

FULL AMATEUR RADIO LICENCE NOTES

CAPACITANCE

$$C = \frac{A \epsilon_0 \epsilon_r}{d} = \frac{k A}{d}$$

Plastic film capacitors can be lossy at higher frequencies - the dielectric absorbs energy, transferring it as heat energy. Polystyrene, mylar & PTFE are more stable. High-k ceramic capacitors allow relatively high capacitances in low volumes but are lossy & unsuitable for radio frequencies.

Beware the danger from high voltage capacitors even after switch off! a discharge path e.g. a high value resistor should be provided.

INDUCTANCE

Current through a wire induces a magnetic field around the wire. A changing current leads to a changing magnetic field.

Faraday's Law: induced emf $\propto \frac{d\Phi}{dt}$ (rate of change of magnetic flux)

- induced emf leads to an induced current in a complete circuit.

$$E = (-) L \frac{dI}{dt}$$

Lenz's Law: direction of the induced current is such to oppose the motion which caused it. (This is "BACK EMF")

Inductance increases with N of turns, increased diameter & length. A coil of more turns will have a greater back EMF for the same ^{rate of} change in current. An inductor stores energy in its magnetic field.

Inserting a core made of a high permeability material can increase the intensity of the magnetic field i.e. increase the inductance of a coil. A slug of ferrite material, the length of which is in the coil can be varied, allow the inductance of the coil to be varied. 'Slug tuning' uses this principle to vary the resonant frequency of an LC network.

Different grades of ferrite are optimised for different frequency ranges. The ability of a material to concentrate a magnetic field is its permeability.

The rate at which current rises in an L-R circuit can be quantified in the same way as an R-C circuit.

$$\text{time constant} = \frac{L}{R}$$

Inductors combine in series and parallel in the same way as resistors.

Alternating currents

CIVIL: In a capacitor, current leads voltage by 90° ,
in an inductor, voltage leads current by 90°

Reactance is the opposition to current flow in a purely capacitive or inductive circuit where the phase difference between current and voltage is 90° .

$$X_C = \frac{1}{2\pi f C} \quad X_L = 2\pi f L$$

An inductor is a short circuit to DC: on AC its reactance increases with frequency.
A capacitor, once charged, is an open circuit to DC, but on AC its reactance falls with frequency.

X_C and X_L cannot simply be added as the voltages are not in phase.

However the current is common and so is the reference vector - 'phasor'.

The voltage across the resistor is in phase with the current so is drawn parallel to the current phasor. V_C lags current by 90° so is drawn vertically downwards. At any point, V_s must be the vector sum of V_R & V_C . Use Pythagoras' theorem to solve.

Impedance is the opposition to alternating current posed by both the reactive and resistive portions of a circuit.

$$\text{impedance, } Z = \sqrt{R^2 + X_C^2} = \sqrt{R^2 + X_L^2}$$

Coupling, decoupling and blocking

Where we need to feed the output signal of one stage to the next without affecting the DC voltage needed to power the circuit, this is known as coupling. A capacitor is used as it passes AC but blocks DC. The capacitor used must have a reactance lower than the resistance of the circuit at the frequency of interest.

Decoupling is used to ensure there are no alternating signals at a particular point in a circuit: this requires a (shunt) capacitor from that point to ground/0V. At the lowest frequency of interest the reactance of the capacitor must be significantly lower than the resistance of the circuit.

An RF choke is an inductor used to provide DC power to a part of a circuit where radio frequency signals are present. The inductor needs to have a fairly low DC resistance, but be able to present a high ^{impedance} reactance to radio frequencies.

Resonance

At the resonant frequency, $X_L = X_C$

A series ~~etc~~ LC network gives a dip in impedance at f_0 , while a parallel LC network gives a peak in impedance at f_0 .

In a parallel tuned circuit the reactive components do cancel — at resonance the small current and voltage are in phase. The high impedance at resonance is thus resistive and is the dynamic resistance, R_D .

Effective resistance of a parallel tuned circuit at resonance, $R_D = \frac{L}{RC}$

Magnification, or 'Q' factor, is a measure of the selectivity of a tuned circuit — its ability to select only the wanted frequency and reject nearby frequencies. It is defined by the ratio of reactance X_L or X_C to the coil resistance R .

$$Q = \frac{X_C}{R} = \frac{1}{2\pi f C R} = \frac{X_L}{R} = \frac{2\pi f L}{R} = 2\pi f C R_D \quad (\text{as } R_D = \frac{L}{RC})$$

Notice that a high Q implies a high R_D — a high Q occurs if the series resistor (often the resistance of the coil) is low or R_D high.

$$Q = \frac{f_0}{\text{bandwidth}}$$

The bandwidth is the range of frequencies over which the power gain does not fall below $\frac{1}{2}$ the maximum, or the voltage gain below $\frac{1}{\sqrt{2}}$ of the maximum.

If the Q -factor is too high it can often be lowered through the use of a damping resistor, which will bring down the height of the peak of the resonance curve and increase the bandwidth.

High- Q filters can have quite high currents circulating in a parallel LC circuit, and voltages in a series circuit, so we need to ensure the components are adequately rated.

Shape factor is the ratio of the -6dB bandwidth to the -60dB bandwidth — an indicator of how well a system rejects adjacent off-frequency signals.

TRANSFORMERS

Electrical energy is transferred between the primary and secondary coils as a result of changing magnetic flux (due to the changing current) and the resulting induced EMF. The closer the two coils, the better the energy transfer (need to maximise flux linkage). When two coils are magnetically coupled, they can be said to have mutual inductance.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \quad \text{but} \quad \frac{I_p}{I_s} = \frac{N_s}{N_p} \quad (\text{the other way round})$$

Impedance is transformed by the square of the turns ratio

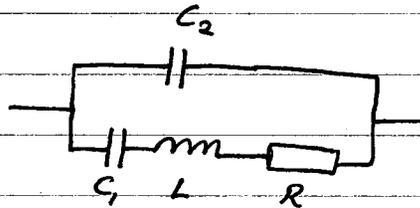
$$\frac{Z_{IN}}{Z_{OUT}} = \left(\frac{N_p}{N_s}\right)^2$$

'Eddy currents' can be induced in solid transformer cores, and have a heating effect which introduces inefficiencies — they can be avoided by using a

Laminated core. The ferrite material needed for radio frequency is held in a non-conducting binder for the same reason.

CRYSTALS

The equivalent circuit:



Crystals can act like tuned circuits: they exhibit series and parallel resonance, so they can be used in single frequency oscillators and filters.

Response curve has a series response (peak) & parallel (dip) (in terms of voltage).

Key advantage of a crystal is the Q -factor is much greater than for a real LC circuit.

TEMPERATURE EFFECTS

Mixing positive and negative coefficient components in a tuned circuit can aid stability - the variations cancel each other out to some extent.

It is also wise to locate temperature sensitive subsystems such as oscillators and tuned circuits well away from those that generate heat eg power amplifiers.

Crystals can be placed inside an oven to further stabilise them - warming element in an enclosure to maintain a steady temperature.

SOLID STATE DEVICES

Doping semiconductor material can create P-type (missing electrons) or N-type (extra electrons).

Actual (i.e. not conventional) current flow is the movement of electrons - the direction of which must be from negative to positive due to the negative charge on the electron, but we can imagine it as the movement of 'holes' (where an atom is missing an electron) from positive to negative (so in the same direction as conventional current flow).

At a P-N junction, electron/hole movement takes place and the mobile electrons & holes cancel each other out to form a narrow depletion layer. The depletion layer has no mobile electrons or holes, so no further movement can take place naturally - it is in equilibrium.

When not biased, the 'p' side with holes is the anode, and the 'N' side with electrons is the cathode.

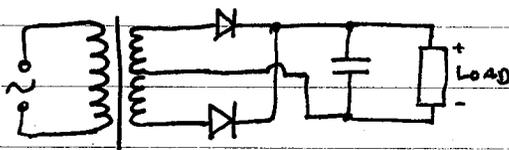
If forward biased, the P side of the junction is connected to the positive power supply terminal, and the N side to the negative. Electrons move towards the positive terminal & holes towards the negative, narrowing the depletion layer - if the potential difference is great enough ($\approx 0.6V$) ($\approx 0.6V$) there will be enough movement to form a continuous path and current can flow through the P-N junction.

If in reverse bias, the P side is more negative ~~th~~ and the N side more positive - this results in the electrons and holes moving away from the centre of the P-N junction and so the depletion layer widening as the area with no mobile holes or electrons widens. No current can flow through the junction.

RECTIFICATION

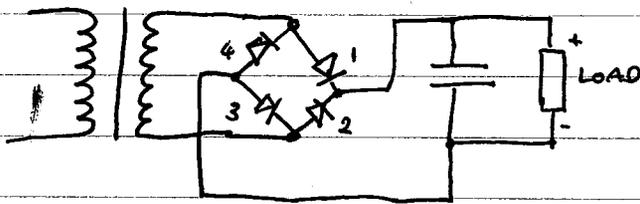
HALF-WAVE rectification makes use of a diode and smoothing capacitor. The diode means that only the positive portions of the input waveform can pass, and the smoothing capacitor helps to 'fill in the gaps' left by the missing negative portion. The bigger the capacitor the less the 'ripple'. Note missing $\sim 0.6\text{ V}$ due to V_{fwd} of the diode.

FULL-WAVE rectification requires two diodes and a centre-tapped transformer. One diode conducts during the positive portion, and the other in the negative portion — giving twice as many positive (or negative) pulses, reducing the time the smoothing capacitor has to fill



Compared to $\frac{1}{2}$ wave, half the total current flows in each diode & each half of the transformer winding.

If a centre-tapped transformer is not an option, the BRIDGE RECTIFIER could be used.



When input is positive, current flows through $D_1 \rightarrow \text{LOAD} \rightarrow D_3 \rightarrow \text{transformer}$.

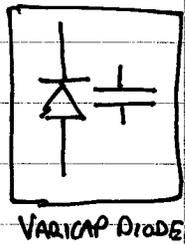
When negative: $D_2 \rightarrow \text{LOAD} \rightarrow D_4 \rightarrow \text{transformer}$.

The current through the load is always in the same direction regardless of the polarity of the transformer output.

A diode used in a rectifier could have the full supply p.d. (with one polarity) and the smoothing capacitor's charge (with the other polarity) across it, it must be able to handle twice the ^{PEAK} supply voltage — this is the PEAK INVERSE VOLTAGE (PIV)

ZENER DIODE - only a small reverse current flows up to a set point, at which there is a significant increase in the reverse current which can flow. At this point the reverse voltage across the diode becomes constant so long as a minimum current flows - this is the zener voltage and is determined during the manufacturing process. The breakdown is not destructive so long as a maximum rated current is not exceeded. Beware that if a zener diode is placed in forward bias it will conduct just as any normal diode would - possible exam trap here.

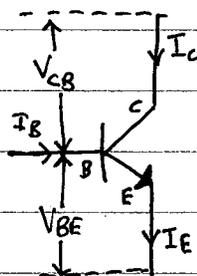
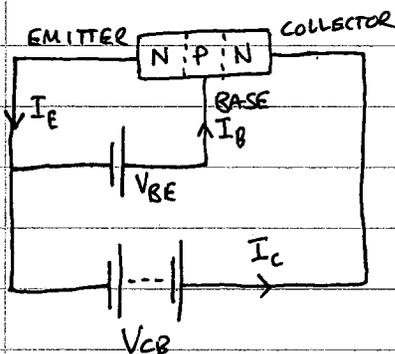
VARIABLE CAPACITANCE DIODES - often referred to as varicap or varactor diodes (both are the same thing).



- takes advantage of an effect present in all diodes: the depletion layer in a reverse biased diode forms the dielectric of a capacitor, and the magnitude of the bias affects the width of the layer and so the capacitance (greater bias = wider layer = lower capacitance = increased frequency).
- Varicap diodes are often used to tune circuits - the biasing voltage and so the capacitance is varied using a potentiometer. This is instead of using a variable capacitor, which is mechanically more complex.

(BIPOLAR) TRANSISTORS

Transistors could be considered as two diodes back-to-back



$$I_E = I_B + I_C$$

If the base did not have forward bias, the electrons would not cross the E-B junction and so could not progress to the collector. By controlling the small base current, I_B , we can control the much greater collector current, I_C . The ratio of I_C to I_B is the current gain β (DC). h_{FE} is the gain of an a.c. signal superimposed

on the DC bias current

$$\text{DC current gain, } \beta = \frac{I_c}{I_B}$$

The operation of the PNP transistor is similar, but the voltages and currents must be reversed. The emitter is now made from P-type material and the current/charge carriers are holes instead. These imaginary holes cross from the emitter to the N-type base, where some will combine with free electrons and the majority will make it through to the collector.

To function correctly, a transistor needs to be BIASED - this is where the appropriate voltages are applied to it. For an NPN transistor:

- The base-emitter junction must be forward biased - greater V_{at} base than emitter.
- The base-collector junction must be reverse biased - greater V_{at} collector than at base.
- The resistors used for biasing must be selected to provide the minimum biasing current at the appropriate voltages.
- base-emitter junction is forward biased so will have approx same voltage drop as a diode: $\sim 0.6V$.

AMPLIFIERS

All ~~bip~~ bipolar junction transistor amplifiers work on the principle that small base current causes large collector current.

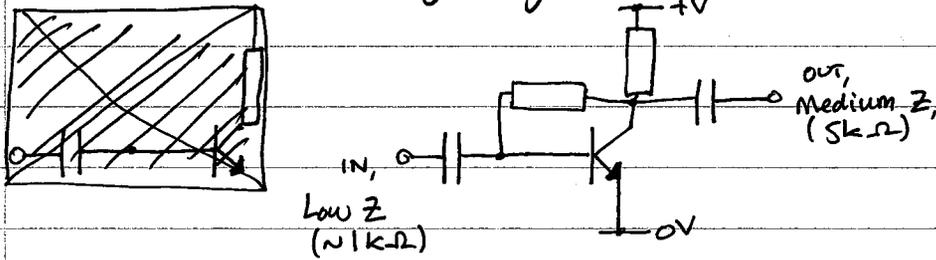
- note DC input power is always more than RF or AF output power. Unless otherwise stated efficiency is assumed to be 60%

THREE main transistor amplifier configurations:

- ① common emitter
- ② common base
- ③ common collector/emitter follower

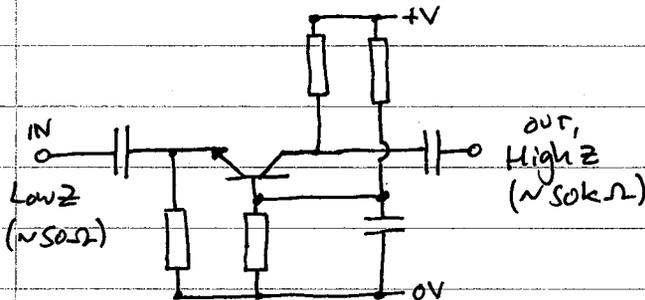
Think about which connection is common to both input and output, and which pin does NOT have an input or output signal connection.

Common emitter is the only configuration which inverts the signal.



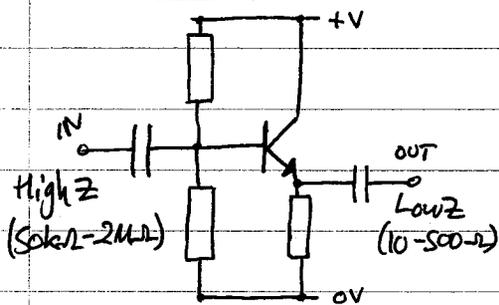
A positive input voltage increases V_{BE} and $I_B \Rightarrow$ increasing I_C and causing a fall in collector voltage. Phase is inverted.

A common base amplifier has the base common to both the input and output.



There is no current gain in this circuit, only voltage gain. This mode also has the highest maximum operating frequency.

The emitter follower circuit uses a common collector.



The voltage gain of this system cannot be more than 1.

- B - Low High output
- C - High in Low output
- E - Medium output

Low \rightarrow B \rightarrow HIGH \rightarrow C \rightarrow LOW \rightarrow E \rightarrow MEDIUM

The CLASS of an amplifier depends on how it is BIASED.

CLASS A: collector current flows all the time, (so least efficient)
no distortion as amplifier on both positive & negative cycles

CLASS B: transistor is biased just on the edge of conduction. Any positive-going signal is amplified, but negative portions of the signal are ignored
— so more efficient, but introduces some distortion

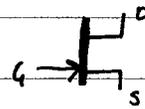
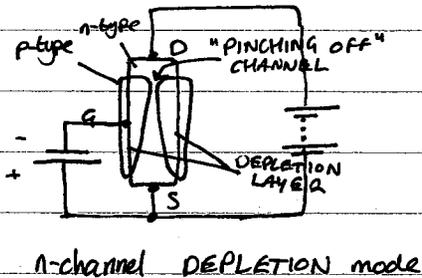
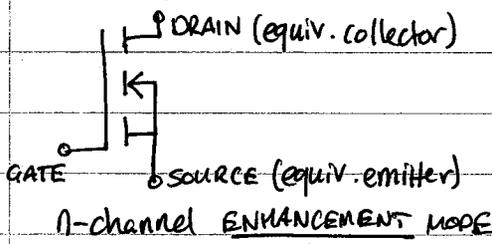
CLASS A/B: between A & B. Some collector current flows in quiescence.
Positive-going signals are amplified normally as are some of the negative-going parts of the signal. A large negative input would result in the collector current falling to 0 & the bottom of the

CLASS C: Here the base is reversed-biased and no collector current flows. A large positive input signal is needed to turn the transistor on. If the drive signal is very large the transistor is turned completely on, the collector voltage becomes zero and the current is limited only by any resistance in the circuit connected to the collector. Here the transistor is essentially used as a switch — but at high frequencies.

This is the most efficient amplifier class but comes with high levels of distortion, and many harmonics.

A PUSH-PULL amplifier uses two transistors in CLASS B bias, but sharing current. One transistor handles positive aspects and the other negative. Current is shared between the two transistors so there is less heat and less distortion. Quiescent current is very low.

FIELD EFFECT TRANSISTORS consist of a channel of n-type material with a ring of p-type material around the middle (the reverse is true for the p-channel MOSFET).

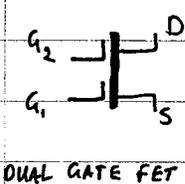


There is a ~~PN~~ depletion layer at the P-N junction, as made. A voltage at the gate opens or closes the channel as the depletion layer widens or narrows.

- Voltage applied to the gate increases the reverse bias on the P-N junction, making the depletion layer wider
- widening the depletion layer 'pinches off' the channel, and no current ^{can} flow.
- depletion layer is tapered along the length of the channel due to the voltage drop
- gate is always reverse biased so no current flows into the gate (reverse leakage current is very small)
 - so FET has a very high input impedance, which is further increased by the addition of ^{an} insulating metal oxide layer between the n-channel & p-gate.

If the device is constructed so that the channel is narrower and is pinched off without additional biasing, it operates in enhancement mode. Here, a small forward bias is needed to achieve conduction

It is possible to have the channel formed from p-type material and surrounded by n-type material instead. This is the equivalent of the PNP transistor.



With a dual gate FET, gate 1 (nearest the source) is used as for a single gate FET, and gate 2 is often connected to a small positive voltage - the magnitude of which will vary the FET's characteristics. Gate 2 could also be used as an additional signal input.
eg RF amp: G_2 voltage used to control signals into G_1 , or can be

used as a mixer if each gate has an input signal.

SMOOTHING CAPACITORS - designers use the principle of the capacitor being fully charged after 5 time periods when selecting values of smoothing/reservoir capacitors. Note that they need to be able to charge and discharge quickly to handle rapid fluctuations in the power supply.

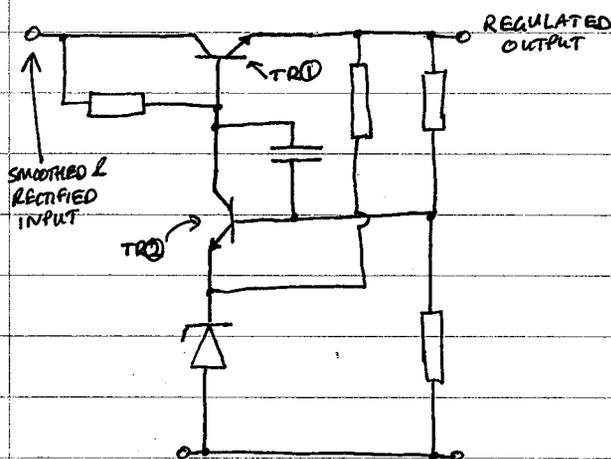
The remaining unevenness is 'RIPPLE' - 50 Hz in half-wave rectification, and 100 Hz in full-wave rectification. It can lead to hum in the receiver.

REGULATING POWER SUPPLIES

① Integrated circuit

- requires the input to be a few volts higher than the output voltage
- input and output must both have decoupling capacitors to prevent spurious oscillation
- some IC setups have additional components to allow adjustable output i.e. a variable power supply.

② Pass transistor with Zener diode



- TR1 is the series pass transistor that is actually carrying the regulated output - it passes a high current to the load.
- TR2 compares the regulated output with a reference ^{voltage} output, which is set by a suitably rated zener diode on the emitter of TR2.
 - zener passes very little current! makes use of high β of TR2

- Output V stabilised against changes of load current and against input voltage changes.
- Capacitor avoids any tendency to instability or self-oscillation - often will also have a small decoupling capacitor across the output eg if powering an AF stage.

DECIBELS

$$3\text{dB} = \times 2$$

$$10\text{dB} = \times 10$$

$$7\text{dB} = 10\text{dB} - 3\text{dB} = 10 \div 2 = \times 5$$

$$\text{Formula for dBW} = 10 \log \frac{\text{large}}{\text{small}} \quad (\text{if } \text{op} < \text{ip}, -\text{ve})$$

In the licence schedule, power in dBW is calculated relative to 1W.

When working out gain in terms of voltage:

• input and output impedances must be equal

• 6dB = double and 20dB = $\times 10$ (twice as much as for power)

$$\text{formula for dBV} = 20 \log \frac{\text{large}}{\text{small}}$$

TAKING MEASUREMENTS

Analogue meters are based on a moving coil — a coil carrying the meter current is able to move in a static magnetic field. The current in the coil creates a magnetic field which interacts with the field due to the permanent magnet, rotating the coil against the hair spring which tries to return the coil and pointer to the zero position. The greater the current, the greater the deflection of the meter.

To convert the ammeter to operate as a voltmeter, a series resistor is added. The value of the series resistor is calculated by applying Ohm's Law with the desired full scale voltage divided by the current needed for full scale deflection. This resistance is the total resistance of the meter itself plus the added series 'multiplier' resistor. The meter resistance is typically $75\text{k}\Omega$, which strictly should be subtracted from the value calculated using Ohm's Law to get the resistor value, but in practice the error caused by not doing so is less than the basic accuracy of the meter.

If we want to measure large currents (more than a few mA), a shunt resistor is needed in parallel with the meter, taking most of the current.

$$\text{Voltage across meter} = I_{\text{meter}} \times R_{\text{meter}} = V_{\text{max}}$$

$$\text{Shunt current, } I_{\text{shunt}} = I_{\text{measured}} - I_{\text{meter}}$$

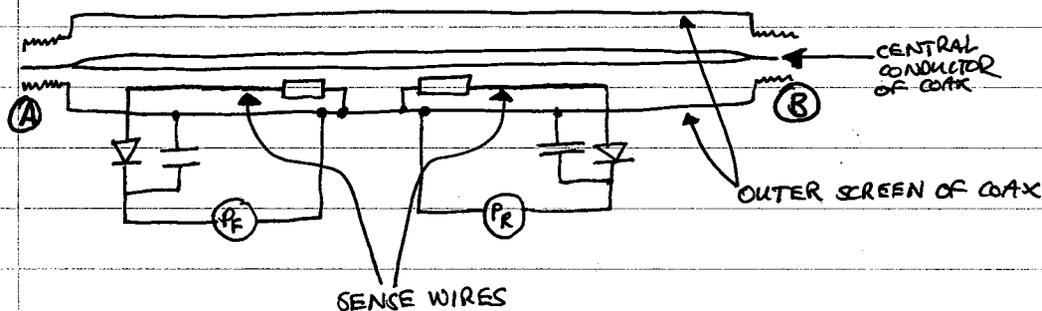
$$\text{so shunt resistor, } R_s = \frac{V_m}{I_s} \Rightarrow \text{expect to be very low. } (< 1\Omega)$$

The presence of the meter can influence the circuit we are measuring. Analogue meters draw current from the circuit under test, and could have resistances comparable with those in the circuit. If the meter's resistance was $10\times$ that of the circuit, an error of about 10% in the reading would occur. The issue is mitigated by using meters with as high resistances as possible e.g. ELECTRONIC meters (which could be analogue or digital) with input impedances of the order 10-100 M Ω .

• Generally a test meter should have a resistance $>10\times$ the circuit

In order to measure alternating currents they must be rectified. We can measure the a.c. through directly through diodes, or indirectly through a transformer and then diodes.

STANDING WAVE RATIO METER



If the main feeder power flow is in direction \vec{AB} then the forward (P_F) meter will respond and reverse meter (P_R) read zero. This is a 'DIRECTIONAL COUPLER': only signals flowing in one direction in the main feeder are coupled into the sense wire.

If the feeder is not correctly matched at the antenna, some power will be reflected and this will be indicated on the reverse meter. By comparing the indications of forward and reverse/reflected power the standing wave ratio on the feeder can be calculated.

Some devices have a single meter and a forward/reverse switch, which allows a meter to have adjustable sensitivity through the inclusion of a variable resistor.

The degree of coupling increases as the frequency rises and the sense wire becomes a greater proportion of the wavelength. This makes the device frequency sensitive - the sense wire should never be more than a few percent of the wavelength of the highest frequency of use. These meters are not very accurate.

Most SWR meters feature an 'RF transformer' to 'sample' some of the RF power and two diodes. Using a current transformer and voltage divider can reduce the error that comes from "apparent" SWR varying along the feeder. The current transformer design is independent of frequency across the HF bands.

$$\text{SWR} = \frac{\text{sum of forward \& reflected VOLTAGE}}{\text{difference between fwd \& refl VOLTAGE}} = \frac{V_{\text{max}}}{V_{\text{min}}}$$

This formula must be used as sometimes forward & reflected waves will add together (when in phase) and subtract when not in phase.

RF POWER MEASUREMENT

Note (b) to the Licence Schedule: Peak Envelope Power is the "average power supplied to the antenna by a transmitter during one RF ^{cycle} ~~signal~~ at the crest of the modulation envelope under normal operating conditions"

① Dummy Load & RF VOLT METER

Constant amplitude modes (CW, FM) allow for easy measurement: one RF cycle is much the same as any other where power is concerned.

- RF is applied to a dummy load and dividers are used to rectify to DC — a voltmeter or equiv (eg oscilloscope) is then used to measure V_{oc}
- Then use $P = \frac{V^2}{R}$ to calculate power in W
 - ONLY works if voltage is RMS

② Dummy Load, Oscilloscope & 2-TONE TEST

More complex to measure AM & SSB due to non-constant amplitude.

- Applying two non harmonically related tones to the transmitter will produce a steady modulated carrier for measurement.

— two tones intended to represent the human voice (not just one tone)

- By monitoring on an oscilloscope, can mark peak-to-peak for a known power: can then monitor for speech to see that peaks do not exceed known RF power marks on the oscilloscope display.

③ Dummy Load & THROUGH-LINE WATTMETER

Many SWR meters are effectively inline/through-line power meters measuring forward & reflected voltage. If they are used with a dummy load of the correct impedance there should be no reflected power and so the forward reading can be used to measure RF power output.

• Some meters already calibrated, others need to be calibrated using an RF volt meter.

• The difficulty of AM & SSB signals can be overcome by adapting the meter to hold peak values → peak reading RF power meter.

All three systems use a dummy load to ensure accuracy — measuring power into an antenna system which is not exactly 50-Ω won't give an accurate measurement.

ABSORPTION WAVEMETER (FREQUENCY MEASUREMENT)

• should cover 2nd & 3rd harmonics of transmitted signal.

• needs RF energy to make it work

• plug-in coils to extend frequency range

• Resolution of frequency display not good enough to measure if the signal is just inside/outside an amateur band

• Simple visual output — meter or bulb

HETERODYNE WAVEMETER (used for VFO calibration)

• Makes use of an oscillator and mixer. More sensitive & precise than absorption — but more expensive.

• simple tx, tune to zero beat frequency & read frequency.

NB by default: "wavemeter" = absorption type

FREQUENCY COUNTER/METER counts the number of cycles in a given period.

• always an uncertainty of ± 1 count as we could have only just missed the next cycle

• 1ms gate has uncertainty ± 1 kHz while 1s gives ± 1 Hz

• accuracy of the crystal oscillator sets the limit of the accuracy of the meter.

Resolution is set by the gate time itself.

MIXING to final frequency

- modulate to one fixed frequency and then mix with other oscillators to get the final frequency
- other oscillators can be CRYSTAL OSCILLATOR, VFO (COLPITTS LC), FREQUENCY SYNTHESISERS or a mixture.
- Mixing will produce sum and difference products
 - this can be used to good effect by designing such that the sum is on one band and the difference on the other eg 9 MHz SSB generator with 5 MHz to 5.5 MHz VFO gives products at 3.5 MHz and 14 MHz, with tuned circuits being used to select the wanted output of the mixer.
- the frequencies must be chosen carefully so there are not unwanted frequencies from oscillators, harmonics or other mixing products close to the sum/difference desired.

Modern transmitters have more than just one mixer: more mixers mean more unwanted frequencies, so careful tuning is required. A wavemeter can be used to check.

- All oscillators need to be stable and free from unwanted ^{modulation} oscillation eg ripple on a DC power supply. Any instability in the oscillator will be mixed (or multiplied) to appear on the final output.

MULTIPLYING to final frequency

- For the purposes of the Advanced exam, this is used only at UHF/microwave frequencies.
- Only suitable for CW or FM (~~constant amplitude mod~~) due to the complexities of the modulation process in AM & SSB ($8\text{kHz} \times 5 = 15\text{kHz}$ wide)
- A CLASS C amp can be used to deliberately generate harmonics, with a tuned circuit selecting the wanted harmonic.
- Using a stable but fairly low frequency oscillator and several multiplier stages, VHF & UHF signals can be obtained with relative ease.
- Must take care to select the correct harmonic at each stage, or the final output could be out of the allocated band - check with wavemeter.

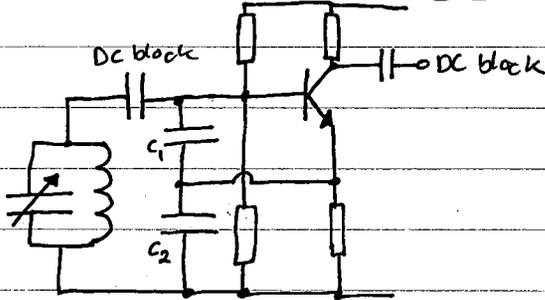
Note small changes in frequency are multiplied too, so a small ^{level} drift or instability in the oscillator will be increased after the multiplication stages

OSCILLATORS

- Main carrier oscillators tend to be based on a crystal for stability on a single frequency
- Remaining oscillators must be variable to allow coverage of multiple frequencies
- Modern transmitters = frequency synthesisers, older models = traditional VFO with inductor & variable capacitor
 - multiple crystals would allow for channelised 'sets'
 - VFO allows continuous tuning over a whole band

Whatever oscillator is used must be free from drift i.e. stable to stay on frequency during use.

TRADITIONAL VFO (COLPITTS)



- Zener diode or regulator IC is needed to stabilise the supply voltage.
- Resistors are used to set the bias of the transistor and/or in series to limit current
- Transistor acts as an amplifier

• Capacitors can have 3 uses:

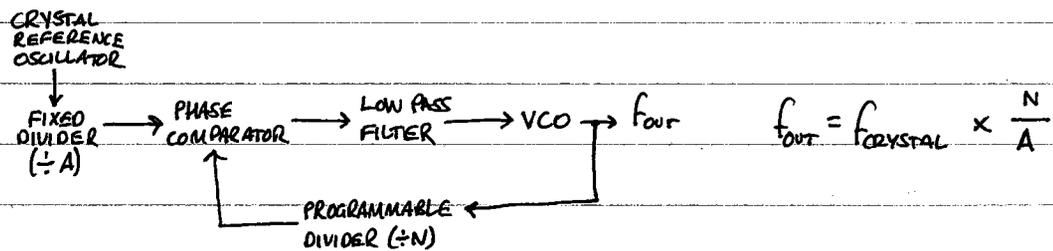
1. Feedback
 2. Decoupling DC supply (ground unwanted DC)
 3. Coupling AC signals to next stage (while blocking DC)
- temperature compensating capacitors are often used in tuned circuits to prevent thermal drift: some ptc, some ntc, some NPO
- A variable capacitor tunes the VFO or trims the crystal.

Other design features:

- rigid construction - prevent mechanical movement
- screening - limit temperature variation & reduce stray RF
- buffer amplifier - isolate oscillator from rest of tx, prevent loading.

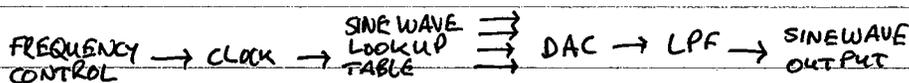
PHASE LOCKED LOOP SYNTHESIZER

- Stable crystal reference oscillator of fixed frequency and uses fixed divider to produce a single frequency, which then determines the final frequency 'steps'
- Second oscillator, Voltage Controlled Oscillator (VCO) is divided down by a programmable divider which gives a variable frequency
- Crystal & VCO are compared by the phase comparator which gives a DC voltage which is proportional to the (phase) difference.
- Phase comparator output is fed via a LPF to the VCO to change the frequency, correcting the difference between the two signals.
- Process is repeated until there is no difference & the PLL 'locks' on nearest frequency step.



DIRECT DIGITAL SYNTHESIS produces an approximation of a sine wave using digital 'steps'.

A higher sampling rate \Rightarrow smaller steps \Rightarrow smoother sine wave



Digitally derived sine waves have errors in amplitude and time due to the discrete steps used - these errors distort the sine wave output resulting in harmonics and timing 'jitter'. Produces sidebands on the wanted signal - 'phase noise'

AMPLITUDE MODULATION

- carrier + 2 sidebands, total bandwidth $\approx 6 \text{ kHz}$
- amplitude and bandwidth depend on modulation
- AM bandwidth = $2f_m$ (for voice, $f_m \approx 3 \text{ kHz}$)
- Amplitude of change depends on the 'power' of the modulating signal: modulation depth

$$\text{modulation depth, } m = \frac{\text{signal amplitude, } b}{\text{carrier amplitude, } a} (\times 100\%)$$

- exceeding m of 100% causes distortion and 'splatter' to adjacent frequencies
- when $m = 100\%$, carrier amplitude is doubled at peaks and reduced to zero at troughs
- Target 80% - 90% modulation. If modulation depth is too low then weak Rx audio
- At $m = 100\%$, the amplitude of each sideband = half that of the carrier, and each sideband contains a quarter of the power of the carrier.
 - * total sideband power is sum of LSB + USB power so \therefore half carrier power.
- $m = 100\%$ the troughs will touch the zero line with a single tone
- an OVER MODULATED waveform has the modulation amplitude more than twice the carrier and gaps between half-cycles.

• previously AM generated using a large audio amp into a modulation transformer: 'high level' modulation. Now generated at a low level at a fixed frequency and mixed to a final frequency, amplified & filtered for harmonics.

SINGLE SIDE BAND has a 'suppressed' carrier & only one sideband

- Same principles as for AM: bandwidth increases with modulating frequency (f_m), but is only $\approx 3 \text{ kHz}$ for voice
- How is SSB generated?
 1. BALANCED MODULATOR mixes AF & RF to form two sidebands while suppressing carrier
 2. Narrow BPF removes one sideband
 3. SSB signal mixed to final frequency

FREQUENCY MODULATION

- Imagine 1V across a varicap diode produces one frequency in the oscillator & applying 2V will change the capacitance & \therefore frequency. So a varying voltage e.g. an ^{AC} signal will give a varying voltage frequency. So the carrier deviates from its normal frequency at the frequency of the AC signal
 - AC signal could be the output of a microphone
- DEVIATION determined by AMPLITUDE. Maximum deviation is limited by electronics and is the 'PEAK DEVIATION'. NFM $\Delta f_{pk} \approx 2.5 \text{ kHz}$, WFM $\Delta f_{pk} \approx 75 \text{ kHz}$ (broadcast FM)
- Excessive AF amplitude from the microphone amplifier = OVER DEVIATION

- FM bandwidth = $2(f_m + \Delta f)$
 - because the modulation process causes sidebands
 - in theory a frequency modulator creates an infinite number of sidebands.

DATA MODULATION

- AUDIO FREQUENCY SHIFT KEYING, AFSK — feed audio tones into FM gives F2B. Bandwidth determined by the highest audio tone and the peak deviation.
 - can also feed tones into SSB modulator = J2B. Here the tones produce different frequencies directly related to the tones, and because unlike FM, with SSB there is no transmitter RF where there is no audio, the bandwidth can be very small if few tones are used.

- FREQUENCY SHIFT KEYING, FSK — generated by applying DC data voltages directly to a varicap diode in the oscillator tuned circuit: F1B.
 - This does not use the audio 'subcarrier' as for AFSK
 - Causes oscillator to shift to different fixed frequencies
 - At Rx, indistinguishable from SSB AFSK (J2B)
 - DC could be direct from a data port (as opposed to a sound card).

POWER AMPLIFIERS

- AM/SSB require LINEAR amps: perfect copy of input with no distortion
class A or A/B
- FM & CW don't need linear amplification so class B or C can be used.
- CLASS A least efficient, $< 50\%$
- CLASS C most efficient, $\sim 66\%$, but output rich in harmonics \therefore needs good filtering
- PAs must be matched at input and output if maximum efficiency is to be obtained
 - matching can be by LC network, can also filter unwanted emissions
 - may be done via transformers, more common in multiband equipment which uses broad-band/untuned amplifiers.

POWER RATINGS

- Not all modes use 'full power' all the time
 - FM is 100% duty cycle as constant amplitude
 - AM/SSB/CW not always at full amplitude so $< 100\%$ DC
 - Data modulation more constant than voice so even SSB ASK approaches 100%
 - Speech processors increase 'average power' so can increase duty cycle $\leq 20\%$
 - Quoted max power on some radios NOT suitable for 100% duty, may need to reduce to 40% of P_{max} for modes such as FM

AUTOMATIC LEVEL CONTROL (ALC) reduces output power automatically.

- can be connected to external linear amp, ALC ensures input to amp at correct level so as not to overdrive.
- may be linked to SWR meter to reduce power if poor & avoid damage.
- can use ALC to limit output to F1 and 1st lenses if no variable control fitted.

VALVES

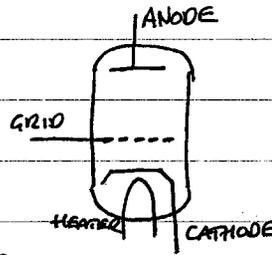
Main electrodes of thermionic valve:

ANODE: +ve DC

CATHODE: -ve DC

GRID: control electron flow between ANODE & CATHODE

HEATER: heats CATHODE so electrons 'boil off'. Can be combined w/ CATHODE



Cloud of mobile electrons produced near cathode by heating it up. Negative electrons flow from CATHODE (-) to ANODE (+). A small signal applied to GRID can control a large electron flow — can be used for amplification. If signal on GRID is AF, then electron flow is modulated.

Advantages: high power, up to kW; can withstand high SWR w/o damage

Disadvantages: need high (100s to 1000s V) V; fragile glass construction; aging process reduces efficiency; physical size & need for large power supply.

MIXER PRODUCTS

Eg: likely mixer products of 4 MHz & 10 MHz signal?

Tabulate sums and differences of all fundamentals & all (up to 6th, maybe 5th) harmonics.

Including headings, if an answer does not appear anywhere in either table it is not likely to be an unwanted mixing product.

TRANSMITTER INTERFERENCE

• OSCILLATORS CHANGING FREQUENCY can cause the transmission to go out of band and/or make the signal difficult to receive.

- results from drift or lack of stability

- poor stability over time is usually due to changes in temperature, a slow change in supply voltage, or the ageing of components

- more rapid changes in frequency result from changes in loading, a rapid voltage change, stray capacitance or mechanical shock

- there are also some problems specifically related to synthesizers which come under this category.

Temperature changes cause drift due to the various inherent temperature coefficients of the components in oscillator tuned circuits. Circuits take time to warm up, so some drift is expected at start-up but should soon settle down as the system reaches its operating temperature. Heat can also result from the system itself eg valve heaters and power amplifiers: hence need for heat sinking.

Can fix/mitigate this issue

- allow circuits to stabilise before transmitting, scan the band prior
- locate the oscillator well away from PA & other heat sources
- use of components with temperature coefficients so changes cancel out
- screening of oscillators can also help minimise temperature changes

Changes in supply voltage

- poorly regulated power supply can have voltage drop as current draw increases
- if using batteries, voltage can fall as the battery discharges

Fixes:

- ensure power supply is sufficiently rated for current, with some wiggle-room.
- run oscillator from a separate, regulated power supply less than main power supply
- keep batteries topped up/carry spares. Monitor cell voltage.

"CHIRP" is a short-term rapid change in frequency in CW transmission, mainly caused by poor supply voltage regulation and/or changes in loading, but only when the key is first pressed.

AGEING

• Crystals can change frequency with age

- accuracy in PPM (parts per million), so 14 MHz at 10 PPM could be

$$\frac{10}{10^6} \times 14 \times 10^6 = 140 \text{ Hz off-frequency.}$$

• Need to thus check the frequency of transmissions 'from time to time' and making any necessary adjustments

Changes in circuit loading

- As tx circuits are energised the input impedance can change as transistors start to conduct \Rightarrow oscillator may be working into a different load than when the transmitter was idle \Rightarrow cause oscillator to shift in frequency.
- Mitigated by placing a buffer amplifier between the transmitter and the oscillator, which provides constant load and helps prevent changes

Stray capacitance

- Hands and parts of the transmitter can act as unwanted capacitors, with additional capacitance resulting in a change of frequency
- Can isolate the oscillator using a metal case or by placing an earthed metal screen between the transmitter and the controls
 - also earth metal control shafts or use insulated shafts.

Mechanical shock

- Force on chassis can cause parts to move - preset trimmers or inductors may change values which would make the dial calibration inaccurate when next used.
- Vibration eg when mobile could cause frequency modulation of parts shaken back & forth.
- Fix: rigid construction, short direct wiring/component connections, coating coils with lacquer, supporting air-wound coils on low-loss formers, use of good quality variable capacitors.

PLL synthesiser: 'out of lock' inhibit/indication. Occur if change in programmable divider is too rapid for the PLL.

- 'phase noise' can be an issue.

UNWANTED EMISSIONS include unwanted mixer products, spurious oscillations, key clicks and harmonics.

- Unwanted mixer products are normally the sum/difference NOT on the wanted frequency.
 - also includes harmonics & their mixing products, & the fundamentals too.
 - need good selection via tuned circuits in each stage and/or good output filtering

SPURIOUS OSCILLATIONS can be self oscillations or parasitic oscillations.

• SELF OSCILLATIONS

- on or near the wanted frequency, caused by unintentional feedback.

Amplifier's tuned circuits intended to select the wanted frequency can also result in spurious oscillations on that frequency as if amp circuit becomes oscillator circuit.

- Fixes include lowering the drive from the previous stage, reducing the gain of the amp by changing the biasing, better decoupling of the DC supply, and lowering the Q-factor of tuned circuits by adding series resistance and/or winding VHF coils on high value resistors.

• PARASITIC OSCILLATIONS

- on frequencies caused by unintended resonances: similar to self-oscillations but the frequency is less predictable

- resonances may be formed by inductors and decoupling capacitors: normally at HF frequencies in VHF amplifiers

- can also be formed by long leads to capacitors because the long leads can act like inductors: normally VHF oscillations in HF amplifiers

- Fixes as for self oscillations, also keeping component leads as short as possible, and putting ferrite beads onto supply leads to choke off any stray RF

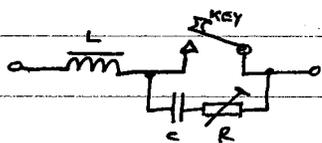
Key Clicks

• Sparking at the key contacts can cause localised interference across a wide range of frequencies; unlikely in modern transmitters thanks to lower keying voltages and currents.

• If the rise and fall of the Morse characters is very steep then the waveform appears more like a square wave than a sine wave

- square waves more likely to generate harmonics \Rightarrow wide b/w & adjacent channel interference

• Fix with a key click filter



Aide-memoire: a Cross contacts, in Line

• Filter slows the rise and fall of the character to make it more like a rounded sine wave

- back EMF from inductor slows rise time on key down, discharge from capacitor slows fall on key up (resistor slows)

OVER MODULATION (AM/SSB)

- overmodulated signals will have gaps in the waveform and 'flat-topping'
- causes harmonics of the modulating (AF) frequency, which in turn widens the bandwidth of the sidebands
- distortion caused by the harmonics also makes the signal more difficult to read.
- caused by having the microphone gain set too high, or shouting into the microphone.
 - fix by setting the AF level to no more than 100% modulation, which can be viewed on an oscilloscope set to the AF range
- speech compressors average out peaks and troughs in the amplitude of the AF signal - gives an increase in average power (~20% more) without increasing the bandwidth.

OVER DEVIATION (FM)

- If microphone gain is too great on an FM transmitter the AF amplitude will cause the signal to exceed the pre-set peak deviation, causing interference to adjacent channels & making the modulation unintelligible
 - ensure the microphone gain is not turned up too much.

OVERDRIVING AMPLIFIERS

- 'Intermodulation' of the carrier and sidebands producing a distorted wanted signal: like over-mod but resulting from RF rather than AF issues.
- Driving an amplifier beyond its designed working parameters means that it will no longer be linear. Distortion of RF can cause harmonics = interference on multiple frequencies
 - Limit the drive power: increase until the amplifier output saturates and then back off slightly

RF HARMONICS are multiples of the wanted frequency (the fundamental)

- Generated by non-linear amplification (eg class C amp)
- Can be filtered out, but better avoided in the first place
 - do not overdrive amplifiers
 - use inductive coupling between transmitter stages
 - use push-pull amplifiers to cancel even harmonics.

OUTPUT FILTERING

- LPF will remove harmonics above the cutoff frequency
- Cutoff frequency defined by power -3dB or voltage -6dB "Half power point"
- VHF/UHF has output filter of a BPF due to presence of unwanted frequencies below the wanted frequency as well as above. This is especially true where frequency multiplication is employed.
 - VHF output filtering may also include a band-stop or notch filter to increase attenuation at a specific harmonic

RECEIVERS

TERMS

- Selectivity - ability to accept the wanted signal & reject others
 - performance often quoted as "60dB bandwidth": how far away from an identical signal do we need to be for the receiver to make it -60dB ($\frac{1}{100}$) less than the wanted.
- Bandwidth - need to select the best selectivity for the mode of transmission. Don't want ~~less~~ too narrow or will not get the whole signal, but if too wide then the receiver will pick up other signals/noise
 - can be quoted differently for different modes, and using -3dB or -6dB (must check)
- Signal-to-Noise Ratio - ratio between the wanted audio signal and receiver noise in total output.
 - 10dB SNR gives a readable signal
- Sensitivity - ability to receive weak signals
 - usually quoted as the signal voltage required for a particular SNR. Lower = better
- Dynamic range - the difference between the strongest signal a receiver can handle without overloading and the weakest signal it can detect. Normally expressed in dB

RF AMPS/PRE-AMPS

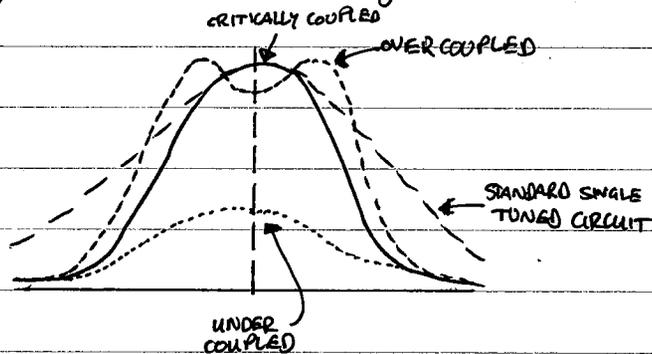
- Many receivers have a 'tuned' RF amp built into the 'front-end' which boosts the weak RF signals from the antenna before being mixed with signals from the local oscillator (LO)
- pre-amps are additional amplifiers that can be switched in to the circuit ahead of the normal RF amp, with the intention of making the receiver more sensitive by adding gain.
- Pre-amps do have disadvantages however:
 - stronger signals will overload the receiver, previously good strong signals will become distorted.

- very strong signals can cause intermodulation and spurious signals within the receiver - the RF amplifier transistors are no longer working as they were intended to do so.
- amplifier may generate internal noise meaning more signal voltage is needed for the same SNR, cancelling out the benefit of the gain.
- joint effect is to reduce the dynamic range of the receiver - normally by the same figure as the gain of the pre-amp.
- RF amps can be ICs or transistors (dual gate FET popular). In all cases they will have one RF input and one RF output.

MIXER & LOCAL OSCILLATOR

- Mixer can be an IC, single transistor or a diode ring. In all cases there are RF & LO inputs and an IF output.
- Local oscillator can be a VFO, tuned by a variable capacitor or varying the voltage across a varicap diode, or could be a frequency synthesiser.
- IF tuned circuits and/or filters select the chosen filter frequency and reject the others.
- IF is sum or difference of the RF ^{and} LO. Normally the difference, with $LO > RF$
 - This is because if $LO > RF$ there is no chance of LO harmonics being picked up by antenna/RF circuits
 - and there will be a lower tuning range by percentage of LO frequency:
 - 500 kHz @ 10 MHz (5%) easier than 500 kHz @ 2 MHz (25%)
- Possibility of second channel "image" response
 - $LO > RF$, image $f = RF + 2IF$
 - $LO < RF$, image $f = 2IF - RF$ or image $f = RF - 2IF$
- IF choice based on need for selectivity and to avoid second channel interference.
 - high IF will put the image frequency well away from the wanted RF, making rejection of the image frequency easier, though good quality tuned circuits are more difficult to manufacture at higher frequencies.
 - low IF gives easier construction of good quality filters, but puts image quite close to wanted RF.
- One solution is to have two IFs, one at higher frequency for good image rejection and one at lower frequency for good selectivity. "DOUBLE CONVERSION SUPERHET". Needs a second mixer & second local oscillator though. 1st IF is always the higher to deal w/ image first.
 - modern receivers can have 3 IFs to give even better performance.

IF Amps are RF amps which are tuned to a single frequency, the IF. Receivers may have several IF amps ~~tuned~~ to add gain and selectivity, normally linked by a small IF transformer (IFT) - a transformer with two windings and a ferrite slug which can be threaded to tune the transformer (one or both windings will be tuned to the IF).



IF amp has one IF input and one IF output

Sometimes there will be a high-quality bandpass filter between IF amps to deliberately limit the bandwidth: usually a crystal filter.

• Q factor = $\frac{f_0}{f_s}$, shape factor = $\frac{f_{80dB}}{f_{6dB}}$

DEMODULATORS

- AM demodulator = simple diode, aka "envelope detector". IF in \Rightarrow AF out via electrolytic capacitor. "Rectifies" AM signal
- FM demodulator aka "ratio detector" / "frequency discriminator". IF in & AF out, but large number of diodes & capacitors in circuit compared to AM single diode. Rectifies changes in frequency, ratio of differences above/below centre frequency
- SB & CW demodulator requires carrier insertion oscillator (CIO) or beat frequency oscillator (BFO) fed into a special balanced mixer - "product detector". Can be IC, transistor or diode mg. Circuit has 3 inputs/outputs: IF in, CIO/BFO in, AF out.
 - Effectively a mixer, sum will be RF which is then filtered out, but difference will be AF.

AF Amp can be recognised due to the use of electrolytic capacitors to pass the AF signal

AGC adjusts the RF and/or IF gain as the strength of the incoming signal varies: it is intended to give constant volume under changing conditions.

- Normally samples the output of the final IF amp, but could sample demodulator & adjust IF/RF gain
- Often used to drive the S-meter: ^{as} gain is reduced the S-meter shows a stronger signal

A DOWN CONVERTER can be used to allow a HF receiver to receive VHF/UHF bands

- RF amp (tuned to higher band), mixer and oscillator
- oscillator usually using a crystal at the V/U frequency required MINUS the HF band.
- can be housed with a transmitter up converter, to form a TRANSVERTER.

TRANSCEIVERS are combined transmitters and receivers

• needs additionally:

- antenna changeover circuit to switch antenna from rx input to tx output
- mute circuit to silence rx during tx
- RIT = receiver incremental tuning to follow a drifting other station without changing your transmit frequency.
- some circuits can be shared
- Rx LO = tx mixer oscillator
- Rx CIO = carrier osc. tx
- Rx IF filter = tx AM/SSB/CW filter
- Tx LPF = limit rx RF input

} note common circuits tend to be filters and/or oscillators

FEEDERS

- Coax is more lossy than balanced feeder. • Losses increase with frequency.
- WAVEGUIDES used above UHF; connect RF generator to antenna. Straight rectangular metal tubes
- size related to λ : ie $10\text{GHz} = 3\text{cm} = 1.5\text{cm waveguide}$

SWR: ratio of VOLTAGE maximum and voltage minimum of the standing wave at any point in the feeder.
(hence VSWR)

If x V_f and y V_r , they can combine constructively or destructively: so $V_{max} = V_f + V_r$ & $V_{min} = |V_f - V_r|$.

or given $V_r = 50\%$ of V_f , $V_{max} = 150\%$ & $V_{min} = 50\%$ ($100\% - 50\%$)

When calculating based on power in the exam, will be given at a known voltage ref
ie recall that at the half power point, $V \approx 70\%$ max.

Return Loss uses the idea that radiated power is 'lost' from the system while reflected power 'returns' to the source.

$$\text{Return Loss} = 10 \log \frac{P_R}{P_{in}} \quad (\text{eg } 100W \text{ in } \text{SWR} \text{ and } 10W \text{ reflected} = -10 \text{ dB})$$

The lower the return loss, the higher the SWR (more power being returned), so
a low SWR = a high return loss.

Losses in the feeder linked to return loss explains why having a longer feeder can give a lower apparent SWR, even if the antenna system is still a poor match.

$$\text{TOTAL RETURN LOSS FOR ANTENNA SYSTEM} = (2 \times \text{FEEDER LOSS}) + \text{ANTENNA RETURN LOSS}$$

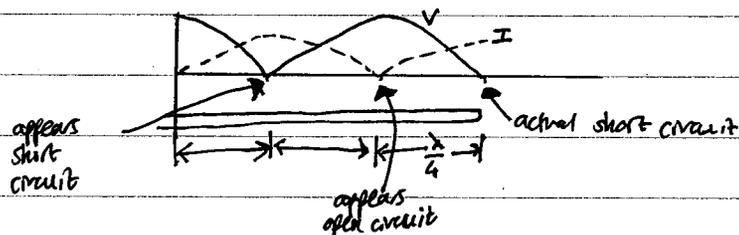
$\frac{1}{4}$ lengths of feeder can be used as IMPEDANCE TRANSFORMERS

$$Z_0^2 = Z_{in} \times Z_{out}$$

Z_{in} = impedance at one end, Z_{out} = at antenna feedpoint

Z_0 = characteristic impedance of the coax.

If had $\frac{1}{2}$, would get the $\frac{1}{4}$ effect twice, ending up back where we started.



Velocity Factor

Physical lengths of coax feeders are less than those calculated in wavelengths, which are the theoretical 'free space' length/electrical length. This is because RF does not travel as fast in wire or across plastic insulation as it does in vacuo.

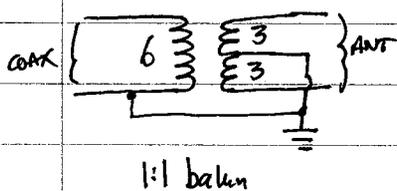
- Velocity factor is a correction for this. For BALANCED feeder ≈ 0.9 , COAX ≈ 0.67
- Eg $\frac{1}{2}$ for 150MHz is 1m free space length, but 0.67m physical length.

Baluns

Recall should use balun when feeding a balanced antenna with unbalanced feeder and its purpose is mainly to prevent RF coming back down the outside of the coax and causing interference.

TRANSFORMER BALUN: earthed centre-tapped winding for the antenna and a single earthed winding for the coax.

- If $N_p = N_s$ then impedance same eg 50Ω coax into dipole



- Remember impedance transformed by square of turns ratio
- At HF, baluns tend to be broad-band, but at VHF + they are more likely to be single band devices.

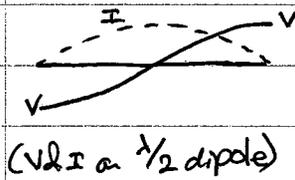
CHOKE BALUN - uses number of ferrite beads over the top of the coax next to feedpoint to 'soak up' any RF on outside of the feeder.

- Very wide bandwidth
- No impedance transformation
- Similar result by looping feeder into coil 5-20 turns.

SLEEVE BALUN uses the $\frac{1}{4}$ coax idea by placing a second 'braid' over the coax (usually a metal tube).

- Sleeve is open circuit at feedpoint but connected to coax braid @ other end.
- $\frac{1}{4}$ transformer action appears to be a dead short to any RF on outside of coax
- Will only work on one band.

ANTENNAS



- No current can flow beyond the end of the wire, and as radio signals are sine waves, max current \therefore in centre of $\frac{1}{2}$
- Ohm's Law: if no current, high V, if low I (centre) = low V
- At the end of $\frac{1}{2}$, high Z and in centre, ~~low~~ low Z @ $\frac{1}{4}$ point.
- so feed $\frac{1}{2}$ dipole in centre with low Z feeder.

Angle of radiation is measured between the radio wave and the ground. Best long distance HF communication achieved from low θ rad = greatest 'skip' distance.

• If antenna is close to the ground then some radiation will be reflected up, increasing θ rad. \Rightarrow antennas are always best placed as high as possible.

END CORRECTION is necessary - real life antennas are shorter, by 5% for $\frac{1}{2}$ dipole

- $\frac{1}{2}$ DIPOLE has a figure 8 radiation pattern, balanced
 - feedpoint Z $\approx 75 \Omega$; though depends on height.
- FOLDED DIPOLE is like 2 parallel dipoles joined at the ends, and one joined at the feedpoint too, forming a long narrow loop.
 - balanced, total length of λ ($2 \times \frac{1}{4} + \frac{1}{2}$). 5% end correction. Fig. 8 radiation pattern
 - feedpoint Z $\approx 300 \Omega$
- TRAP DIPOLE: balanced, $\frac{1}{4}$ each side on 2 or more frequencies with traps to separate.
 - length tends to be physically shorter than the equivalent single-band dipole (some wire in trap inductors)
 - trap is PARALLEL ("rejector") tuned circuit so high ~~impedance~~ impedance at resonant frequency = end of dipole
 - 75Ω feedpoint Z
- YAGI = $\frac{1}{2}$ dipole between two or more other dipoles.
 - the DIRECTOR is $\sim 5\%$ SHORTER than the driven element,
 - REFLECTOR $\sim 5\%$ LONGER than the driven element.
- Presence of director and reflector LOWERS the feedpoint Z, so driven element often = folded dipole; 300Ω Z drops to $\sim 50 \Omega$ due to proximity of other elements.
- Alternatively there are other feeding arrangements e.g. γ match = AMU @ feedpoint.
- Traps can be added to each element to form a multiband Yagi.

- QUARTER WAVE ($\frac{1}{4}$) VERTICAL is unbalanced: physically $\frac{5}{8}\lambda$ but electrically $\frac{3}{4}\lambda$
 - Loading coil is used to make antenna physically shorter - omnidirectional radiation pattern
 - 50- Ω feedpoint impedance
- $\frac{1}{4}$ END-FED WIRE also unbalanced, longer vertical bent to fit available space.
 - Low feedpoint impedance when fed against earth; fed via a series tuned circuit
 - Less predictable radiation pattern
- $\frac{1}{2}$ END-FED WIRE again unbalanced
 - High feedpoint impedance when fed against earth; hence fed by parallel tuned circuit
- QUAD LOOP has 4 sides each $\frac{1}{4}$, so total length of λ . "stretched folded dipole"
 - Figure 8 radiation pattern with a maximum through the centre of the loop.
 - Feed on horizontal side for horizontal radiation, or vertical side for vertical radiation.
 - 100- Ω feedpoint Z , common use of $\frac{1}{4}$ 75- Ω transformer to 50- Ω TX. additional loop forms cubical quad beam and feedpoint Z falls to 75- Ω

ANTENNA MATCHING UNITS 'tune out' (cancel/balance/match) any reactance in antenna system so the transmitter sees a 'pure' resistance. Rarely actually tunes the antenna.

- AMU at antenna end of feeder much better as no SWR on feeder then = reduced losses
- can provide additional harmonic filtering, though T-match = HPF, so not to be relied upon.
- components can pass very high currents so need to be of high ratings: wide spaced capacitors & thick inductors
- T NETWORK: inductor between TX & antenna system w/ 2 variable capacitors between ends and ground - so circuit looks like T.
- T-MATCH: 2 possible configurations: 2L 1C or 1C 2L. Either way circuit looks like a T. Disadvantage of 1C 2L is acts as HPF, so limited value in attenuating harmonics
- L-MATCH: single variable inductor in series between transmitter & antenna system with a variable capacitor to ground. Can be at either end, could be fixed components for single band. Looks like an L, could be inverted shape.

PROPAGATION

Measuring RF intensity:

- Power Flux Density: unit $W m^{-2}$; follows inverse-square law.
 - Field Strength: unit $V m^{-1}$; reduces in linear fashion, symbol E.
 - Radio waves are made up of electric & magnetic fields, which are at right angles and in phase
 - Polarisation is described based on that of the electric field
- Circular polarisation can be clockwise or anticlockwise rotation - TX & RX MUST match, or massive losses will result

Modes of Propagation

- Ground wave up to 2 MHz main mode of propagation
 - range at HF only a few km due to ground losses, generally unaffected by time of day / atmospheric, but can be affected by ground conditions (dry/wet, sand/salt)
- Tropospheric (space) wave - troposphere is above ground & below the ionosphere.
 - main mode of propagation for VHF & UHF; normally line of sight
 - temperature and pressure changes can cause 'ducting' to extend range - not very predictable
- Ionospheric (sky) wave - main mode of propagation for HF
 - waves refract in the ionosphere, caused by ionised gaseous particles
 - ionisation is caused by UV & X-rays from the Sun, so affected by:
 - day/night, summer/winter, 11 year sunspot cycle, solar flares

Layers of the Ionosphere

- D ≈ 100 km, $100 < E < 200$ km, $200 \leq F1 < 300$ km, $300 \leq F2 < 400$ km
- F2 is the ~~highest~~ ^{highest} so best for long ~~term~~ distance comms
- $F1 + F2 = F$ at night and in winter.
- E layer can reflect VHF when condx are good, usually in summer. Sporadic E too.
Single hops ≈ 2000 km under sporadic E
- D layer absorbs LF so has an adverse ~~effect~~ ^{effect} on propagation. It disappears at night which makes LF DX possible.

- CRITICAL FREQUENCY - maximum frequency of vertical incidence to be reflected back to transmitter - low frequencies absorbed and high frequencies pass through.
- MAXIMUM USABLE FREQUENCY - highest frequency reflected on a path between two stations, can reach 50 MHz at the peak of the sunspot cycle. Winter sees highest MUF just after midday, and biggest contrast between day and night
- LOWEST USABLE FREQUENCY - the lowest frequency able to penetrate the D layer AND be reflected on a path between two stations
 - If $LUF > MUF$ no propagation can take place - signals that would reflect from F layer are absorbed by the D layer before even reaching it.

Fading (QSB)

1. Multimode/multipath interference - may cause 'fluttering'
2. Changes in the ionosphere - slower fading, minor changes should be ^{corrected} ~~extract~~ by rx AGC
3. Solar flares - cause intense ionisation, can cause D layer to absorb all RF so it never gets to F layer, leading to total loss of communications ("Dellinger fadeout" or Sudden Ionospheric Disturbance)

Typical bands

- 80m / 3.5 MHz: D layer absorbs during day due to lower HF frequency, so tends to be for local inter-~~inter~~-UK working during the day. D layer reduces in the evening \Rightarrow DX
- 15m / 21 MHz: D layer normally has little effect as higher HF frequency - can be open all day & evening up to midnight. Not always open though as MUF can be < 21 MHz. Good at the height of the sunspot cycle.

ELECTROMAGNETIC COMPATIBILITY

Routes for break through:

1. Directly through case - usually only an issue in proximity; metal cases provide screening
2. Via antenna - unlikely for HF due to λ difference: UHF could interfere w/ TV though
3. Through leads (most common)
 - Feeder, outside of coax (braid)
 - Mains cable
 - Speaker leads (two leads can form dipole)
 - Interconnecting leads: braid of screened cable or direct to unscreened eg SCART

Effect of breakthrough

- at or ^{near} ~~near~~ the wanted frequency
 - rx likely to accept the extra signal too, which may drown out the wanted signal or cause severe distortion
 - more likely to be harmonics rather than the fundamental local transmission.
- at or near the intermediate frequency
 - VHF FM often 10.7 MHz IF, AM broadcast receives 455 kHz IF
- rectification in PN junctions
 - not frequency related
 - common examples inc. triggering of alarms; AF on audio system not affected by the volume setting
- rectification in passive metalwork ("rusty bolt effect")
 - unusual, Passive Intermodulation Products (PIPs) caused by two metal surfaces not being in full contact, forming a crude diode: can rectify RF, generate harmonics and/or mix unwanted signals.
 - Corroded antenna connectors, metal gutters & towers main culprits
- amplification by signal boosters/distribution boxes
 - contain broad band amps i.e. no/ poor filtering; not screened
 - pre-amp = reduced dynamic range = breakthrough / over loading due to even weak signals
- Intermodulation - two signals mixing together to produce unwanted products
 - intermods can be on or near to the image frequency, IF, or even the wanted frequency and therefore breakthrough the receiving equipment
 - more likely with wideband high-gain amps.

Types of breakthrough

- Cross modulation - linked to changes in amplitude: caused by AM/SSB/CW
 - note: can also be caused by intermodulation
 - strong unwanted signals trigger AGC \Rightarrow interference and/or loss of TV/radio reception
 - breakthrough comes and goes with modulation
- Blocking - similar effect as cross mod but caused by signals of constant amplitude i.e. FM/data modes
 - breakthrough constant during tx so minor cases may go unnoticed

• Digital TV tends to be all or nothing. Symptoms range from minor pixellation to picture freezing, through to complete loss of sound & vision

"Radio housekeeping"

- use minimum power needed for the contact
- RF cables should be ran away from mains & other cables.
- good RF earth, though still need short connecting lead.
- Moving antenna away has more of an impact on E than reducing exp.

FILTERS

- CUTOFF FREQ = -3dB / 'half power point' / $\frac{1}{\sqrt{2}} V_{max}$
- FERRITE - choke RF currents, unwanted RF energy converted to internal energy (heat)
 - adds inductance to wire, increasing reactance to any RF
 - often fitted to base of transistors to prevent RF reaching base-emitter PN junction & switching on the transistor.
 - Where used with coax: any unwanted RF travels on outside of coax so sees high X of ferrite
- In triple cables / twisted pairs differential mode currents used with the wanted AC so fields cancel, minimising radiation
 - unwanted RF is common mode current and sees high X \therefore doesn't pass
 - DC not impacted as no reactance, but RF as a ^{choke} DC lead choke.
 - note both conductors of the pair need to be wound onto the ferrite ring.

NAWS FILTER

- Live & Neutral wound on ferrite
- Capacitors between LE & NE decouple RF

BRAID-BREAKER eg on TV down lead

- Break inside metal box to maintain RF screening
- Ferrite ring on outside of coax or separate filter w/ physical break in braid
- One filter also includes HPF to allow TV signals to pass and resistor to aid static discharge.

NOTCH FILTER - parallel tuned circuit in signal path / series tuned circuit to ground

- open circuit $\frac{1}{4}$ coax stub in T-adaptor can be used; looks like dead short @ unwanted frequency

AMATEUR RADIO SAFETY

- HV equipment - use master switch
 - earth exposed surfaces, avoid live work where possible
 - RCD, remove rings etc, one hand in pocket, no headphones
 - thermionic valve equipment uses high voltage - up to 2kV
- Portable ops
 - power transmission lines; damp ground; excessive field strengths
 - take sensible precautions
- Mobile - use dedicated fused DC lead to battery; neg to chassis

RF exposures

- WHO \Rightarrow ICNIRP in $W m^{-2}$ (W/m^2)
- ICA Reference Levels $V m^{-1}$ (V/m): recommended maximum exposures
 - Lowest reference level / "investigation" level $28 V m^{-1}$ 10-146 MHz

PROTECTIVE MULTIPLE EARTHING

- Mains ~~main~~ earth wire is connected to mains neutral wire at entry to house.
 - Not every house has a "real" earth connection
- All metalwork in every PME house is bonded together
- FAULT CONDITIONS can cause high potential between metalwork and earth.
- Benefit is all metal at same potential, so someone touching two surfaces will not have potential across.
- RF Earth is "real" - fault cordx can cause very high current through RF earth.
 - \therefore bond RF earth to mains earth with heavy duty cable

LIGHTNING forms high potential difference between cloud & ground.

- charge can ionise surrounding air \rightarrow low R path to earth \rightarrow HIGH CURRENT = lightning bolt