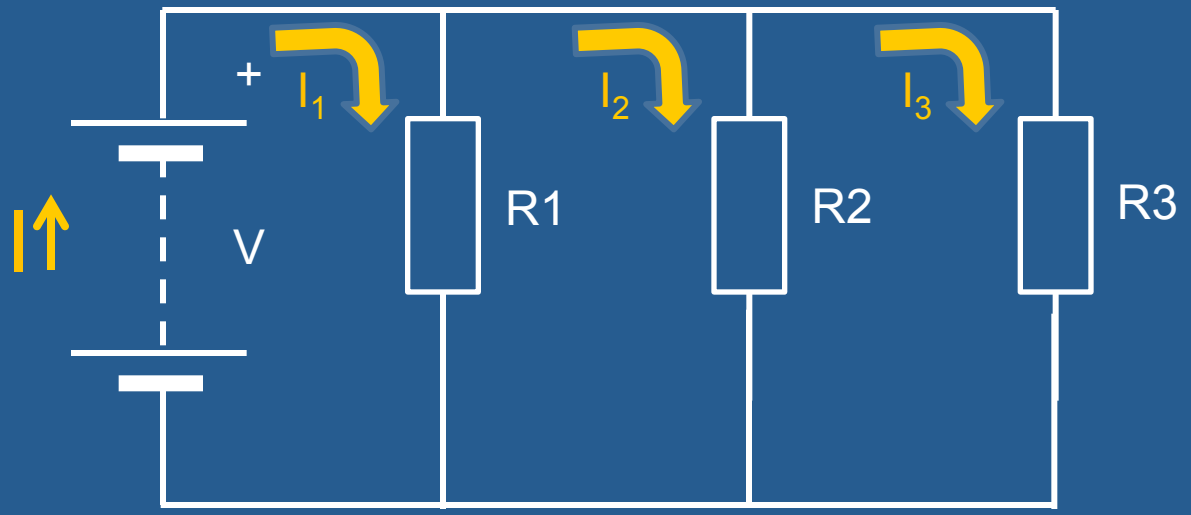
Current Through A Series Circuit

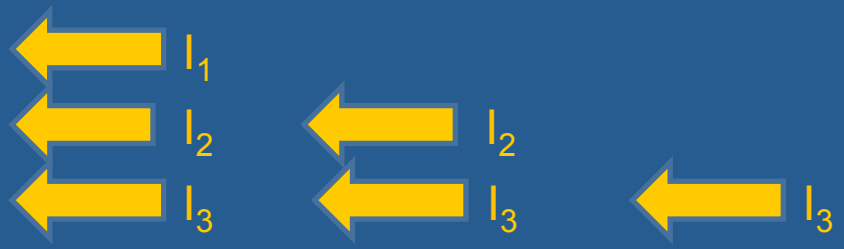
$$V_1 + V_2 + V_3 = V$$



In a series circuit the current (I) passes through each of the elements. The current is common to every element.

Voltage Across Parallel Components





$$I = I_1 + I_2 + I_3$$

In a parallel circuit all of the components appear across a single voltage source. They all experience a common, identical voltage across them.

Measuring Current

Current is a *"Through Variable".*

This means that it flows *through* an item or circuit.

A perfect ammeter would have an input resistance of zero ohms. This would avoid it reducing the current through the circuit under test by adding its own resistance in series with the circuit.

High currents are measured by measuring the voltage drop across a very low value, precision, metal resistor (a meter "shunt") in series with the circuit.

Measuring Potential Difference

Voltage is known as an *“Across Variable”.*

This means that it appears *across* or between two points in a circuit.

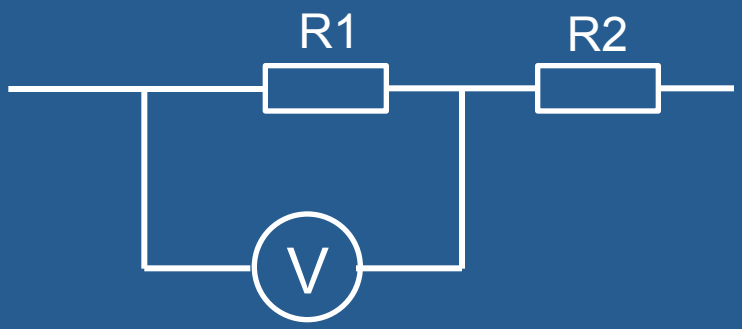
A perfect voltmeter would have an infinite input resistance. (ie It would draw zero current from the circuit under test and not put a significant resistance in parallel with the two test points causing a change in the voltage between them.) Modern digital voltmeters (DVM) approach this ideal.

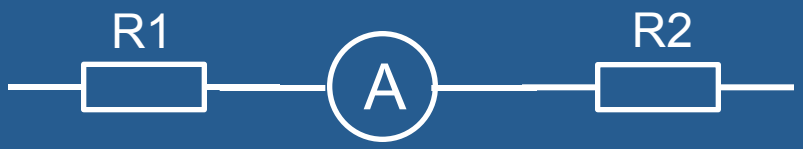
Ideal Voltmeter and Ammeter

The *ideal* voltmeter would have an *infinite* input resistance.

The *ideal* ammeter would have *zero* input resistance.

Modern digital meters approach this ideal.

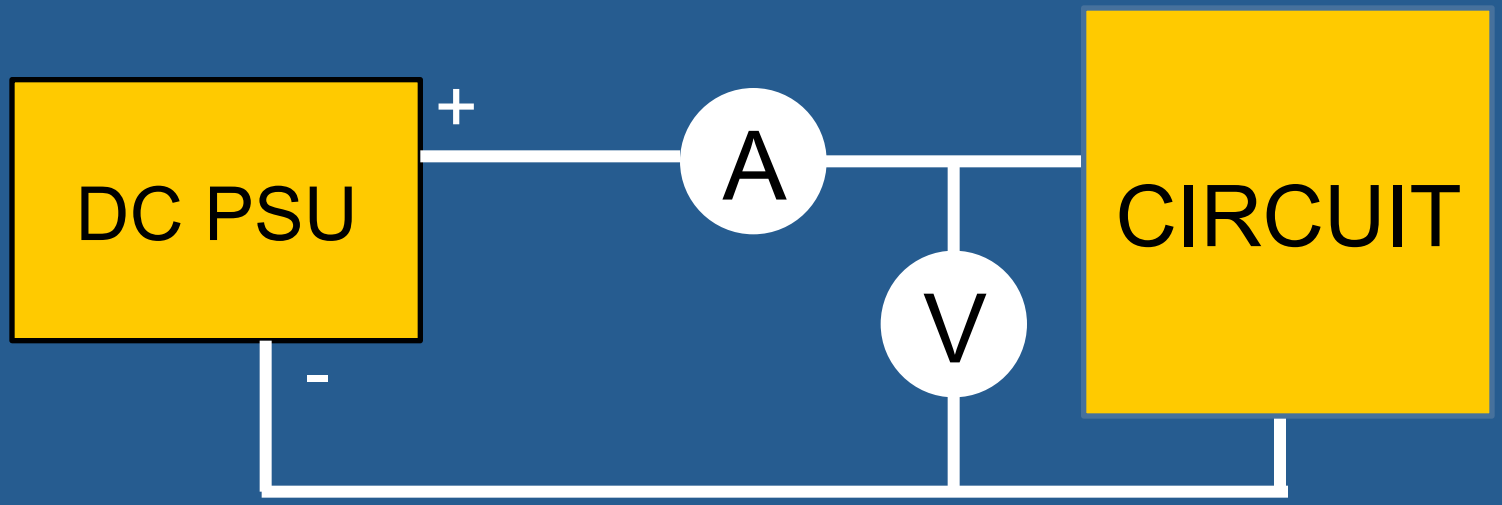




A voltmeter with an infinite input resistance would not load R1 and bring its value down through a parallel combination. This would give a *LOWER* voltage reading than actually exists.

An ammeter with zero input resistance would not add an additional series resistance and reduce the current. This would give a *LOWER* current reading than actually exists.

Measuring (Calculating) Circuit Power



By making a series of measurements using one multimeter you can determine the voltage across a circuit or circuit element and the current flowing into it. The power is then simply:

$$P = V \times A$$

NB: Meters will generally read RMS voltage and current –unless the meter reads peak values. Be aware of what the meter is displaying.

Power, Potential Difference and Current

Power is the rate at which energy is transferred or dissipated. Only resistance can dissipate electrical power.

Potential Difference is the electrical pressure applied across a circuit or component causing the electrical gradient along which the electrons will move.

Current is the flow of electrons along the potential gradient. The more electrons in motion the greater the electrical current.

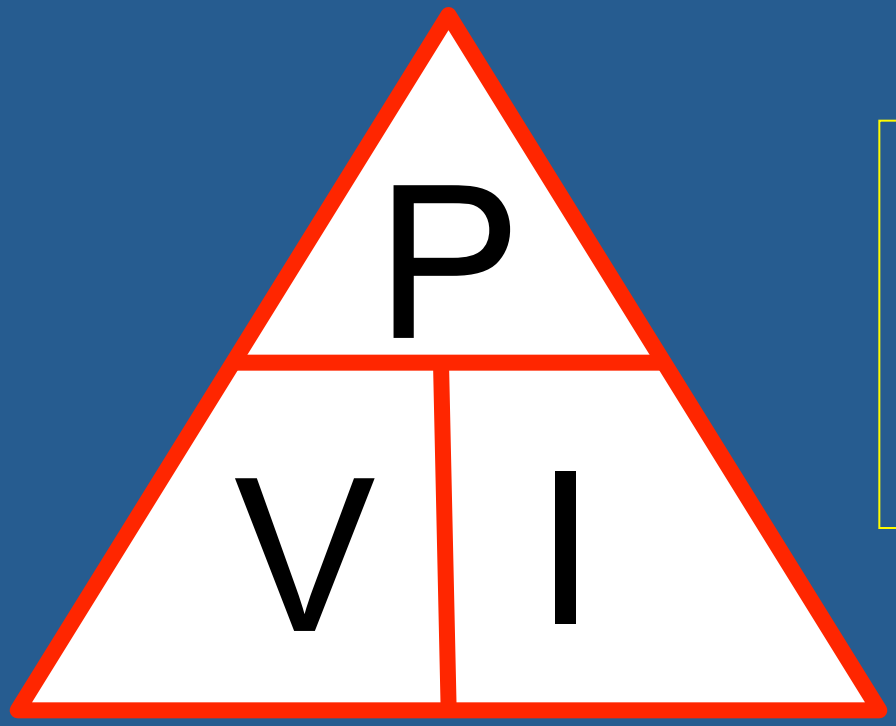
In dc circuits Power (P), Potential Difference (V) and Current (I) are related by:

$$\text{Power} = \text{Potential Difference} \times \text{Current}$$

$$P = V \times I$$

In an AC circuit remember to use the RMS values of voltage and current for power.

Power Triangle



P = V x I

V= (P / I)

I = (P / V)

eg. V=5 Volts, I=3 Amps, P= 5 x 3 = 15 Watts

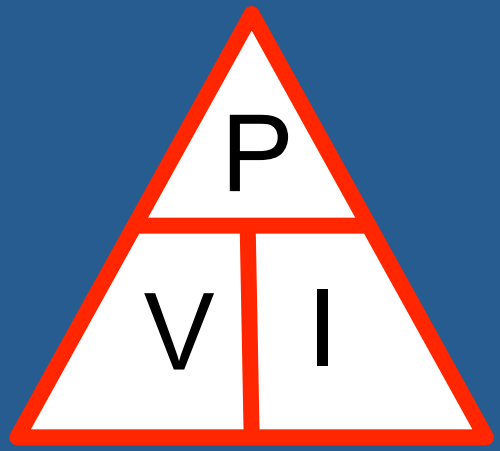
Power Examples

V = 9V, I = 10mA, P =
V = 10kV, I = 1mA, P =

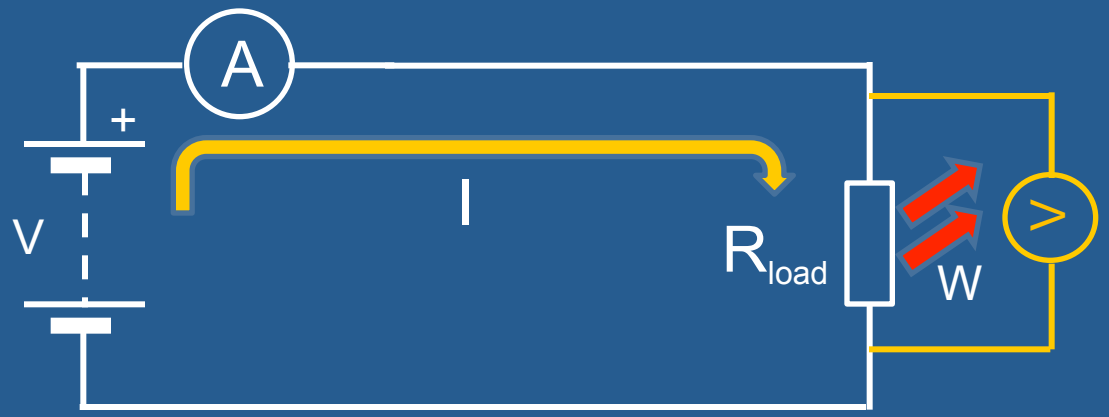
P = 5W, V = 5V, I =
P = 2kW, V = 230V, I =

I = 1.5A, P = 15W, V =
I = 20mA, P = 400mW, V =

V = 9V, I = 1mA, P =



Measuring dc Power



A voltage source V drives a current I through a load resistance R. The current flowing through R will dissipate power in this resistance.

Ohms law links V, I and R by the relationship $V = I \times R$

The Power (W) dissipated in R is given by $W = I \times V$

By measuring the voltage and current at the load resistor you can calculate the power that the resistor is dissipating.

Measuring The Power

You can calculate the power dissipation in a number of ways.

The basic relationship is, as previously, $P = V \times I$

You know from Ohms Law that $V = I \times R$

Replacing V with(I x R) in the basic power equation you can rewrite it as:

$P = I \times (I \times R)$

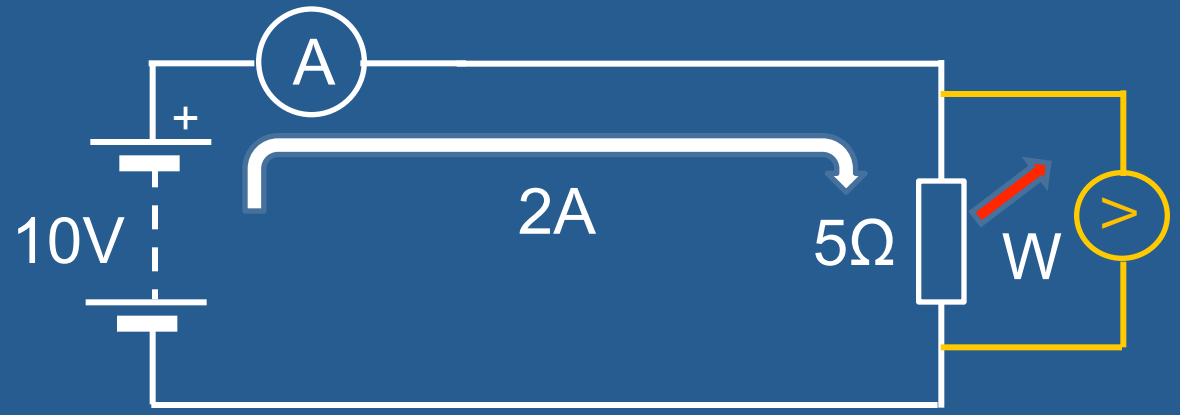
$P = I^2R$

Or, knowing that $I = V / R$, you can similarly replace I with (V / R) to get

$P = V \times (V / R)$

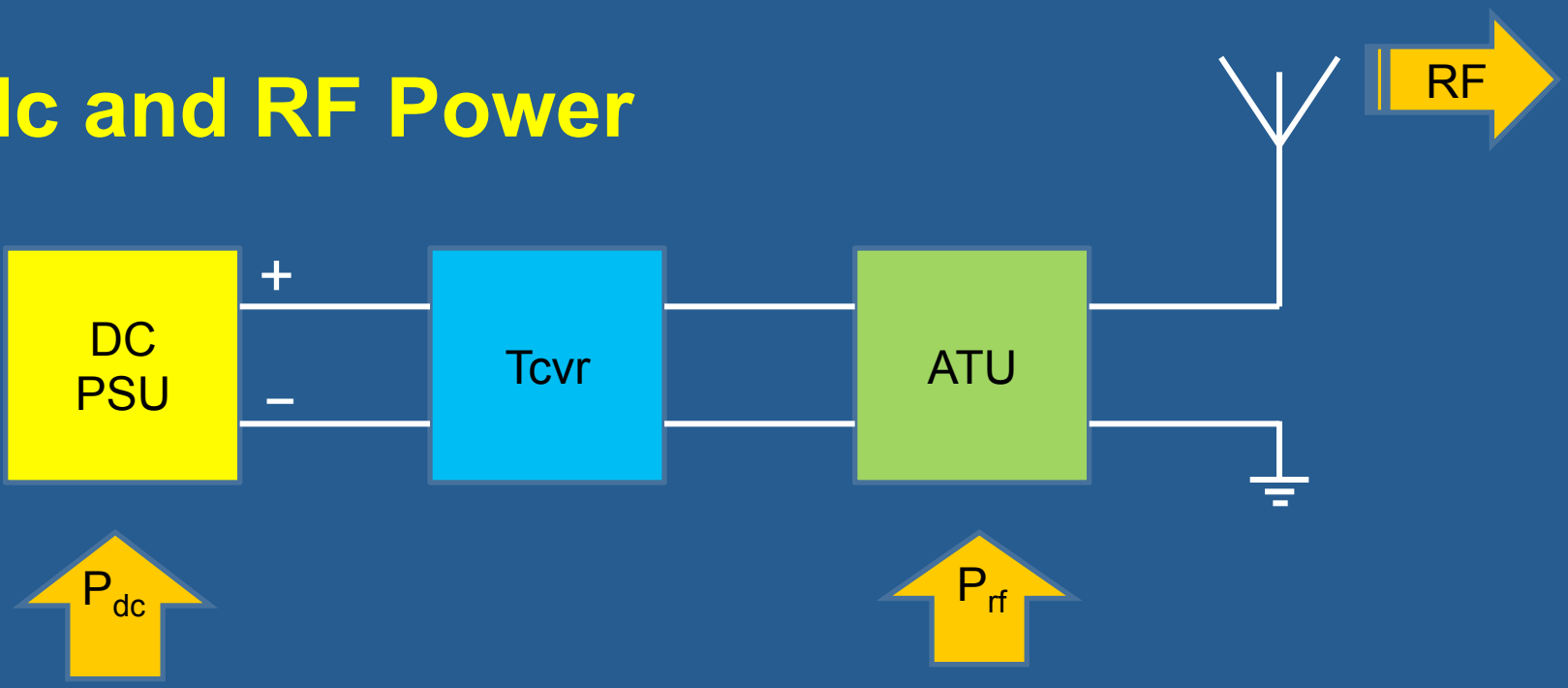
$P = V^2/R$ (Useful if you know R and either V or I but not both.)

Power Worked Example



$P = V \times I;$	$P = (10 \times 2);$	P = 20 Watts
$P = I^2 \times R;$	$P = (2 \times 2 \times 5);$	P = 20 Watts
$P = V^2 / R;$	$P = (10 \times 10 / 5);$	P = 20 watts

dc and RF Power



The dc power (P_{dc}) that you measure at the dc Power Supply Unit (PSU) is always greater in value than the RF power (P_{rf}) that you measure at the ATU that is being delivered to the antenna.

There are always losses in the system. These are the ohmic losses in the wire, feeders and ATU. As the frequency increases the losses in the feeder – particularly coaxial feeder – also increase.The transmitter is not 100% efficient. An efficiency of 50% is not uncommon. (ie for every 2W of dc power provided 1W of RF power will be produced with 1W dissipated as waste heat at the Tx.

9B Decibels (dB)

The Decibel (dB)

The decibel is a POWER RATIO term. It ratios (Power Level2) to (Power Level1). *For example (Output Power) to the (Input Power).*

This means that it has multiplication or division embedded within it. The decibel is defined as:

$$\frac{P2}{P1}\,dB = 10\log_{10}\frac{(Power2)}{(Power1)}$$

Expressing the ratio as a logarithm to base 10 makes manipulating power gains and losses in a system very easy.

You will soon get to recognise the key ratios.

So Why Is This Useful?

In a complex system where there are both gains and losses – such as in working out a signal path – all you have to do is to ADD up the gains and losses (+ and - dBs) that form the signal path to find out what the output power of the system will be relative to the input power.



The above system has an overall gain of +45dB – 42dB = 3dB (or x2)

So if you injected 10W in you would expect to see 2x10 or 20W out.

In dealing with space communications the path losses may be minus tens of dB or even minus a hundred dB. – needing a lot of amplification to recover the signal from the space craft.

Remember : -10dB means the power is *reduced* by a factor of ten

Know These db Power Ratios!

0db = 1
3db = 2
6db = 4
9 db = 8
10db = 10
20db = 100
26db = 400
30db = 1000

A minus sign in front of the db

(-db)

means a loss.

Eg -3dB means that the power is halved.

Using The dB As A Comparison Base

Using the dB as a basis for comparative measurements is useful. There are three prinicipal ones which you need to know.

dBW (Comparison with 1W);
dBi (Comparison with an isotropic radiator);
dBd (Comparison with a dipole antenna).

In particular antenna adverts often use the dB as a figure of merit for the gain of the antenna. *This is meaningless unless it is referenced either dBi or dBd.*

9C Components

The Resistor Colour Code

Leaded resistors often indicate their value by means of coloured bands. Surface mount devices (smd) are marked (if at all) with a different system. Physically large, high power rating resistors are more likely to indicate their value directly with a number printed on the body.

The Resistor Colour Code: This colour code is a universal way of indicating digits You will also find it used to indicate the value of capacitors – but with a small modification. The colours and their associated digits are:

Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

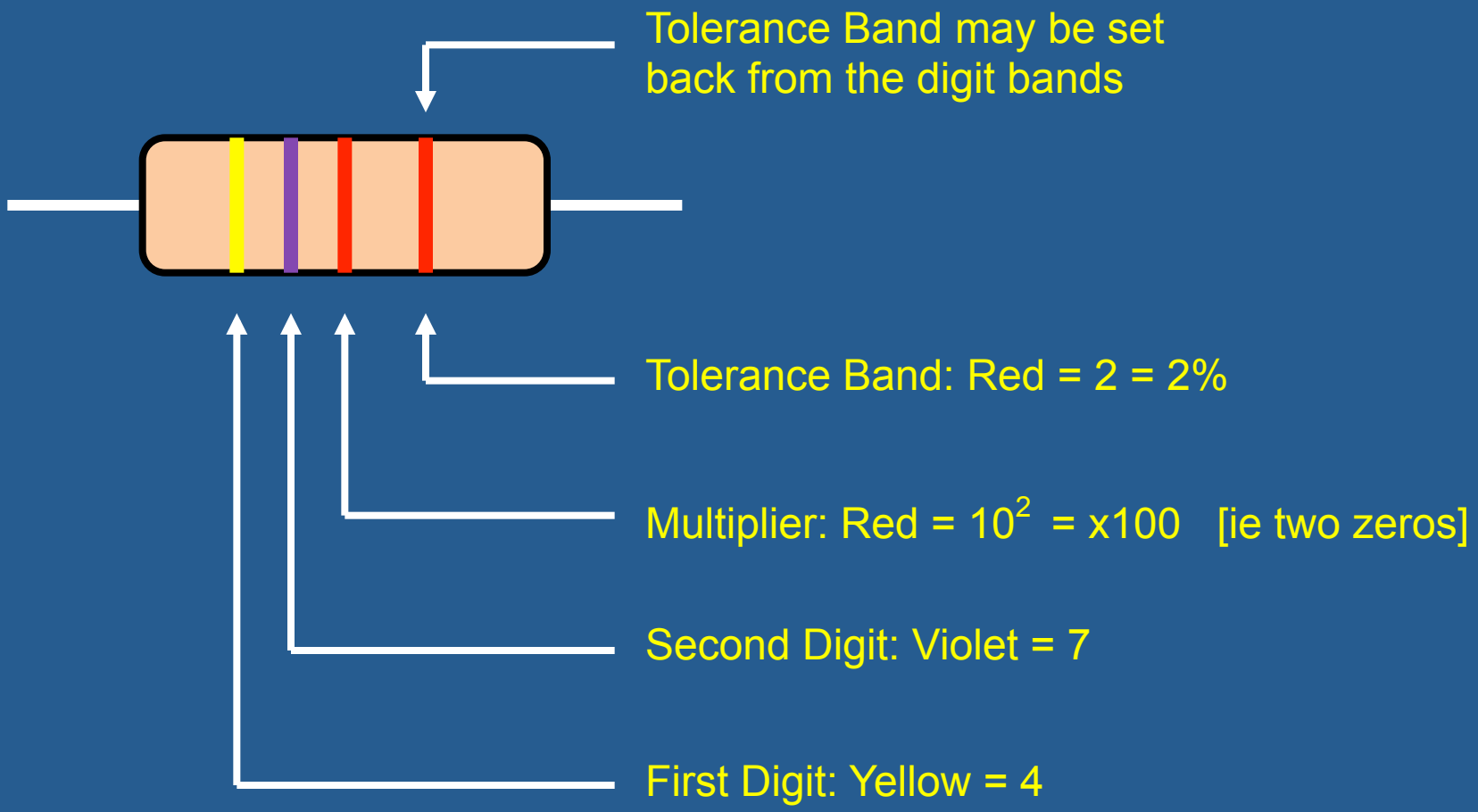
The same order as the spectrum. (ie As in a rainbow)

Tolerance Colours	
Silver	10%
Gold	5%
Red	2%
Brown	1%

Special Multiplier Colour	
Gold	0.1

Using The Resistor Colour Code

The Four-Band Code: A 4,700Ω resistor would look like:



The Multiplier Band

Black	0	Green	5
Brown	1	Blue	6
Red	2	Violet	7
Orange	3	Grey	8
Yellow	4	White	9

The digit indicated in the multiplier band is the power-of-ten which defines the magnitude of the multiplier. So a yellow band indicates that the power-of-ten is "ten raised to the power of 4".

ie. 10^4 or 10x10x10x10 which equals 10,000 times.

Remember that $10^0 = 1$. A black multiplier band means multiply by 1.

If it's easier just think of the multiplier digit as indicating the number of zeros to write down after the first two digits – remembering that "black" means "Do not write down any zeros."

A Gold band as the multiplier means "Divide the first two digits by 10"

The Tolerance Band

Tolerance Colours	
Silver	10%
Gold	5%
Red	2%
Brown	1%

This defines the (+/-) limits within which the resistor value will lie. It is impossible to make an absolutely accurate value for a resistor. The closer to an absolute precision you move the more expensive the resistor becomes to make. For most applications a resistor value sufficiently close to the nominal value will be good enough.

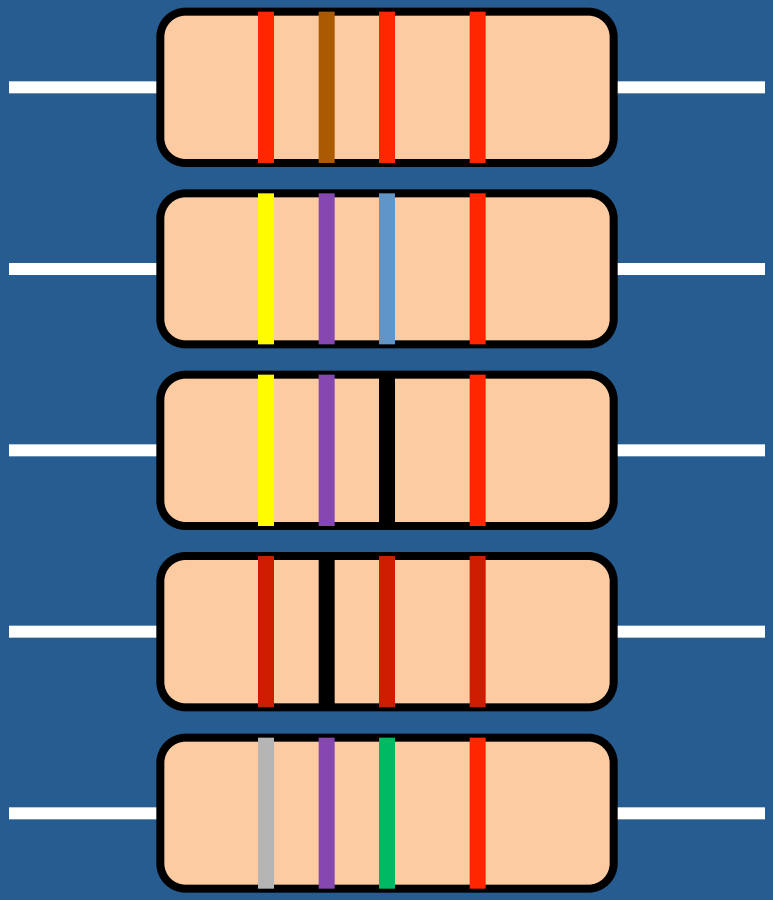
Suppose we have a nominal 1000Ω (1k) resistor with a tolerance of 2%. Between what limits of resistance would we expect the actual (measured) value to be ?

1% of 1000Ω is (1000/100) or 10Ω.
2% will be 2 x10Ω ie 20Ω

Our resistor should have a value between 1000Ω +/- 20Ω

ie. No bigger than 1020Ω and not less than 980Ω

A Few Examples To Try (Calculate the Tolerance Limits Too.)



red; brown; red; red

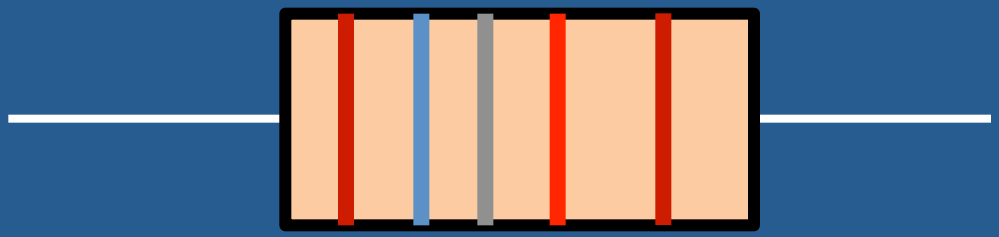
yellow; violet; blue; red

yellow; violet; black; red

brown; black; brown; brown

grey; violet; green; red

The Five-Band Colour Code



Brown = 1

Red = 2

Grey = 8

Blue = 6

Brown = 1

168 x 100 1%

16k8 1% or

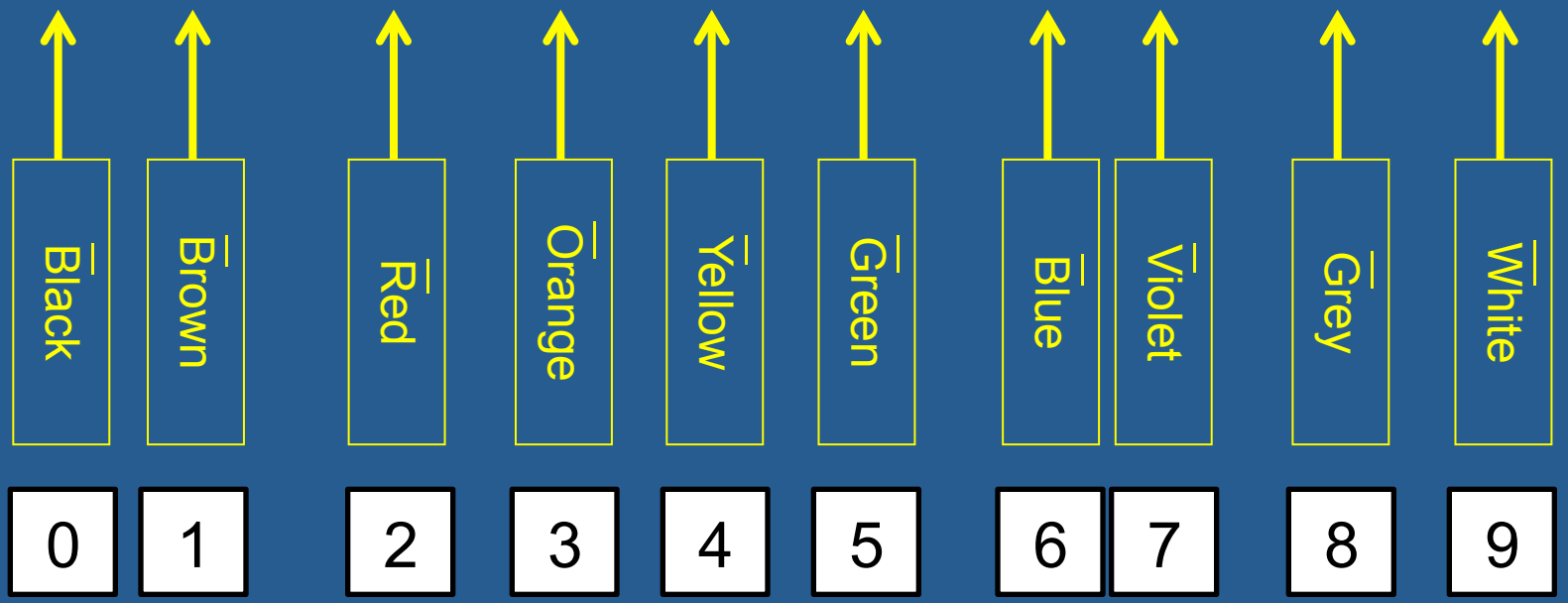
16.8k 1%

Preferred

How To Remember The Colour Code

A simple little mnemonic (where the first letter of each word is the initial letter of the colour) will fix the order of the colours in your head.

Billy Brown Runs Over Your Grass But Violet Grey Wouldn't



Capacitor Numerical Code

The first two numbers describe the value of the capacitor and the third number is the multiplier expressed as a power of ten. (This is the index.)

- When the first two numbers are multiplied by the multiplier the resulting value is the value of the capacitor in **picofarads**.

- If there are only two numbers, it means there is no multiplier. The first two numbers give you the value of the capacitor. in **picofarads.**

Examples

103	Red, Red, Black, Silver
104	Yellow, Violet, Red, Gold
15	
224	Yellow, Violet, Silver, Silver
	Yellow, Violet, Gold, Silver
4k7	
4R5	
0R47	
10M5	
3k3	

9D Construction

Screening

Single or double-sided paper-based pcb is a very good material with which to build an enclosure. It gives screening to the components within it.

It is easy to cut and shape. With a soldering iron of at least 30W you can solder the seams to make a box.

Avoid fibre glass pcb. It is expensive, blunts the cutting tools very quickly and produces an irritant dust.

9E Soldering

Soldering

Soldering is a method of joining together metal wires and components using solder and a hot soldering iron.

Solder is a low melting point, eutectic alloy. Many solders contain a flux to help the solder to flow and to prevent a layer of oxide forming on the surfaces to be joined

Some metals are easier to solder than others

The tip of the soldering iron has to be cleaned to help remove any oxide and then tinned to prevent the oxide reforming and to improve the conduction of heat to the joint.

Prior to soldering you should “tin” any wires. This melts a thin layer of solder over the wire. When you join two tinned wires together the solder flows easily and combines optimally to produce a perfect joint.

Remember!

The job of the soldering iron is to heat the two components to be joined so that they are hot enough to melt the solder.

You *cannot* solder two items together by transferring a blob of solder from the tip of the iron to the two components.

Poor joints are probably a result of too cold an iron, or, taking the iron away too soon once the solder starts to melt on the components.

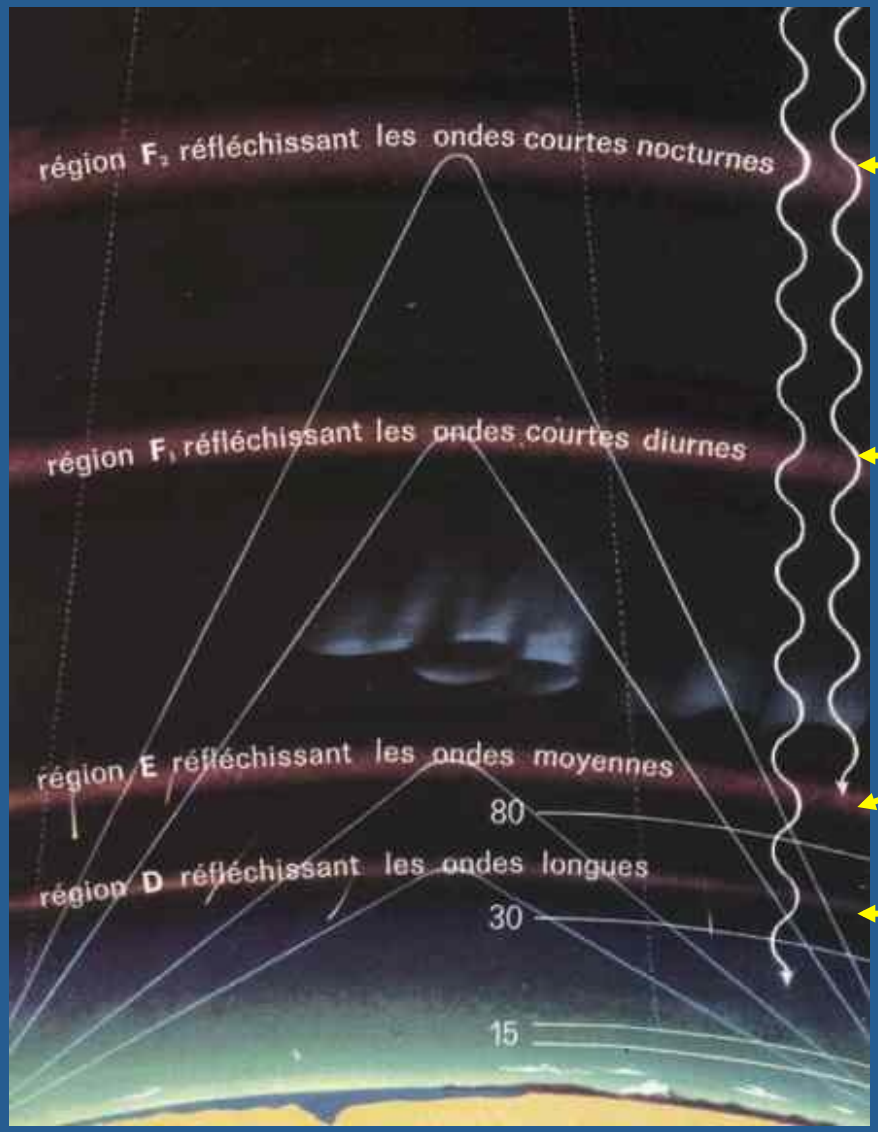
End Of Syllabus Material

Supplementary Information Follows

Annex 1 Ionosphere

Ionospheric Basics

This is a simplified description of ionospheric layers and their effect.



~300km

~160km

Aurora

~110km

Meteors

~80km

F_2 Region – Night-time refraction of HF. Lowers in altitude at night.

F_1 Region – Daytime refraction of HF . Disappears at night.

E Region – MF refracting region.

D Region – LF refracting region. There is a high daytime absorption of 1.8 - 3.5MHz signals

Ionospheric Basics

- High above the Earth (>80km) the atmosphere is so rarefied that *ultra-violet radiation* from the Sun can detach electrons from the gas atoms.
- These charged particles can both *absorb* and *refract* the incident radio waves.
- The *frequency* of the incident wave determines whether it is *absorbed, refracted or passes straight through* the ionosphere.
- *The level of solar activity and day / night variations* strongly influence the height and intensity of the ionosphere and its *effects on propagation*.

Ionospheric Basics: The D-Layer

- The D-layer is the lowest of the ionospheric layers.
- It exists between 60 and 92km.
- At this low level of the atmosphere electrons recombine quickly and ionisation is less directly related to sunshine.
- It begins at sunrise, peaks at noon and disappears at sunset.
- The frequencies 1.8MHz and 3.5MHz suffer highest daytime absorption.
- At times of high solar activity the above frequencies can be totally absorbed during high sun angles.
- The diurnal effect is less-marked at 7MHz and slight at 14MHz.
- The D-layer is ineffective at bending HF waves back. This makes frequencies up to 7MHz useful for short contacts during the day.

Ionospheric Basics: The E-Layer

- The E-layer is the lowest ionospheric layer useful for long-distance communication by amateurs. It is about 100-115km above the Earth.
- Ionisation varies with sun angle above the horizon. Solar X-rays and meteors also play a part in ionising the atmosphere at this level.
- Ionisation increases rapidly at dawn, peaks at noon and drops off quickly at sunset. The minimum is at local midnight.

Ionospheric Basics: The F-Layer

- Most long-distance communication comes from the tenuous outer reaches of the Earth's atmosphere known as the F-layer.
- The F-layer starts at about 160km above the Earth. Electrons at this level recombine more slowly.
- The region retains its ability to refract wave energy well into the night.
- The layer may be from 160km to 500km high depending upon the season, latitudes, time of day and what the solar activity has been doing over the past few minutes.
- During summer days the F-layer may split into a low, weak F_1 layer and a higher F_2 layer.
- The F_1 layer does not contribute greatly acting more like the E-layer.
- At night the F_1 layer disappears and the F_2 layer descends in height.

Annex 2 Electrical Safety

Fitting A 13 Amp Plug & Electrical Safety

You will fit a 13A plug to a 3-core cable during the practical weekend. The worksheet in the book provides a comprehensive guide to fitting a plug. A few salient points:

- If it's not fitted perfectly then cut off the plug top and re-terminate the cable. (You risk a fire or electrocution if the fitting is badly executed.)
- The fuse is there to protect the cable – not the equipment.
- Always fit the correctly rated fuse.
- Don't use equipment that has a damaged cable or plug - or which shows signs of a fault. (scorch marks, smell of burning. etc.)
- There is no safety device that will trip and protect you if you *"put yourself across the supply".* (You will appear as a normal load to the supply.)
- Use an RCD to protect against earth faults.
- **NEVER** interfere with, or use as an RF earth, the circuit protective wiring (earth wiring) of your electrical installation.
- Keep well clear of High Voltage (HV) overhead distribution lines.



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I popped to the supe
– and got diverted

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Jogger killed by 11,000 volt cable

Respected scientist, 41, dies in freak accident while out with running club

ADAM LUKE

A SCIENTIST died from severe burns while out jogging after running into a fallen electricity cable.

Dr James Kew, who studied neuroscience at Cambridge University before rising to be a director at pharmaceutical giant Glaxo-SmithKline, was jogging with his running club on Tuesday evening when the incident happened.

Dr Kew was killed after coming into contact with an 11,000 volt cable, which was hanging from a pylon, at 8.40pm in fields off Debden Road, near Newport in Essex. It started a blaze in the surrounding area. He was pronounced dead at the scene by the emergency services, who treated two other runners for minor electric shocks.

Dr Kew, of Radwinter Road, Ashdon, who was married with children, was a keen member of Saffron Walden-based running group Saffron Striders, who he was out with on Tuesday – just days before his 42nd birthday.

He regularly competed in races across the local area and this year took part in his first London marathon.

Turn to page 5

TRAGIC: Dr James Kew. Left, an officer at the scene of the incident

POLICE ROAD CLOSED

Shepre
animal
cool of
INSIDE
ROSIE
The Co
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Cambridge News
July 26th 2012

It does happen……

Annex 3 Antennas and Feeders

Radio Frequency Currents

At radio frequencies (RF) the current travels on the surface of the conductor.

A single conductor (such as the wire in one of the legs of our dipole) will radiate if it is carrying an RF current. This is fine if we want an antenna. This is a problem if it occurs anywhere else - particularly if it's in the feeder. (cf a leaky hose-pipe.)

Balanced feeder contains only two conducting surfaces – one on each of its conductors. The resulting magnetic fields (caused by the RF currents) are equal and opposite ("balanced out" if you will). *This feeder will therefore not radiate*.

Co-axial cable, however, has three, potential conducting surfaces:
the inner conductor;
the inner surface of the braid "tube";
the outer surface of the braid "tube".

Any current travelling over the outer surface of the braid in a co-axial cable will cause the feeder to radiate.

Out-of-Balance Currents 2

Maximum power transfer (which is what you want) between the transmitter and the antenna occurs when the transmitter output impedance, the characteristic impedance of the feeder and the feed-point impedance of the antenna are all equal. Ideally this will be around 50 ohms. (You hope!)

The transmitter output impedance is typically designed to be 50 ohms at all frequencies. (Fixed Value). The characteristic impedance of the co-axial cable is 50 ohms at all useable frequencies. (Fixed Value). This leaves just the antenna – which as we have seen only approaches 50 ohms at resonance. Its impedance varies with the applied frequency.

As the applied frequency moves away from the antenna's natural resonant frequency the antenna increasingly reflects RF power back down the feeder to the transmitter. (The out-of-balance or reflected current.) With ladder line the two conductors always carry an equal and opposite current. (It can't do anything else!). Hence no radiation from the feeder – however bad the mismatch at the antenna may be.

With co-axial cable any out-of-balance current takes the path of least resistance. This is down the outside of the braid to earth. This current radiates and the feeder becomes part of the antenna. The reflected RF current also causes other problems ("hot mike") and can damage the transmitter and cause RF interference to other devices.

Out-of-Balance Currents 3

At or very near resonance there is no current flowing on the outer of the co-axial cable. There are just the equal and opposite currents on the inner conductor and the inner surface of the braid. Thus the co-axial cable will not radiate.

At VHF and above the change in resonant length for a dipole at the band edges is insignificant. Hence you can happily use co-axial cable because the out-of-balance currents will be insignificant for a well-designed antenna system. Co-axial cable is easy to route around a building and is the best choice at these frequencies for the feeder.

You can use co-axial cable to feed a wire, HF doublet BUT YOU HAVE TO INSERT A BALUN AT THE ANTENNA FEEDPOINT.

The balun (BALanced to UNbalanced) is a device which prevents the out-of-balance current from getting onto the outer co-ax braid at the source of the reflection. It doesn't solve the problem – it just masks the symptoms. Ladder line is always the best choice for HF, wire dipoles. (Period!)

Out-of-Balance Current 4

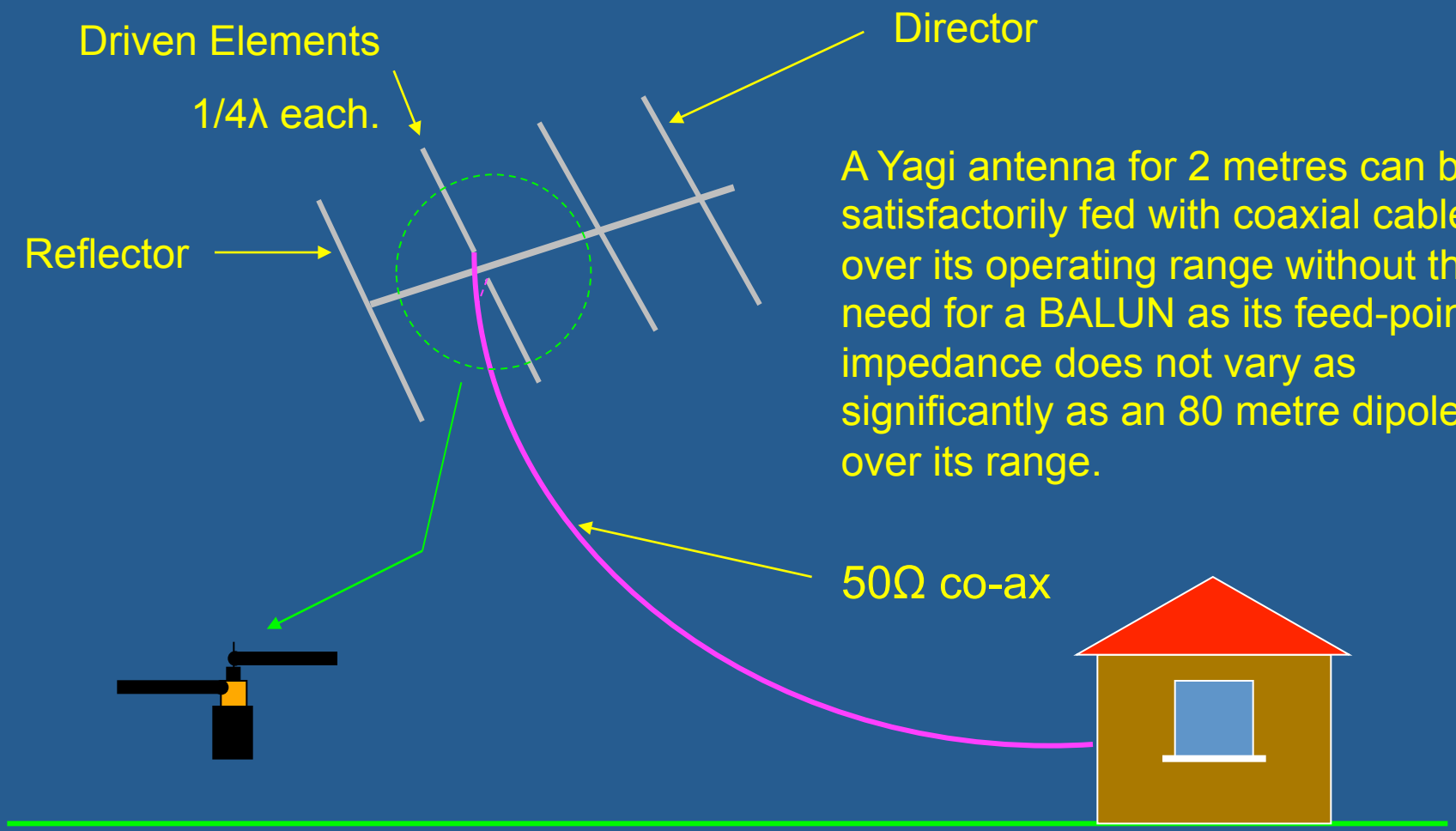
Cautionary Note! The previous explanation about conducting surfaces and balanced currents sufficiently mirrors reality for any exam questions.

The explanation assumes that our antenna feed-point is sufficiently high above the ground (at least half a wavelength) so that its capacitance to earth is low. If the antenna is near to the ground (or buildings, trees, metal poles, guttering – in fact anything) then an additional "displacement current" will flow from the antenna to ground and back to the transmitter. (It's like an additional , invisible "conducting surface" in parallel with the feeder.)

This all adds to the out-of-balance current and contributes to the mismatch. It is not a simple situation.

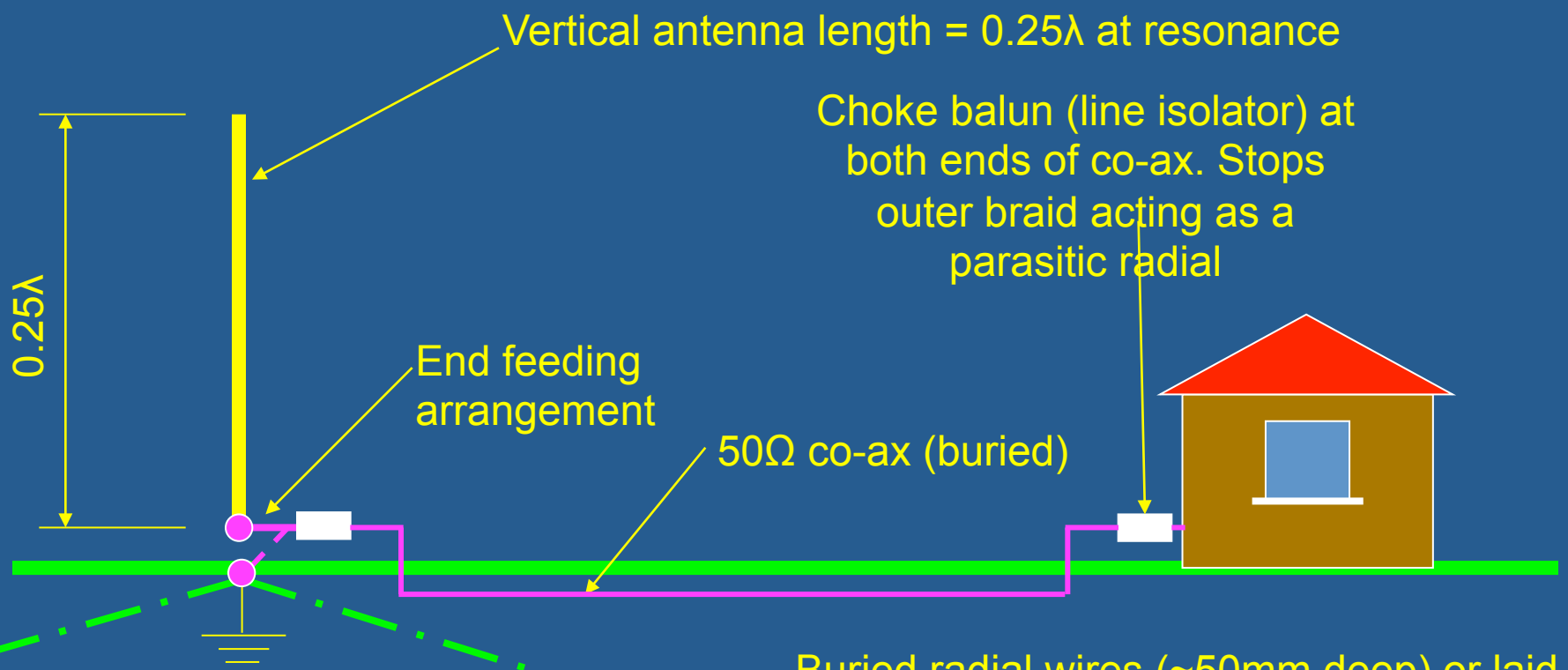
Antennas and feeders are complex - not just bits of wire!

The Centre-Fed Yagi



A Yagi antenna for 2 metres can be satisfactorily fed with coaxial cable over its operating range without the need for a BALUN as its feed-point impedance does not vary as significantly as an 80 metre dipole over its range.

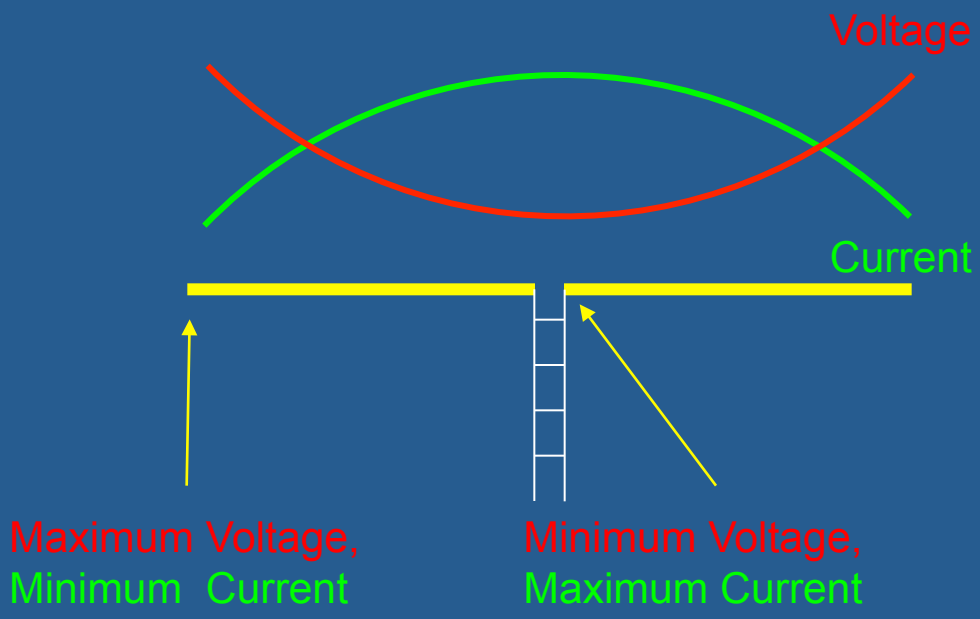
The End-Fed Vertical

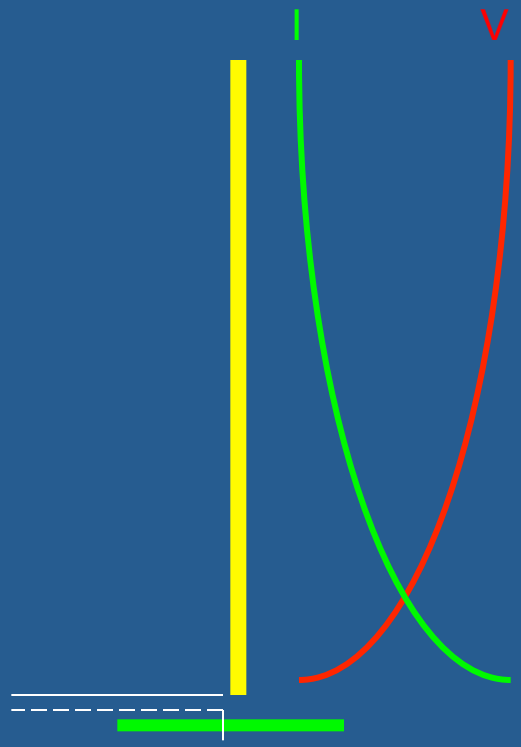


The braid is (wrongly) often just connected to an earthed metal stake which supports the antenna. The antenna will work but not very efficiently! (Beware the “careful” wording in the adverts for so-called “no-radial” verticals.)

Buried radial wires (~50mm deep) or laid on the ground. The radial star-point is connected to the co-ax feeder braid. At least 4 radials of about 0.25λ are needed. More radials (up to 120) are better. Wire mesh is an alternative.

Current and Voltage Distribution in an Antenna.





The feed point is where the current is greatest. The end of the antenna is where high voltages are generated. Most of the radiation occurs in the vicinity of the feed point – which needs to be as high as possible for a centre-fed dipole. *(Never touch the ends of an antenna as you can receive a high voltage shock when the antenna radiates. The ends of an inverted Vee antenna should be placed sufficiently high above the ground to avoid accidental contact and RF burns.)*

Dummy Antenna Load

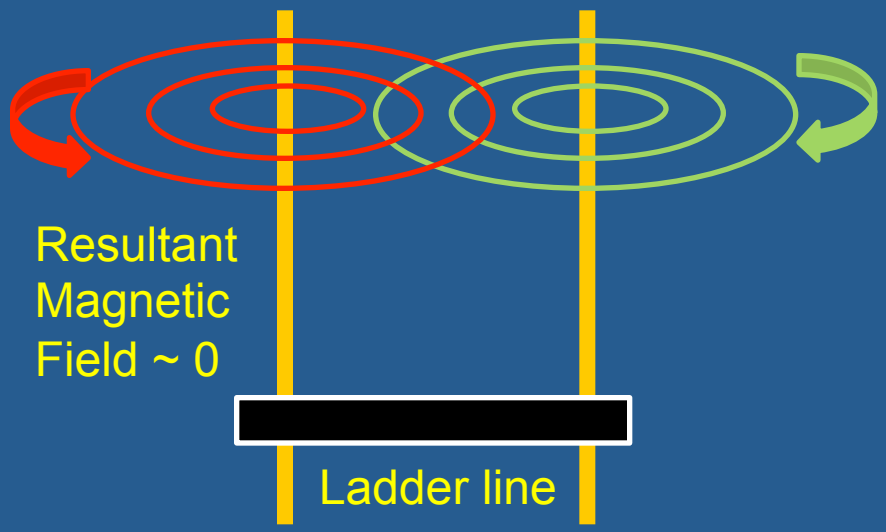
The dummy load is a very useful device. It is a non-inductive and non-reactive resistance which provides a matched termination to the transmitter. The commonest value you will encounter is 50Ω.

It allows you to present the transmitter with a non-transmitting, "perfect" match. It enables transmitter controls to be adjusted under transmitting conditions *without actually radiating a signal. (You will actually radiate a very small signal. However it will be unlikely to cause problems to others.)*



A typical, low power, dummy load.

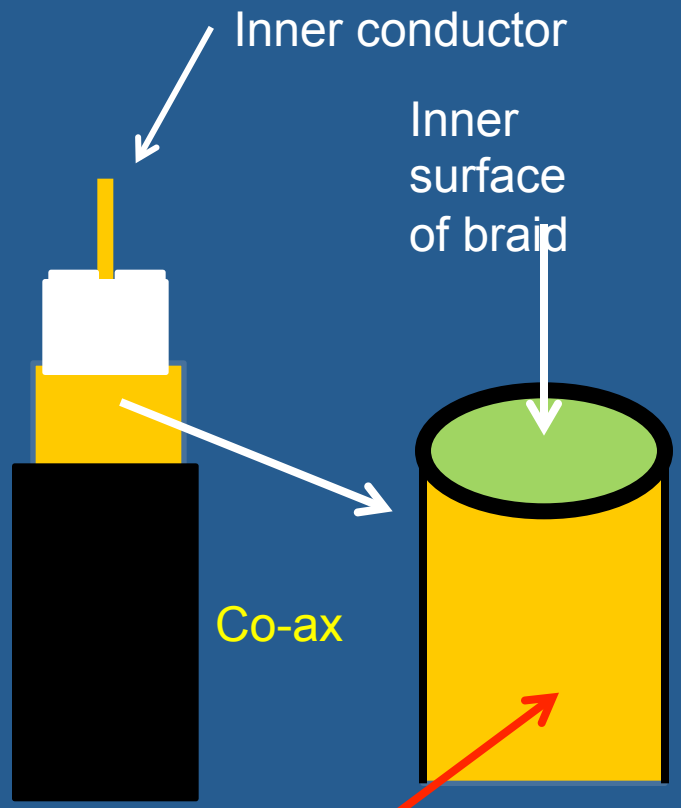
Balanced Feeder



Antenna feed currents and resultant magnetic fields are equal an opposite. No radiation from feeder

Two RF conducting surfaces

Unbalanced Feeder



Three RF conducting surfaces

The term “balanced” refers to earth. Coaxial cable at some point will have the braid connected to earth. It is thus not balanced about earth potential.

"So, Why Can't I Feed The Doublet With 50 Ω Co-Axial Cable?"

Because a dipole antenna is a *"balanced antenna".* This means that neither side (pole / wire) has a connection to a common RF Earth.

Ladder or window line is a *"balanced feeder".* This means that neither of its two conductors is connected to a common RF Earth.

Co-axial cable, however, is an *"unbalanced feeder".* This means that the outer or braid is connected to a common RF Earth.

Only at the *resonant frequency* of the antenna can you successfully use co-axial cable as the feeder. WHY……?

Feeder Requirements

- The feeder transports the radio frequency energy from where it is generated in the transmitter to where it is radiated at the antenna.

- The feeder also transports the radio frequency energy from the antenna where it is induced on receive to the receiver where it is demodulated.

Feeder Requirements

- The feeder has to:
  - Not dissipate energy by having a high resistance.
  - not radiate any RF energy it is carrying.
  - be able to safely withstand high transmit voltages.
  - be able to withstand the weather without degrading.
  - be flexible enough to be routed around obstacles.
  - be cheap enough for use by amateurs.
  - have stable, repeatable characteristics.
  - be able to be terminated in a variety of connectors.

Note on Feeders and ATUs

In this and the previous worksheet we have really only just scratched the surface on the subject of antennas, feeders and AMUs. You should bear in mind the following:

ATUs are essential on a multi-band dipole. However, they are not lossless. A well-made ATU will have only a small insertion loss. Under normal conditions it will not get hot but will always contain circulating currents.

If you use a properly designed mono-band antenna you do not need an ATU – because the antenna will be resonant by design and thus have a feed-point impedance of around 50Ω and can be safely fed by 50Ω co-axial. So you avoid any ATU loss by not having one. Important if you want to operate QRP.

Similarly the losses in co-axial cable increase with increasing VSWR. Ladder line uses an air dielectric (insulator) and thus can withstand higher voltages across it. At 10 Watts you won't have significant loss problems. Feeders and ATUs are not simple components – but are relatively easy to use!

END