Mauritius Amateur Radio Society

www.3b8mars.org

Radio Amateur Class A Examination

Training Notes

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Training Notes for Class A Radio Amateur Licence Examination

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Training Notes: Class A Radio Amateur Licence Examination

The Class A Licence Exam

The RA23 exam will be managed and administered by the Mauritius Amateur Radio Society (M.A.R.S) on behalf of the I.C.T.A in a mutually agreed format.

The examination is a written examination of 60 multiple-choice questions, each with 4 possible answers, based on the Mauritius Class A syllabus. The time allowed for the examination will be two hours (120 minutes).

A pass of the Class B examination is an entry requirement for the Class A examination programme. There are no set age limits for commencing study, although it should be noted that the minimum age to hold a Radio Amateur licence in Mauritius is 16 years of age.

Examination results will be notified by MARS to the ICTA licensing department. Candidates who have successfully passed the examination must use the ICTA appropriate Radio Amateur licence application form when applying for a licence. . Examinations will be carried out at a MARS DESIGNATED examination Centre.

The Class A Licence Exam

Section 1 – Operating and Licensing conditions

Licensing Conditions

International Telecommunications Union (ITU)

The International Telecommunication Union (ITU) is the United Nations agency for information and communication technologies.
The **ITU Radio Recommendations** govern the legal and technical requirements of all users of radio frequencies, whether they be government, commercial, amateur or any other group.
The Radio Regulations that are relevant for Radio Amateur Licence Examination candidates are covered in this section of the Training Notes.

Purpose of the Amateur Service

The Radio Regulations define the **Amateur Service** as a radio communication service for the purpose of:

> Self-training,
> Intercommunication and
> Technical investigations

carried out by amateurs, that is, by duly authorised persons interested in radio technique solely with a **personal aim** and without **pecuniary interest**

Permitted Communications

Radio communication between amateur stations in different countries:

a. Is permitted unless the administration of one of the countries concerned has **notified that it objects** to such radio communications
b. Is limited to communications **incidental to the purposes of the amateur service** and to remarks of a personal character
c. **Cannot be encoded for the purpose of obscuring their meaning**, except for control signals exchanged between earth command stations and space stations in the amateur-satellite service.

(So, for ordinary communications, Morse Code can be used, as can any other form of encoding, such as computer-generated digital modes, provided the form of encoding is not secret)

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In general, licensed amateur stations are permitted only to contact other licensed amateur stations. This restriction and the restriction on the content of transmissions (point b. above) may be eased for communications on behalf of third parties in case of emergencies or disaster relief.

An example of the emergency communications referred to above would be where radio amateurs operators taking part in providing support communications facilities during a national emergency (e.g. cyclone). In such cases, licensed radio amateur operators are permitted to pass third party messages for, and on behalf of, designated Emergency Services such as the Police, Coast Guard, Fire Service and other Government designated agencies.

Call Sign Usage

Amateur stations are required to transmit their call sign when establishing a contact with another Amateur and at least once every 15 minutes during the course of ongoing transmissions.

Call signs must be suffixed with **/A** when operating from an alternative location (i.e. away from the main station address), **/P** when operating portable, **/M** when operating from a **land based mobile** and with **/MM** when operating **maritime mobile.**

When operating /A, /P, /M or /MM it is useful to periodically broadcast the location or position of the station for reference purposes.

Primary and Secondary Allocations

Frequency allocations are allocated by the ITU on a **Primary** or **Secondary** basis – in effect, determining the **priority** of the individual radio services.

Most of the amateur bands, within the scope of the exam syllabus, are allocated on a **Primary** basis

[Although outside the scope of the exam syllabus, it is worth noting that some of these allocations are on a Primary Shared basis, i.e. the band is shared with other non-amateur primary users]

Some of the amateur bands within the scope of the exam syllabus are allocated on a **Secondary** basis (see Operational Bands)

- o The 10 MHz, 50 MHz bands are allocated to radio amateurs on a Secondary basis

The Radio Regulations specify that stations with a Secondary allocation …

- o shall not cause harmful interference to stations of Primary services, and
- o cannot claim protection from harmful interference from stations with a Primary allocation

Emission Designations

The ITU uses an internationally agreed system for classifying radio frequency signals. Each type of radio emission is classified according to a number of factors which describe the **characteristics of the signal** – not the transmitter used.

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This classification, referred to as the **Emission Designation**, has a minimum of 3 characters, showing:

1. Type of modulation
   Example: **J = Single-sideband, suppressed carrier**
   Example: **F = Frequency modulation**
2. Nature of modulating signal
   Example: **1 = One channel containing digital information, no subcarrier**
   Example: **3 = One channel containing analogue information**
3. Type of information transmitted
   Example: **D = Data, e.g. RTTY**
   Example: **E = Telephony, e.g. voice**
   For purposes of the exam, these emission designations should be known:

   - **A1A = CW (Morse, on/off keying of the carrier)**
   - **J3E = SSB (single sideband, suppressed carrier, speech)**
   - **A3E = AM (amplitude modulation, speech)**
   - **F3E = FM (frequency modulation, speech)**
   - **F1B, F2B, J2B = RTTY / AMTOR**
   - **F1D, F2D, J2D = Packet / Data**

Section 1

Licensing Conditions

National Regulations and Guidelines

Telecommunications Act

The **Information and Communications Technologies Act 2001 (as amended)**, provides for the licensing and regulation of all commercial and amateur radio stations in Mauritius.

The Act deals primarily with administrative requirements that are not relevant for exam purposes. However, these Class A course notes cover the issues in the Act that are within the scope of the exam Syllabus.

ICTA Regulations and Guidelines

The Information and Communications Technologies Authority (ICTA) is the statutory government body in Mauritius responsible for the regulation of the electronic communications sector (telecommunications, radio communications and broadcasting transmission, etc.).

ICTA is therefore responsible for the regulation of radio amateur station licences.

ICTA's **Radio Amateur Licence Conditions** sets out the terms under which an amateur station must be operated – for example, the frequency bands, operating modes and power limits as well as technical and engineering requirements.

These Guidelines form an important part of the *Licensing Conditions* section of the examination Syllabus.

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It is important to note that the ICTA Radio Amateur Licence Conditions do not exempt the licensee from having to comply with any other statutory requirements or obligations as may apply (for example - safety, etc.)

Operational Bands

Annex 1 of the ICTA Licence Conditions includes full details of the frequency bands which an amateur station is authorised to operate on, along with details of the power limits, modes and other stipulations for each band. By way of example, the frequencies covered in the table range from 1.8 MHz to 440,000 MHz However, the Syllabus covers the full table as published by ICTA in Annex 1 of the RA 23 licence document, a copy of which will be supplied to candidates during the examination.

The table below shows an example of commonly used frequency allocations, the status of these allocations and power limits, all of which would be relevant for exam purposes.

Frequency (MHz)	Status	Power Limit
1.810-1.850	Primary	800W (29 dBW)
3.500-3.800	Primary	800W (29 dBW)
7.000-7.200	Primary	800W (29 dBW)
10.100-10.150	Secondary	800W (29 dBW)
14.000-14.350	Primary	800W (29 dBW)
18.068-18.168	Primary	800W (29 dBW)
21.000-21.450	Primary	800W (29 dBW)
24.890-24.990	Primary	800W (29 dBW)
28.000-29.700	Primary	800W (29 dBW)
50.000-52.000	Secondary	800W (29 dBW)
144.000-146.000	Primary	800W (29 dBW)
430.000-432.000	Primary	800W (29 dBW)
432.000-440.000	Primary	800W (29 dBW)

See Primary and Secondary Allocations for more information on Status

For the purposes of the above Power Limits, the **power is measured at the final output of the transmitter or amplifier.**

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Land Mobile

Where an amateur station is installed in a **land-based vehicle** the following additional provisions apply …

The call sign must be suffixed by '/M' ("slash mobile")
The particulars of the mobile station's location must be sent at the beginning and end of a contact with each station or at intervals of 15 minutes.

Maritime Mobile

An amateur station operating on water – whether at sea or on any waterway / river / lake – is considered to be a **maritime mobile station**, and is subject to the following additional provisions …

Approval to operate is required from the Ship's Master and / or owner
The call sign must be suffixed by '/MM' ("slash maritime mobile")
The particulars of the mobile station's geographic position must be sent at the beginning and end of a contact with each station or at intervals of 15 minutes whichever is the more frequent. This geographic position must be included in the logbook when recording communications
The amateur station cannot be used for the sending or receipt of any message which would, if there were no amateur station on the vessel, be sent by means of the vessel's wireless telegraphy station
The amateur station must not interfere with the wireless telegraphy station on the vessel. Should such interference occur, use of the amateur station must cease until the cause of the interference has been remedied.

Logbook Keeping

A detailed logbook must be kept up to date at the amateur station, and made available for inspection at the request of ICTA. The details to be included in the logbook are –

1. dates of transmission
2. the times in UTC during each day on the first and last transmissions from the station and changes made to the frequency band, mode of emission or power
3. frequency band of transmission
4. mode of transmission
5. power level (dBW or W)

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6. details of tests carried out
7. the call sign of licensed amateur stations with which communications have been established, and
8. location when the station is operated other than at the main amateur station address

A logbook may typically include additional information, such as signal reports sent and received and/or the name and QTH of the person contacted, however this information is entirely optional

Additional Authorisations

An amateur station licence permits the keeping and operation of an amateur station, using the frequency bands, modes and powers specified in the licence – these bands / modes / powers would generally be those specified in Annex 1 of the ICTA Guidelines (see the reference to Annex 1 in Operational Bands)

The amateur station licence also specifies the call sign to be used

Additional privileges or other licence types may be requested: typically, these might include …

- o Additional frequency bands and / or power levels, for experimental purposes
- o Licence to operate a station marking a special event or occasion
- o Automatic or remote station licence (for example, a repeater, beacon or stand-alone Internet gateway)

Formal authorisation from ICTA is required for using any of the above.

Technical Requirements

The general conditions attached to an amateur station licence include a number of technical requirements for the purposes of ensuring that:

a. no harmful interference is caused to other licensed services, and
b. the amateur station is constructed and maintained in such a manner as to ensure that the safety of persons or property is not endangered

The licence conditions do not include detailed equipment specifications. However a number of broad requirements are listed;

Mechanical and electrical construction of the amateur station installation must be in accordance with best practice

All controls, meters, indicators and terminals should be clearly labelled

The licensee should have a device capable of measuring Standing Wave Ratio (SWR). See VSWR

The licensee must have an accurate method to ensure that operations take place on the correct frequency. In the case of home constructed equipment a simple frequency counter or synthesised main receiver/ transceiver would suffice. See [Frequency Counter](#)

Attention should be paid to the location of antennas and feeders in regards to their proximity to buildings and areas accessible to third parties. Particular care should be taken when operating at temporary locations for the purposes of contests, expeditions and during mobile use. See [Antenna (Aerial) Safety.](#)

The licensee must ensure that non-ionising radiation emissions from their amateur station are within any limits specified by the guidelines published by the ICTA. The ICTA Guidelines include limits for spurious emissions (also called "spurious radiation"), which vary according to frequency band and installation date of the transmitter.

- o Quantitative limits for non-ionising radiation or spurious emissions are not within the scope of the exam syllabus, however the aims of these limits should be understood: see [Non-Ionising Radiation](#) and [Electromagnetic Compatibility](#)

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CEPT Regulations

CEPT and Amateur Radio

CEPT – The European Conference of Postal and Telecommunications Administrations is a European organisation where policy makers and regulators collaborate to harmonise telecommunication, radio spectrum, and postal regulations

Two areas of CEPT's work have been of significant benefit to radio amateurs …

a. The Harmonised Amateur Radio Examination Certificate (HAREC), which enables radio amateurs who have successfully passed a HAREC-standard exam in one country to obtain a licence in another country (the Mauritius Class A examination is a HAREC-standard examination)
b. Arrangements which make it possible for radio amateurs from CEPT countries to operate during short visits to other CEPT countries without obtaining an individual temporary licence from the visited CEPT country

The CEPT regulations regarding operation during visits to other participating countries – i.e. point (b) above are not within the scope of the exam syllabus and are outlined on the next page for information

CEPT Radio Amateur Licence

Under **CEPT Recommendation T/R 61-01**, the holder of a "CEPT Radio Amateur Licence" may, when visiting a country that has adopted Recommendation T/R 61-01, operate on all frequency bands allocated to the amateur service **that are authorised in the country being visited**. These arrangements are subject to a number of conditions, including –

These arrangements are valid only for non-residents, for the duration of their temporary stays.

The regulations (frequencies / modes / power limits etc.) in force in the country being visited must be observed

Technical restrictions imposed by national, local or public authorities must be respected Protection against harmful interference cannot be requested by the visitor

The visitor must use his/her call sign preceded by the call sign prefix of the visited country, with the character '/' ("stroke") separating the two

Example: Mauritius **visitor to Scotland:** *GM***/3BxABC**
Example: UK **visitor to Mauritius:** *3Bx***/G3ABC**

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[Note: some countries require the visited country's call sign prefix to be preceded by a number indicating the region where the station is operating]'

A number of non-European countries that are not members of CEPT, have adopted Recommendation T/R 61-01, allowing visitors to and from their countries to benefit from these arrangements.

The details of participating countries is on the [Information for Visitors to Mauritius](#) page of the ICTA web site (note that it is not necessary for exam purposes to know which countries are in the list, nor is it necessary to know the call sign prefixes to be used in visited countries other than the call sign prefixes specified in the *Operating Rules and Procedures* section of the syllabus – see [National Call Sign Prefix.](#)

It should be noted that Mauritius is currently not a signatory to the CEPT Recommendation T/R 61-01 and reciprocal licences must be applied for on a personal basis.

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Operating Rules and Procedures

Composition of Call Signs

A <u>normal</u> amateur radio call sign contains three sections:
  i.   **one or two characters** identifying the nationality of the operator (at least one character will be a letter : letter-number, number-letter or letter-letter combination is possible)
  ii. **a single digit** (i.e. a number)
  iii. a group of **not more than four characters**, the last of which must be a letter
There are many exceptions to the above rules (often for special event call signs) however, for exam purposes only, the above <u>normal</u> rules are relevant.

Some examples of *correct* call signs:
[The dashes (–) in these examples are included simply to highlight the separate call sign sections, they are not part of the call sign]

> 3–B–XYZ
> 2E–3–ØRGD
> M–6–A

And some *incorrect* call signs:

> 3B–A–BCD — no number in section (ii).
> EI–4–RGD7 — ends in a number
> 2–6–A — no letter in section (i).

Mauritius Call Signs

In Mauritius, normal call signs consist of the country identification letters **3B** ("Three Bravo") as the prefix, a single digit secondary location identifier and either a one, two, three or four letter suffix

> *eg: 3B8xx (Mauritius Island – Class A licence)*
> *eg: 3B8Bxx (Mauritius Island – Class B licence)*

For (Class A) stations operating from other islands the prefix **secondary locator digit is used to identify the location**

> *eg: 3B9xx – Rodrigues Island*
> *eg: 3B6xx – Agalega Island*
> *eg: 3B7xx – St. Brandon Island*

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National Call Sign Prefixes

Call sign prefixes identify the country (and sometimes the region and licence class) of the operator. Many hundreds of prefixes are in use. Exam candidates are expected to know the principal call sign prefixes used in Europe and North America. These are listed in Annex 1 of the Syllabus and are as follows:

OE	Austria	**TF**	Iceland	**OM**	Slovakia
ON	Belgium	**EI**	Ireland	**S5**	Slovenia
LZ	Bulgaria	**I**	Italy	**EA**	Spain
9A	Croatia	**YL**	Latvia	**SM**	Sweden
5B	Cyprus	**LY**	Lithuania	**HB**	Switzerland
OK	Czech Republic	**LX**	Luxembourg	**UR**	Ukraine
OZ	Denmark	**9H**	Malta	**G,M**	England
ES	Estonia	**PA**	Netherlands	**GM,MM**	Scotland
OH	Finland	**LA**	Norway	**GW,MW**	Wales
F	France	**SP**	Poland	**GI,MI**	Northern Ireland
DL	Germany	**CT**	Portugal	**GD,MD**	Isle of Man
SV	Greece	**YO**	Romania	**GJ,MJ**	Jersey
HA	Hungary	**UA**	Russia	**GU,MU**	Guernsey
North America					
K,N,W	USA	**VE**	Canada		

ITU Radio Regions

The ITU has divided the world into three Regions for administrative purposes. In summary the three Regions comprise:

Region 1: Europe, Africa, the Middle East, Russia, Iraq and Mongolia

Region 2: North and South America, Greenland and some eastern Pacific Islands

Region 3: Asia, Oceania (Australia and New Zealand) and Japan

The International Amateur Radio Union (IARU) is the worldwide representative body for amateur radio and is organised in three Regions similar to those of ITU

Section 1 – Operating and Licensing Conditions

Band Plans – Introduction

1. The three IARU Regions adopt voluntary recommended band plans for the frequency bands allocated to the amateur service by the ITU. For exam purposes, we are concerned only with the Region 1 band plans
2. Band plans allocate specific segments to particular modes based on bandwidth. Typically CW is at the low frequency end of the bands, wide band modes such as SSB or FM are at the high frequency end, with data modes somewhere between the two.
3. Note that CW may be used across all bands, except within beacon segments.

4. (Frequencies or segments reserved for propagation beacons should never be used for normal transmissions)
5. Band plans are widely accepted by amateurs and adherence to them minimises interference between modes
6. The band plans are defined in considerable detail to provide for a wide range of requirements. The summary tables on the next two pages deal with key aspects of the band plans that exam candidates should be familiar with
7. In some instances, the Region 1 band plan allows modes on certain frequencies that the table of "Radio Amateur Authorised Frequencies" in ICTA's Guidelines does not permit. Also, ICTA's Guidelines would allow modes on some frequencies that are not allocated under the band plan. Where the Guidelines and band plan differ, we have adjusted the allocation so that it conforms to both, as well as simplifying them for exam purposes
8. The band plans incorporate bandwidth limits, which would in practice qualify the meaning of allocations such as "All modes". In simplifying the band plans for purposes of the Training Notes, we have largely excluded references to bandwidth limits

Following on the adjustments referred to in notes 5, 6 and 7 above, it is important to note that the band plan tables in this Guide are not intended to be definitive.

Region 1 Band Plan – HF
Note: the data shown here has been simplified for exam purposes.

kHz	Preferred Mode and Usage
1.8 MHz (160 metres) Band – Contests Permitted	
1810-1850	CW
1850-2000	All modes
3.5 MHz (80 metres) Band – Contests Permitted	
3500-3510	CW, priority for intercontinental operation
3510-3560	CW, contest preferred
3560-3580	CW

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kHz	Preferred Mode and Usage
3580-3600	Narrow band modes / digimodes
3600-3650	All modes, SSB contest preferred
3650-3700	All modes
3700-3800	All modes, SSB contest preferred
3775-3800	All modes, priority for intercontinental operation
Lowest dial setting for LSB voice mode is 3603	
7 MHz (40 metres) Band – Contests Permitted	
7000-7040	CW
7040-7050	Narrow band modes / digimodes
7050-7060	All modes
7060-7100	All modes, SSB contest preferred
7100-7130	All modes
7130-7200	All modes, SSB contest preferred
7175-7200	All modes, priority for intercontinental operation
Lowest dial setting for LSB voice mode is 7053	
10 MHz (30 metres) Band – Contests Not Permitted	
10100-10130	CW
10130-10150	Narrow band modes / digimodes
14 MHz (20 metres) Band – Contests Permitted	
14000-14060	CW, contest preferred
14060-14070	CW
14070-14099	Narrow band modes / digimodes
14099-14101	Beacons only
14101-14125	All modes
14125-14300	All modes, SSB contest preferred
14300-14350	All modes
14300	Global emergency centre of activity
18 MHz (17 metres) Band – Contests Not Permitted	
18068-18095	CW
18095-18109	Narrow band modes / digimodes
18109-18111	Beacons only
18111-18168	All modes
18160	Global emergency centre of activity

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kHz	Preferred Mode and Usage
21 MHz (15 metres) Band – Contests Permitted	
21000-21070	CW
21070-21149	Narrow band modes / digimodes
21149-21151	Beacons only
21151-21450	All modes
21360	Global emergency centre of activity
24 MHz (12 metres) Band – Contests Not Permitted	
24890-24915	CW
24915-24929	Narrow band modes / digimodes
24929-24931	Beacons only
24931-24990	All modes
28 MHz (10 metres) Band – Contests Permitted	
28000-28070	CW
28070-28190	Narrow band modes / digimodes
28190-28225	Beacons only
28225-29100	All modes
29100-29700	All modes – FM

Note: 29100 to 29700 is the only segment of the HF bands where the wide bandwidth required by FM transmissions is permitted; on all other bands, the bandwidth limit mean that "All mode would exclude FM

"Narrow band modes" in the above table refer to modes with a maximum bandwidth of 500 Hz Below 10

MHz use lower sideband (LSB), above 10 MHz use upper sideband (USB)

Region 1 Band Plan – VHF/UHF

Note: the data shown here has been simplified for exam purposes.

The examiners have informed us that questions on band plans for the 50 MHz and 430 MHz bands will not be included in the exams. Any questions on these bands will be confined to the data in the ICTA Guidelines, which is covered in the Operational Bands section of the Course Guide

For exam purposes, only the 144 MHz (2 metres) band plan needs to be considered

MHz	Preferred Mode and Usage
144 MHz (2 metres) Band	
144.000-144.150	CW
144.150-144.400	SSB
144.400-144.500	Beacons only

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MHz	Preferred Mode and Usage
144.500-144.794	All modes
144.794-145.000	Machine Generated Modes ‡
145.000-145.1875	FM – Repeater Input only
145.200-145.575	FM – Simplex
145.600-145.7875	FM – Repeater Output only
145.800-146.000	All modes
	‡ = outside the scope of the exam syllabus

Contests are permitted on the 50 MHz, 144 MHz and 430 MHz bands

Distress Signals

A distress signal is an internationally recognised way of calling for help: using radio communications, the recognised distress signals are:

Radiotelegraphy (Morse) SOS • • • — — — • • •

Radiotelephony (Voice) Mayday, Mayday, Mayday

Such signals must only be used where there is grave and imminent danger to life

Emergency and Natural Disaster Communications

Amateur stations under ITU regulations may be used for transmitting international communications on behalf of third parties **only** in case of emergencies or disaster relief. Administrations determine the applicability of this provision to amateur stations in their jurisdictions

Administrations are encouraged to take the necessary steps to allow amateur stations to prepare for and meet communications needs in support of disaster relief.

The MARS Repeater Network, which is approved by ICTA, is an example of this.

Band plans make provision for 'Global Emergency Centres of Activity' on the 14, 18 and 21 MHz bands. The relevant frequencies are noted in the Region 1 Band Plan – HF

Format of General (CQ) Calls

Before calling on a frequency ask …

example: is this frequency in use from 3B8xx

A CQ call inviting any station to reply … [phone]

example: CQ CQ CQ from 3B8xx, CQ CQ CQ from 3B8xx, 3B8xx standing by

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A CQ call inviting any station to reply … [Morse]
example: CQ CQ CQ de 3B8xx, CQ CQ CQ de 3B8xx, K
(The 'K' is an invitation for any station to reply)
A CQ call to a specific station … [Morse]
example: CQ CQ CQ OM2ABC de 9A3XYZ,
KN
(This is the Croatian station 9A3XYZ calling the Slovakian station OM2ABC, the 'KN' indicates that only the called station should reply)
A CQ call to a specific station … [phone]
example: CQ CQ CQ SP7XX from
LZ3ABC
(This is the Bulgarian station LZ3ABC calling the Polish station SP7XX) A CQ call to a specific area … [phone]
example: CQ CQ CQ Japan from 3B8xx
(Only stations in Japan should reply to this call)

The call sign of the station being called or worked comes first with the call sign of the station calling or handing over the transmission coming second.

Q Codes

Q Codes are standard three-letter codes, developed originally to facilitate commercial Morse transmissions to speed up the sending of messages and to act as a form of 'international language for messages. Q codes continue to be used extensively in amateur Morse (CW) transmissions and are also commonly used in amateur voice transmissions, assisting conversations between operators speaking different languages

The Q codes within the scope of the exam syllabus are:

Code	Question	Answer
QRK	What is the readability of my signals?	The readability of your signals is …
QRM	Are you being interfered with?	I am being interfered with
QRN	Are you troubled by static?	I am troubled by static
QRO	Shall I increase transmitter power?	Increase transmitter power
QRP	Shall I decrease transmitter power?	Decrease transmitter power
QRT	Shall I stop sending?	Stop sending
QRZ	Who is calling me?	You are being called by …
QRV	Are you ready?	I am ready
QSB	Are my signals fading?	Your signals are fading
QSL	Can you acknowledge receipt?	I am acknowledging receipt
QSO	Can you communicate with … direct?	I can communicate … direct

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Code	Question	Answer
QSY	Shall I change to transmission on another frequency?	Change transmission to another frequency
QRX	When will you call again?	I will call you again at … hours on … kHz (or MHz)
QTH	What is your position in latitude and longitude (or according to any other indication)?	My position is … latitude, … longitude (or according to any other indication)

Operational Abbreviations

Like Q Codes, Operational Abbreviations are used in radio communications to speed up the sending of messages and to facilitate conversations between operators speaking different languages. The relevant Operational Abbreviations are:

BK	Signal used to interrupt a transmission in progress
CQ	General call to all stations / call for a contact with another station
CW	Continuous wave
DE	From, used to separate the call sign of the station called from that of the calling station
K	Invitation to transmit
MSG	Message
PSE	Please
RST	Readability, signal-strength, tone-report
R	Received
RX	Receiver
TX	Transmitter
UR	Your

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Phonetic Alphabet

The internationally recognised Phonetic Alphabet for amateur radio is shown in the table below. While Q Codes and Operational Abbreviations have more relevance for Morse communications, the Phonetic Alphabet is used mainly in "phone" (voice) communications as a means of ensuring that key information such as call signs can be understood even when signals are weak or distorted, and/or when those involved in the communication speak different languages:

A = Alpha	**G** = Golf	**M** = Mike	**S** = Sierra	**Y** = Yankee
B = Bravo	**H** = Hotel	**N** = November	**T** = Tango	**Z** = Zulu
C = Charlie	**I** = India	**O** = Oscar	**U** = Uniform	
D = Delta	**J** = Juliett	**P** = Papa	**V** = Victor	
E = Echo	**K** = Kilo	**Q** = Quebec	**W** = Whiskey	
F = Foxtrot	**L** = Lima	**R** = Romeo	**X** = X-ray	

eg: **3B8AB = "Three Bravo Eight Alpha Bravo"**

eg: **OM4WZH = "Oscar Mike Four Whiskey Zulu Hotel"**

RST Code

The RST Code is used to report on the quality of a radio signal that is being received …

R = Readability – this is an assessment of how hard or easy it is to correctly copy the information being sent during the transmission

S = Signal Strength – this indicates how powerful the received signal is at the receiving location

T = Tone – used only in Morse code and digital transmissions, it describes the quality of the transmitter's modulation. While this part of the RST Code is still in use, its relevance has diminished as modern transmitter technology can generally be expected to deliver high tonal quality signals

Readability

R1   Unreadable

R2   Barely readable, occasional words distinguishable

R3   Readable with considerable difficulty

R4   Readable with practically no difficulty

R5   Perfectly readable

Section 1 – Operating and Licensing Conditions

Signal Strength	
S1	Faint signal, barely perceptible
S2	Very weak
S3	Weak
S4	Fair
S5	Fairly good
S6	Good
S7	Moderately strong
S8	Strong
S9	Very strong signals

Tone	
T1	Extremely rough hissing note
T2	Very rough AC note, no trace of musicality
T3	Rough AC tone, rectified but not filtered
T4	Rough note, some trace of filtering
T5	Filtered rectified AC but strongly ripple-modulated
T6	Filtered tone, definite trace of ripple modulation
T7	Near pure tone, trace of ripple modulation
T8	Near perfect tone, slight trace of modulation
T9	Perfect tone, no trace of ripple or modulation of any kind

example: **59 = "perfectly readable, very strong signals" (voice)**

example: **44 = "readable with practically no difficulty, fair signals" (voice)**

example: **589 = "perfectly readable, strong signals, perfect tone …" (Morse)**

Section 2 – Theory & Technology

Electrical & Electronic Principles including Components & Circuits

Resistors

Current
Movement of negatively charged electrons constitutes an electric current
By convention, it is said that current flows from **positive** to **negative**
the letter **I** is the symbol for electric current
The unit of current is the **Ampere (A)**, abbreviated to **Amp**

DC & AC Current   (Check validity of section)
DC means **direct current** – the current flowing in the circuit (or the potential difference applied to the circuit) is in ONE direction only. The current (or potential difference) may vary with respect to time but DOES NOT REVERSE DIRECTION

AC means alternating current – the current or applied voltage **changes direction** periodically with time, e.g., current from the mains supply.

The **rms value** is the value used in most calculations. It will be dealt with in more detail in subsequent sections

Voltage
To keep a current flowing in a circuit a difference in "electric pressure" **(potential difference)** must be maintained between the ends of the circuit
This **potential difference** is known as voltage
The letter **V** is the symbol for voltage
The unit of voltage is the **Volt (V)**

Resistance
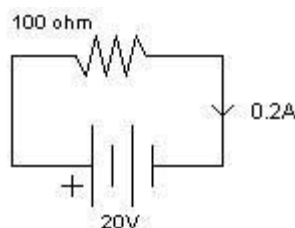Resistance is the **opposition to current flow**
Different conductors oppose current by different amounts
The current flowing depends on **the value of the resistance** and the **applied voltage**
The letter **R** is the symbol for resistance
The unit of resistance is the **Ohm Ω**

Ohm's Law

Current flow depends on (is proportional to) **voltage** and **inversely** **proportional to resistance**

Section 2 – Radio Amateur Theory & Related Topics

$$V = I \times R \quad \text{or} \quad R = V / I \quad \text{or} \quad I = V / R$$

If V is 20V, and R is 100Ω then I is
0.2A Try other examples!
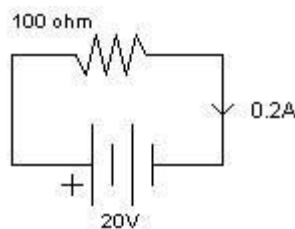
Power

Power is the rate of the use of energy
The letter **P** is the symbol for Power. The unit of power is the **Watt (W)**

$$\textbf{Power (Watts) = V (Volts)} \times \textbf{I (Amps)}$$

$$\textbf{P = V} \times \textbf{I}$$

Using Ohm's Law:

$$P = I^2 \times R \quad \text{also} \quad P = V^2 / R \quad \text{also} \quad R = V^2 / P$$

The power dissipated in the resistor is

$$\textbf{P = V} \times \textbf{I}$$

$$= \ \ \textbf{20} \times \textbf{0.2} \ = \ \textbf{4W}$$

$$\text{or } P = V^2 / R \ = (20)^2 / 100 \ = \ 4W$$

Electrical Units

Some electrical units are inconveniently large or small, so multiples or sub-multiples described by a prefix are used:

| Prefix	Letter	Index	
giga	G	One thousand million	10^9
mega	M	One million	10^6
kilo	k	One thousand	10^3
milli	m	One thousandth	10^{-3}
micro	μ	One millionth	10^{-6}
nano	n	One thousand millionth	10^{-9}
pico	p	One million millionth	10^{-12}

Section 2 – Radio Amateur Theory & Related Topics

Resistors
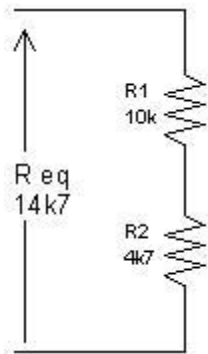
<u>Series</u>   Values add together! The equivalent value R_{eq} of the resistors is
$$R_{eq} = R1 + R2 + R3 ..$$

Resistors in series increase value: The equivalent value is always greater than the biggest!
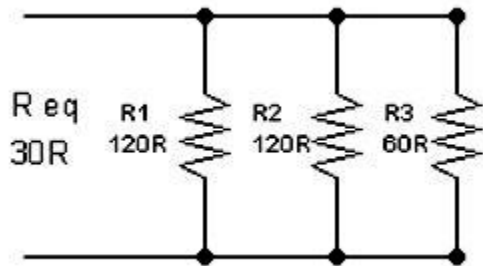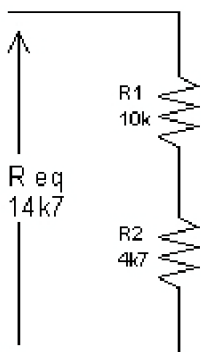
<u>Parallel</u>
$$(1 \div R_{eq}) = (1 \div R1) + (1 \div R2) + (1 \div R3) ...$$

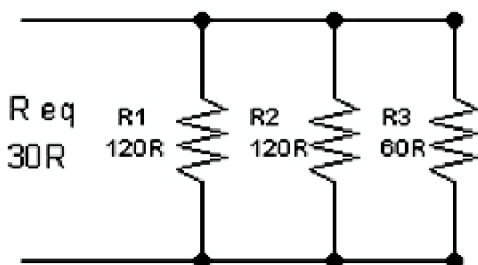If **two** in parallel formula can be simplified to
$$R_{eq} = (R1 \times R2) \div (R1 + R2)$$

Resistors in parallel reduce value: The equivalent value is always less than the smallest!

For combinations reduce parallel into equivalent value first, then calculate series value to give current/voltage
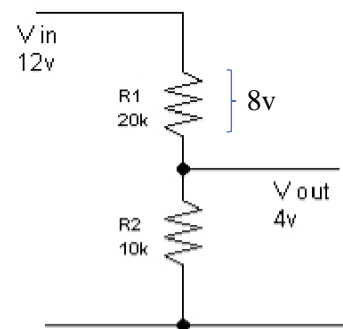
$$R_{eq} = R1 + R2 = 10 + 4.7 = 14.7k$$

$$(1 / R_{eq}) = (1 / R1) + (1 / R2) + (1 / R3)$$
$$= (1 / 120) + (1 / 120) + (1 / 60)$$
$$= (4 / 120) = (1 / 30)$$
Therefore total resistance R_{eq} =   30
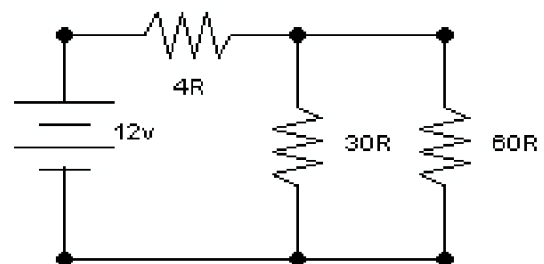
Section 2 – Radio Amateur Theory & Related Topics

Two resistors in series, as shown, are known as a **potential divider**. Assuming there is negligible current drawn from V_{out}:

$V_{out} = V_{in} \times ((R2) \div (R1 + R2))$

Question: Given voltage of battery and values of resistors as shown calculate voltages, currents and power in the example circuit —
answer below

First we calculate the equivalent value of the parallel resistors $(30 \times 60) \div (30 + 60) = 20\Omega$
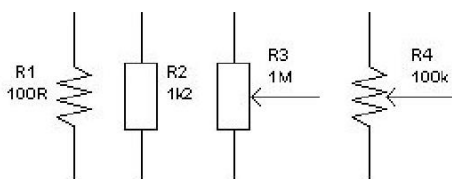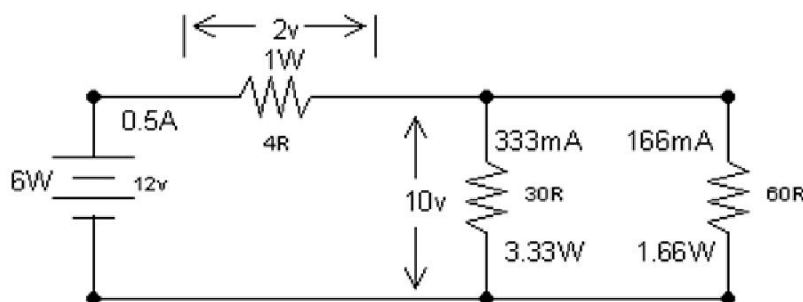So now have 4 and 20 in series which is 24Ω

So total current is $12 \div 24 = 0.5A = 500$ mA
The current divides between the parallel resistors

In a SERIES circuit the SAME CURRENT flows in all parts of the circuit.

In a PARALLEL circuit the same VOLTAGE exists across all the parallel components.

Shown left are typical symbols used for:
(R1 & R2) fixed resistors.
(R3 & R4) potentiometers.

Note that you will see both systems of symbols on your journey through radio.

Section 2 – Radio Amateur Theory & Related Topics

Summary:

Remember: Resistance is measured on **Ohms (Ω)**
Resistors obey **Ohm's Law, V = IR**

as applied voltage increases, current through the resistor increases proportionately.

Resistors dissipate power as heat

$(P = I^2R = V^2 \div R)$

Resistors have specific rated power dissipation

0.25W, 0.5W, 1W, 2W, 5W...

If you exceeded the power ratings, the component will probably fail!

Tolerance
Resistors have a specific tolerance, expressed as a percentage, 1%, 5%, 10%...
A nominal 100Ω 10% tolerance resistor can have an actual value between 90Ω and 110Ω

This has to be taken into account in circuits
Lower value gives higher current through resistor, higher power dissipation in resistor and lower voltage drop across resistor
100 ohm and 500 ohm in series, ± 10% (plus or minus) can give a total resistance between 540 and 660 ohms
120 ohm and 60 ohm in parallel ± 10% can give a total resistance between 44 and 36 ohms

Conductivity
In some substances electrons cannot move easily from one atom to another. They have a high resistance to current flow and are called **insulators**

Examples are Glass, Perspex, Rubber, Mica, most Plastics, Oil, Air
Some substances have a low resistance to current flow and are called **conductors**

Examples are metals (Silver, Copper, Aluminium, Iron), Carbon, some liquids

Semiconductors
A **semiconductor** is a substance whose resistance is between that of a good **conductor** and a good **insulator**

Examples are silicon, germanium, gallium arsenide, cadmium sulphide
Semiconductors form the basis of most modern electronic devices
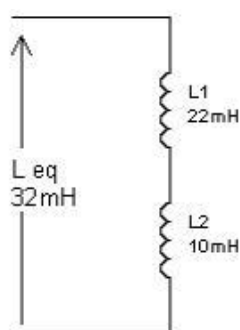
Inductors

Inductor (Coil)

Any wire carrying a current is surrounded by a magnetic field; winding the wire into a coil strengthens this field. When the current through a coil changes the magnetic field resists the change; this resistance to change is called inductance

The unit of inductance is the Henry (H) but as this is a large unit the milli-Henry (mH), micro–Henry (µH) and nano-henry (nH) are more commonly used.

In electronic circuits, inductors are mainly used where the current is alternating – such as in audio frequency or radio frequency circuits. However, the resistance to change of the magnetic field will also affect a direct current (i.e. non-alternating) circuit during the switch-on phase: if an inductor is connected to a DC power supply, the sudden increase of current in the inductor is initially resisted, but when the current becomes stable, the inductor no longer resists the current

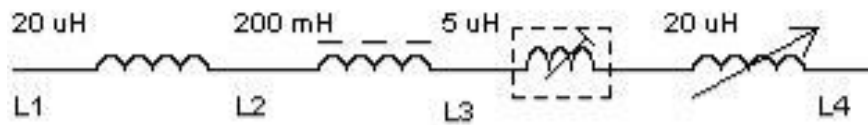## Inductor

L eq
32 mH

L1
22 mH

L2
10 mH

Series **Values add together!** $L_{eq} = L_1 + L_2 + L_3 \dots$

Inductors can, in exceptional circumstances, be connected in parallel but this is a very specialised situation and will not be dealt with here – suffice to say that when we connect inductors in parallel the end result, the effective inductance, is LESS than the original inductors (just like resistors!!)

Section 2 – Radio Amateur Theory & Related Topics

Construction / Characteristics

Inductor symbols and marking

Inductance **increases** with number of turns, coil diameter and **decreases** if spacing between turns is increased

Adding a conducting core changes inductance depending on the **permeability** of the core material; ferrites **increase** inductance, brass **decreases**

Inductive Reactance

When an a.c. voltage is applied to an inductor the ratio of voltage to current is the reactance (X_L) measured on Ohms)
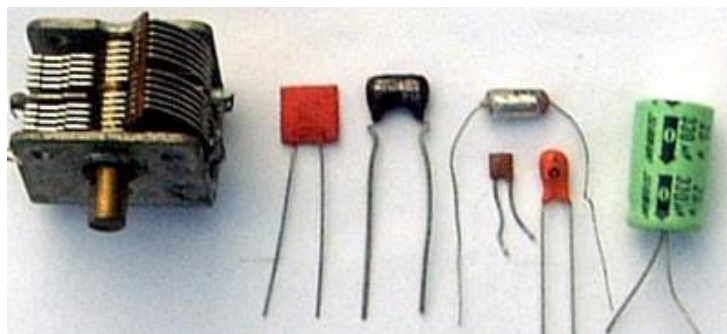
$$X_L = V \div I$$

$$I = V \div X_L$$

$$V = I \times X_L$$

Reactance depends on the value of the inductor and also increases with frequency $X_L = fL$

Capacitors

Capacitor

Two metal plates close to each other with an insulator (the **dielectric**) between them will store an electric charge. This ability is known as capacitance

The unit of capacitance is the **Farad (F)** but as this is a very large unit the micro-, nano- and pico-Farad (F, nF, pF) are used

Capacitance depends on
1. the area (**A**) of the plates,
2. the distance between them (**d**), and
3. the **dielectric constant** (**K**) of the material between them

$$C = KA / d$$

Dielectrics

Air – used for variable capacitors with a set of fixed and moving plates allowing the effective plate area to vary. Used for tuning circuits. As plate spacing determines working voltage, capacitors used for antenna matching where high voltages are often encountered require large spacing, up to 1cm

Paper – layers of metal foil (aluminium) separated by paper: physically large, high working voltages (not often met these days).

Plastics – High working voltage. Polythene, polypropylene, mylar can be lossy at HF; polystyrene, PTFE less lossy, more stable

Mica, silvered mica, ceramic – low values, stable, suitable for HF

Hi-k ceramic – relatively large capacitance in small size, not suitable for radio frequencies (RF)

Very large capacitance require thin dielectrics formed chemically in **electrolytic capacitors**

Electrolytic capacitors are **polarised** (i.e. have specific + and – terminals); in use we must avoid reverse polarity or overvoltage as either will result in failure of the capacitor. Electrolyte can dry up over time causing failure.

Characteristics

Fixed   Electrolytic   Variable capacitor
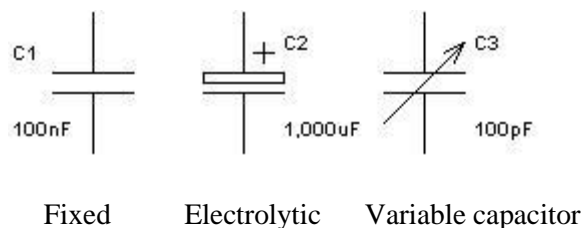
Capacitor symbols and marking

A **capacitor** is a fixed or variable component with a specific value of capacitance
Capacitors have a specific tolerance, expressed as a percentage, 1%, 5% or even more!… of their value

The **working voltage** of a capacitor is the maximum voltage that can safely be applied – we should always try to keep the capacitor well below this voltage.

When d.c. is applied to a capacitor there is an initial surge of current as the capacitor charges and then, when charged, no further current flows.
In a practical capacitor there will be some current through the dielectric. This is known as the **leakage current**
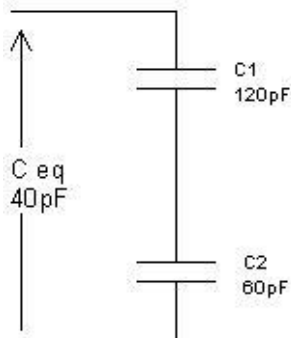A capacitor will block dc. but allows ac. to flow
A capacitor can store an electric charge.

Section 2 – Radio Amateur Theory & Related Topics

Capacitors

Opposite formulae compared
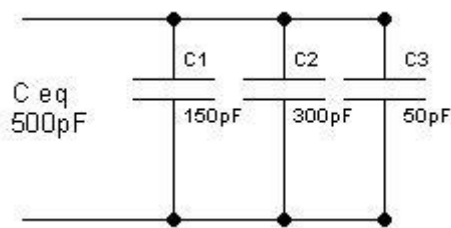with resistors

C_{eq} is the SINGLE capacitor that
could replace the combination of
capacitors without altering the
functioning of the circuit

Series $(1 \div C_{eq}) = (1 \div C_1) + (1 \div C_2) + (1 \div C_3) \dots$
If two in series formula can be
simplified to
$C_{eq} = (C_1 \times C_2) \div (C_1 + C_2)$

Parallel $C_{eq} = C_1 + C_2 + C_3 \dots$

Capacitive Reactance

When a.c. is applied to a capacitor it will charge it, first in one direction, then the other,
i.e. a current flows.
The ratio of voltage to current is the capacitive reactance **(Xc)** measured on Ohms

1. $X_C = V \div I$
2. $I = V \div X_C$
3. $V = I \times X_C$

$X_C = 1 \div (2\pi f C)$ Ω

Reactance decreases as frequency increases

Temperature coefficient

Ideally component values should not vary with temperature. Resistors and capacitors
can be manufactured whose value changes with temperature.
They have a **negative** [value decreases with temperature] or **positive temperature
coefficient** (**PTC / NTC**), specified in parts-per-million per degree Centigrade (ppm/°C)
Such resistors are called **thermistors** and are used as temperature sensors and
current limiters

Capacitors are frequently used to compensate for drift due to temperature
variation in tuned circuits.

Impedance, Resonance and Reactance

Reactance

An alternating current (a.c.) circuit is affected by the inductance and capacitance of the circuit

This effect is called **Reactance**

There are two types, inductive and capacitive …

Inductive reactance: An inductor opposes changes in current

Capacitive reactance: A capacitor opposes changes in voltage
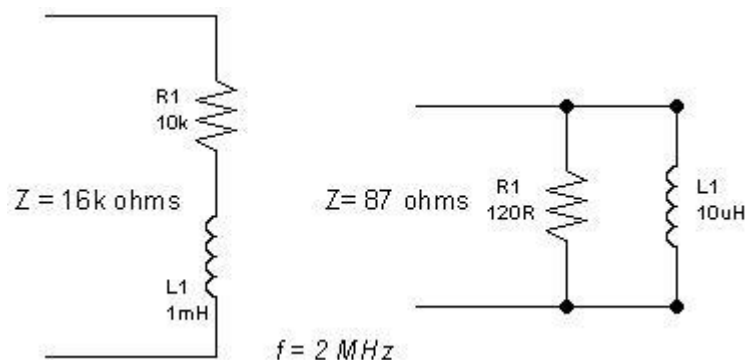
Value is expressed in Ohms

Reactance and Frequency

Reactance varies with frequency …

Inductive Reactance **increases** as frequency **increases**

Capacitive Reactance **decreases** as frequency **increases**

Impedance

Impedance (Z) is the combination of resistance **(R)** and reactance **(X)**

The unit of impedance is **Ohms (Ω)**
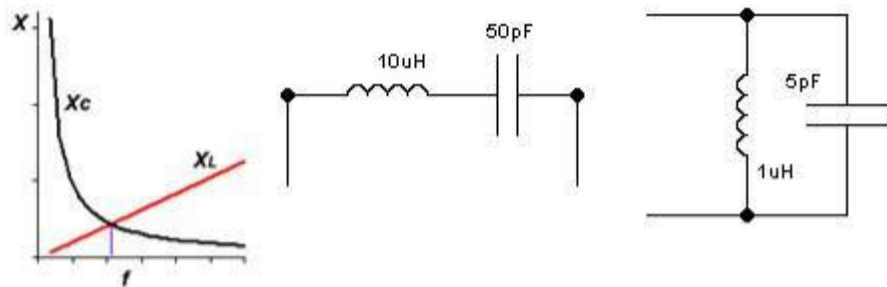
Resistance and reactance in series

$$Z = \sqrt{(R^2 + X^2)}$$

Resistance and reactance in parallel

$$Z = (R \times X) \div \sqrt{(R^2 + X^2)}$$

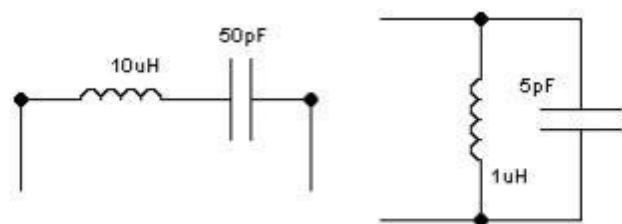# Section 2 – Radio Amateur Theory & Related Topics

Resonance

Inductive reactance **increases** with frequency; capacitive **decreases**

Frequency at which inductive and capacitive reactance are equal is called the
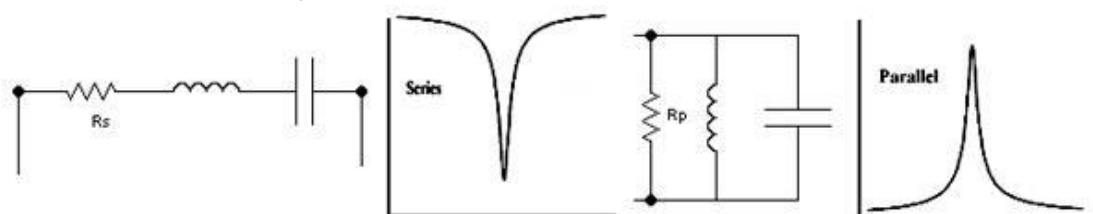**resonant frequency (f_R)**

Tuned Circuits and Filters

Theoretical impedance of a series resonant circuit is zero – it is an **acceptor** circuit and will either short out or pass signals through at resonant frequency depending on how connected

Theoretical impedance of a parallel resonant circuit is infinity – it is a **rejector** circuit and will either block signals at resonant frequency or short out signals not at resonant frequency depending on how connected

These acceptor and rejector circuits form the basis of tuned circuits and filters

Typical Tuned Circuits Responses

A series tuned circuit has a low impedance at resonance. It can be used as a tuned notch to attenuate signals over a narrow frequency range

A parallel tuned circuit has a high impedance at resonance. It can be used to enhance signals over a narrow frequency range

Section 2 – Radio Amateur Theory & Related Topics

Losses – Q factor

An ideal inductor has no resistance to d c. In practice there will be losses due to wire resistance, core losses (due to induced currents in conductive cores) and **skin effect**, whereby as frequency increases ac. tends to flow only on the conductor surface

The ratio of reactance to resistive losses for an inductor is called the **Q-factor**
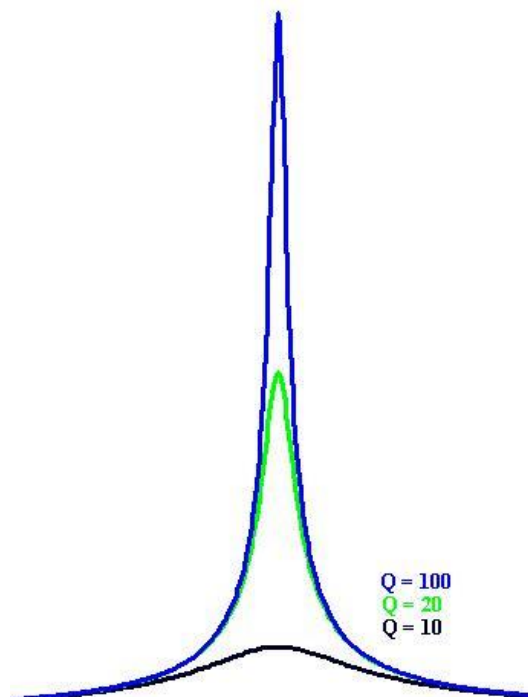
$$Q = X \div R \quad [Q \text{ has no units}]$$

It is a measure of the "goodness" of the inductor or circuit

Q & Bandwidth

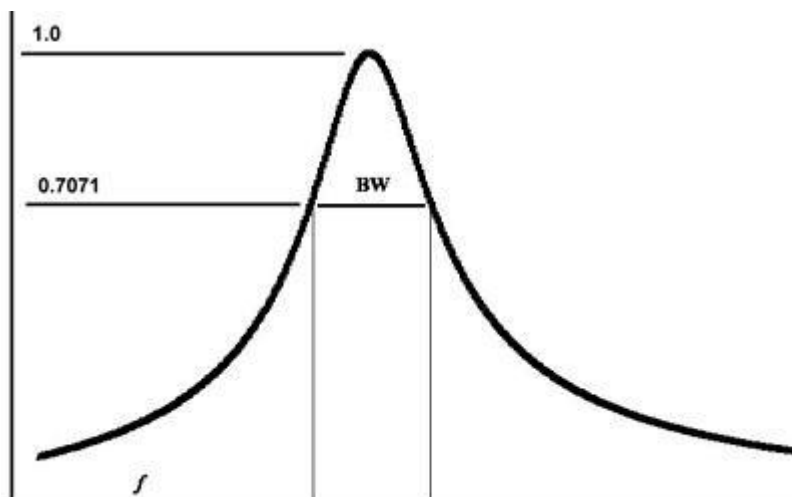The Q of a circuit determines the bandwidth

A circuit with a **high Q** has a **narrow** bandwidth

A circuit with a **low Q** has a **wide** bandwidth

Q = 100
Q = 20
Q = 10

Section 2 – Radio Amateur Theory & Related Topics

Tuned Circuit and Filter Bandwidth

Either side of resonance the response falls off. When the response in voltage terms reaches 0.707 (½) of the value at resonance, this range of frequencies is known as the **(half power) bandwidth** or -3dB bandwidth

For filters another important parameter can be **shape factor** which is the ratio of (-)6/60dB bandwidth; less than 2:1 is acceptable.

Section 3 – Components

Diode

A diode is a device which conducts electricity in one direction only

Now generally manufactured from **N** and **P semiconductor** material

Characteristics

The amounts of forward current (I_F) and **peak inverse voltage (piv)** i.e., the reverse voltage that the device can tolerate are limiting parameters in diode selection

When reverse biased a practical diode will have some **leakage current** which may be important

Diode has a forward voltage drop depending on material

used: Silicon 0.6V; Germanium 0.3V; Schottky 0.2V

Uses
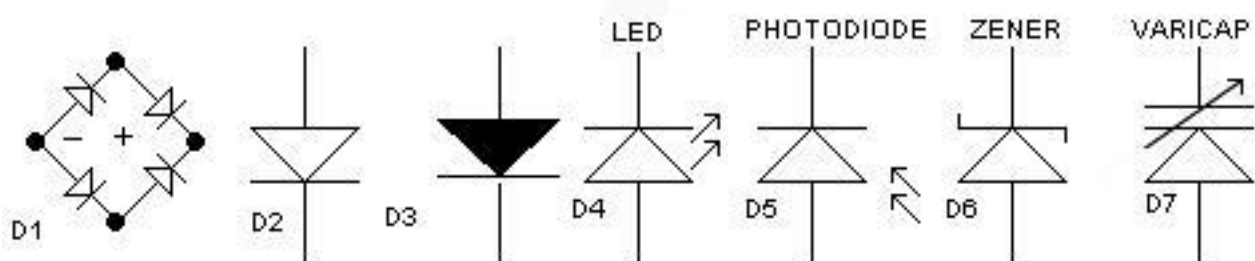
Rectifier diode is used to convert a.c. to d.c. **(rectify)** in power supplies; diodes are normally silicon with voltage drop of 600mV and suitable **IF** and **piv** rating

Germanium Signal diode can be used as a simple **amplitude modulation detector**

# Section 3 – Radio Amateur Theory & Related Topics

A Gallium Arsenide diode can be forward biased and used as a **light-emitting diode (LED)**

When a **Zener diode** is reverse biased a constant voltage appears across it terminals; it is used to set and stabilise the output voltage of power supplies

A reverse-biased **photodiode** conducts when exposed to light and can act as a switch

A **varicap** diode has a capacitance that varies with reverse voltage; it can be used in a tuning circuit

Diodes
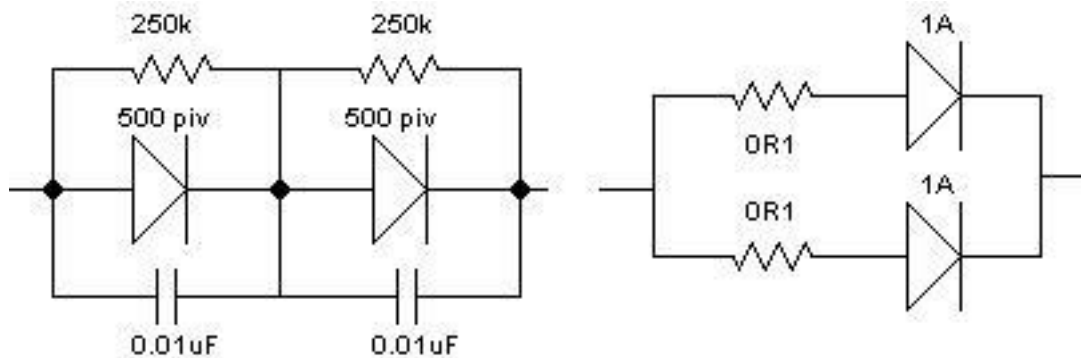
Diodes of the same type will have differing **forward voltage drop** and reverse **leakage current**

If connecting in series to increase effective **piv rating**, some recommend that high values of resistor (to balance voltages) and capacitors (to protect against transients) should be connected in parallel

If connecting in parallel to increase **forward current rating**, low value resistor should be put in series to balance currents

# Section 3 – Radio Amateur Theory & Related Topics
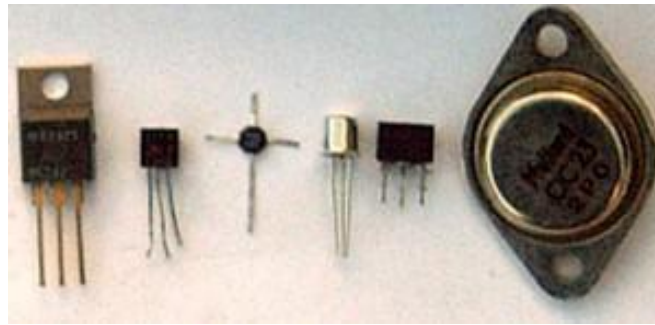
Transistor

Three layers of doped (process of adding minute quantities if impurity) semiconductor (either PNP or NPN) are sandwiched together to form a bipolar transistor

The layers are called the **collector (C)**, **base (B)** and **emitter (E)**

The B-E junction can be considered as a forward biased diode, whilst the C-E behaves as reverse biased diode junction.

The transistor can be used as an amplifier or switch

Two typical transistors – note the DIRECTION of the arrows which depicts the direction of current flow
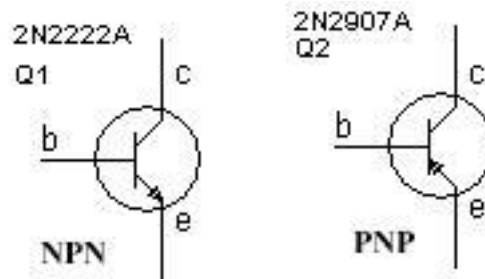
$I_E = I_C + I_B$; Large collector current is controlled by small base current giving gain (amplification)

Current gain (β Beta) is the ratio of change in collector current I_c for change in base current I_b which can be 500 or more depending on the particular transistor.

Arrowhead on symbol shows direction of conventional current flow

Section 3 – Radio Amateur Theory & Related Topics

Field Effect Transistor (FET)
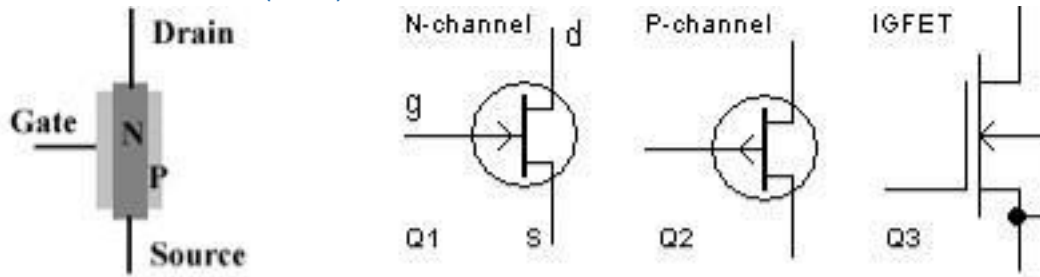
N channel Junction Field Effect Transistor (j-FET) comprises a channel of N material surrounded by a ring of P material; P channel is the opposite

Current flow along the channel between **source** and **drain** is controlled by the **gate** voltage

A small change in **gate voltage** causes a large change in **drain current**; the ratio **g (mA÷V)** is called the **transconductance**

Thermionic devices (Valves)

Triode – simplest type (apart from the Diode)– three active elements, cathode, grid, anode
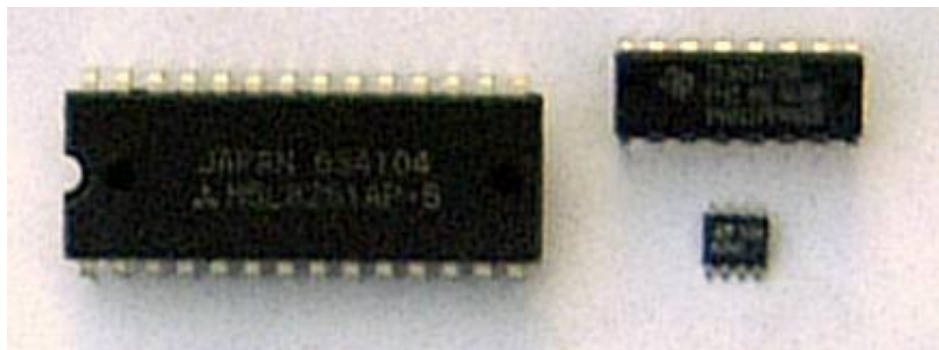
Cathode is heated by "heater" (filament), emits electrons which are attracted to the anode (or plate [U.S.]), connected to high tension (HT) supply sometimes **hundreds or thousands of volts**

A small change in Grid voltage controls Anode current giving gain

One variant of this, the **beam tetrode** (four elements), commonly used in HF power amplifiers
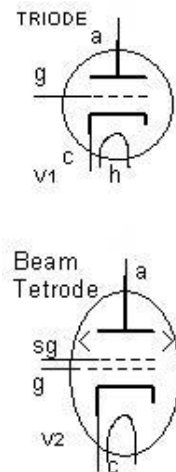

Integrated Circuits

ICs are complete digital or analogue (linear) building blocks

Digital ICs range from logic gates, counters, memories to complete microprocessors (MPU) and analogue-to digital converters (ADC)

Linear ICs can range from transistor arrays to complete custom amplifiers, mixers, voltage regulators or complete radio receivers

# Section 3 – Radio Amateur Theory & Related Topics

Transformers
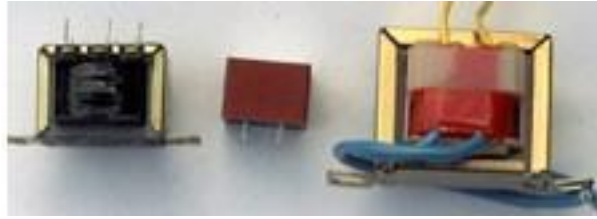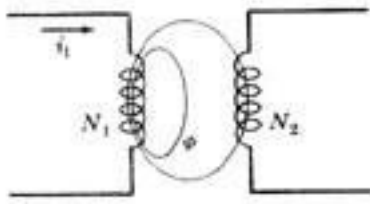
Two coils share the same magnetic field — **mutual inductance**

Transformer used to step up/down (or simply isolate) voltage or current or impedance

Ideal transformer is lossless, but wire resistance, core losses, skin effect cause losses

For ideal transformer the power in the **primary** windings (input) equals the power in the **secondary** (output**) Pprim = Psec**

Types of transformer
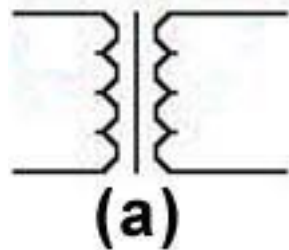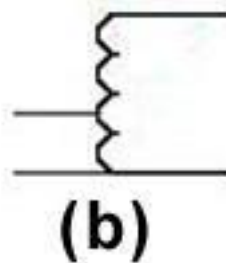
(a) Two separate windings isolate output from input – isolation transformer (b)

Single tapped winding, output not isolated from input – auto transformer

Step Up or Step down depends on number of turns on primary and secondary

Section 3– Radio Amateur Theory & Related Topics

Characteristics

10:1

50V
10mA
5k

5V
100mA

50R

Voltage ratio $V_{sec} \div V_{pri}$ = $N_{sec} \div N_{pri}$

Current ratio $I_{sec} \div I_{pri}$ = $N_{pri} \div N_{sec}$

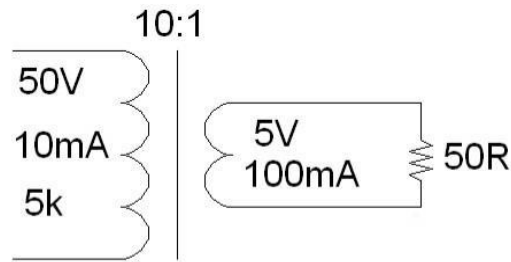Impedance $Z_{sec} \div Z_{pri}$ = $(N_{sec} \div N_{pri})^2$
   where N is the number of turns

Voltage ratio is same as turns ratio; current is inverse

Sources of Electricity

Devices such as batteries and power supplies are **voltage sources**. They provide the push necessary to maintain current flow

This source voltage is called an **emf (electromotive force)**

A practical voltage source *behaves is if it* has an **internal resistance** which limits current and causes a voltage drop under load conditions

Internal R

+
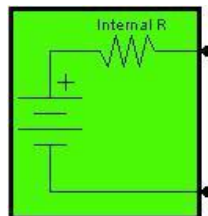
This will limit the total current to the **short circuit current** if the device is short-circuited

The output **terminal voltage** is equal to the **emf** under no load conditions, dropping as current is drawn

Series/Parallel Connection

When voltage sources are connected in series the total voltage is the sum of the individual voltages

When voltage sources are connected in parallel the voltage across each will be the same; current capacity is increased as current drain is shared between the sources

Caution is needed if voltage sources are to be connected in parallel as small differences in terminal voltage may cause a circulating current between the sources, dependant on internal resistance

Section 3 – Radio Amateur Theory & Related Topics

Quartz Crystals
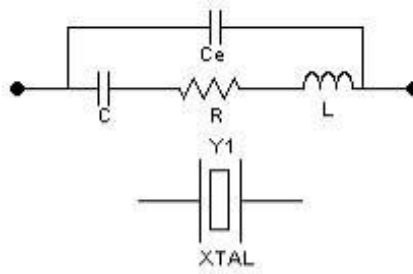
A quartz crystal is held between two electrodes. The piezo-electric effect which converts a mechanical stress into a voltage and vice versa results in a high-Q tuned circuit

In addition to resonance at its fundamental frequency the crystal can vibrate and exhibit resonance on **overtones (odd harmonics)**

Typical uses are in a tuned circuit in an oscillator to provide accurate and stable frequency output

Also used as resonant element in filters

Crystals have high temperature stability and are used as tuned circuits in oscillators (mostly **parallel mode**) and in filters (mostly **serial mode**)

Specification of crystals requires information on frequency, mode and load impedance

In parallel mode the frequency of a crystal may be varied (pulled) slightly by changing the load impedance

The current through the crystal needs to be limited to avoid mechanical failure

Crystal Filters
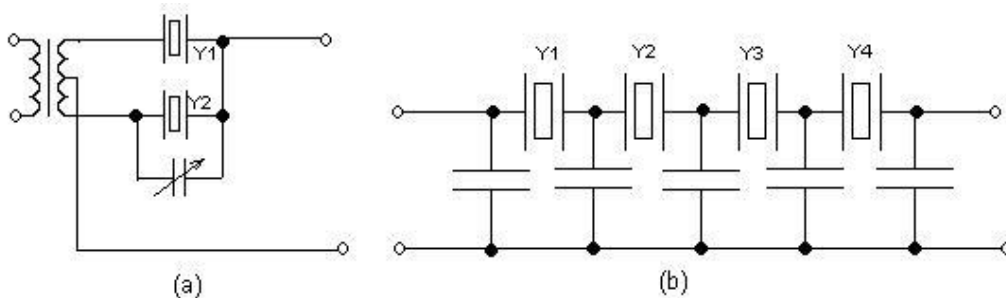
The high-Q of crystals means that they can be used in effective filters in radio receivers and transmitters

Section 4 – Radio Amateur Theory & Related Topics

Section 4 – Circuits

Diodes

Diodes of the same type will have differing **forward voltage drop** and reverse **leakage current**

If connecting in series to increase effective **piv rating**, some recommend that high values of resistor (to balance voltages) and capacitors (to protect against transients) should be connected in parallel

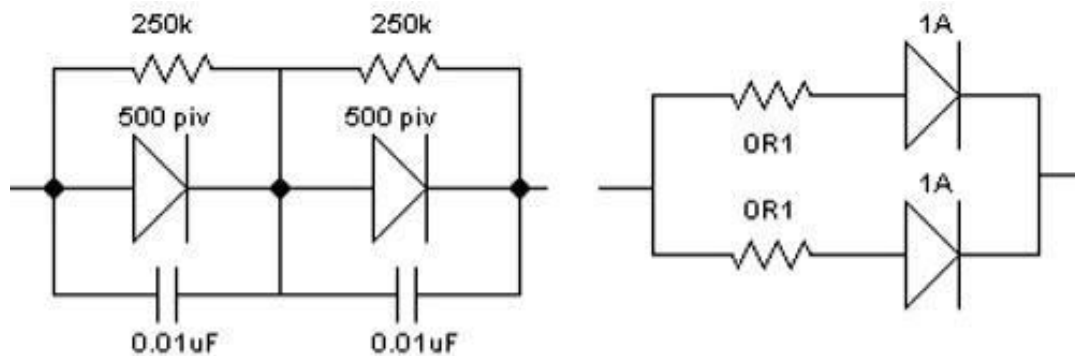If connecting in parallel to increase **forward current rating**, low value resistor should be put in series to balance currents

Transformers

(a)   (b)   (c)
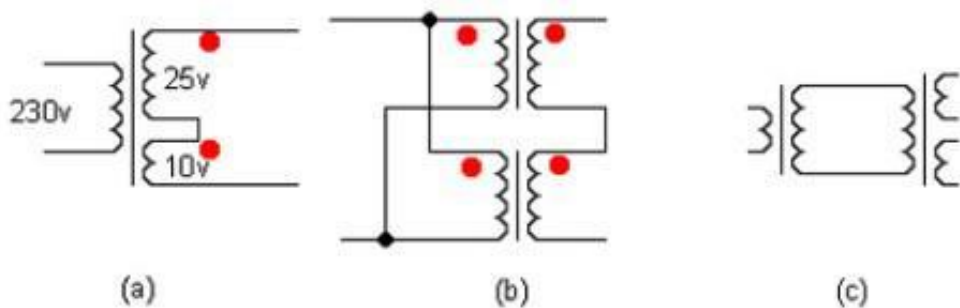
Secondary windings (a) or transformer output (b) can be connected in series to increase output voltage

The important factor is the winding sense or phase, indicated in these diagrams by the red dot

If cascading transformers (c) it is important not to exceed the winding to core insulation voltage limit

Connecting transformers in parallel is deprecated as unless the windings are absolutely identical there will be circulating currents between them

Section 4 – Radio Amateur Theory & Related Topics

Power Supplies

(a)   (b)

Conversion of a.c. to d.c. — **rectification**

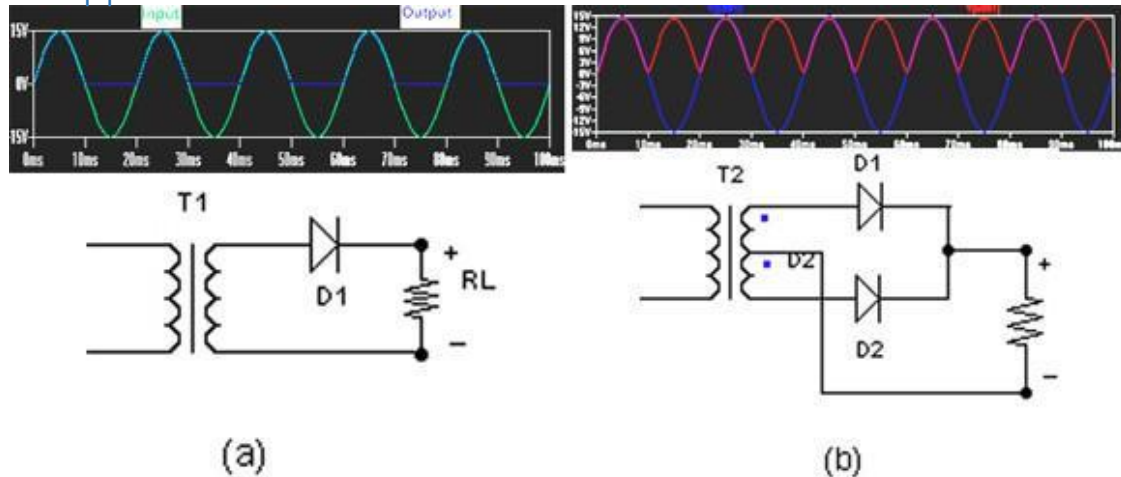Diodes convert a.c. into d.c.(direct current), since the d.c. is varying in amplitude we must find a way of **smoothing** the output. We use a large value capacitor to store charge in between the missing half cycles.

(a) Half wave: D1 conducts on positive half cycles (alternate half cycles are "missing")

(b) Full wave: On **+** half cycle top of transformer is + so D1 conducts, on **–** half cycle bottom is + so D2 conducts- the result is a continuous series of half cycles of d.c.

(c)
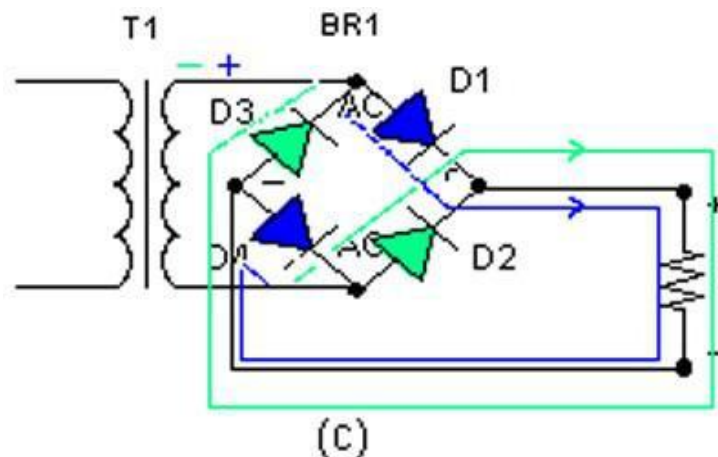
Bridge Rectifier: Full wave: on **+** half cycle diodes D1 and D4 conduct; on **–** half cycle D2 and D3 conduct; note diode and current flow.

Smoothing — with full wave, two charges of capacitor per half cycle so makes job easier.

Section 4 – Radio Amateur Theory & Related Topics

Power Supplies

Capacitor supplies current to top up voltage, smoothing output (**blue**) from full-wave input (**green**)

R1 is bleeder resistance to discharge the cap for safety reasons when supply is switched off; it also provides a minimum load, improving stability

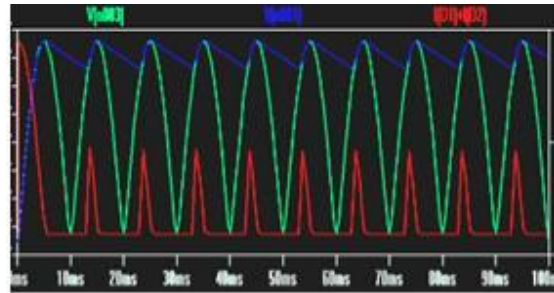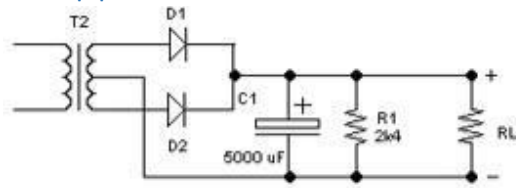Large current into capacitor at switch on; pulses of current into capacitor each half cycle (**red**). Diode rating must take account of this
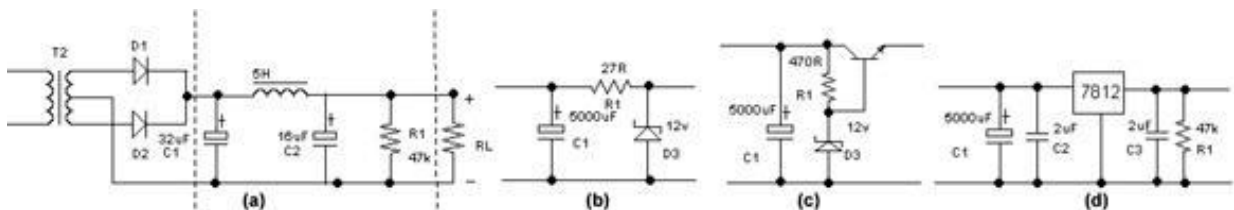
In higher voltage supplies a pi smoothing circuit of two capacitors and a choke is normally used (a) — **capacitor input circuit**

In low voltage supplies, (b) a **zener diode** (with no load the diode passes load current), (c) a zener diode and pass transistor (emitter follower), or (d) an **i.c. voltage regulator** are commonly used; the i.c. requires C2 and C3 (low-inductance tantalum) for stability

A transformer operating at 50Hz can be bulky and heavy; Power Supply Unit (**PSU**) can be inefficient; ripple needs large capacitors to filter

The **switched mode power supply** does this. The mains drives an oscillator or chopper directly (not isolated) to generate a voltage at 50-200 kHz. This is then transformed to near required voltage by a much smaller, lighter transformer, (smaller core useable at higher frequency) rectified, smoothed by smaller value components

Efficient but Electrically noisy, can give **EMC (ElectroMagnetic Compatability)** problems due to switching/oscillator harmonics if not properly shielded

Section 4 – Radio Amateur Theory & Related Topics

Transistor – Common Emitter Amplifier

Common emitter means emitter is connected to the "ground" or common signal bus

C3 decouples emitter resistor providing a path to ground for signal

Input impedance: Medium (though note R1/ R2 are in parallel with input)

Output impedance: High

Current Gain: High
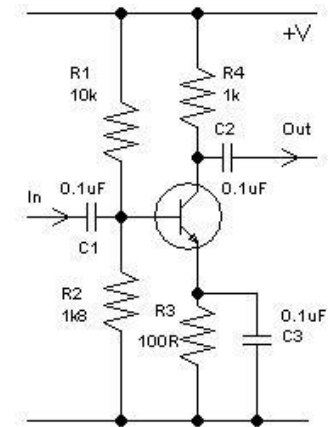
Transistor – Common Collector Amplifier

Also known as **Emitter Follower**; emitter signal voltage has same value as base signal voltage

Note: +V is at signal ground due to decoupling capacitors (not shown)

Input impedance: High (though note R1/ R2 are in parallel with input)

Output impedance: Low

Current Gain: High

Voltage Gain: ~1
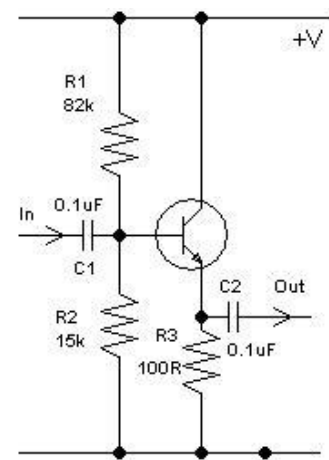
Transistor – Common Base Amplifier

C3 provides path to ground for signal

Input to emitter; output from collector

Input impedance: Low

Output impedance: High

Current Gain: ~1
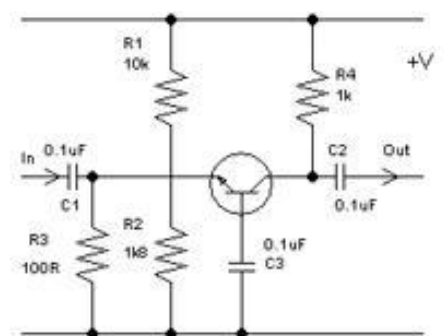
Section 4 – Radio Amateur Theory & Related Topics

Amplifiers – AF (Audio Frequency)
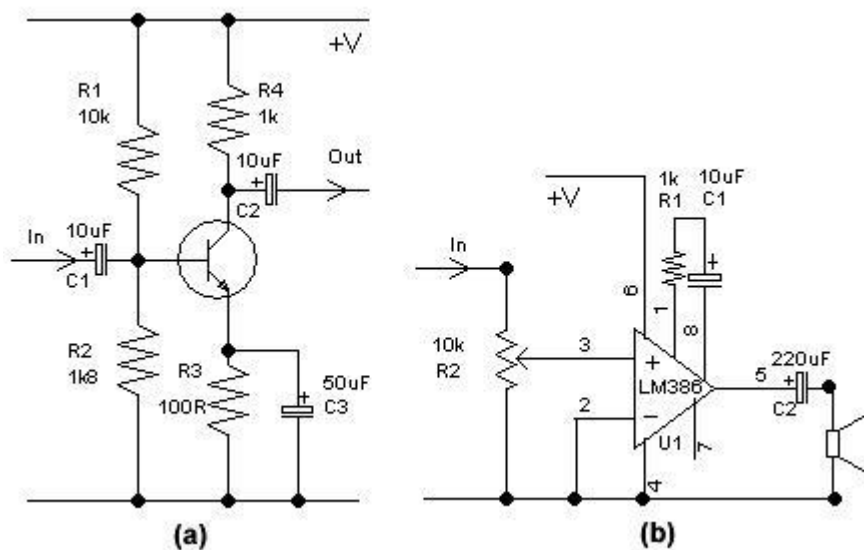
(a) Shows a simple transistor audio amplifier. It operates in **common-emitter mode** giving around 40dB power gain; C3 should be chosen to have a small impedance compared with R3 at working frequencies

(b) shows an i.c. audio output stage. The LM386 gives about 300mW; R1 & C1 are for stability

Amplifiers – RF (Radio Frequency)
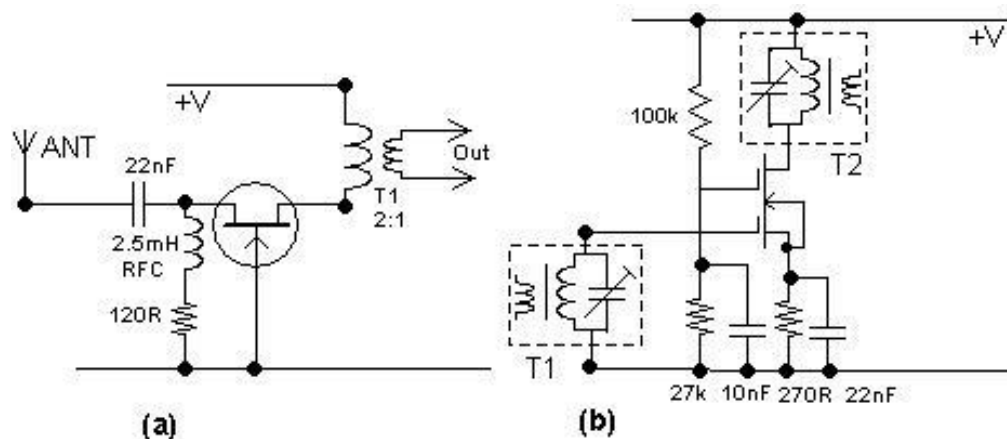
(a) Is a broadband small signal common gate RF amplifier, gain around 10dB, bandwidth 3-40MHz determined by device characteristics and stray capacitance

(b) Uses a dual gate MOSFET with tuned input and output, bandwidth determined by the tuned circuits, gain around 18 dB

Section 4 – Radio Amateur Theory & Related Topics

Amplifiers – Biasing

Amplifier devices may be biased so that when a sinusoid is applied the device conducts (collector or drain current flows) for all or a portion of the cycle

Where the amplifier does not conduct for a complete cycle the missing part is restored by the **flywheel effect** in a parallel resonant (**tank**) circuit

Audio and signal amplifiers operate in Class A where the device is biased to conduct for all of the cycle (360°); these are linear, theoretical efficiency is 50% but 25-30% is more normal

Class AB — some collector current flows in quiescent case. Positive and part of negative cycle amplified; reaches 50-60% efficiency. Linearity and lack of harmonic output not as good as Class A but it is acceptable

Class B — the transistor is biased on the edge of conduction (600mV for Si), only 180° amplified; efficiency reached 65% with acceptable linearity and harmonic output
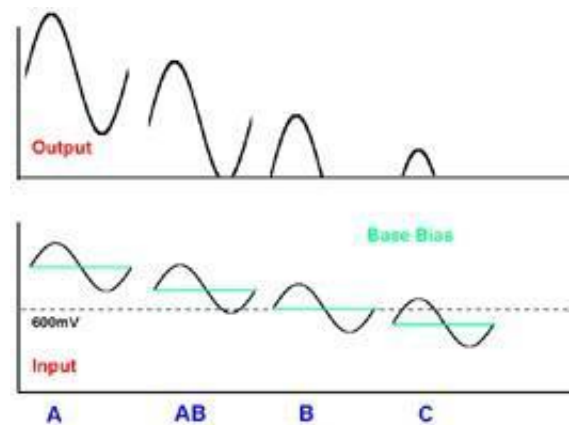
Class C — biased below cut-off, typically 90° conduction; efficiency up to 80%, not suitable for amplification of SSB or AM. Very non-linear, high harmonic output requires output filtering

Distortion

Distortion is due to non-linearity

Harmonic distortion is where integer multiples of the input frequency occur

Intermodulation distortion is where two signal components multiply together to make new ones

Every amplifier has some non-linearity; good design and operation within the intended power input (drive) / output range, i.e., not **overdriving** it minimises distortion

Distortion manifests itself as interference and splatter

Section 4

Alternating Current

Sinusoidal Signals
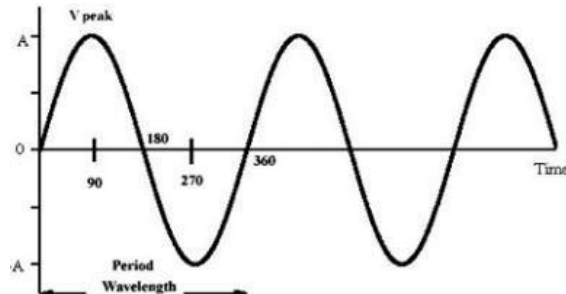
To specify a wave its **Amplitude**, i.e., **Vpeak [V max]** and the time to complete one complete cycle (**period**) is needed

The **frequency** in **Hertz (Hz)** is the number of complete **cycles** in one second

The peak to peak value of a wave is the sum of the peak positive and negative excursions of the wave. In the case of a sinusoid $V_{pp} = 2V_{peak}$

The **instantaneous value** is the value of the sinusoid at any chosen point in time

The **average value** of each half cycle is **Vavg = 0.636 Vmax**

If a sinusoid is applied to a resistor, power will be dissipated as heat.

$P = V^2 \div R$ for d.c.

The effective voltage (equivalent d.c.voltage) for a sinusoid is called the **rms voltage** (root mean square)
This is the voltage normally indicated by an a.c. voltmeter.
Vrms = 0.707 Vmax ; and **Vmax = 1.414 Vrms**

So **P = Vrms^2 ÷ R** for a.c.

Alternating Current
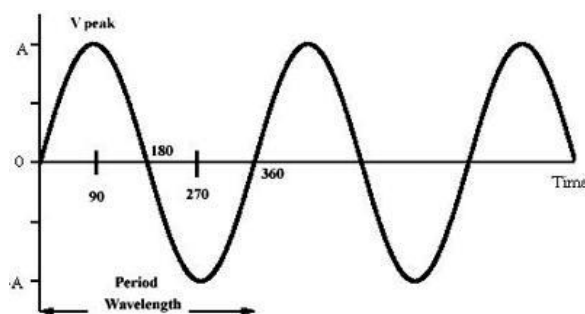
Alternating current is a sinusoidal signal

typical mains voltage is 230 Volts (rms)

Frequency is 50 Hz

Period is therefore 20ms

Section 4 – Radio Amateur Theory & Related Topics

Phase
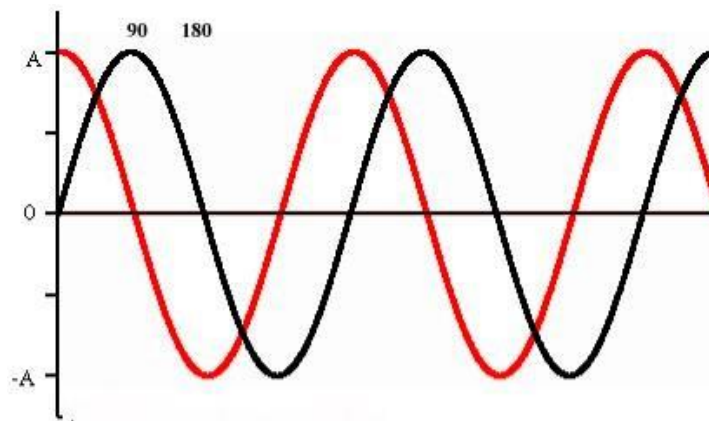
If two signals have exactly the same frequency and cross the zero line at different times they have a **phase difference**

The **red** wave crosses the zero line ninety degrees before the black. It **leads** the black by 90° or ¼ cycle. The black **lags** the **red** by 90° (one cycle is 360°)

Harmonics
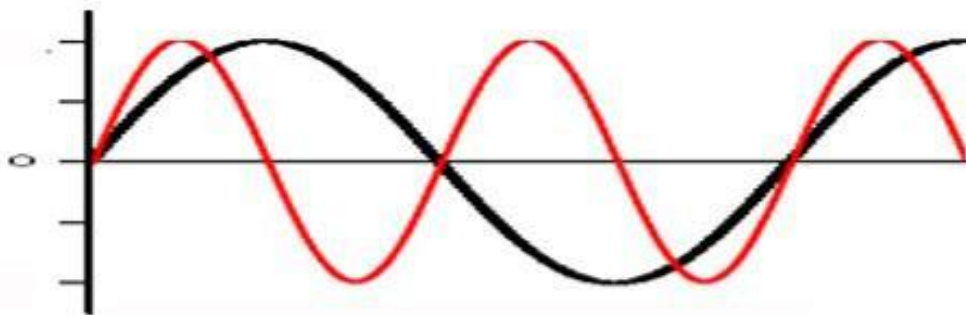
A second wave whose frequency is an exact multiple of another is called a **harmonic**. The other (lower frequency) is the **fundamental**

The example shown is the second **harmonic** (in **red**) of the fundamental. It is twice the **fundamental** frequency

Non-Sinusoidal Signals
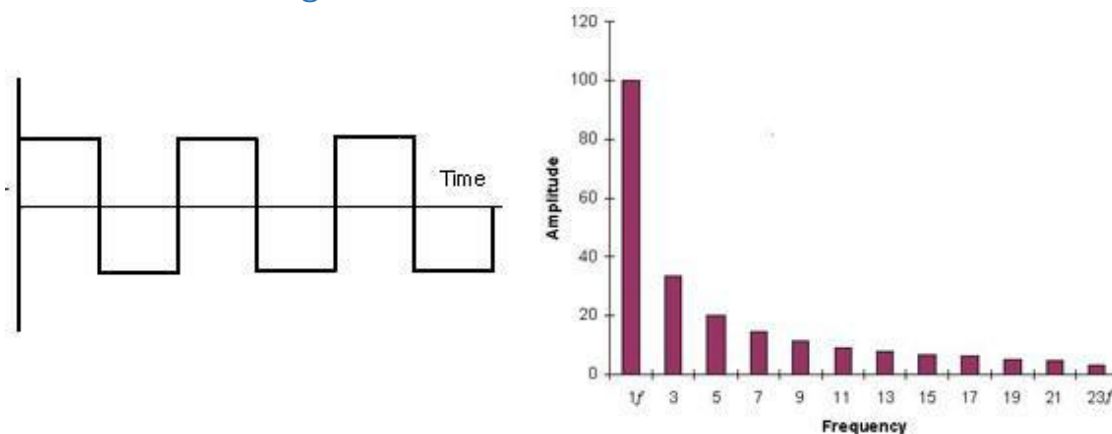
The square wave comprises an infinite series of odd-harmonics (3rd, 5th, 7th) of decreasing amplitude

Section 4 – Radio Amateur Theory & Related Topics
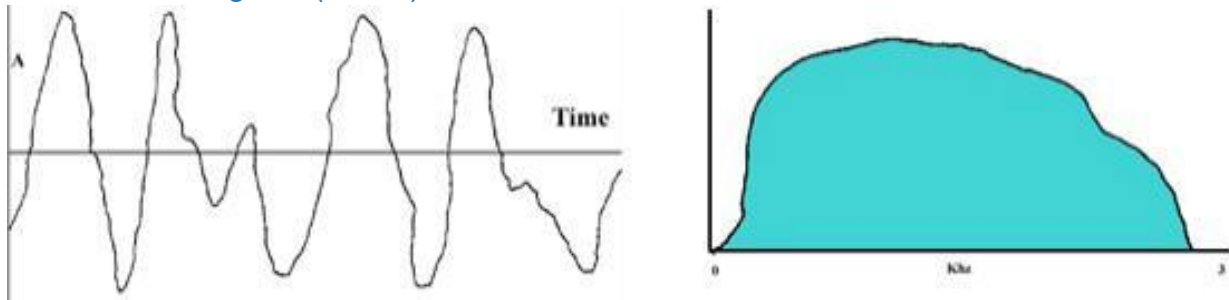
An audio speech signal is the sum of sinusoids of a range of frequencies (20Hz – 20 kHz) and differing amplitudes

For speech, frequencies in the range from 300Hz to around 2.7kHz make a significant contribution to intelligibility and the signal is tailored to this range for amateur use to conserve bandwidth

Capacitive Reactance
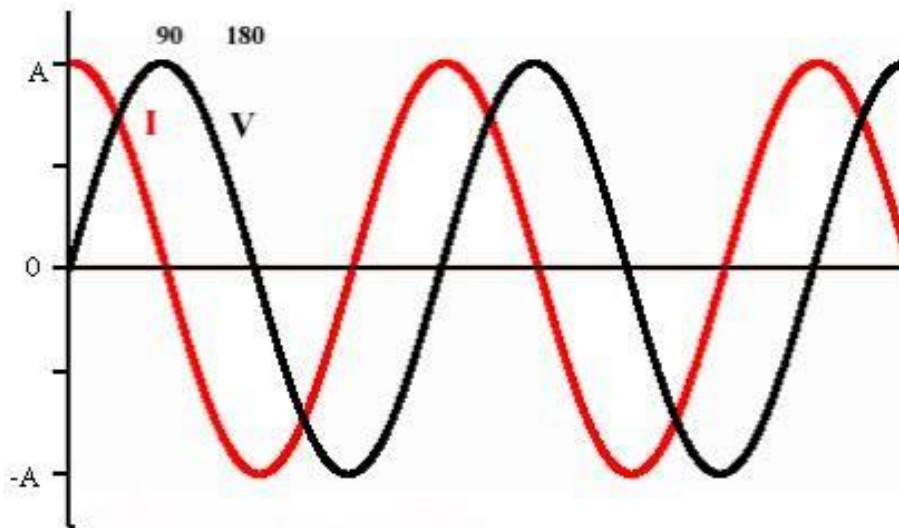
When a.c. is applied to a capacitor it will charge it, first in one direction, then the other; max. current flows when the voltage is changing most rapidly, least as voltage peaks

The current **leads** the voltage by 90°

The ratio of voltage to current is the reactance (X_C) measured on Ohms)

$$X_C = V \div I; \quad I = V \div X_C; \quad V = I \times X_C$$
[V, I are rms values]

$$X_C = 1 \div (2 \; f C)$$

Reactance decreases as frequency increases

Section 4 – Radio Amateur Theory & Related Topics

Inductive Reactance
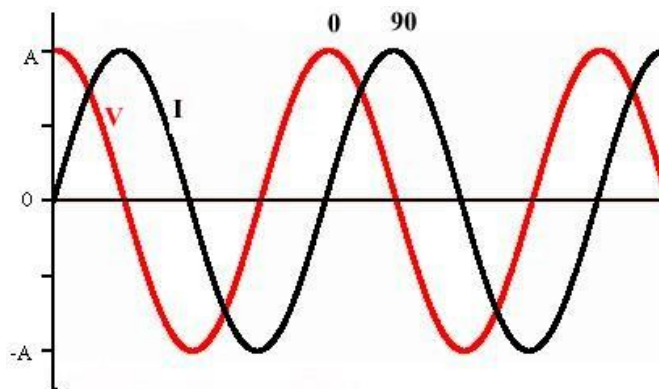
If an a.c. voltage is applied to an inductor the reverse voltage (**back emf**) generated causes the current to **lag** the voltage by 90°

The ratio of voltage to current is the reactance **(X_L)** measured on Ohms

$X_L = V \div I$; $I = V \div X_L$; $V = I \times X_L$
 [V, I are rms values]

$X_L = 2\pi f L \Omega$ Reactance increases with frequency

Section 4 – Radio Amateur Theory & Related Topics

Section 4 Miscellaneous

deciBels

A logarithmic unit the **deciBel (dB)** is often used to express the ratio of output to input signal levels

- o 0dB means zero power gain
- o 3dB means a doubling of power
- o 6dB : 4 times
- o 10dB : 10 times
- o 20dB : 100 times
- o -3dB : ½
- o -6dB : ¼
- o -10dB : 1/10
- o -20dB : 1/100

When amplifiers and or attenuators are connected in series the overall gain in dB is calculated by adding (or subtracting) the individual dB gains

Digital Signal Processing (DSP)

Analogue signals can be converted to digital signals by **sampling** them at very frequent intervals. The digital signal is just a sequence of numbers that represent the instantaneous value of the analogue signal each time it is sampled

The sampling rate has to be **at least twice the highest frequency contained in the analogue signal** or it will not be possible to reconstruct the analogue signal from the digital data

For an audio signal in the range 0 – 4 kHz the lowest sampling rate would be 8 kHz

The device that does all of this sampling and measuring is an **analogue to digital converter (ADC)**

The digital signal can then be processed by a Digital Signal Processor which can shape it like a filter and/or remove noise

A **digital to analogue converter (DAC) reconstructs** the analogue signal as processed by the Digital Signal Processor

Section 4 – Radio Amateur Theory & Related Topics

DSP Subsystem
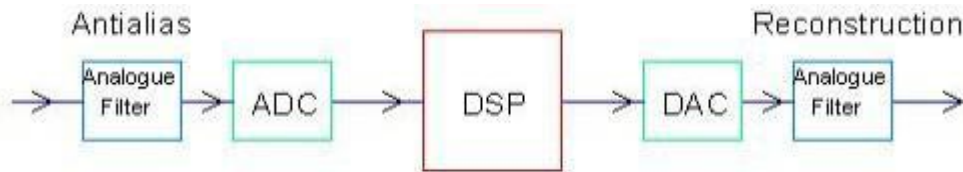
Sampling is done by an **analogue to digital converter (ADC)**

The digital signal can then be processed by a Digital Signal Processor (DSP), a microprocessor that manipulates the digital information

A **digital to analogue converter (DAC) reconstructs** the analogue signal as processed by the Digital Signal Processor

Oscillators
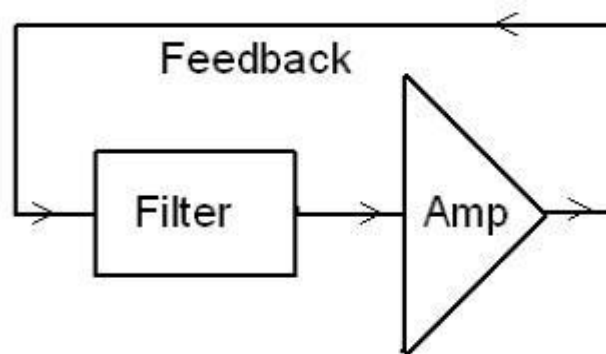
An oscillator is used to generate a sinusoidal signals at a particular frequency

A practical oscillator is an amplifier with positive feedback provided by a resonant circuit acting as a filter; the resonant circuit determines frequency; harmonics (**overtones**) can also be extracted

The stability of the resonant circuit and stray reactances affect frequency stability, which may vary with temperature or loading

LC Oscillator (where the frequency is controlled by an LC circuit)

Colpitts LC oscillator

Feedback from source of FET via C3, C4

C3 = C4

Frequency determined primarily by L & C1 and to a lesser extent by C2, C3, C4

L, C1, C2 can be replaced by a series tuned circuit, called Clapp oscillator

Temperature compensating capacitors and good mechanical construction in a practical circuit!
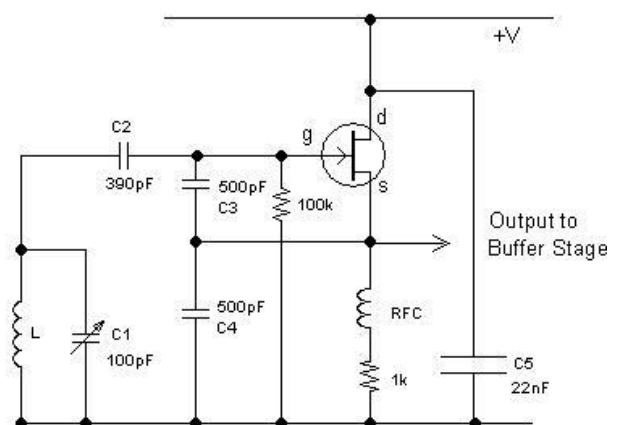
Section 4 – Radio Amateur Theory & Related Topics

Crystal Oscillator (the frequency is controlled by a quartz crystal "xtal")

The tuned circuit in the previous slide can be replaced with a **quartz crystal** to make a highly stable oscillator

Shown is a xtal oscillator where the mode (**fundamental** or **overtone**) is determined by the tuned transformer T1

The xtal acts in series resonant mode; **3rd and 5th overtones** can normally be extracted
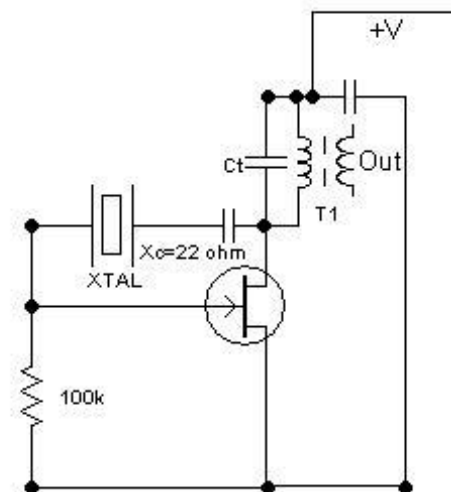
Oscillators

LC oscillators are normally tunable and used to tune a receiver or transmitter to a particular frequency, often in combination with a fixed-frequency crystal oscillator

Crystal oscillators are also used as Carrier Insertion Oscillators or Beat Frequency Oscillators in receivers

LC oscillators are liable to drift if not properly designed while crystal oscillators provide stable output at a single frequency.

Section 5 – Receivers

Purpose

The purpose of a radio receiver is to acquire a radio (RF) signal containing information in the form116 of modulation and to process it into an audible (AF) sound

A receiver should have:

- **Sensitivity** – to resolve weak signals satisfactorily without introducing noise
- **Selectivity** – to separate the required signal from unwanted or interfering ones

Essentials

Amplify weak signal from antenna
Select required signal
Filter out unwanted signals
Demodulate (detect) signal
Amplify audio output

Super heterodyne Receiver
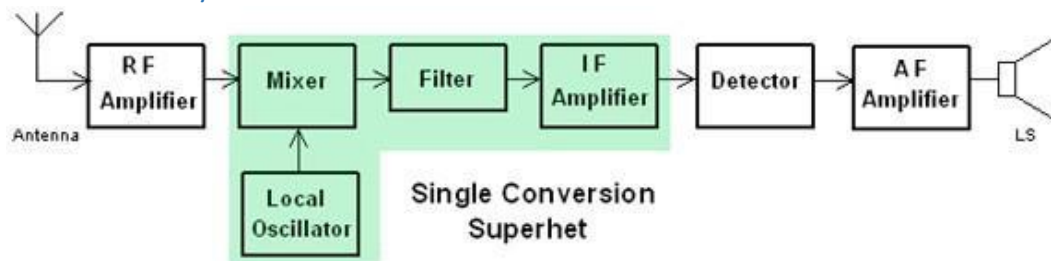
Most common form of receiver
The incoming signal is converted to a fixed Intermediate Frequency (IF) by the local oscillator and mixer
Receiver selectivity and gain are determined at this fixed frequency

Double Conversion Super heterodyne Receiver
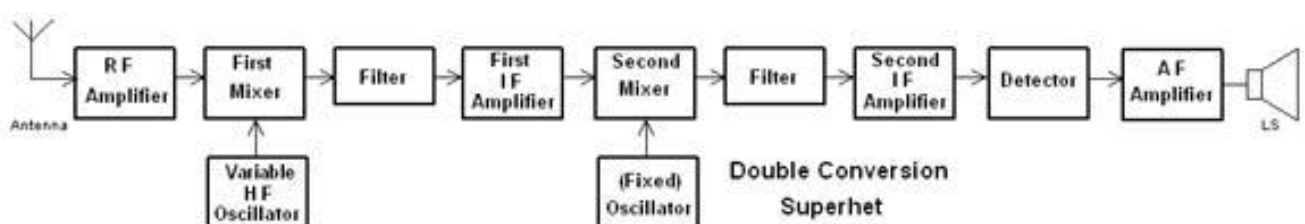
The incoming signal is first converted to an I.F. of say 10.7 MHz or 1.6 MHz where it is filtered
Then converted to final I.F. (455 kHz) for further filtering and amplification

Section 5 – Amateur Radio Theory & Related Topics

RF (Radio Frequency) Amplifier
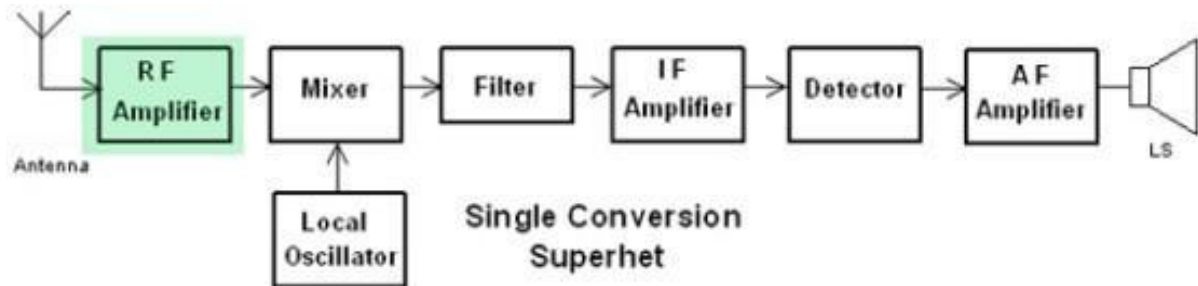
Amplifies weak input signal
Provides some selectivity
Should be low noise
Has a manual or automatic gain control (AGC) or switched attenuator to
prevent overload by strong signals

Local Oscillator
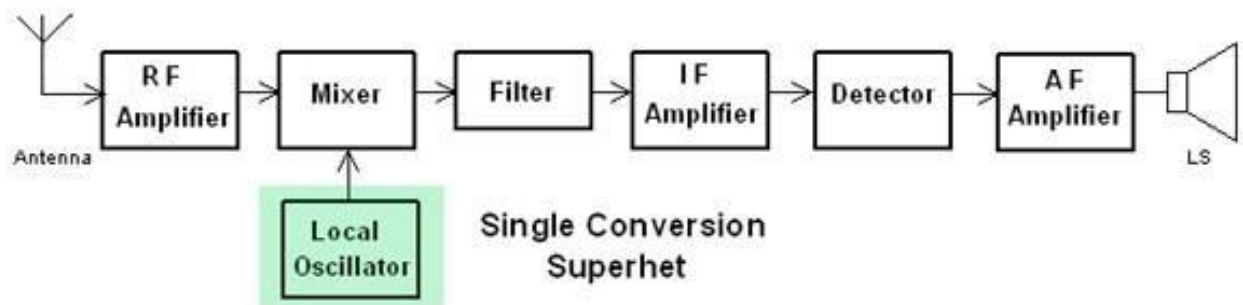
Produces a local signal always offset from desired incoming (RF) signal
by Intermediate Frequency (IF)
Combined with incoming signal in Mixer to produce the IF. Has variable tuned
circuit or may be digitally synthesised

Mixer
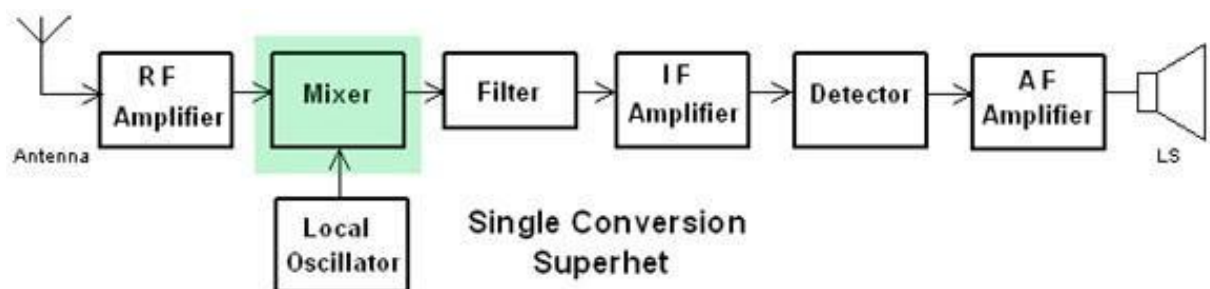
Has two inputs – RF signal and Local Oscillator
(LO) One output – Intermediate Frequency (IF)
A Mixer produces an output equal to the difference of the input signals

Section 5 – Radio Amateur Theory & Related Topics
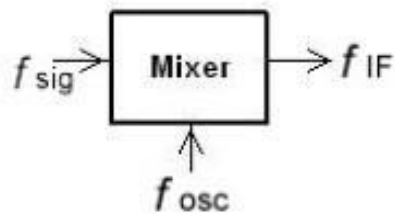
$$f_{IF} = |f_{osc} - f_{sig}|$$

Difference of two frequencies

455 kHz = 7455 – 7000 kHz

IF Amplifier
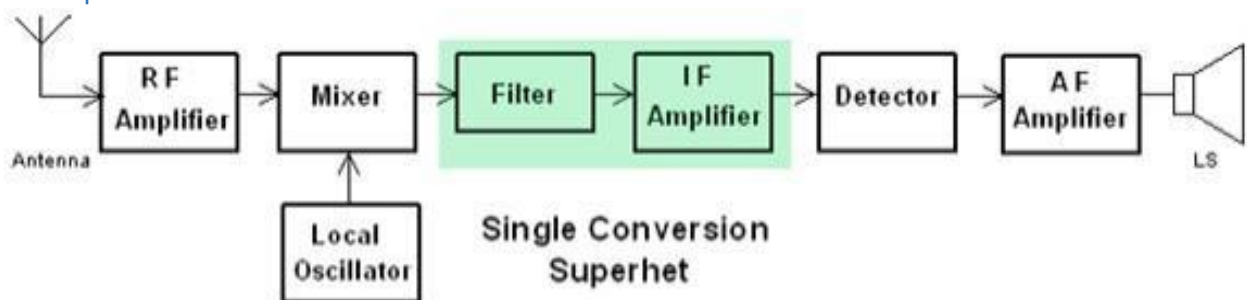
IF — Intermediate Frequency
  Provides gain and Selectivity at IF
  Fixed selective tuned circuits at IF
Usually preceded by a crystal or ceramic filter

IF Filter
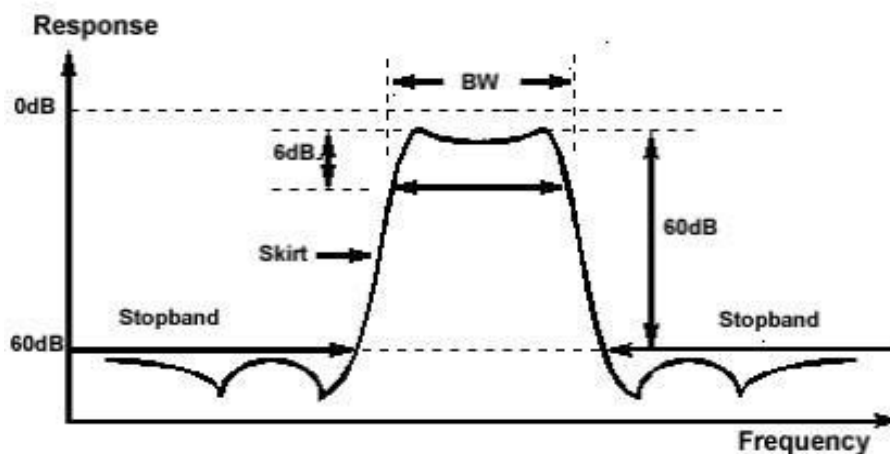
The bandwidth (BW) of the filter is the difference between the upper and lower cut-off frequencies
Shape factor (ratio of BW measured at 6dB and 60 dB) determines how effectively signals are attenuated outside the passband
Provides adjacent channel Selectivity depending on shape factor (i.e. the steepness of the skirt). Better than 2:1 shape factor desirable

Section 5 – Radio Amateur Theory & Related Topics

Typical BW of filters:
- CW 100 – 300 Hz
- SSB 1.8 – 2.4 kHz
- FM 12.5 kHz

Detector (Demodulator)

Single Conversion Superhet
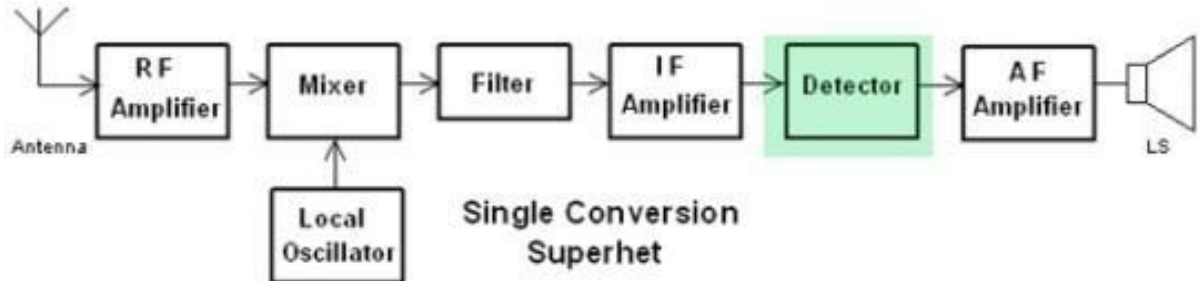
Recovers modulation from the signal
Amplitude modulation (AM) detector is often a simple diode rectifier

Product Detector

SSB / CW Receiver
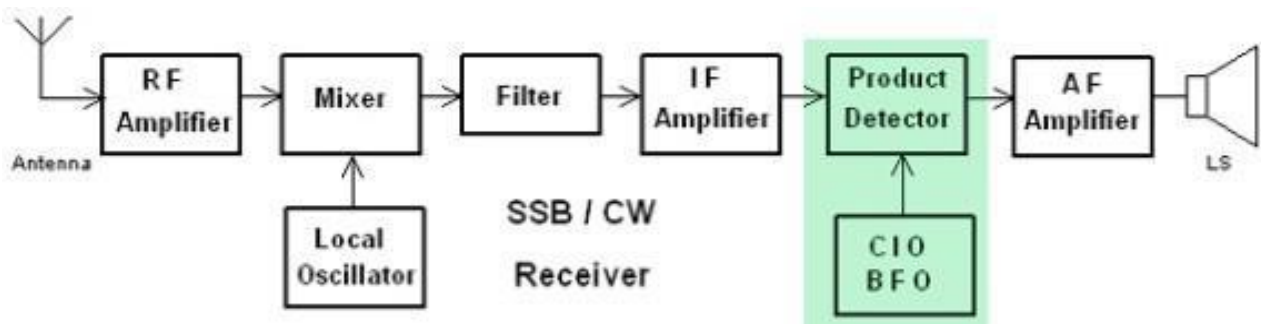
For CW and SSB a product detector (mixer) is used
SSB – Oscillator on IF frequency is mixed with IF signal to give audio (Carrier Insertion Oscillator, CIO)
CW – Oscillator offset from IF frequency by say, 800Hz, is mixed with IF signal giving an audible beat note (Beat Frequency Oscillator, BFO)

FM Detector

FM Receiver
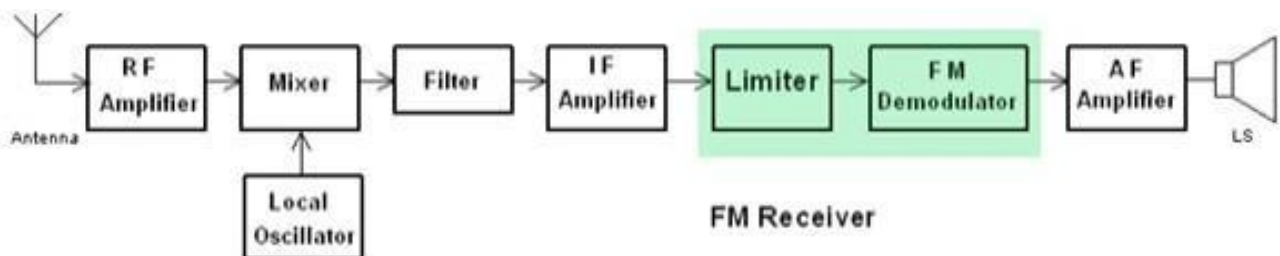
In the case of FM (frequency modulation) the modulation causes the carrier frequency to vary
Amplitude variation due to propagation or noise is first removed by a limiter A common type of FM demodulator is called a **discriminator**
A **phase locked loop (PLL)** makes an excellent FM demodulator

Section 5 – Radio Amateur Theory & Related Topics

Audio Amplifier
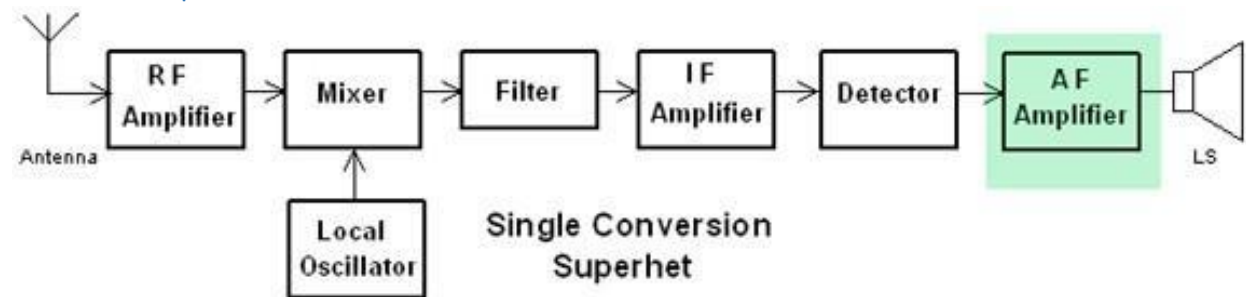
Amplifies the audio signal
has manual gain control
Provision for loudspeaker, headphone or line output

Automatic Gain Control (ACG)
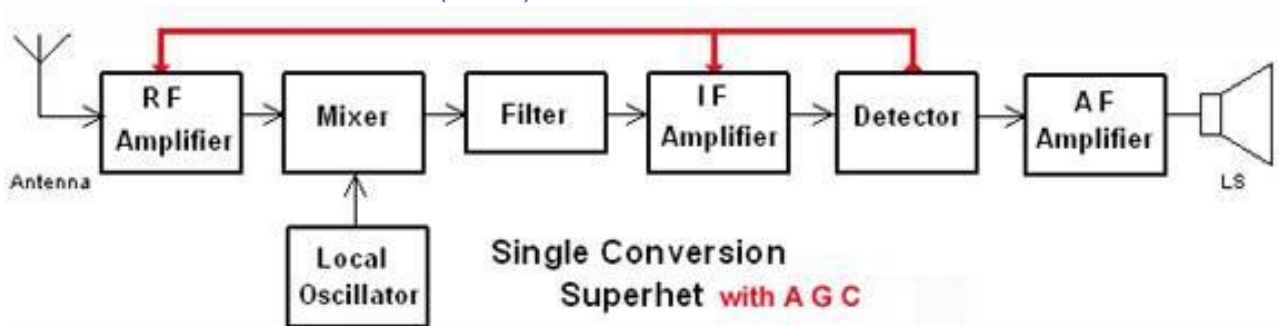
Automatically controls receiver gain to maintain constant output level
Gain of RF and IF amplifiers reduced proportionate to signal strength
Prevents overload of amplifier stages
May drive S-meter

S Meter

Indicates the strength of the received signal usually as measured at the output of the
I.F. stage or detector (audio-derived)
Calibrated in S-points (0 – 9) and 10 dB points above S9
Very variable implementation of standards. S9 about 50µ V
or -73 dBm
One S point about 6dB Varies with receiver and band

Squelch

Used primarily in FM receivers
Suppresses audio output in the absence of sufficiently strong input signal and
thus excludes lower-power signals or noise
Has a control knob which sets the threshold level at which signals will open the
audio output

Receiver Characteristics, Adjacent Channel Characteristics

Ability of receiver to separate signals on closely adjacent frequencies (channels) is
determined by its *selectivity*
Switching to a narrow passband can reduce interference

Section 5 – Radio Amateur Theory & Related Topics

Usable passband width is determined by the bandwidth of the mode to be received,
e.g: 200 - 500 Hz for CW

1.8 - 2.4 kHz for SSB

12.5 kHz for NBFM

Receiver Characteristics, S/N Ratio

Measure of sensitivity – signal to noise ratio
Defined by stating the minimum signal voltage at input to produce an output with a
certain ratio of signal above noise level in a specified bandwidth at a particular frequency
Typical 0.5 V for 10dB S/N in 3 kHz for SSB at 28 MHz

Receiver Characteristics, Dynamic Range

The dynamic range of a radio receiver is essentially the range of signal levels over
which it can operate
The low end of the range is governed by its sensitivity whilst at the high end it is
governed by its overload or strong signal handling performance
Typical range 90dB to 110dB

Receiver Characteristics, Image Frequency

$$\text{Sig} \quad \text{Lo} \quad \text{IF}$$
$$7000 - 7455 = 455\text{kHZ}$$

$$\text{Sig} \quad \text{Lo} \quad \text{IF}$$
$$7910 - 7455 = 455 \text{ KHZ}$$
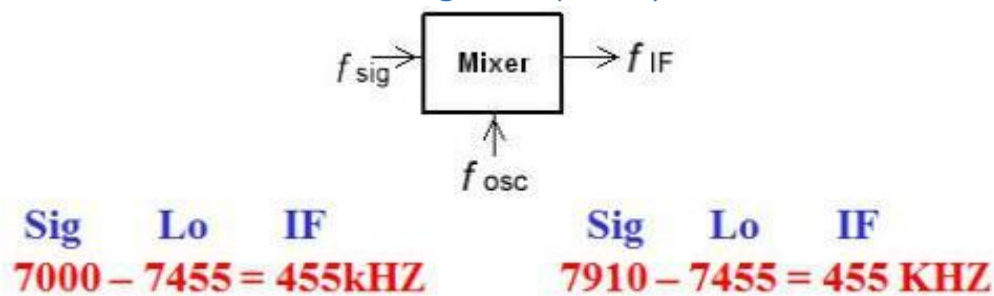
In superhet, mixer can produce an output at IF for frequencies on either side of
local oscillator
Thus two signals separated by twice IF appear in passband (image frequency)
Can only be removed by selectivity before mixer
A high IF (10.7 MHz) makes this easier than a low IF (455 kHz) due to greater separation
of wanted and unwanted signals
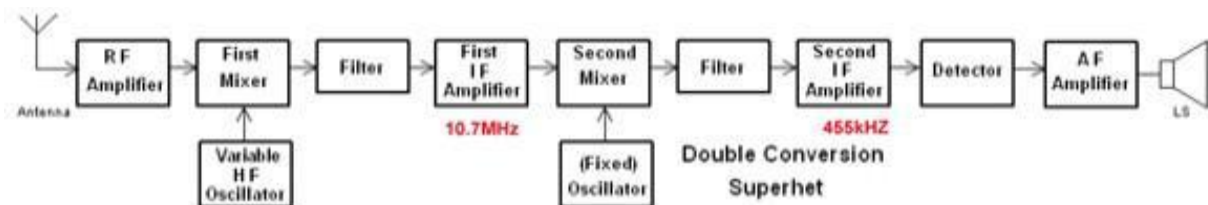
Increasing IF separates image frequency further from required signal, easing filter
requirements
However with higher IF generally more difficult to achieve adjacent channel selectivity
Double superhet uses high first IF (image rejection) and low second IF (adjacent channel)

Receiver Characteristics, Noise Figure / Factor

Noise figure is the degradation in signal to noise ratio as a signal passes through an
amplifier or system (receiver)
Vital amplifier and Rx characteristic at VHF/UHF, less so at LF

Section 5– Radio Amateur Theory & Related Topics

Receiver Characteristics, Stability

The ability of a Rx to remain tuned to a particular frequency is determined by its *stability*

Depends on the electrical and mechanical stability of tuned circuits, particularly oscillators Effect of heat on tuned circuits and components

Less of problem with modern semiconductor circuits than older valve equipment

Receiver Characteristics, Desensitisation

Strong signals not far removed from the wanted signal may cause **desensitization** (SSB) or **blocking** (CW) of early receiver stages

May come from local amateur stations or strong stations well outside the I.F. passband Amplifier overdriven so response to weak signal reduced

Receiver Characteristics, Intermodulation

Intermodulation distortion (IMD) is where two signals mix together due to non-linearity and produce spurious signals

Raises receiver **noise floor** due to large number of products

Receiver Characteristics, Cross-Modulation

Non-linearity may cause stage to act as a 'modulator'

AGC system may cause gain to vary with the modulation of the interfering signal

Modulation of strong unwanted signal is impressed on the wanted signal

SSB / CW Receiver
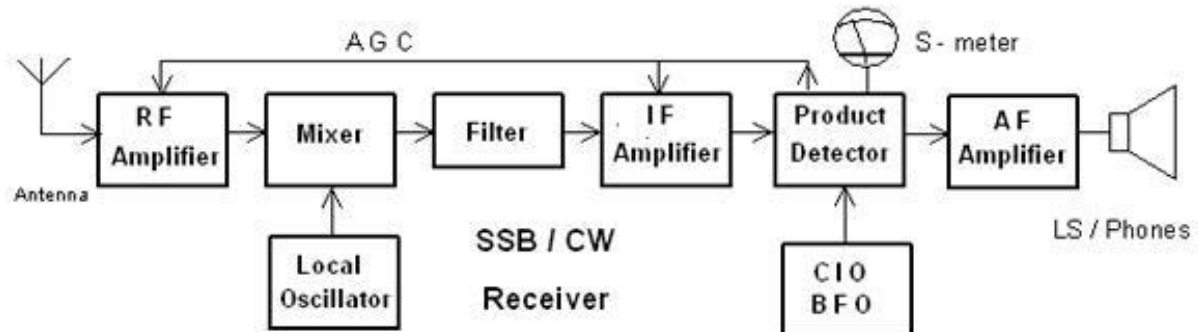
FM Receiver
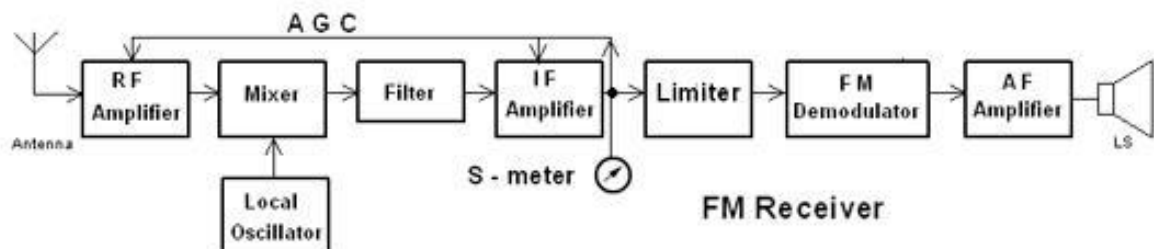
Section 5 – Radio Amateur Theory & Related Topics

Transverter

A transverter is a receive converter and a transmit converter joined by a common local oscillator

It converts a transceiver to a different band

Most functions of the transceiver will also be the same on the converted band. Generally the transverter may be used in any mode that the transceiver is capable of

Typically might be used to allow an hf transceiver to operate on vhf (28 MHz to 144 MHz transverter)

Transmitters

Duty Cycle
Transmission duty cycle depends on mode and affects transmitter ratings
> Operational duty cycle typically rarely exceeds 50% of transmission duty cycle and affects exposure limits

CW (A1A)
Continuous Wave
On-Off keying of transmitter output by Morse Key – about 40% transmission duty cycle
> – Constant amplitude when keyed
> Narrow Bandwidth about 50–100 Hz
> Simple CW-only transmitter realisable

AM (A3E)
Amplitude Modulation
> Output amplitude varies in proportion to amplitude of modulating signal
> Original carrier plus two sidebands transmitted
> Occupies a bandwidth equal to twice the modulating frequency – about 6 kHz 100% duty cycle

SSB (J3E)
Single Side Band (Amplitude Modulation)
Carrier is suppressed, generally by a balanced modulator
> Information in both sidebands of an AM wave is identical so one sideband is suppressed, generally by a filter
Bandwidth equals that for speech – about 2.6 kHz
> No carrier, all power in sideband so more efficient, and no "beats" or heterodyne whistles
Transmission duty cycle 20% rising to 40% with speech processing

FM (F3E)
Frequency Modulation
> Deviation of carrier output frequency is proportional to amplitude of modulating signal. Amplitude of carrier constant
> Amateurs use narrow band FM (NBFM) – audio BW 2.8 - 3kHz and deviation 2.5 kHz, giving a signal bandwidth of approximately 11 kHz
Transmission duty cycle 100%

Section 6 – Radio Amateur Theory & Related Topics

Modulation index

        = peak deviation ÷ max audio frequency

        = 2.5kHz ÷ 3 kHz

        = 0.8 typically

Bandwidth – (Carson's Rule)

      BW = 2 × (max audio freq + peak deviation)

        = 2 × (3kHz + 2.5kHz)

        = approx 11kHz

Digital

Digital Station
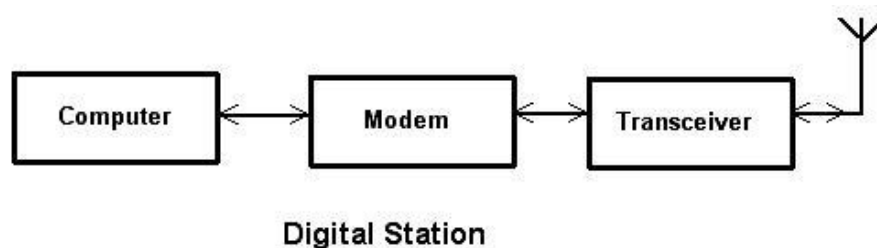
Text is encoded on a computer depending on mode being used

    Modem (software or hardware) generates audio tones which modulate an SSB or FM
        transmitter

Can be very narrow bandwidth, e.g., PSK31 or wider, e.g., RTTY

    Transmission duty cycle 100% – power output should be reduced to about 50% (as for
        AM)

CW Transmitter

CW Transmitter
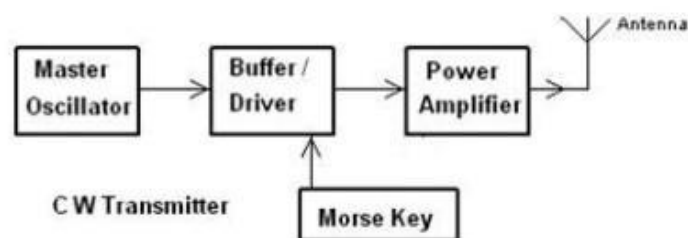
Carrier keyed on-off by Morse key
Connected to Driver/Buffer

Section 6 – Radio Amateur Theory & Related Topics

Master Oscillator
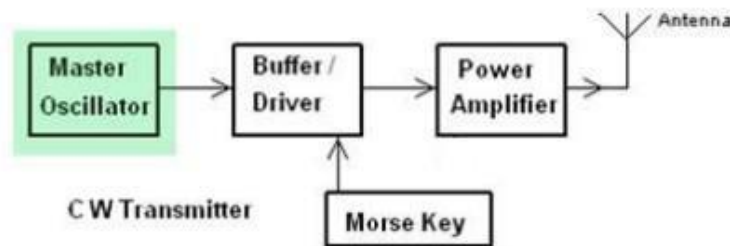
Generates carrier at required frequency

  Crystal controlled or variable frequency (VFO) (LC, Frequency Synthesiser)
  Provide stable signal with low noise

Buffer / Driver
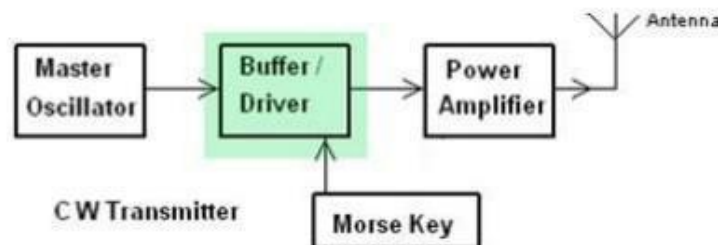
Buffer isolates oscillator from PA to prevent "pulling" due to varying load
Buffer can be keyed for CW
Driver amplifies output to provide sufficient power for PA

Power Amplifier
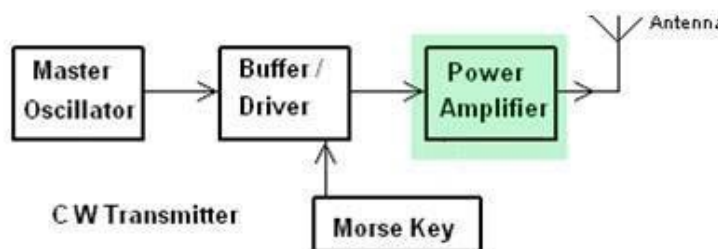
Class C amplifier (non-linear, but most efficient, up to 80%) may be used for CW
Tuned network to match output impedance to 50 ohm of feeder/antenna
Provides harmonic filtering
May have Pi tank Circuit with adjustable tune/load controls, especially in valve
amplifiers

Section 6 – Radio Amateur Theory & Related Topics

SSB Transmitter
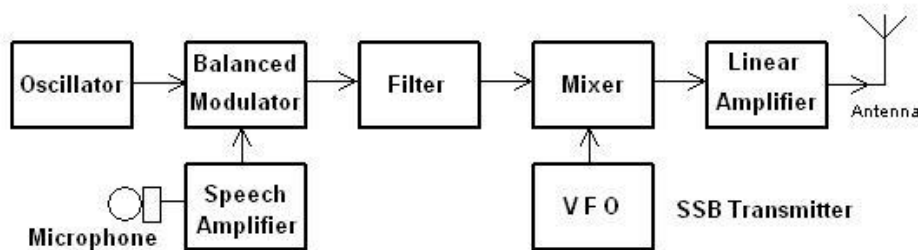
SSB signal generated at fixed low frequency and then translated to output frequency. The Variable Frequency Oscillator (VFO) is combined in the mixer with the fixed frequency SSB signal to tune to the desired frequency

SSB Generation
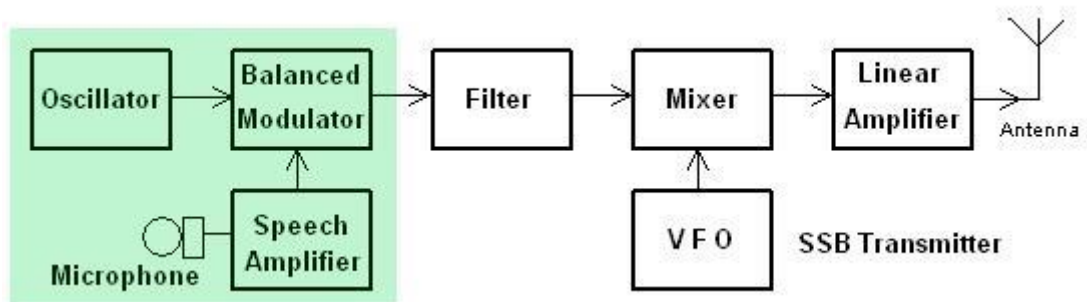
Speech amplifier will process/tailor audio
Balanced modulator "mixes" oscillator and audio to produce identical upper and lower sidebands at a fixed frequency (DSB) and almost entirely suppresses the carrier

SSB Generation - Filter
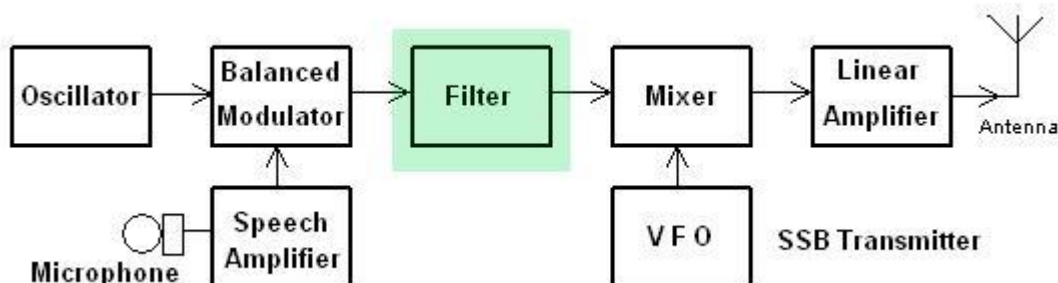
Bandpass filter (crystal or mechanical) removes unwanted sideband
Filter characteristic determines bandwidth of signal
Typical filters bandwidths between 1.8 kHz and 2.4 kHz

Section 6 – Radio Amateur Theory & Related Topics

SSB Generation - Mixer
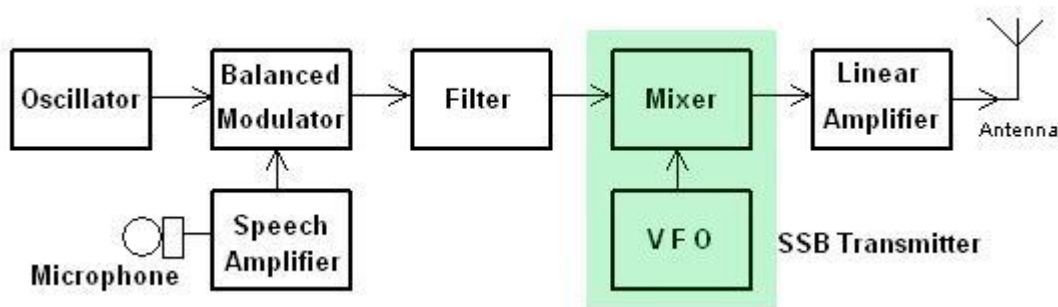
Mixer mixes fixed frequency SSB and VFO signals up to final frequency
Output of mixer is sum or difference of Oscillator and VFO frequencies (and their harmonics)
Important only wanted frequency is selected

SSB Generation – Linear Amplifier
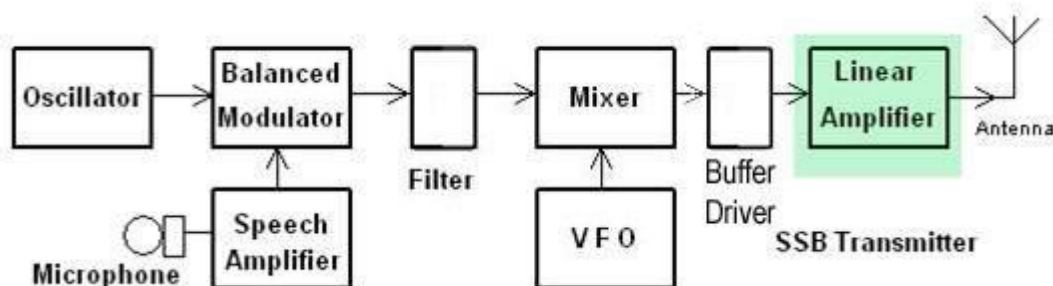
SSB signal passes through buffer/driver stage to Linear Power Amplifier
Must be linear Class A (efficiency up to 30%) or, more efficiently, AB1, AB2 (up to 60%)
Care needed with high duty cycle modes not to exceed power rating
Must not be over driven as non-linearity and thus **splatter** will occur. This is important with digital modes where the operator may not be conscious of levels

Automatic Level Control (ALC) is a feedback circuit from the Linear Power Amplifier which seeks to avoid overdriving the transmitter with too much audio. Often indicated on front panel meter

Section 6 – Radio Amateur Theory & Related Topics

FM Transmitter
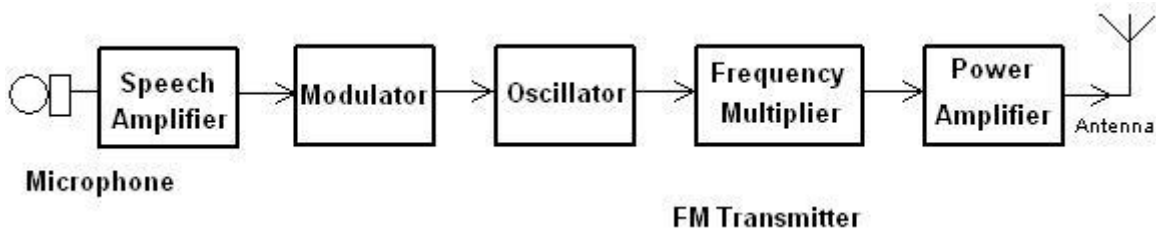
FM Transmitter

Typically an FM signal generated at a low frequency for fixed channel transmitter and multiplied up to required frequency or a VFO and mixer arrangement is used

FM Generation

FM Transmitter
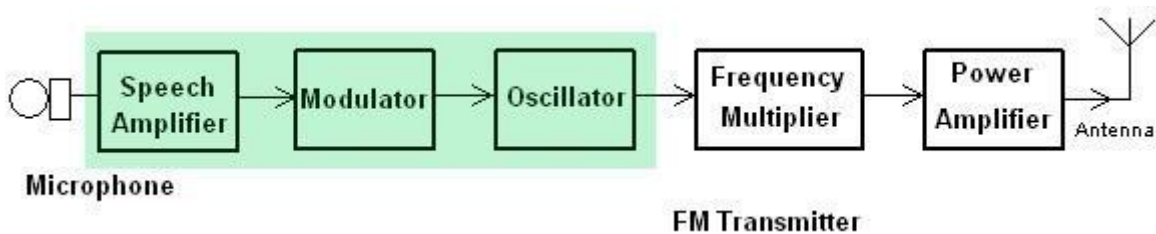
In this diagram FM signal is generated at a sub-multiple of required frequency
The **Modulator** causes the frequency of the **Oscillator** to vary in proportion to the amplitude of the audio
May be a variable capacitance diode (varicap)

Frequency Multiplier

FM Transmitter
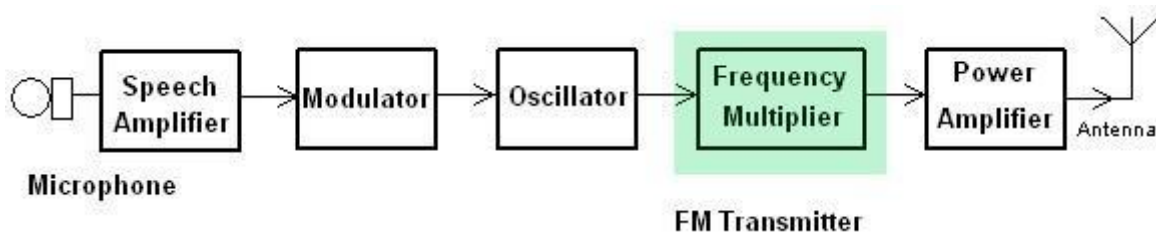
Frequency Multiplier is an amplifier with its output tuned to a harmonic (often 3rd) of input signal
Modern Tx often uses frequency conversion rather than multiplication

Section 6 – Radio Amateur Theory & Related Topics

Power Amplifier
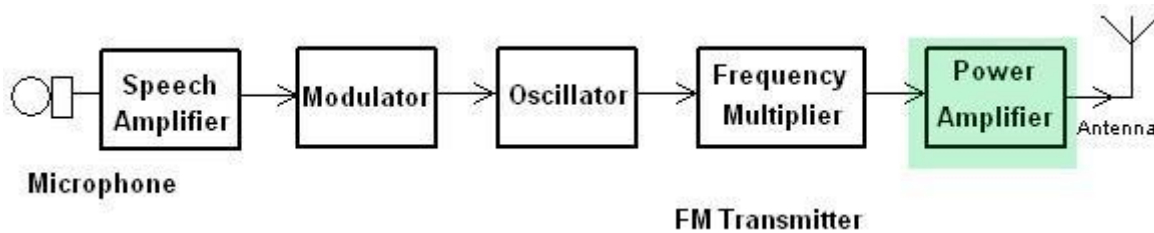
Power Amplifier does not need to be linear for FM
Has matching and filtering network

Tx Characteristics

Frequency stability – ability to maintain same frequency over a period of time, i.e., not to drift. Affected by heat and mechanical considerations

Non-Linearity

Non-linearity is where an amplifier introduces distortion, i.e., the output is not an exact magnified copy of the input
The signal becomes clipped leading to generation of harmonics/sidebands
Overdriving of amplifiers is a major cause of wide signal bandwidth and splatter

Output Impedance

Maximum power is delivered to a load (antenna) when the **output impedance** of the generator (transmitter) is equal to the load impedance
Standard is 50 ohm
Output network (Pi tank) matches the output impedance of the amplifier final device to 50 ohm

Output Power

Output power is the power from the transmitter
For CW and FM it is the d.c. (steady state) power
For SSB it is the Peak Envelope Power
Measured in dBW, power relative to 1 watt
  10 dBW = 10W
  20 dBW = 100W
  26 dBW = 400W
  32 dBW = 1.5kW (31.7 dBW)

Section 6 – Radio Amateur Theory & Related Topics

ERP Effective Radiated Power

ERP is Effective Radiated Power of the station in a given direction

It is calculated by adding the transmitter power (dBW), antenna gain (dB) and subtracting feeder loss

For a 100W Tx into an 7dB Gain antenna with a feeder loss of 1dB

- o   ERP = 20 + 7 – 1
- o   = 26dBW   (400W ERP)

This power level may have a bearing on radiation exposure limits

Key Clicks and Chirps

When a carrier is interrupted, as in CW, a sharp interruption will cause sidebands which manifest as **Key Clicks**. The rise time must be conditioned with a key click filter
If the frequency of the transmission varies instantaneously as the key is depressed this give a **chirp**-like sound, which occupies more bandwidth than necessary. It is caused by poor power supply regulation or poor oscillator/buffer isolation/design

Spurious / Unwanted Radiation

Even a "linear" amplifier has some residual non-linearity leading to harmonic generation
Over-driving an amplifier makes it non-linear
Unwanted mixer and inter-modulation products
Self-oscillation where an amplifier oscillates near the working frequency
Spurious (parasitic) oscillations where internal feedback causes an amplifier to oscillate at a frequency not necessarily related to the working frequency
Spurious signals from frequency synthesisers
Excessive audio bandwidth and over modulation or over deviation

Section 6 – Radio Amateur Theory & Related Topics

HF Station

H F Station   Transmit direction shown >
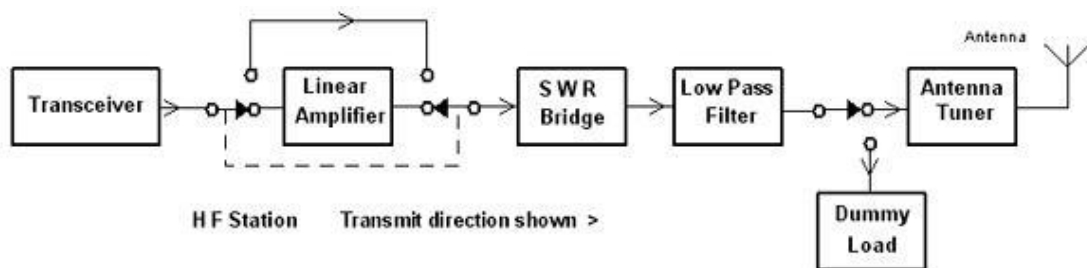
Standing Wave Ratio (SWR) bridge indicates impedance match between the antenna system and transmitter. Ideally should be 1:1. In this condition there is maximum forward power and minimum reflected power

Low Pass Filter cuts off frequencies above 30MHz suppressing harmonic unwanted radiation

Dummy load (50 ohm) is used to test and tune the transmitter without radiating a signal

High Power Linear Amplifiers

Transistor linear amplifiers operate at high currents. Proper fusing is essential. A 100W linear would typically be fused at 20A

Valve linear amplifiers have high voltages applied to the anodes of final valves, often several kV

Usually the top cap of the valve is the anode

Extreme caution should be used if working on a valve linear amplifier as voltages can be lethal

Section 7 – Antennas and Transmission lines

Feeders

Purpose

Feeders, also called transmission lines, carry radiofrequency (RF) power from the output stage of the transmitter to the aerial as efficiently as possible

The ratio of power transferred to the aerial compared to that dissipated (lost) in the feeder line must be as high as possible, i.e., the transmission line should be low loss

Types of Feeder

Open wire, where two parallel conductors are held apart by spacers (wide) or a polyethylene ribbon (narrow)

Coaxial cable which has an inner conductor and an outer concentric

conductor Waveguide which is a rectangular duct of the order of 25 x 20 mm

Characteristic Impedance

Every transmission line has a **Characteristic Impedance, Z0**, determined **solely** by the physical properties of the line, viz., spacing, dielectric, conductor type/size and construction

Parallel Conductor Line
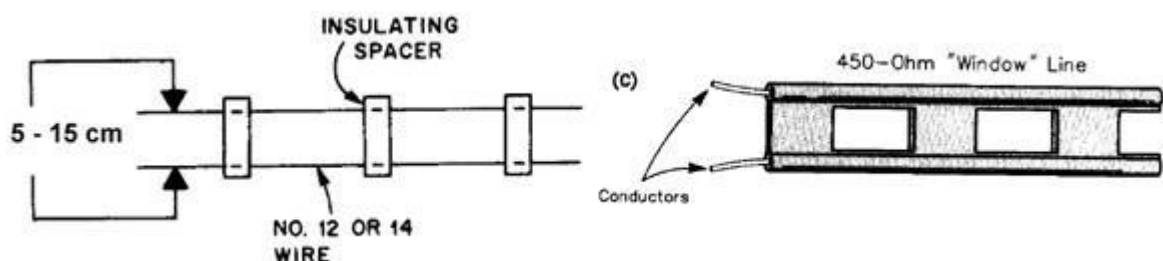
Two parallel length of wire held apart by insulating spacers (left above) also called **open wire** or **balanced line** or by a polyethylene ribbon with windows cut in it (right above) called **ladderline**

Characteristic impedance is determined by the diameter of the conductors and the distance between them.

Section 7 – Radio Amateur Theory & Related Topics

Preventing Line Radiation
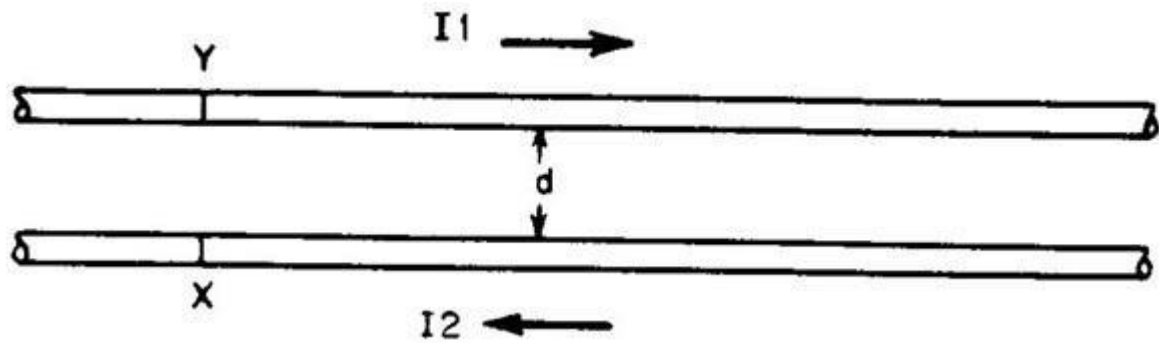
By using two conductors the electromagnetic field from one is balanced everywhere by an equal and opposite field from the other – resultant field is zero

There is no radiation from the feeder with **openwire** or **ladderline** – they are **balanced** lines

Balanced Line

16 SWG conductors about 115mm apart has an impedance of about 600 ; often built using spacers – open wire line

Twin (Window) line is available in impedances of 300 and 450   – ladder line

75 twin balanced line with conductors embedded in polyethylene is also available – twin feeder

Balanced line may be unbalanced by proximity to metal or earthed objects

Co-Axial Line
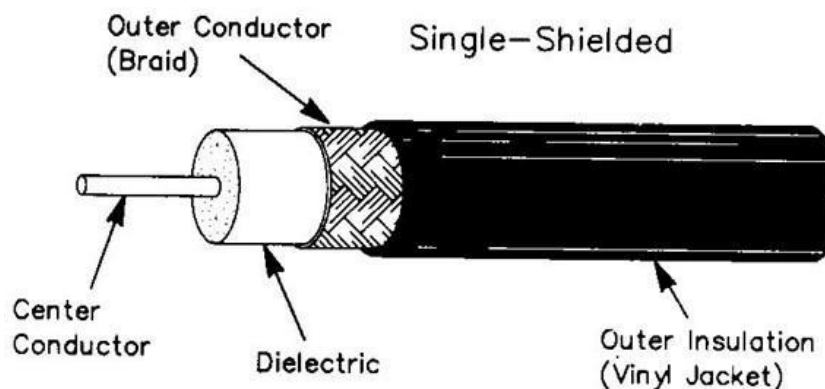
One conductor (the outer) is tubular braid and encloses the other conductor (the inner); a dielectric separates the two conductors; coax is an unbalanced transmission line

Characteristic impedance (normally 52 or 75 ohm) is determined by the ratio of diameter of the inner conductor to inside diameter of the outer conductor

Cable is flexible, can be run near or strapped to metal objects

Typical cable used in amateur use (52)

- o   RG58 – 5.0 mm outside diameter
- o   RG213 – 10.3 mm outside diameter

Section 7 – Radio Amateur Theory & Related Topics

Wave Guide

Above 2 GHz cables cannot always be used for RF signals because of losses

Waveguides are conducting tubes (circular or rectangular) through which electromagnetic waves of ultra high frequency are transmitted with very little loss

Waveguides confine the energy fields inside them and the signals are propagated by reflection against the inner walls

Typical outside dimensions of waveguide for use at 10 GHz would be 25.4 x 12.7mm

Warning: never look into an active waveguide

Velocity Factor

Electromagnetic waves in free space travel at the speed of light

In transmission lines the speed of the wave is slowed down by a factor K called the **velocity factor** of the line

A half wave in free space is:

- o **150÷f** , where f is in **MHz**, **result** is in **meters**
- o **(492÷f** result in **feet**)

A half wave transmission line length in **meters** is the free space value × **K**, where K (**the velocity factor**) is always less than 1 and depends on the type of cable used

For open wire line K is about 0.85

For coaxial cable it is about 0.66

The big reduction in the speed of a wave in coaxial cable is due to the effect of the solid dielectric

A half wave when account is taken of the velocity factor of the cable is called an **electrical half wave** and it is always shorter than the free space half wave

Terminated Line (Matched Case)
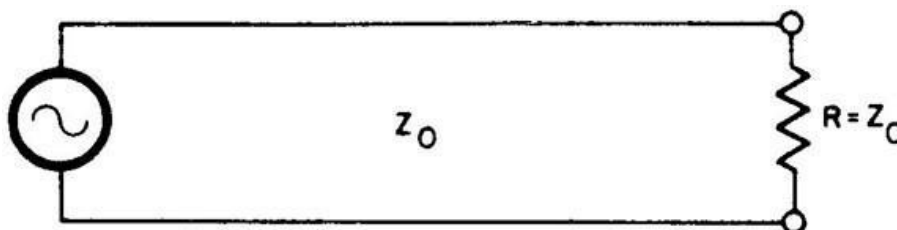
A transmission line terminated with a resistive load (usually an antenna) equal to its characteristic impedance Z_0 is said to be **matched**

It acts as an infinitely long line – all the RF power is absorbed/radiated by the resistive load – none reflected

Section 7– Radio Amateur Theory & Related Topics
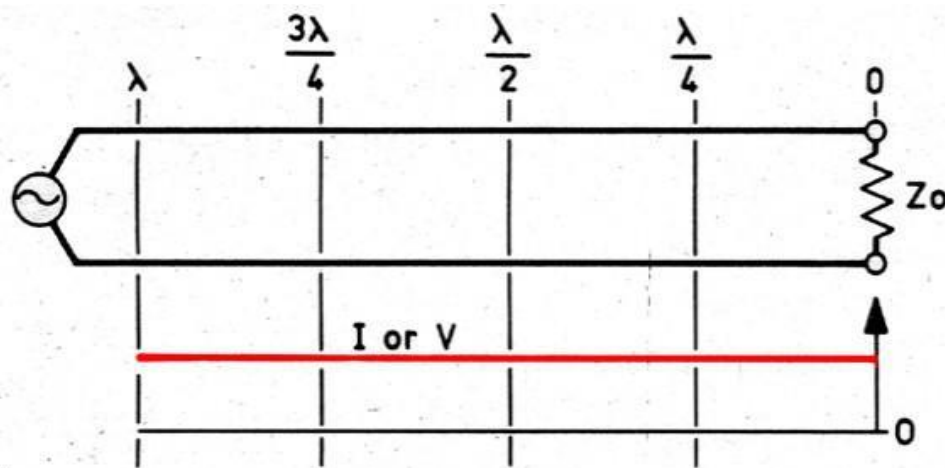
On a matched line the voltage (or current) measured at any point on the line will have the same amplitude

Terminated Line (Un-Matched Case)
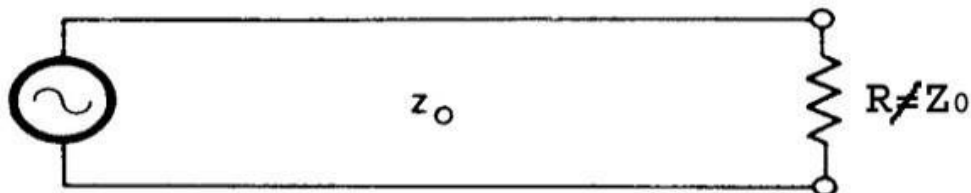
A line terminated by a load of a value other than its characteristic impedance is said to be **unmatched**

Some power is reflected back towards the source (generator) by the load causing **standing waves**

The power (voltage and current) reflected from an unmatched load adds to and subtracts from the incident wave from the generator to form the standing waves

The greater the mismatch, the greater the standing waves

Standing Waves
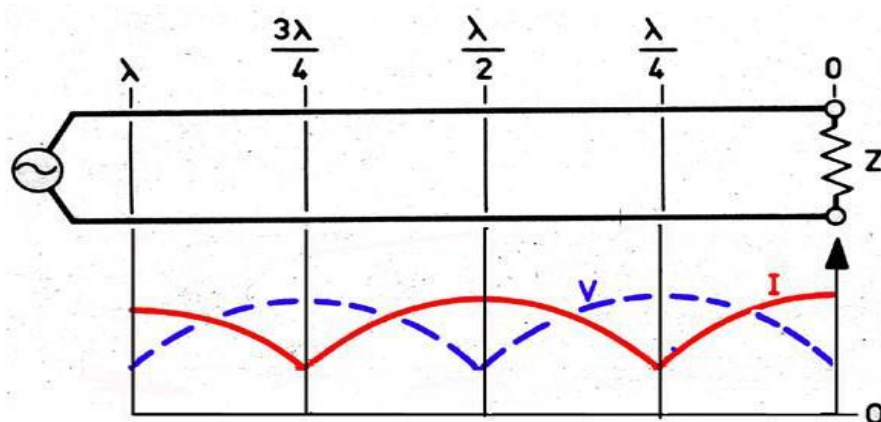
With unmatched load voltage and current and consequently impedance ($Z = V \div I$) at the input to the feeder **differs** from the characteristic impedance and the load impedance

Ratio of max value of voltage standing wave to its minimum value is the **voltage standing wave ratio VSWR** or simply **SWR**

Section 7 – Radio Amateur Theory & Related Topics

Values of SWR will vary from 1:1 in the matched state to a very high value in a badly mismatched state

Special meters called SWR Meters used to measure SWR

High SWR on the feeder due to a difference in antenna and feeder impedance increases losses, particularly in the case of coaxial cable which may contribute to interference by radiation from the cable

A high SWR can cause a mismatch between the feeder input and transmitter output which will result in poor power transfer and high voltage or currents which may damage the transmitter output stage; modern transmitters will not tolerate an SWR in excess of 3:1

Line Loss

Open wire and ladder line are very low loss lines – about 0.15dB per 30m into a matched load at 28 MHz (insignificant loss)

Attenuation (loss) in coax is higher than in open wire line due to the solid dielectric

Loss in a matched line increases with increasing frequency; for coax 1dB per 30m at 10 MHz rising to 3.3dB at 100 MHz for typical RG58-U (3.3dB – over half the power is dissipated in the feeder)

At VHF/UHF losses can be very significant; need to use good quality cable

If feeder and load are mismatched losses increase

Increases in loss with higher frequency in open wire line are small and can be disregarded

Open wire line can be operated with a relatively high SWR on the feeder without significant loss

Matching

Max power transfer from transmitter to aerial system occurs when transmitter√ output impedance and antenna system input impedance are equal

Half wave dipole antenna in free space has theoretical impedance of about 72Ω at its centre; lower near ground

Coaxial cable can be used to feed power to this system as the antenna presents a reasonable match to the feeder keeping losses low; the coax presents a good match to the transmitter

Matching – Quarter Wave Transformer

On an unmatched transmission line impedance at any point varies due to **standing waves**

A transmission line **stub** that is an **electrical** quarter wavelength long (/4) at the operating frequency **(i.e. velocity factor is taken into consideration)** may be used as a matching transformer to match an antenna and feeder

The relationship is …

$$Zstub = \sqrt{(Zantenna \; x \; Zfeeder)}$$

———
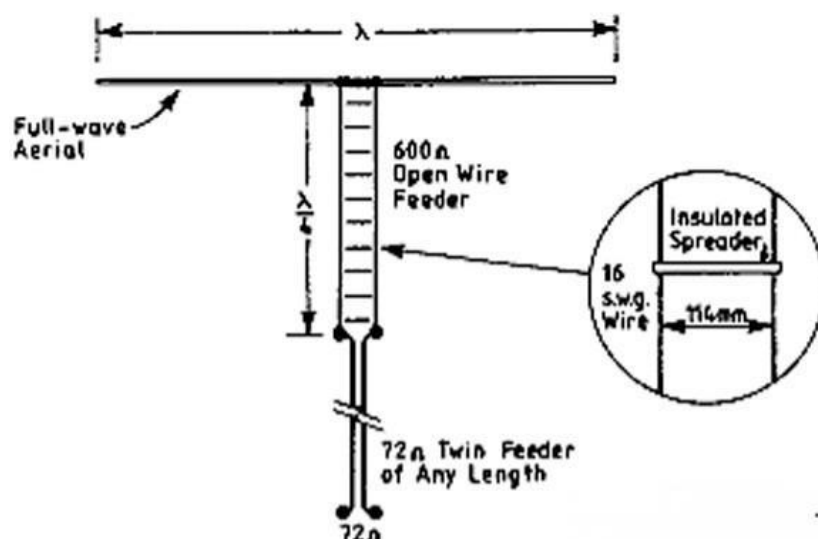
In above case aerial impedance of 5000 has to be matched to 72 balanced line

$$Zstub = \sqrt{(Zantenna \; x \; Zfeeder)}$$

$$= \sqrt{5000 \; x \; 72}$$

$$= 600\Omega$$

Lines as Tuned Circuits

Electrical quarter wave of **short-circuited line**, at the resonant frequency for which the line is cut, acts as a parallel tuned circuit with **high impedance**

Electrical quarter wave of **open-circuited line**, at the resonant frequency for which the line is cut, acts as a series tuned circuit with **low impedance** – can be used to **bypass** an interfering signal at its resonant frequency

Open Circuit
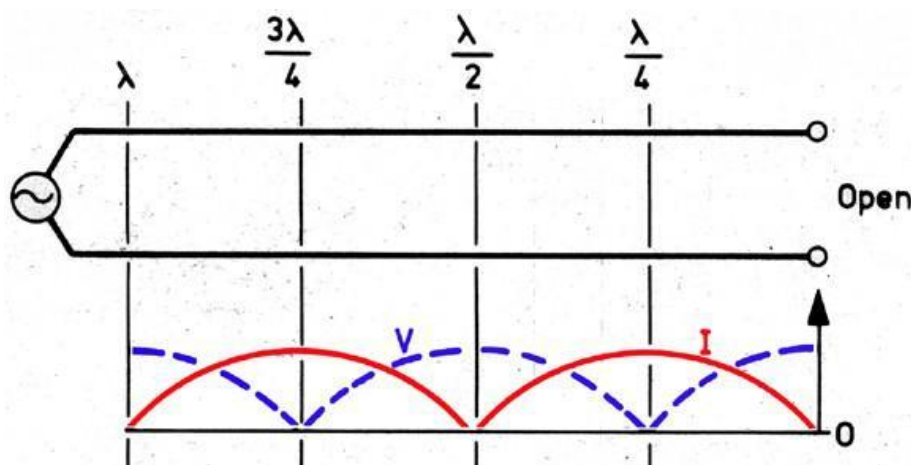
With an open circuit line the open circuit appears at half wavelength intervals from the load

At quarter wavelength intervals the open circuit is **transformed** into a short circuit

Section 7 – Radio Amateur Theory & Related Topics

Short Circuit
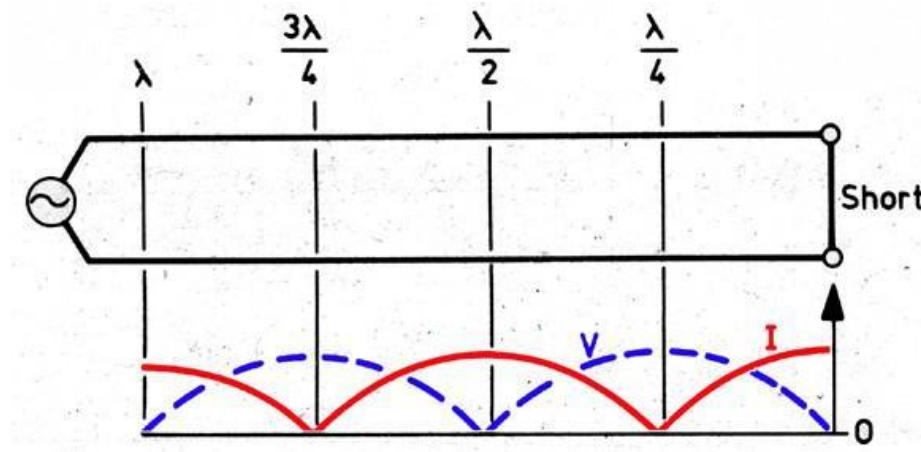
With a short circuit line the short circuit appears at half wavelength intervals from the load
at quarter wavelength intervals the short circuit is **transformed** into an open circuit

Stubs

A transmission line stub that is less than /4 long can be used as a low loss inductor or
capacitor
If the line termination is an open circuit the input appears as a capacitance
If the line termination is a short circuit the input appears as an inductance
These stubs can be used in antenna matching

Type of Stub	Open	Shorted
λ/4 and Odd multiples	Low impedance – Short Circuit	High impedance – Open Circuit
λ/2 and multiples	High impedance – Open Circuit	Low impedance – Short Circuit

Section 7– Radio Amateur Theory & Related Topics

Antenna Tuning Units - ATU
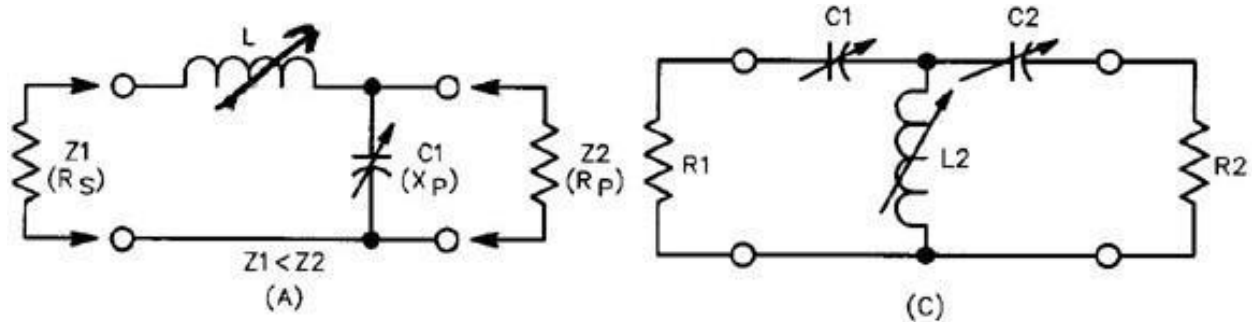
Common types are **L-Match** (left) and **T-Match** (right above)

Used to match the output impedance of the transmitter (50 unbalanced) to the complex impedance presented by the antenna and feeder combined

Comprise tunable or switched coils and variable capacitors to provide impedance match

Commonly used with random length antennas centre fed with balanced line to provide multiband operation; when used with balanced line a **Balun** should be used at the tuner output

Balance / Unbalance

Half wave dipoles, yagis and loops are balanced antenna, i.e., voltage and current are balanced each side of the centre feed point; coaxial cable is an **unbalanced** line

A **Bal**ance to **Un**balance matching device called a **BALUN** is used at feed point. If not, radiation can occur from coax outer, reducing efficiency

The antenna's radiation pattern changes if the currents in the driven element of a balanced antenna are not equal and opposite

A **Balun** can also be designed to provide impedance transformation (transformer balun) Alternatively, a balanced line and ATU could be used

Section 7 – Radio Amateur Theory & Related Topics

Baluns

A Voltage Balun is one whose output voltages are equal and opposite (balanced with respect to ground)

True balance occurs only if the Balun's load is symmetric with respect to ground

Voltages Baluns are easily constructed and commonly used in spite of their inability to provide true current balance

A Current Balun is one whose output currents are equal and opposite (balanced with respect to ground)

With the exception of the 1:1 current Balun, current Baluns are more expensive to construct than voltage Baluns and thus are less widely used

Typical Baluns

Choke Baluns are current Baluns and cause equal and opposite currents to flow

A choke Balun may be constructed by coiling the feedline at the point of connection to the antenna. The inductance of the choke isolates the antenna from the remainder of the feedline

Alternatively a series of ferrite beads (often up to 50) may be threaded onto the coax feeder

1:1 Current Balun

This is the simplest current Balun, consisting of two coils of wire connected as shown the coils may use an air core or a ferrite core

1:1 Current Balun
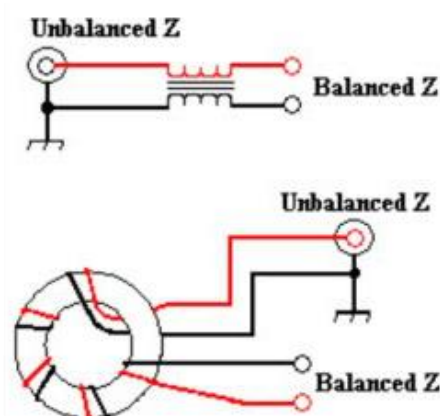
Often a current Balun is made by winding coaxial cable into a coil, with or without a ferrite core

The load impedance is not changed by the Balun

The inductive reactance of the windings prevents common mode currents from flowing and ensures a balanced output

Section 7 – Radio Amateur Theory & Related Topics

The inductive reactance should be 10 times the load impedance at the lowest frequency of operation

4:1 Voltage Balun

This is the simplest voltage Balun, consisting of two coils of wire connected as shown the coils may use an air core or a ferrite core
Current flowing through the lower coil induces an equal and opposite voltage in the upper coil

The primary circuit contains N turns and the secondary 2N, so the input impedance is:

$$Z_L(N \div 2N)^2 = ¼ \, Z_L$$

4:1 Voltage
Balun

Z UNBALANCED

4 Z BALANCED

Toroidal
Core

Unblanaced Z = Z/4

B
A
A
B

Balanced
Z
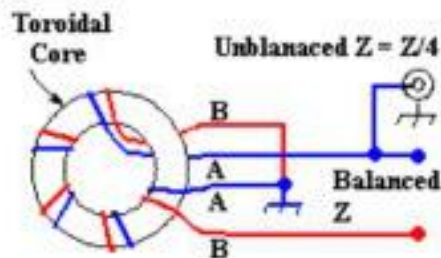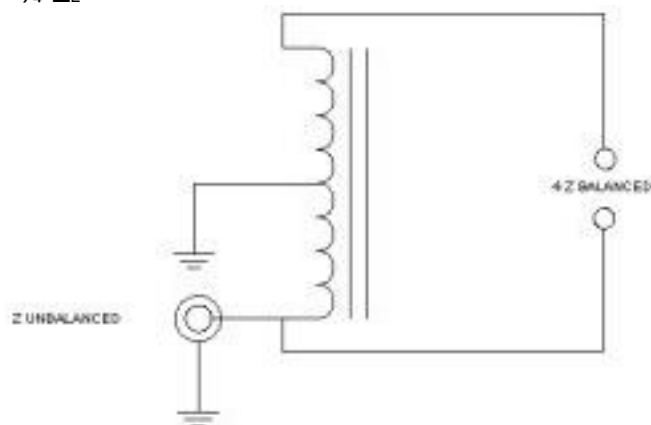
Section 7 – Radio Amateur Theory & Related Topics

1:1 Voltage Balun

This voltage Balun is similar to the 4:1, but uses 3 windings connected in series
The coils may use an air core or a ferrite core
Current flowing through the lower coil induces an equal and opposite voltage in the upper coil
The primary circuit contains N turns and the secondary N, so the input impedance is $Z_L(N \div N)^2 = Z_L$
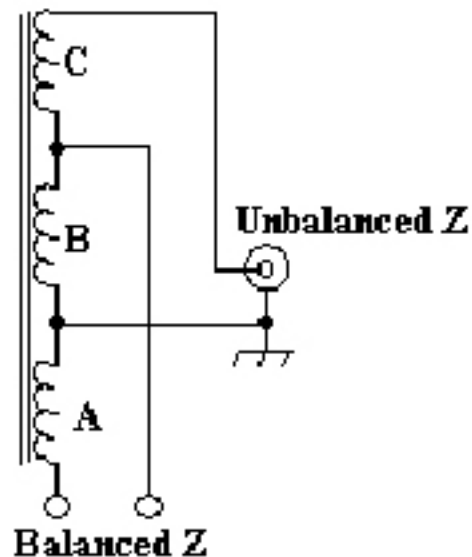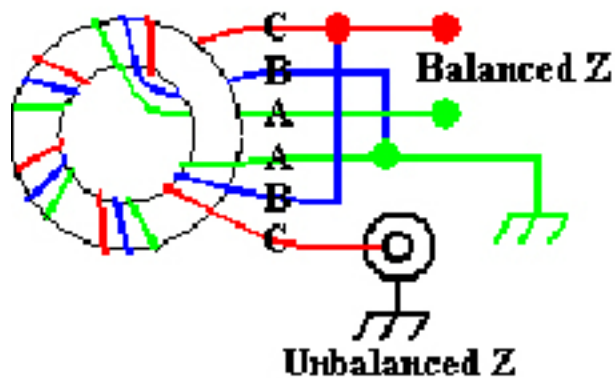
Section 7 – Radio Amateur Theory & Related Topics

4:1 Transmission Line Voltage Balun

This voltage Balun is constructed solely from transmission line and requires no cores

Unlike the transformer-type Baluns, this Balun may be used only over a narrow range of frequencies

The extra half wave section causes the voltage at its output to be equal and opposite to the voltage at the input
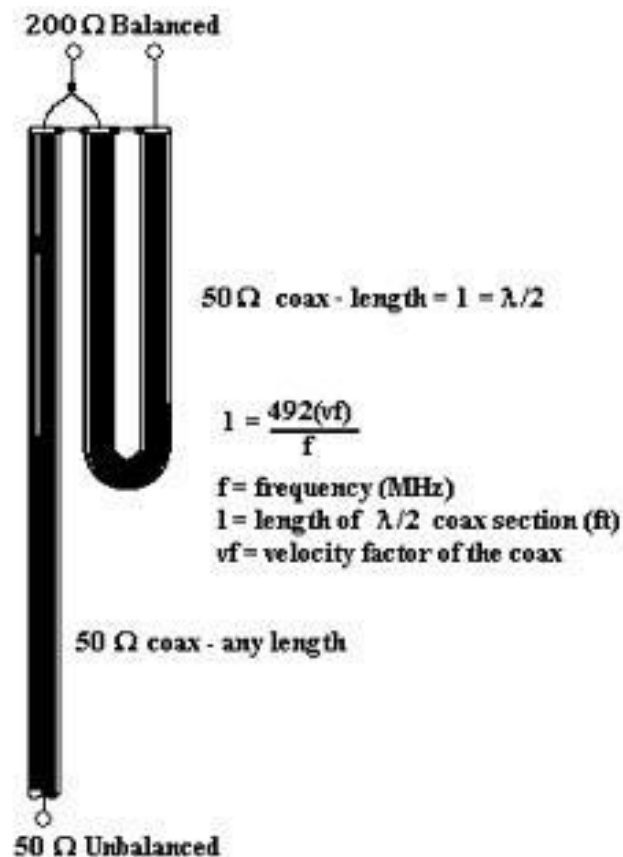
200 Ω Balanced

50 Ω coax - length = $l = \lambda/2$

$$l = \frac{492(vf)}{f}$$

f = frequency (MHz)
l = length of $\lambda/2$ coax section (ft)
vf = velocity factor of the coax

50 Ω coax - any length

50 Ω Unbalanced

Section 7 – Antennas and Transmission lines

Antennas (Aerials)

Antenna Overview

An antenna is a device that
- converts RF power applied to its feed point into electromagnetic radiation (transmitting)
- intercepts electromagnetic radiation which then appears as RF voltage across the antenna feed point (receiving)

The intensity (density) of radiation propagated by an antenna is not usually the same in all directions. The **radiation/capture** pattern is the same whether the antenna is used for transmitting or receiving

The ratio of maximum radiation by a given antenna in a particular direction to the radiation of a reference antenna in the same direction (usually a half wave dipole) is called **directivity**

Antennas can be made from any conductive material although high conductivity materials such as copper or aluminium are the preferred choices

RF currents flow only on or near the conductor's surface (**skin effect**) and so antennas can be made from tubing without reducing performance

Meshed elements can be used provided the mesh holes are smaller than the wavelength at which the antenna will be used by a factor of 12 or more, e.g., some satellite dishes

Frequency and Wavelength

Frequency (f) multiplied by wavelength (λ) for a radio wave equals the speed of light (c)

$$\mathbf{c = f \times \lambda \quad or \quad \lambda = c \div f}$$

$$\mathbf{\lambda(meters) = 300 \div f \, (MHz)}$$

So 60 meters = 5MHz

Half-Wave Antenna
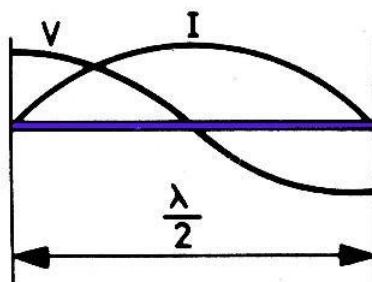
Section 7 – Radio Amateur Theory & Related Topics

The fundamental antenna is a length of wire which is an electrical half wavelength long

    The antenna is said to be **resonant** at the frequency at which it is an electrical half wavelength long; it will present a resistive load

The voltage and current distribution on a half wave antenna is shown above

    Note that the voltage is highest (greatest danger of RF burns!!) at the ends of a half wave dipole

At the centre of a half wave dipole, the current will be highest and the voltage low

    Similarly, at the base of a quarter wave antenna, the current will be highest and the voltage low

    The ratio of voltage to current **(impedance)** varies along the wire – at the ends the current is low and the voltage is high (high impedance) while at the centre the current is high and the voltage is low (low impedance)

    Feed-point impedance depends on where the feed point is. It varies from high impedance at the ends reducing to low impedance at the centre

    At the centre of a resonant half wave antenna the impedance is resistive and in **free space** is about **70**

Half-Wave Dipole

    If a half wavelength of wire is cut at the centre and fed with RF power at **the frequency at which it is resonant** it is called a half wave dipole and has a feed point impedance of about 40-70 depending on height above ground

    A half wave dipole is a balanced antenna and needs a balanced feed. This can be either typically coaxial cable and a **balun (balance-to-unbalance transformer)** or 75 or 450 balanced line. The loss due to the 6:1 mismatch (6:1 SWR) on 450 line is inconsequential because this type of line is very low loss, though it needs to be matched to the Tx output

Half-Wave Antenna

    An antenna that is **shorter** than a half wavelength at the frequency of operation will have **capacitive reactance as well as resistance** at its feed point

    An antenna that is **longer** than a half wavelength at the frequency of operation will have **inductive reactance as well as resistance** at its feed point

    An aerial tuning unit would generally be used to "tune out" the capacitive or inductive reactance and present a resistive load to the 50 output of the transmitter (Tx)

The antenna system and Tx are then said to be "**matched**"

Section 7 – Radio Amateur Theory & Related Topics

End-Fed Half-Wave Antenna
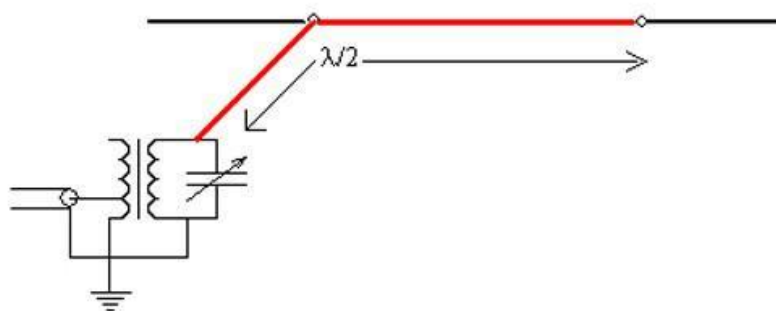
As discussed, a half wavelength antenna has high voltage and low current at its ends, i.e., the ends are **high impedance feed points**

A parallel-tuned matching network comprising a coil and variable capacitor suitable for the frequency is used to resonate the system and the feeder is tapped to the point on the coil that gives the lowest SWR

A good **ground** (earth) for one end of the matching network and the braid of the coax is required

Care must be taken as there is high RF voltage at the feed point. It should be located so that it cannot be touched by humans or animals

The matching network should preferably be located outside the shack, protected from the environment. This is safer and will help to eliminate RF in the shack and reduce the likelihood of interference to TV, Radio and Telephones

Half-Wave Antenna – Radiation Patterns
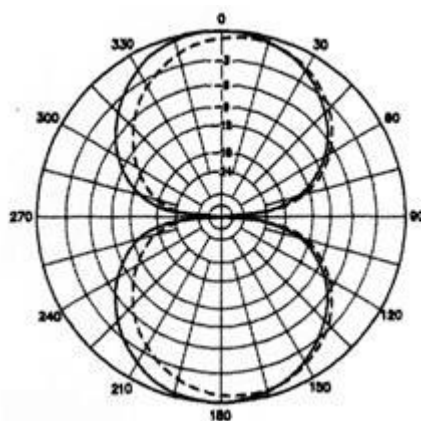
The theoretical radiation pattern in the **horizontal plane** from a half wave dipole is shown above

The theoretical radiation pattern is in the form of a "ring doughnut shape", i.e., the radiation is maximum all around the wire and at right angles to it with little or no radiation off the ends
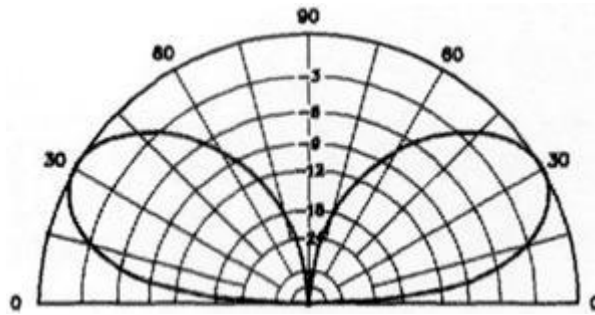
The radiation pattern in the **vertical plane** of a half wave antenna one half wavelength above **perfectly conducting ground** is shown above

Due to ground reflection the pattern is modified and maximum radiation takes place at right angles to the wire and at an angle of 30° from the horizontal

Folded Dipole Antenna
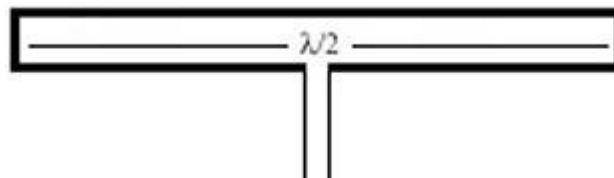
Another conductor is placed slightly above a half wave dipole and connected to it at the ends

Has the **same radiation pattern** and a broader frequency response between the 2:1 SWR points than a single wire dipole

Feed point impedance is about 300 so it is a better match for 450 line than a single wire dipole

Will **not** operate on harmonics of its resonant frequency

Feed point impedance can be modified by varying the diameter of the conductors and their spacing

Quarter-Wave Ground Plane Antenna
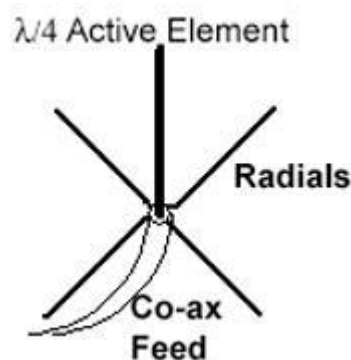
A half wave dipole cut in half and standing on a mirror would look like a full dipole The mirror can be the earth, a metal sheet or a number of **radials** as shown above

Section 7 – Radio Amateur Theory & Related Topics

Feed point impedance is about **35Ω** and is **unbalanced**

At the base of a quarter wave antenna the RF current will be high and the voltage will be low (similar to the centre of a half wave dipole)

It can be fed with coaxial cable, the inner to the vertical radiator and the outer to the radials Radiation is omni directional and is maximum at about 30° elevation to the ground
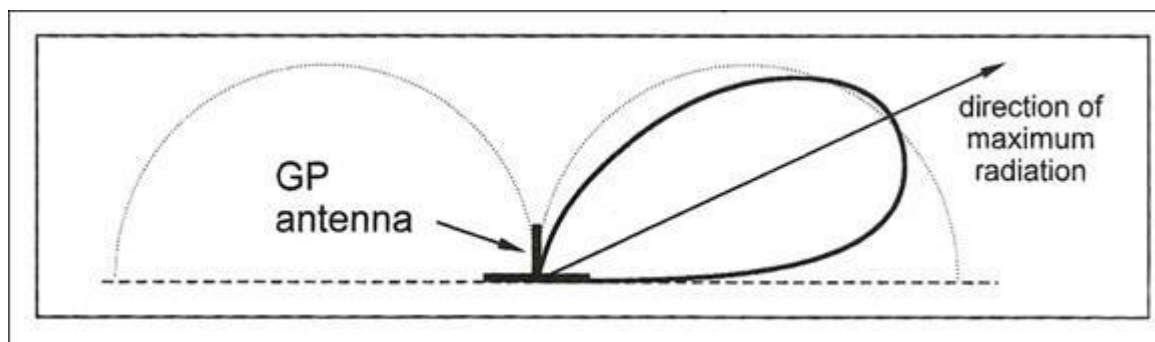
Elevating the feed point and drooping the radials downward at an angle of 25-30° will help provide a better match to 50 coaxial cable; elevated radials are normally **tuned** by cutting to length of /4

Increasing the number of radials improves the efficiency of a ground plane antenna

Trap Dipole Antenna
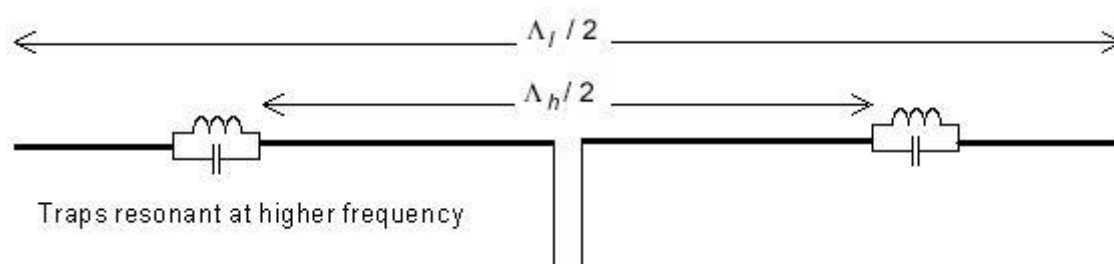
A 7 MHz half wave dipole fed with a balanced line will look like two end fed half waves on 14 MHz; feed point impedance will be very high and consequently there will be a high SWR on the feeder

To construct a dual-band antenna a **parallel resonant circuit** called a **trap** can be inserted in each half of the antenna, constructed from a coil and capacitor

The traps are resonant at the **higher frequency** (14 MHz) and present a high impedance to RF energy at that frequency, effectively cutting off the parts of the antenna **outside the traps**

The traps are placed so that the **centre portion** of the antenna inside the traps resonates at the **higher frequency** (14 MHz)

To 7 MHz RF energy the traps just look like inductors and the **whole antenna resonates** at the **lower frequency** (7 MHz)

The traps add to the **electrical** length of the antenna so that at resonance at 7 Mhz the physical length of antenna will be somewhat shorter than that of a half wave dipole

Section 7 – Radio Amateur Theory & Related Topics

Yagi Antenna
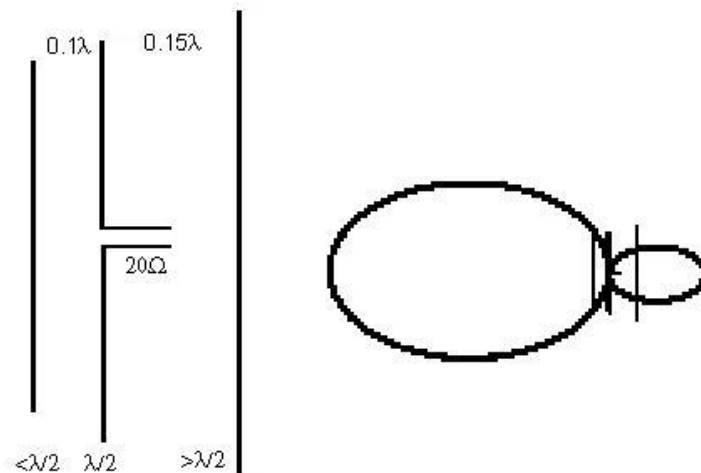
The pattern and direction of maximum radiation from an antenna can be modified by the addition of one or more extra elements **(directors)** in front of and an extra element **(reflector)** behind the element to which RF energy is fed, i.e., the **driven** element.
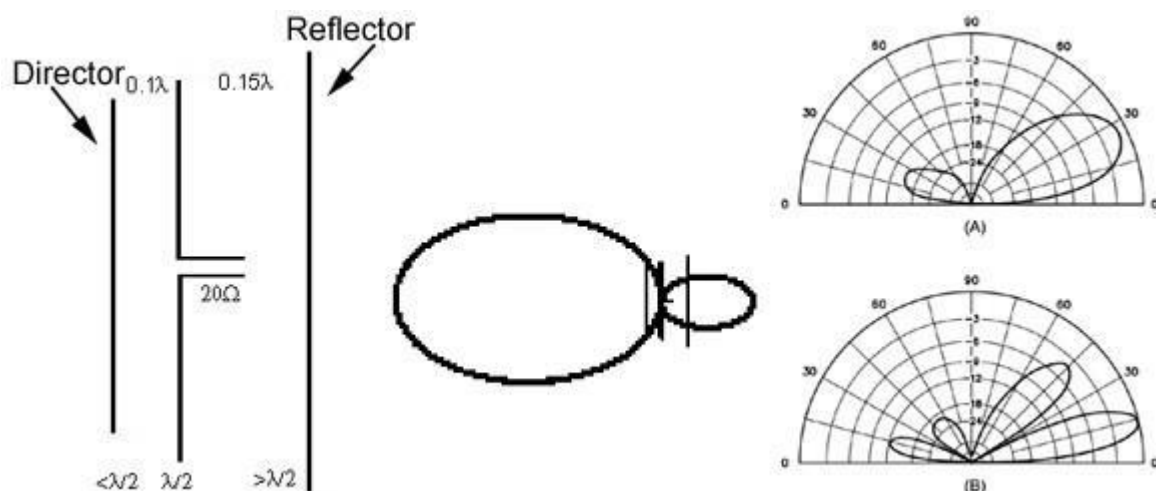
The Yagi antenna has a balanced feed-point. Radiation Pattern in horizontal plane is shown

In vertical plane it is at approximately 30° for an antenna placed at /2 above ground (a) while at above ground there are two lobes at 15° and 45° (b)

Where no RF energy is fed to these extra elements they are called parasitic elements and they get power through electromagnetic coupling with the driven element

The three element Yagi shown on the previous slide has a parasitic reflector, a parasitic director and a dipole driven element to which the RF signal is fed

Parasitic reflectors and directors are respectively about 5% longer and shorter than the driven element and further directors would usually get progressively shorter

The length and spacing of the parasitic elements are such that they reinforce radiation in the direction of the director and reduce it in the opposite direction. This is how the antenna achieves its gain over a half wave dipole (see radiation pattern on a previous slide)

Section 7 – Radio Amateur Theory & Related Topics

Because of the radiation pattern of Yagi antennas they need to be rotated in the direction to which a signal is to be transmitted/received

The maximum theoretical gain of a three element Yagi antenna over a half wave dipole is about 7dBd (about 5 times). An important advantage is that the gain also applies to received signals

Gain and Yagi Antennas

Two common methods of gain measurement —

dBi which is dB (deciBels) relative to an isotropic antenna, i.e., a theoretical antenna in free space with equal radiation in all directions

dBd which is dB relative to a half wave dipole. This is a more meaningful comparison as a half wave dipole has a gain of 2.1dB over an isotropic radiator

Yagi Antenna

Because the Yagi antenna increases gain in one direction (the forward direction) by reducing it in others, particularly in the reverse direction it is said to have a **front to back ratio**. This ratio represents the property of attenuating signals (both transmit and receive) off the reverse side (reflector end) of the beam. A good three element beam would have a front to back ratio of up to 18dB about three 'S' Units

The additional elements reduce the driven element feed point impedance from about 70 to about 20 . A folded dipole is often used to raise this impedance and provide a better match for coaxial cable. More often a matching device called a **gamma match** is used to give an almost perfect match to 50 coaxial cable

Multi-Band Antenna

An antenna about a half wavelength long at the lowest frequency to be used fed with a balanced line of say 450 will operate on all the higher frequency bands

Impedances at the shack end of the feed line will contain reactance and will vary very much from band to band

An aerial tuning unit is therefore essential to "tune out" the reactance and transform the load so as to present a resistive load in the region of 50 to the transmitter output stage

Effective Radiated Power (ERP)

Radiated power is power supplied at the antenna system multiplied by the antenna gain in a given direction. This can be referenced to a half-wave dipole (Effective Radiated Power ERP) or an isotropic radiator (Effective Isotropic Radiated power EIRP)

For a transmitting system it is determined by subtracting system losses from system gains. For example if an antenna system has a 6dBd gain and a feeder loss of 3dB then the system (antenna and feeder) has an effective gain of 3dBd (a power gain of two)

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If the transmitter outputs 100 watts, the system will have a ERP of 200 watts; a Tx power level of 20 dBW becomes ERP of 23 dBW

Recall: Gain in db. If the ratio power out / power in is less than 1, then a loss is involved and the dB figure will be negative

Polarisation
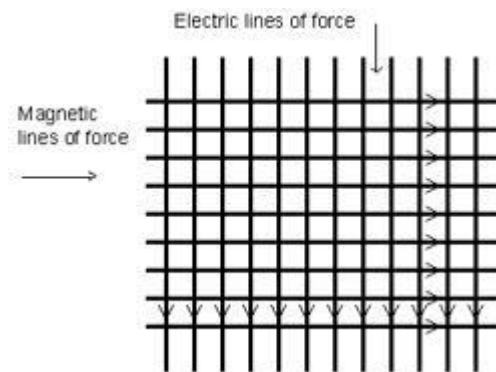
A wave is said to be **polarised in the direction of the electric lines of force** relative to the surface of the earth. In the above diagram the wave is vertically polarised

Polarisation is determined by the transmitting antenna. Horizontal antennas transmit horizontally polarised waves and vertical ones vertically polarised waves

Polarisation of waves will alter during ionospheric propagation

For line-of-sight propagation, transmitting and receiving aerials should have the same polarisation. If one is horizontally and one vertically polarised there are significant losses

Capture Area
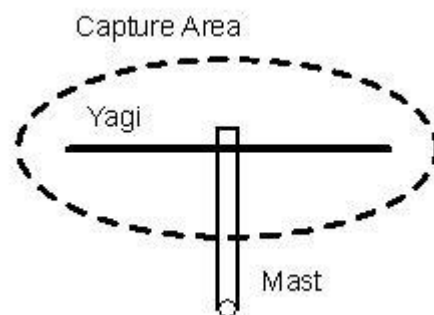
A receiving antenna captures a portion of the power radiated by a remote transmitter

The received power available at the terminals of the antenna depends on the capture area, also called effective aperture of the antenna

For a Yagi it is roughly elliptical as shown above

It is an important parameter at UHF for parabolic and horn antennas

Antenna Length

A half wavelength in free space is **150 ÷ f_{MHz} metres long**

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The velocity of a wave in antenna wire is less that in free space, so antenna lengths are shorter than equivalent free space lengths

This fact coupled with the capacitive effect of end insulators mean that a half wave antenna is about **5% shorter than its free space length**. Use of insulated wire reduces this by a further 3 – 4%

The starting figure generally used for the length of a half wave antenna is: **142.5 ÷ ƒMHz (metres)** or **468 ÷ ƒMHz (feet)**

Typical Half Wave Dipole Lengths

Freq	Band	Length	
1.8 MHz	(160m)	75.2m	247ft
3.5 MHz	(80m)	35.2m	129ft
7 MHz	(40m)	20.3m	67ft
14 MHz	(20m)	10.05m	33ft
21 MHz	(15m)	6.7m	22ft
28 MHz	(10m)	4.93m	16.2ft
50 MHz	(6m)	2.85m	9.4ft
70 MHz	(4m)	2.02m	6.6ft
145 MHz	(2m)	0.97m	3.18ft
430 MHz	(70cm)	0.32m	12.8in

Section 7 – Radio Amateur Theory & Related Topics

Parabolic Antenna

An antenna located at the focal point of a parabolic reflector (dish) can provide considerable gain with a large capture area

A 1.2m diameter parabolic dish at 432 MHz (70 cms) provides about 10dB gain over a half wave dipole

The beam width of the signal will be very narrow provided all of the signal energy is at the focal point of the dish

These antennas are used at UHF and microwaves and specialised feed systems, often using **waveguides** (a rectangular section of tube) are used

Horn Antenna
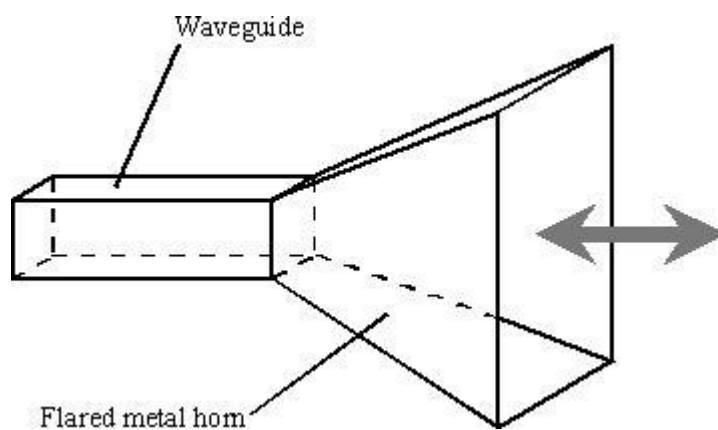
Used at microwaves, can be regarded as "flared out" or "opened out" waveguides

Produces a larger effective aperture (capture area) than that of the waveguide itself and hence gain and greater directivity

Section 8 – Propagation

Propagation

Electric Field

An **electric field** is the force resulting from electric charges
Field strength is measured in **volts/meter (V/m)**, and is **inversely proportional** to distance from the source, i.e. at twice the distance the field strength is halved

Field strength may also be expressed as **Power Density** in **Watts/meter^2 (W/m^2)**. Power Density is proportional to the **inverse of the square of the distance** from the source, i.e. as twice the distance power density is a quarter

Magnetic Field

In addition to an Electric Field every current-carrying conductor has a **magnetic field** around it caused by the current

Electromagnetic Field
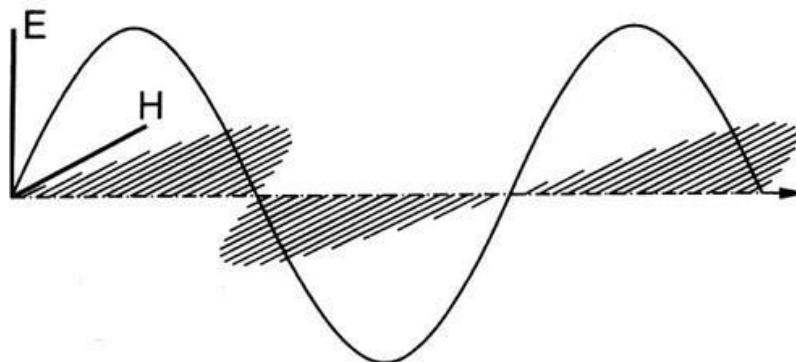
A **radio wave** is an **electromagnetic wave**, consisting **of electric (E) and magnetic (H) fields** at right angles to each other, both at right angles to the direction of travel
The E-field determines **polarisation** and **field strength** (example is vertically polarised)

Propagation Velocity

The speed at which the wave travels (**propagation velocity**) depends on the medium in which it is travelling
In free space it travels at the speed of light (**300 × 106 m/s**). In air velocity is slightly less

velocity = frequency × wavelength

$v = f × λ$

$λ$ (meters) $= 300 ÷ f$ (MHz)

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6 MHz is a wavelength of 50 meters

Signal Attenuation

Radio waves weaken as they travel

Energy is lost due to absorption when waves propagate through the atmosphere or solid medium – effect of atmosphere negligible from 10MHz – 3GHz

Energy is also lost during **reflection, diffraction** and **refraction**

The ability to resolve a particular signal is determined by the **signal-to-noise ratio** at the receiver input

Atmospheric Layers

Troposphere extends from ground to about 10km above the earth. It influences vhf/uhf propagation

Ionosphere is a region 100 to 400 km above earth. It influences hf long distance propagation

Ionosphere

The Ionosphere is a region 100 to 400 km above earth

Air molecules ionised by ultra violet solar radiation

Ionised regions will reflect radio waves by **refraction** (gradual bending) within the layer

Essential for long distance shortwave propagation

Ionisation forms into a number of layers

Layers vary in height and density and with the seasons and the time of day

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Layers:
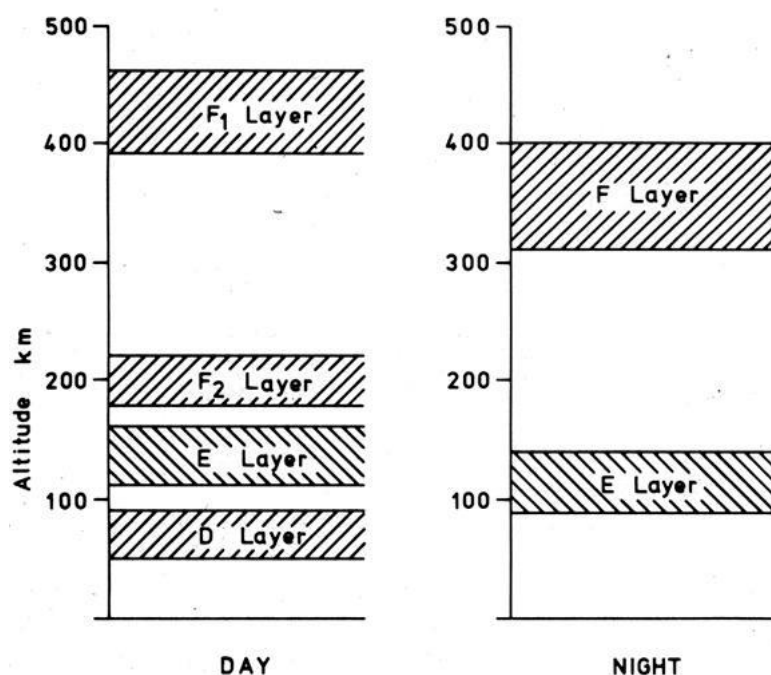
Ionosphere Layer Properties

D layer at 70-80 km is weakly ionised but during the day, particularly in **summer**, can **absorb** frequencies below 3-4 MHz, preventing Dx at these frequencies. The layer disappears at night

E Layer at same altitude day and night (120 km). Intensity increases with sunlight, max at noon

F Layer separates during daylight into F1 and F2

layers **F Layer** (night-time) height is 350 km

F1 (day-time) height is 200 km and **F2** (day-time) is 450 km

Ground and Sky-waves

Ground Wave follows the earth's contour due to **diffraction** and is **not reflected**. Most apparent at LF

Sky Wave (ionospheric wave) returns to earth after being **reflected** by an **ionised layer**. At low frequencies liable to absorption by the D layer

Skip Distance is the distance between the transmitter and the nearest point on the earth that the sky wave can be received

Skip Distance is dependent on the **angle of radiation** from the antenna and frequency. Lower angle gives longer skip distance

Dead Zone is the distance between the end of **ground wave** propagation and the nearest point on the earth that the sky wave can be received

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Skip Distance: At various angles of Radiation.

(a) Ground Wave   (b) Sky Wave   (c) Escape Wave
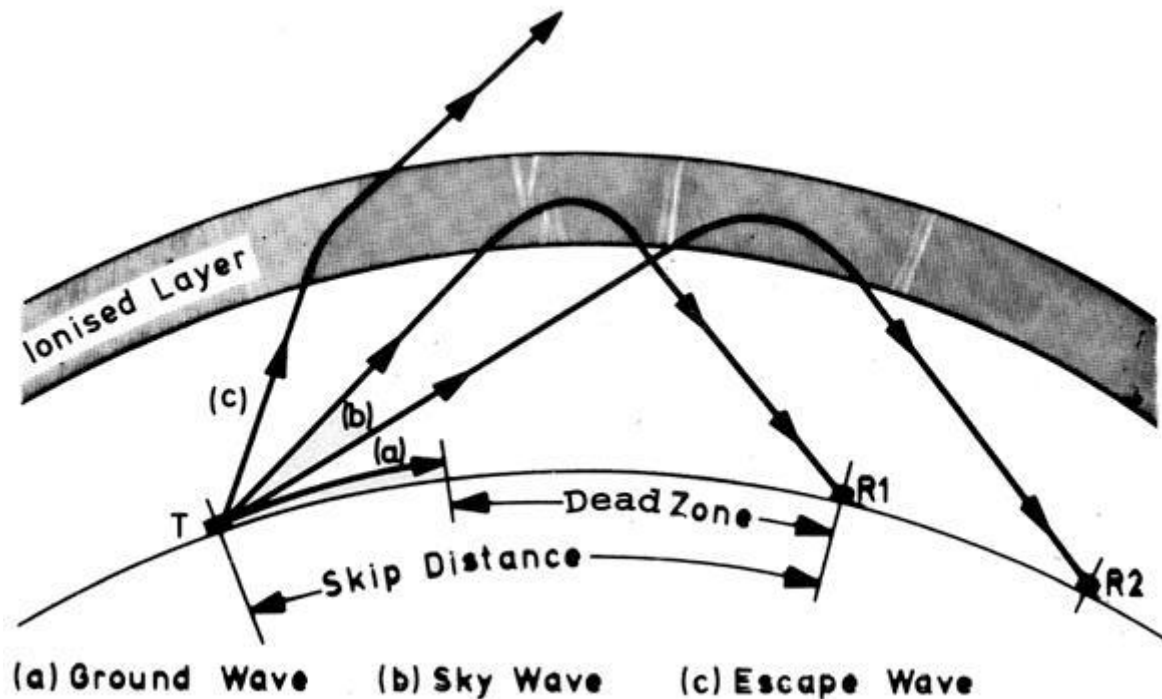
Maximum Usable Frequency (MUF)

The **Maximum Usable Frequency (MUF)** for a defined path is the highest frequency at which reflection can take place; it is independent of transmitter power or antenna gain
Frequencies above the MUF will pass through the ionised layer and not be reflected
The longest signal path for a particular layer is obtained when the wave leaves the earth and approaches the layer at the most oblique angle possible for reflection
Max range for single hop F2 layer propagation is about 4,000 km
Max range for single hop E layer propagation is about 2,500 km
Greater ranges are possible by multi hop propagation where signal is again reflected off ground or a lower layer

Lowest Usable Frequency (LUF)

Lowest Usable Frequency (LUF) is the lowest frequency that can be used on a particular path
It depends on absorption and atmospheric/man-made noise
Can be influenced by power and antenna gain
The LUF can be higher than the MUF in which case there is no frequency that supports communication on the particular path at that time

Section 8 – Radio Amateur Theory & Related Topics

Critical Frequency

The **Critical Frequency** or **Vertical Incidence** is the highest frequency that will return to earth when beamed vertically upwards
For the F2 layer the MUF is approximately three times the F2 critical frequency
For the E layer the MUF is approximately five times the E critical frequency
Critical Frequency is regularly measured by scientific stations

Fading

Fluctuations of the received signal are called
FADING Can be attributed to a variety of reasons
Signals arriving at the receiver by more than one path (**multipath** – due to ionospheric variations) can either reinforce or cancel one another
Polarisation of the radio wave may be changed by propagation conditions resulting in an apparent reduction of strength
At VHF and UHF fading may be attributed to varying atmospheric conditions, temperature, humidity, etc.

Sunspots and Flares

Regions of magnetic disturbance on the surface of the sun
Activity reaches a maximum in **11 year cycles**; level of ionisation follows this cycle
Exceptional long-distance signal paths on higher frequencies at the maximum of the cycle
Severe sunspot disturbances **(Flares)** cause rapid fluctuations of the ionised layers often producing radio blackouts
Solar Flux (solar noise measured at UHF) is used as an indicator of solar activity

Troposphere

Extends from surface of earth to height of 10 km
Refraction of VHF and UHF waves is caused by the varying dielectric constant of air due to water vapour (humidity) and temperature. This causes waves to bend and follow curvature of the earth. This **tropospheric** or **space wave** is the primary mode of propagation at VHF and UHF. **Tropospheric refraction** of waves increases **radio horizon** to around 1.15 times visual line-of-sight
Gradients in the index of refraction due to turbulence and temperature changes cause scattering, creating over-the-horizon paths (**troposcatter**)
Temperature Inversion – humidity at low levels together with increased temperature at higher levels increases refraction significantly. This allows the wave to be '**ducted**' for considerable distances with very little attenuation – **tropospheric ducting**

Section 8 – Radio Amateur Theory & Related Topics

VHF / UHF Propagation

Normally communication is line of sight

Tropospheric Propagation – refraction of waves increases **radio horizon** to about 1.15 times visual line-of-sight

Sporadic E Reflection – reflection of waves off highly ionised sections of the E Layer

Auroral Reflection / Scattering – reflection of waves off ionised regions at higher latitudes (Northern Lights)

Meteor Scatter – reflection from the ionised trails left by meteors. Brief contacts lasting from a few seconds to a minute or more

Earth-Moon-Earth (EME) – reflection off the moon. Maximum power, large antennas and the best receivers are needed to overcome free space and reflection losses and **cosmic noise**

Line of Sight Propagation

Free space attenuation results from signal radiating outward in all directions

Signal power weakens with the square of the distance travelled – double the distance signal power drops by a factor of four (**inverse square law**). Doubling distance halves signal voltage

Line of sight propagation (normal mode at VHF/UHF) approximates the free space model

Limit of line of sight is known as the radio horizon, which **increases as antenna height increases**

Diffraction

Radio waves can be diffracted (bent) around obstacles, e.g. hills giving signal at greater than line of sight distances

Diffraction reduces with increased frequency

Section 9 – Measurements

Making Measurements

Warning: Electronic equipment can contain potentially lethal voltages. Make sure you are familiar with safety procedures before making measurements

DC and AC

D.C. voltages and currents may be measured using digital or analogue meters

The commonly used analogue meter movement is the **moving coil meter** – a small current in the coil sets up a magnetic field that causes the meter to rotate; the rotation is opposed by the spring, so that deflection is proportional to the **average value of the current**

The sensitivity of the meter is defined by the current flow for **full scale deflection (fsd)**

Moving coil meters start at about 50 µA fsd
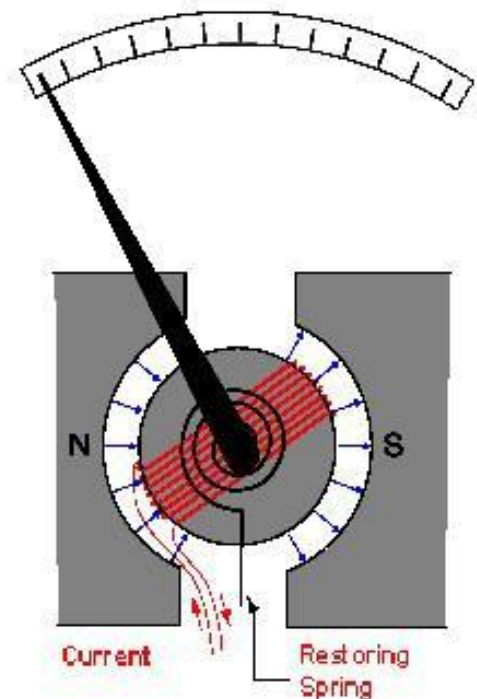
Section 9 – Radio Amateur Theory & Related Topics

Voltage and Current
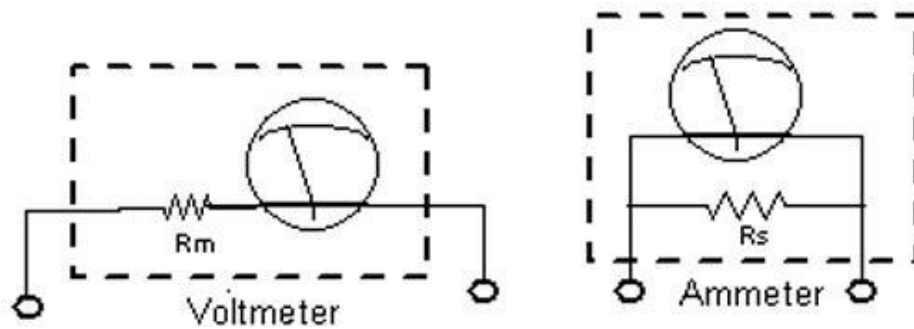
Voltmeter

Ammeter

To make a practical voltmeter a series resistor (**multiplier resistor**) is placed in line with the basic meter; the bigger the value of resistor the bigger the voltage that can be read

To make a practical ammeter, a parallel resistor (**shunt resistor**) is placed across the basic meter

Different values of resistor are used to extend the range of the meter

Moving coil meters only respond to d.c. – to measure a.c. the voltage/current is rectified using a bridge rectifier

The voltmeter responds to **average values of a.c.**, but are **calibrated in r.m.s.** Therefore use on other than a sine wave will lead to errors

The response of the meter changes with frequency and typical meters have a range up to 20kHz

Loading effect of meter

When measuring voltage in high resistance circuits the current drawn by the meter (i.e. internal resistance of the device) may load the circuit and cause inaccuracy

The loading is expressed in ohms/volt for fsd on a particular range; 20k /volt is typical of a reasonably good analogue meter

Voltage and Current

Digital voltmeters consist of an ADC and liquid crystal display (LCD)

They place little loading on circuits under test with an input resistance >10M and give good accuracy

However it is easier to interpret slowly changing readings on an analogue meter, e.g. when making adjustments

Meters can be affected by RF near a transmitter

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Resistance
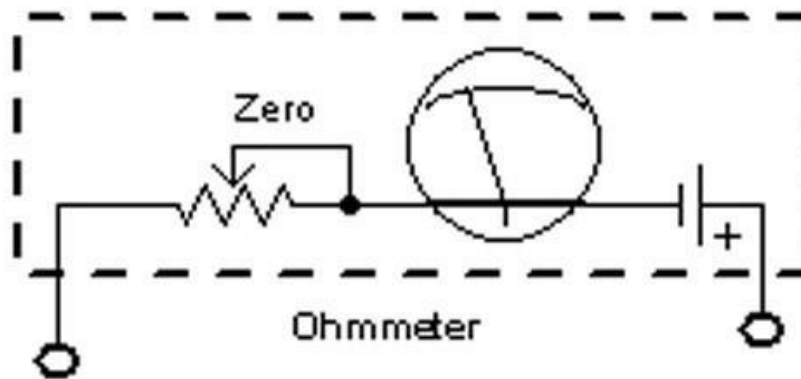
An ohmmeter consists of a battery in series with a meter; a variable resistor is used to set zero when the probes are shorted together; digital meters have auto-zeroing

Analogue ohmmeter scale is non-linear – high values are cramped together at the beginning of the scale

As voltage is applied by the meter, measurement should not be made in live circuits

When checking sensitive semiconductor devices care should be exercised not to exceed voltage limits

Making Measurements – Voltage (V)

To measure voltage the meter is connected across the points of the circuit where voltage is to be determined

Be aware of the size of the voltage to be expected and aware of the loading effect of the meter as discussed

Making Measurements – Current (I)

To measure current the meter is connected in series with the circuit where current is to be determined

Be aware of the size of the current to be expected and aware that the resistance of the meter may affect the operation of the circuit

Making Measurements – Resistance (R)

To measure resistance the meter is connected across the points of the circuit or component where resistance is to be determined

Be aware that the internal batteries may have sufficient voltage to damage semiconductor devices

Be aware that when in-cicuit measurements are being made that multiple components may determine the result

Section 9 – Radio Amateur Theory & Related Topics

Power

D.C. power is the product of voltage and current

$$P = V \times I \quad \textbf{Watts}$$

In the case of a Tx, D.C. Input Power is the d.c. current flowing in the output circuit (collector, drain, anode) of the final amplifier times the applied d.c.voltage

Hot wire ammeter and thermocouple meters can measure average power through its heating effect

RF power is normally measured by a diode probe of adequate bandwidth and a d.c. voltmeter calibrated to measure as watts the voltage across a fixed (50) resistor load; some may be connected inline

$$P_{out} = V^2 \div R$$

Average power is over a period of time; PEP is instantaneous; meters (which also measure VSWR) are available with time constants and calibration to measure both

An oscilloscope which shows the envelope of an RF signal may also be used with a calibration scale

VSWR

Standing waves will appear on a mis-matched transmission line

By sampling the forward and reflected power (or voltage) on a transmission line the Voltage Standing Wave Ratio VSWR (often called SWR) can be determined – this is the principle of the reflectometer
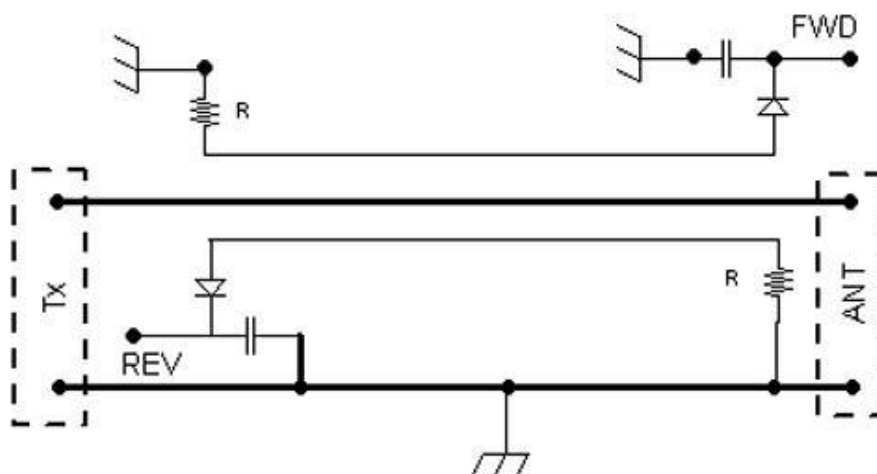
Reflectometers can be designed as VSWR indicators using sampling loops capacitively coupled to a length of transmission line (above)

This results in a deflection roughly proportional to frequency which makes the unit unsuitable for absolute power measurements

However, the use of a ferrite core current transformer to sample renders the meter frequency independent

Section 9 – Radio Amateur Theory & Related Topics

HF Station showing SWR meter
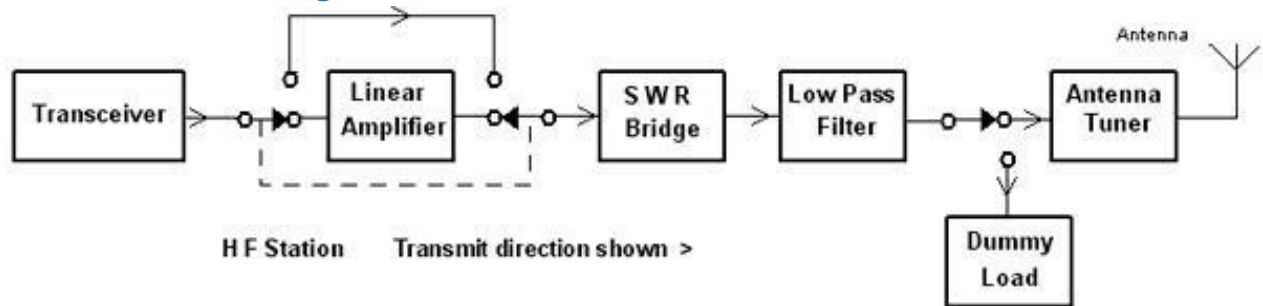
RF Envelope
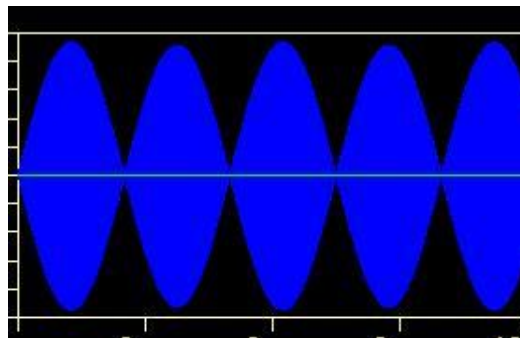
The envelope of an RF signal may be viewed on an oscilloscope of adequate bandwidth with timebase set as if viewing an audio signal

Two audio signals of equal amplitude which are not harmonically related are fed into an ssb transmitter from a two-tone generator resulting in a trace similar to the above

From the trace the power may be calculated and any non-linearity observed

Frequency
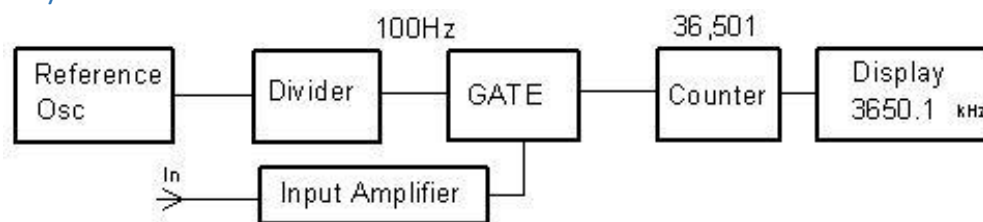
Digital counters which count number of cycles in a known time period can be calibrated to measure frequency – digital frequency meter (DFM)

The gate is opened for a precise time, say, 10mS and the number of cycles counted is 36501; the frequency is 3650.1 kHz

Section 9 – Radio Amateur Theory & Related Topics

Grid Dip Oscillator (GDO)

A GDO is ideal for measuring the resonant frequency of non-energised inductor-capacitor circuits, e.g. traps

If the tuned circuit of a lightly oscillating valve LC oscillator is brought near (coupled with) a tuned circuit with the same resonant frequency a dip in the grid current will occur.

This is the principle of the GDO, though nowadays it is a dip in base current or drain current of a transistorised unit

As a dip in current indicates resonance, a GDO is often called a Dip Meter

The unit has a series of plug-in coils and a calibrated tuning dial to vary frequency, allowing a wide range of resonant frequencies to be measured
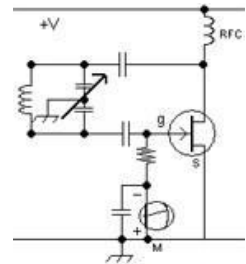
Multirange Meter

A wide range of analogue and digital multi range meters (multimeters) are available to typically measure a.c. and d.c. voltage in a series of steps up to around 1kV, d.c current to 500mA, with a 10A input, while the better models would also measure a.c. current to 10A

In addition the multimeter will measure resistance to several MΩ

Some multimeters will allow measurement of transistor static current gain β.

Unlike digital meters, analogue meters are polarity sensitive

Multimeter Use Summary
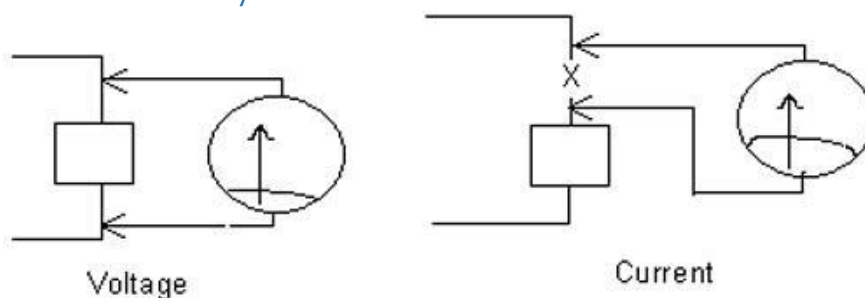
Voltage

Current

Voltage is measured by placing the probes across the circuit where the potential difference (voltage) is to be measured

Current is measured by breaking the circuit and placing the probes in series

Resistance is measured by placing the probes across the circuit. The circuit must be powered off. An analogue meter must be zeroed

Section 9 – Radio Amateur Theory & Related Topics

RF Power Meter

An SWR meter can be calibrated to give average or PEP readings under operating conditions or a separate power meter may be available for use under test conditions

Power meter relies on a proper load; in the case of a transmission line it must have a low SWR

SWR Meter

The SWR meter (reflectometer) often has two meters, one indicating forward power, and the other reverse power; when the forward meter is set by an adjusting knob to fsd the reverse meter calibrated in SWR may be read

Alternatively a dual movement cross pointer meter may be calibrated so that the intersection of the needles gives SWR for any value of forward power

As the meter contains diodes it should be placed before any low pass filter to suppress harmonics

Signal Generator

A signal generator is a variable frequency oscillator that can generate output in the audio and RF range; often the RF output can be modulated

The output level can be set to different values

Thus its output can be fed into a test circuit to measure gain or linearity, the input and output being measured by a voltmeter or oscilloscope

Frequency Counter

Digital frequency meters (DFM) may already be incorporated into a transceiver; stand-alone versions with probe inputs or which connect into the transmission line are readily available

They provide a direct reading of frequency from d.c to the GHz range and are invaluable in calibrating/checking oscillators

Section 9 – Radio Amateur Theory & Related Topics

Oscilloscope

A general purpose instrument for displaying electrical waveforms in the time domain for examination

A display (crt) shows either a single or two traces (dual trace/beam)

The signal normally is fed into the Y-amplifier which means it deflects the trace in the Y direction (vertically) – measuring amplitude

A timebase oscillator normally deflects the trace in the X direction (horizontally)

– measuring time; the speed of the timebase is calibrated in fractions of a second

On the face of the CRT there is a marked graticule (grid like markings) to allow X and Y (vertical) displacement to be measured allowing amplitude (voltage, Y) and frequency (period, X) respectively to be computed

The Y amplifier plus the tube determine the bandwidth of the oscilloscope. Input capacitance and input voltage may restrict uses

Nowadays it is possible to use a PC in conjunction with a suitable Analogue to Digital Converter and appropriate software as an oscilloscope
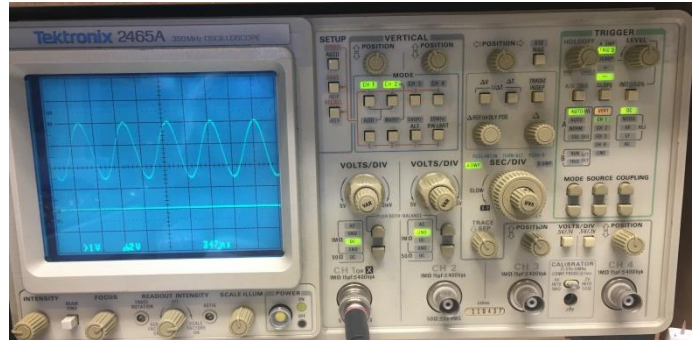
Spectrum Analyser

Allows the display of an electrical waveform in the frequency domain, i.e. shows the spectrum of frequency components (harmonics in this case) contained in the wave as can clearly be seen in the image.

Can be used to check distortion, non-linearity and parasitic output
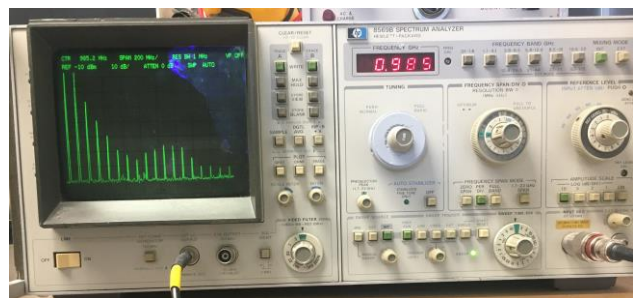
A PC can be used as a spectrum display to enable tuning of digital signals in the audio range

Section 9 – Radio Amateur Theory & Related Topics

Other Instruments

Field Strength Meter – a simple indicating device useful for checking relative field strength from a directional antenna and identifying RF hotspots. The choke can be replaced by a tuned circuit
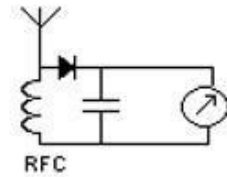
Antenna Analyser – a sophisticated device which comprises an oscillator with a wide tuning range and a bridge. Allows SWR and complex impedance (as series resistance and reactance) to be read when setting up antennas and transmission lines, as well as velocity factor and cable loss

Dummy Load

Used to provide a known load (50Ω) for testing or tuning a transmitter or amplifier for best power output

Should be constructed that it has minimal inductance or capacitance, i.e. it is a pure resistance

Practical loads may be constructed from a combination (series/parallel) of carbon resistors providing it is used for the lower frequencies, typically less than 50MHz.

Section 10 – Interference and Immunity

Electromagnetic Compatibility (EMC)
Electromagnetic Compatibility is the avoidance of interference between two pieces of electronic equipment

Interference and Immunity
Interference from an amateur transmitter falls into two categories:

1. Interference from the legitimate amateur signal to some susceptible piece of equipment – **breakthrough**; Electromagnetic Compatibility (EMC) Standards endeavour to set standards for immunity
2. Interference due to unwanted (spurious) emissions from the amateur station

Overload
TV and radio receiver input stages and mast-head pre-amplifier stages have a **wide bandwidth** to prevent the necessity of retuning or "peaking" as frequency is changed
Amplifier stages become **overloaded and non-linear** resulting in interference to the TV picture or radio signal

Cross Modulation & Blocking
When a strong signal overloads an amplifier it can cause the gain of the amplifier to vary in time with its modulation, imposing its modulation on a wanted AM signal, e.g., TV video, as light and dark horizontal lines; lesser impact on FM signals
SSB is worst for this; interference from FM transmissions might go unnoticed
A strong signal may affect the receiver's AGC circuits, or overload an amplifier stage, turning down gain and causing the wanted signal to become weak or / and noisy; this is known as **desensing** or **blocking**
It is more common from FM or data modes

Intermodulation
Intermodulation distortion (IMD) is where two signals mix together due to non-linearity and produce spurious signals
The TV or radio receiver may have poor **dynamic range** and the spurious signal may appear in, or be generated in, the i.f. passband resulting in interference

Section 10 – Radio Amateur Regulations & Related Topics

Audio Circuits etc.

Audio stages of receivers / hi-fi may experience interference due to rectification in a diode or semiconductor junction in the circuit, or non-linearity

Interference may be caused to security systems, telephones, IR detectors through a similar mechanism

Transmitter Field Strength

An amateur station should only use as much power as is really necessary to make the contact

Field strength falls off over the first few metres from the antenna

A field strength of 3 V/m is near the highest level that electronic equipment might be expected to cope with

Antennas should be kept well away from other antennas and wires

Spurious Radiation

Passive Intermodulation Products (PIPs) the so-called "rusty bolt" effect can be caused by high field strength, causing re-radiation at harmonic frequencies

Transmitter harmonics themselves can cause difficulties and good final amplifier design and operation coupled with low pass or band pass filtering is important

Spurious mixer products should be minimised by good design

Parasitic oscillations, self-oscillation in the transmitter due to poor design or mismatch can lead to interfering signals not related to the band in use

Very poor oscillator stability can result in the Tx drifting outside the allocated amateur band and interfering with other services

Overdriving, excessive microphone/audio gain setting can lead to overloading, non-linearity, excessive bandwidth and harmonic generation in transmitters
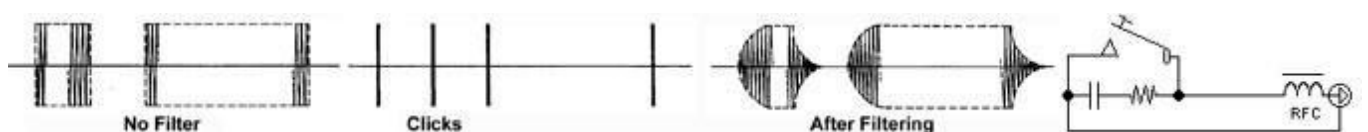
When a carrier is interrupted, as in CW, a sharp interruption will cause sidebands which manifest as **Key Clicks**. These can cause interference over a long distance and wide band of frequencies

Additionally, depending on Tx design, there may be a small spark as the key or keying relay operates which can cause localised interference

The rise time should be conditioned with a key click filter

Routes Taken

Interfering signals can enter TV and radio receivers via the antenna input or down-lead or poor quality cable TV systems

Mains borne interference, either through coupling or the Tx power supply

Coupling into loudspeaker, hi-fi interconnect or telephone leads

Section 10 – Radio Amateur Regulations & Related Topics

Direct radiation from a poorly-shielded Tx

Prevention

Appropriate transmit power

Mode of transmission – FM is the most benign, ssb the worst offender

    Choice of antenna type, location, feeder – balanced antennas and feeders minimise feeder radiation; balanced feed should not run near ground or metal objects as this will unbalance it; use of a balun if feeding a dipole, with good quality co-ax

Appropriate filters

    Suitable filter at the output of the transmitter and/or at the electronic device being interfered with

Ensuring that the complete transmitted signal is inside the allocated amateur band

Types of Filters

Low pass filter passes low frequencies, stops high

(a)
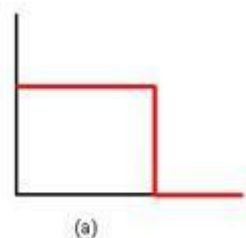
High pass filter passes high, stops low

(b)
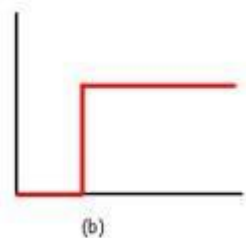
Band Pass passes a range of frequencies and stops (rejects) frequencies outside the passband

(c)
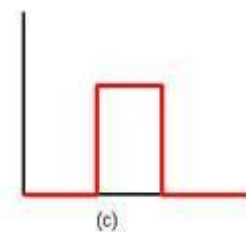
Band stop rejects a range of frequencies and passes all others; if sharp called a **notch**

(d)
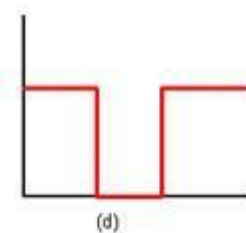
Section 10 – Radio Amateur Regulations & Related Topics
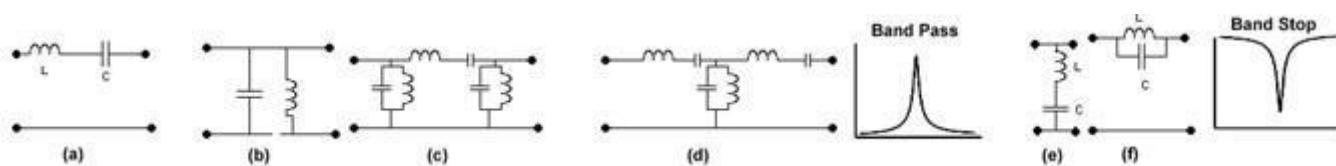
Band Pass (a,b,c,d); shape is not ideal as circuit is only an approximation; in (c,d) filters are **cascaded** to give better response

Band stop (e,f)

LC tuned circuits can be used for either
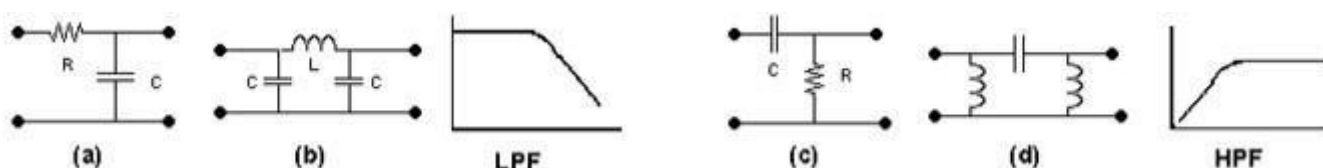
Low pass (a,b)

High pass (c,d)

RC at audio frequencies. LC at RF.

(b) and (d) are known as **Pi filters** due to similarity of configuration to Greek letter
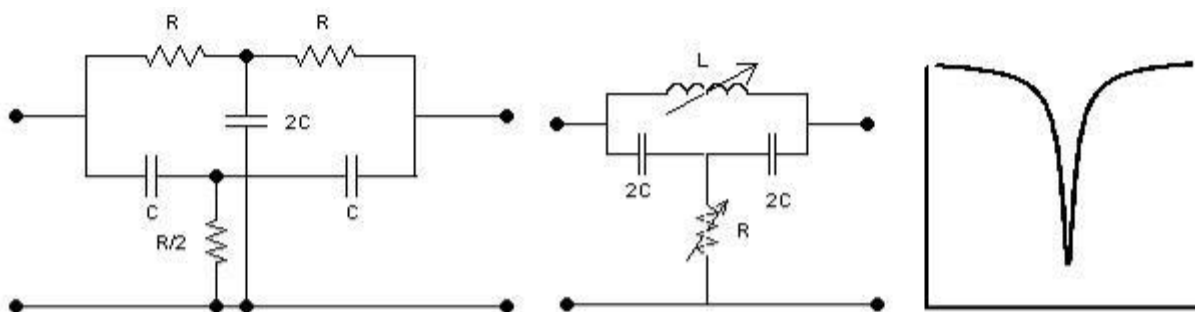
RC **twin T-notch filter** can provide a sharp notch at audio frequencies

LCR **T-notch filter** (bridged-T) can provide notch at higher frequencies. L adjusts frequency, R depth of notch
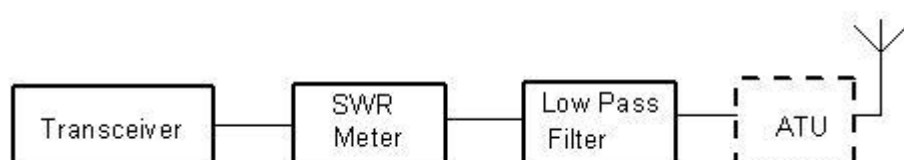
Use of a low pass filter (l.p.f.) with a cut-off at 30 MHz on HF; bandpass filter on VHF

Ideally filter is installed after SWR meter as diodes in this may cause

difficulties Use of an inline mains filter which filters out high frequencies

Section 10 – Radio Amateur Regulations & Related Topics
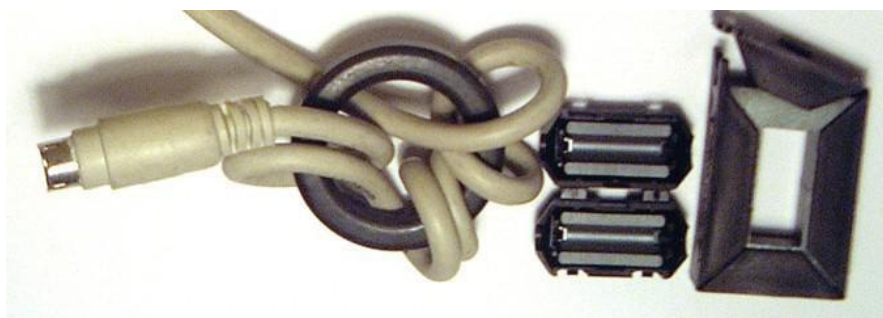
Common mode currents which run on the braid of shielded cables both in the station (microphone, computer, etc.) and on TV/radio downleads, speaker leads and interconnects can be treated with ferrite chokes, also called braid breakers; they are also effective on mains cables

The cable is wound around a ferrite ring (toroid) or passes through a ferrite bead close to where it enters the device to be treated

Use of a high pass filter inserted in the TV antenna down-lead to filter out HF signals

Use of an LC notch filter for specific bands at HF or VHF. Use of an open-circuit electrical /4 stub which will act as a notch (short circuit) at its design frequency

Decoupling

Adequate decoupling by appropriately sized capacitors in homebrew equipment is essential

Leads should be decoupled where they enter the enclosure (power supply, microphone, control lines, etc.)

Decoupling will often eliminate interference to telephones and other devices; however a difficulty is that it involves modifying the device

Shielding & Earthing

Equipment should be adequately shielded, generally in an earthed metal enclosure. This prevents radiation leaving or entering the device

A separate RF earth will prevent signals flowing on the mains (safety) earth; it will also reduce noise pick-up by the amateur station

This separate earth should consist of several earth rods, connected by thick wire or braid

Section 11 – Radio Amateur Theory & Related Topics

Section 11 – Safety

Warning

This module is for examination purposes only. It is NOT intended as a safety manual nor as a substitute for one. No responsibility or liability is accepted by the authors or by MARS for any event or accident occurring as a result of using these notes.

The Law

Note that there is a regulatory requirement for radio amateurs to ensure that "... the safety of persons or property is not endangered ..."

The Human Body

The body is a reasonably good conductor of electricity. Typical resistance from hand to foot is **500Ω** so a considerable current can flow through the body from a high voltage source to earth

Relatively small currents (50mA +) can disturb the electrical conduction system of the heart causing it to go into ventricular fibrillation, a fatal rhythm disturbance

Remember it is current that kills – **"It's the volts that jolt and the mills that kill"**

Even low voltages (above **30/50 volts**) can kill in extremely adverse circumstances

A conduction path from a voltage source through one hand, across the chest cavity to the other hand grounded is the worst scenario; keep one hand behind your back when working on high voltages

Dealing with Electric Shock

Shut off the power

Ensure the person is in a safe place

Call for help

Commence CPR if necessary and you are qualified to do so

Electromagnetic Radiation

Eyes may be damaged through heating by high RF power density common at microwave frequencies; never look into an active waveguide

Chemicals

Soldering should be carried out in a well-ventilated area; avoid inhaling the fumes; use lead-free solder; wear suitable eye protection as solder may splatter

Caution is required with chemicals such as solvents and cleaners; avoid inhalation

Section 11 – Radio Amateur Regulations & Related Topics

Some power transistors contain Beryllium Oxide (BeO). Don't open any device containing it. It is toxic if inhaled in dust form

Polychlorinated biphenyls (PCBs) were used in transformers and high voltage capacitors – names to watch for are Arachlor, Pyrochlor, Pyranol and Asbestos. Special disposal arrangements

Workshop

Etchants and other chemicals for producing Printed Circuit Boards can be highly corrosive and toxic; wear suitable hand and eye protection

When using tools, especially power tools, for operations such as drilling, sawing and filing make sure that the tool/workpiece is securely positioned; wear suitable eye protection

Make sure ladders are at a suitable angle and get someone to support it

Mains Supply

Ordinary 220/230 volt circuits are the most common cause of fatal electrical accidents

Power to the amateur's station should be controlled by a double pole master switch which breaks the live and neutral. Its location and purpose should be known to all family or club members

A **Residual Current Device (RCD)** which should be fitted in the mains feed to the station immediately after the master switch

An **RCD** or **ELCB (Earth Leakage Circuit Breaker)** in a fraction of a second cuts off the power if the current flowing in the live and neutral become unequal by a preset amount (usually 30mA) which would happen if that amount of current flowed from live to earth

Remember a lethal current (50mA) could flow through you to earth without a fuse blowing. An RCD would trip out at over 30mA of current flow to earth

If a person comes in contact with live circuits, switch power off before giving assistance

Installation

All exposed metal surfaces should be properly earthed through a low resistance path to earth. Microphone and morse key cases should be properly connected to a grounded chassis

Wiring should be adequately insulated to avoid short circuits and electric shock. The wire should also be an appropriate power rating for the current involved

In three core flexible mains lead —

- o   the live conductor is **BROWN**
- o   the neutral **BLUE** and
- o   the earth GREEN with a **YELLOW** stripe

Plug tops should have appropriately rated fuses fitted.

Approximate values are —

- o   3A = 660 watts
- o   5A = 1100 watts
- o   13A = 2860 watts

Section 11 – Radio Amateur Regulations & Related Topics

Power Supplies

On/Off switches should be double pole isolating both the live and the neutral

A mains fuse of appropriate value should be fitted in the **live lead only** on the equipment side of the switch. This helps protect the lead to the supply.

A fuse, or fuses, of appropriate value should be fitted on the output/s of the power supply.

Micro switches should be installed so that high voltage supplies for valve power amplifier stages are **automatically disconnected** when the cover is removed

In high voltage power supplies a **bleeder resistor** should be connected across each smoothing capacitor to allow them to discharge after the power is switched off

Do not rely on bleeder resistors. They can go open circuit. Use a shorting stick to ensure high voltage smoothing capacitors are discharged

<mark>Switch off before replacing fuses</mark>

Adjustments

As a general rule always switch off and unplug equipment before undertaking any work.

When adjustments must be made to powered on equipment, use a plug-in RCD in the mains socket. Power will disconnect if more than 30mA flows to earth

Use one hand only to make adjustments and ensure the other hand is not grounded. **Never provide a current path from one hand across your chest cavity to your grounded other hand**

Remove watches, necklaces and other jewellery which might cause a short circuit

Antenna (Aerial) Safety

There can be very high RF voltages on the ends of antennas. Make sure they cannot be touched by humans or animals, as **RF burns** can occur.

Installation should follow good engineering practice. Be very aware and careful of **overhead power lines** and what may happen if the antenna breaks or falls.

Towers, masts and rotators should be rated for the loads (including wind load) involved. Guy ropes should be 60 – 80% of the mast height out from the base.

Towers/Masts should be twice their own height from power lines people and property

A low resistance DC path to ground through a high current RF choke should be provided at the output socket of a transmitter/linear using high DC voltage. Without this a shorted DC blocking capacitor in the anode circuit would put high DC voltage on the antenna.

Lightning

Towers should have each leg connected to a separate ground rod and these should be bonded together. Use heavy duty conductors.

Fit static dischargers (lightning arrestors) in antenna feeders.

When thunderstorms are forecast, disconnect and ground all feeders preferably outside the building.

- Ideally all antennas should be grounded when not in use In open wire feeders use spark gap type static dischargers
- Ground rods should be at least 1500mm to 2400mm (5–8 feet) long and 12.5mm (½ in) in diameter and should be made of copper, galvanised steel rod or stainless steel.

- Several should be used spaced apart and they should be bonded together with a large diameter conductor

Non-Ionising Radiation

Heating of body cells by RF is only a risk if the heat is not dissipated by the body's cooling mechanisms

World Health Organisation recommends that adult exposure should not exceed a power density of 0.2mW/cm^2 (28V/m)

Recommendations

- Keep power output as low as feasible
- Site antennas as far away from people as possible ₒ
  More caution is needed with increased frequency

NIR – RF Exposure

These reference levels are not limits on exposure but compliance with them ensures compliance with the basic restrictions on exposure

Field Strength (V/m) = (7 × erp) ÷ d where "**d**" is the distance in metres from the antenna

Mobile/Battery Safety

Mount equipment securely

Fuse both positive and negative leads. Never short a high capacity battery. There is a risk of fire or explosion

Use a hands-free microphone and an easy to reach one-switch control

Major adjustments (band changes) should be made when stationary

Switch off engine and equipment when refuelling

Carry a suitable fire extinguisher

TABLE 1: SCHEDULE OF FREQUENCY BANDS FOR RADIO AMATEUR (CLASS A)			
Frequency Bands (in MHz)	Status of allocations to the Amateur Service	Status of allocations to the Amateur Satellite Service	Maximum Peak Envelope Power level in Watts (and dB relative to 1 Watt)
1.810-1.850	Primary	Not allocated	800W (29 dBW)
3.500-3.800	Primary. Shared with other services	Not allocated	800W (29 dBW)
7.000-7.100	Primary	Primary	800W (29 dBW)
7.100-7.200	Primary	Primary	800W (29 dBW)
10.100-10.150	Secondary	Not allocated	800W (29 dBW)
14.000-14.250	Primary	Primary	800W (29 dBW)
14.250-14.350	Primary	Not allocated	800W (29 dBW)
18.068-18.168	Primary	Primary	800W (29 dBW)
21.000-21.450	Primary	Primary	800W (29 dBW)
24.890-24.990	Primary	Primary	800W (29 dBW)
28.000-29.700	Primary	Primary	800W (29 dBW)
50.00-51.00	Primary. Available on the basis of non-interference to other services outside Rep of MRU	Not allocated	800W (29 dBW)
51.00-52.00	Secondary. Available on the basis of non-interference to other services outside Rep of MRU	Not allocated	100W (20 dBW)
144.0-146.0	Primary	Primary	400W (26 dBW)
430.0-435.0	Primary	Not allocated	400W (26dBW)
435.0-438.0	Primary	Secondary	400W (26dBW)
438.0-440.0	Primary	Not allocated	400W (26dBW)
1240-1260	Secondary	Not allocated	400W (26 dBW)
1260-1270	Secondary	Secondary. Earth to space only.	400W (26 dBW)
1270-1300	Secondary	Not allocated	400W (26 dBW)
2300-2400	Secondary	Not allocated	400W (26 dBW)
2400-2450	Secondary. Users must accept interference from ISM users.	Secondary. Users must accept interference from ISM users.	400W (26 dBW)

SCHEDULE OF FREQUENCY BANDS FOR RADIO AMATEUR (CLASS A)			
Frequency Bands (in MHz)	Status of allocations to the Amateur Service	Status of allocations to the Amateur Satellite Service	Maximum Peak Envelope Power level in Watts (and dB relative to 1 Watt)
5650-5670	Secondary	Secondary. Earth to space only.	400W (26 dBW)
5670-5725	Secondary	Not allocated	400W (26 dBW)
5725-5830	Secondary	Not allocated	400W (26 dBW)
5830-5850	Secondary. Users must accept interference from ISM users	Secondary. Users must accept interference from ISM users. Space to Earth only.	400W (26 dBW)
10000-10450	Secondary	Not allocated	400W (26 dBW)
10450-10500	Secondary	Secondary	400W (26 dBW)
24000-24050	Primary. Users must accept interference from ISM users	Primary. Users must accept interference from ISM users	400W (26 dBW)
24050-24250	Secondary. Users must accept interference from ISM users	Not allocated	400W (26 dBW)
47000-47200	Primary	Primary	400W (26 dBW)
76000-77500	Secondary	Secondary	400W (26 dBW)
77500-78000	Primary	Primary	400W (26 dBW)
78000-79000	Secondary	Secondary	400W (26 dBW)
79000-81000	Secondary	Secondary	400W (26 dBW)
122250-123000	Secondary	Not allocated	400W (26 dBW)
134000-136000	Primary	Primary	400W (26 dBW)
136000-141000	Secondary	Secondary	400W (26 dBW)
241000-248000	Secondary	Secondary	400W (26 dBW)
248000-250000	Primary	Primary	400W (26 dBW)

SCHEDULE OF FREQUENCY BANDS FOR RADIO AMATEUR (CLASS B)			
Frequency Bands (in MHz)	Status of allocations to the Amateur Service	Status of allocations to the Amateur Satellite Service	Maximum Peak Envelope Power level in Watts (and dB relative to 1 Watt)
1.810-1.850	Primary.	Not allocated	10W (10 dBW)
3.500-3.800	Primary. Shared with other services	Not allocated	10W (10 dBW)
7.000-7.100	Primary	Primary	10W (10 dBW)
10.100-10.150	Secondary	Not allocated	10W (10 dBW)
14.000-14.250	Primary	Primary	10W (10 dBW)
14.250-14.350	Primary	Not allocated	10W (10 dBW)
18.068-18.168	Primary	Primary	10W (10 dBW)
21.000-21.450	Primary	Primary	10W (10 dBW)
24.890-24.990	Primary	Primary	10W (10 dBW)
28.000-29.700	Primary	Primary	10W (10 dBW)
50.00-51.00	Primary. Available on the basis of non-interference to other services inside or outside the Rep of MRU	Not allocated	10W (10 dBW)
51.00-52.00	Secondary. Available on the basis of non-interference to other services inside or outside the Rep of MRU	Not allocated	10W (10 dBW)
144.0-146.0	Primary	Primary	10W (10 dBW)
430.0- 435.0	Primary	Not allocated	10W (10dBW)
435.0-438.0	Primary	Secondary	10W (10dBW)
438.0-440.0	Primary	Not allocated	10W (10dBW)
1260-1270	Secondary	Secondary. Earth to space only	10W (10dBW)
2400-2450	Secondary. Users must accept interference from ISM users.	Secondary. Users must accept interference from ISM users.	10W (10dBW)
5650-5670	Secondary	Secondary. Earth to space only	10W (10dBW)
10000-10450	Secondary	Not allocated	1W (0 dBW)
10450-10500	Secondary	Secondary	1W (0 dBW)

TABLE 1: SCHEDULE OF FREQUENCY BANDS FOR RADIO AMATEUR (CLASS A)

Frequency Bands (in MHz)	Status of allocations to the Amateur Service	Status of allocations to the Amateur Satellite Service	Maximum Peak Envelope Power level in Watts (and dB relative to 1 Watt)
1.810-1.850	Primary	Not allocated	800W (29 dBW)
3.500-3.800	Primary. Shared with other services	Not allocated	800W (29 dBW)
7.000-7.100	Primary	Primary	800W (29 dBW)
7.100-7.200	Primary	Primary	800W (29 dBW)
10.100-10.150	Secondary	Not allocated	800W (29 dBW)
14.000-14.250	Primary	Primary	800W (29 dBW)
14.250-14.350	Primary	Not allocated	800W (29 dBW)
18.068-18.168	Primary	Primary	800W (29 dBW)
21.000-21.450	Primary	Primary	800W (29 dBW)
24.890-24.990	Primary	Primary	800W (29 dBW)
28.000-29.700	Primary	Primary	800W (29 dBW)
50.00-51.00	Primary. Available on the basis of non-interference to other services outside Rep of MRU	Not allocated	800W (29 dBW)
51.00-52.00	Secondary. Available on the basis of non-interference to other services outside Rep of MRU	Not allocated	100W (20 dBW)
144.0-146.0	Primary	Primary	400W (26 dBW)
430.0-435.0	Primary	Not allocated	400W (26dBW)
435.0-438.0	Primary	Secondary	400W (26dBW)
438.0-440.0	Primary	Not allocated	400W (26dBW)
1240-1260	Secondary	Not allocated	400W (26 dBW)
1260-1270	Secondary	Secondary. Earth to space only.	400W (26 dBW)
1270-1300	Secondary	Not allocated	400W (26 dBW)
2300-2400	Secondary	Not allocated	400W (26 dBW)
2400-2450	Secondary. Users must accept interference from ISM users.	Secondary. Users must accept interference from ISM users.	400W (26 dBW)