Online Radio & Electronics Course

FILTERS - IN RADIO COMMUNICATIONS

RADIO SIGNALS

In radio communications we talk a lot about radio signals. A radio signal is a very broad expression. The radio signal from a television transmitter is in the VHF, UHF or higher region of the spectrum and is about 7 MHz wide. An SSB transmission from an amateur station on HF is about 3 kHz wide. Therefore, when we talk about receiving, passing and rejecting 'signals' we need to keep in mind that the bandwidth of the signal can vary greatly.

The bandwidth of a signal is how much spectrum space it occupies.

When radio communication was in its early form, transmitters were very broad. Transmitters used to use a wide band of frequencies. Morse code was the only type of signals sent. Marconi had all sorts of problems selling his invention because multiple transmitting and receiving stations would interfere with each other.

Selectivity is the ability of a receiver to receive only the wanted signal and reject all others.

With tuned circuits and crystal oscillators we can now have thousands of transmitters operating in a small space. Keeping them all from not being heard or interfering with each other is a mighty task, particularly in high-density metropolitan areas. I have worked on interference problems on Sydney tower. At that time, there were over 600 transmitters and receivers within a 600-metre radius of Sydney Tower. When transmitters do interfere with each other for whatever reason, many of which will be discussed, we often have to resort to additional filters other than the ones already built into the transmitter or receiver.

FILTERS

In electronics, radio and communications, filters are used to select or pass desired signals and reject or block undesired signals. Or to put it in other words, there may be frequencies or signals that we want to pass and others that we want to block. The only way of doing this is with a device that is frequency selective - it must behave differently towards different frequencies. Such a device is called a filter.

We have already encountered filtering. If you recall the reading we did on power supplies, the object of the power supply is to convert alternating current to direct current. The first stage of the rectification process is to convert alternating current to pulsating direct current. We converted AC to pulsating DC using rectifier diodes. Immediately after the rectifier we used a capacitive or inductive input filter.

The ripple frequency of a power supply (full wave) is equal to, or twice that of the supply frequency. Typically this is 50 or 100 Hertz. DC can be thought of as zero Hertz. So the aim of the filter of a power supply is to oppose frequencies above zero Hertz. A power

supply filter is then a low pass filter. It passes DC (zero hertz) but blocks or makes it harder for higher frequencies to pass.

We previously defined the property of capacitance as that property of the circuit that opposes changes of voltage, and inductance as that property of a circuit that opposes changes of current. In a power supply filter, whether it is capacitive or inductive input, we are using the properties of capacitance and inductance to convert pulsating DC to smooth DC.

TUNED CIRCUITS

Capacitance and inductance combined, we have learnt, can form a tuned resonant circuit. The tuned circuits have a specific way of behaving at resonance and off resonance. As a summary:

Series resonant LC circuits have low impedance at their resonant frequency and higher impedance at all other frequencies.

Parallel resonant LC circuits have high impedance at their resonant frequency and lower impedance at all other frequencies.

A tuned circuit *cannot* be used to block or pass just one single frequency. We would need an impossibly high 'Q' to do this. Tuned circuits can be designed to pass or block signals or *ranges of frequencies***.**

Using the properties of parallel tuned circuits and series tuned circuits, and the fact that capacitive and inductive reactance change with frequency, we can build circuits to pass certain frequencies and stop others. Inductors and capacitors are ideal components for building filters. However there are other specialist ways to build filters, and we will be discussing these later as well.

TYPES OF FILTERS

Irrespective of the mechanism by which the filter does its job, filters can be broken down into four basic types.

    a) low-pass filter
    b) high-pass filter
    c) band-pass filter
    d) band-stop filter

Low-pass filters pass all low frequencies *up* to a certain frequency; from that frequency and above significant attenuation begins to occur.

High-pass filters pass all high frequencies *down* to certain frequency; from that frequency and below significant attenuation begins to occur.

Band-pass filters pass a band or range of frequencies only; outside this band of frequencies significant attenuation occurs.

Band-stop filters stop or attenuate a band or range of frequencies only; outside this band of frequencies all frequencies are passed with minimal attenuation. Band-stop filters are

sometimes referred to as a notch filters.

It is important for radio engineers to agree on the point where a filter is considered to have significant attenuation. The frequency at which significant attenuation begins to occur is called the cutoff frequency of the filter. The cutoff frequency is the point on the filters characteristic curve where the desired frequency has been attenuated by 3 decibels. Take for example a typical low-pass filter with a cutoff frequency of 36 MHz. This filter should have a very small insertion loss of say 0.2 decibels for all frequencies up to and around 34 MHz. Beyond 34 MHz the filter will attenuate the signal more until, at about 36 MHz, the attenuation has reached 3 dB. This 3 dB cutoff point is considered to be the higher limit of the operating range of the low-pass filter. Above the cutoff frequency the low-pass filter will begin to start attenuating signals dramatically.

Figures 1 to 4 below show the basic schematic diagram of the four basic types of filters.

The circuits shown are the basic features only of each type. It is very common for filters to use a combination of the four basic circuits to obtain the desired filtering effect. However for the exam, you should remember these basic types and the best way to remember is to learn how they operate.

The input of each filter is on the left.

The low-pass filter is just like our power supply filter. The reactance of the inductor is low for low frequencies and increases as frequency increases. As frequency increases the reactance of the capacitor becomes lower and lower, effectively shorting out higher frequencies.

➔ Always remember $X_L = 2\Pi fL$ and $X_C = 1/(2\Pi fC)$.
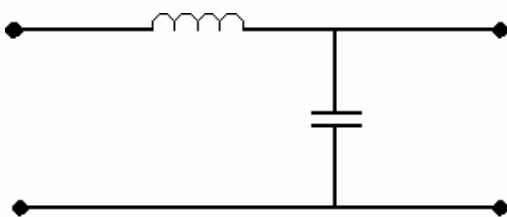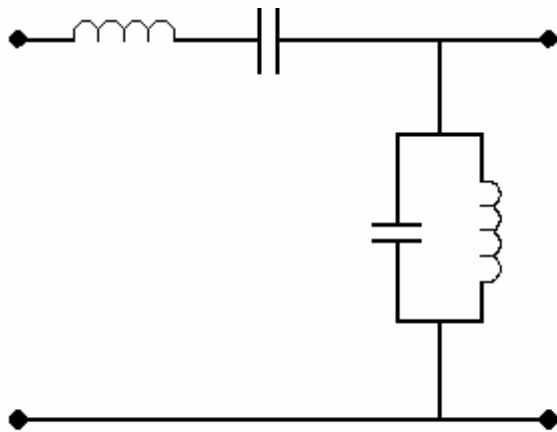

Low-pass filter

Figure 1.
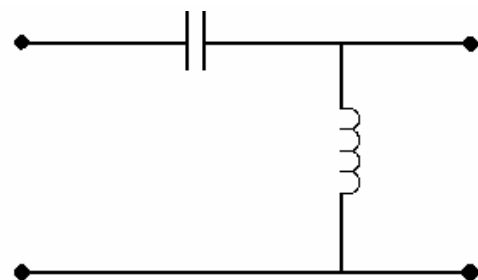
High-pass filter

Figure 2.

The basic high-pass filter just has the components reversed. X_L and X_C change with frequency causing higher frequencies to pass through this type of filter more easily than lower ones.

Band-pass filter

Figure 3.

A band-pass filter could be made by combing the two filters above, and this is sometimes done. However, a better method is to use tuned circuits. The series LC circuit will have low impedance to a narrow band of frequencies on or around its resonant frequency. Say we wanted the band-pass filter in figure 3 to pass 10.7 MHz, +/- a bit of course. Then both LC circuits would be tuned to 10.7 MHz. The series circuit would offer almost no impedance to a 10.7 MHz signal since its impedance is very low at resonance. The impedance of the parallel LC circuit would be extremely high at 10.7 MHz - in fact, so high it would be as if it were not there at all.

Not far away from 10.7 MHz though, the series LC circuits impedance would start increasing, making it harder for signals to flow through it. The impedance of the parallel LC circuit would begin to drop, causing it to effectively short out or shunt frequencies from getting to the output.

The band-stop (notch) filter shown in figure 4 is exactly the same as the band-pass but with the tuned circuits swapped around.

Suppose we wanted to stop a 27 MHz CB band signal. We could use the band-stop filter shown (though I must say there are much easier ways). Each tuned circuit would be resonant in the middle of the 27 MHz CB radio band. Such a filter could be used on the back of a TV set to prevent overload interference from a nearby CB radio.
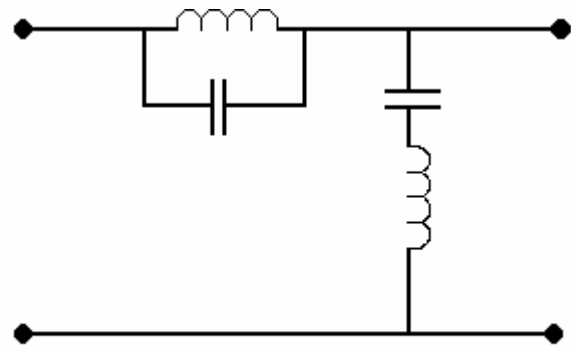
Band-stop filter

Figure 4.

What effect do you think the parallel LC circuit in series, resonant on around say 27.3 MHz, would have on CB radio frequencies? Of course it would present a very high impedance and block them. Likewise the series LC circuit in shunt (parallel) would have low impedance and short circuit them from the output.

The VHF or higher TV signals would be unaffected by this high-pass circuit.

Identification of a filter is determined not only by its electrical function, that is, high-pass, low-pass etc., but also by its physical shape when drawn in the schematic form. The components of a filter may form the letter 'L', 'T', or the shape of the Greek letter for Pi (Π). Use of one of these letters is then made in the description of the filter. For example, low-pass filter 'L' type. For more complex designs letter designations are dropped. A further description of the filter may include the input reactance, such as low-pass, inductive input, L type.

The filters shown above will work as they are, however, more effective filters can be made by joining filter sections together. Each filter shown can be considered a filter section in a more complex filter design.

SCHEMATIC OF A PRACTICAL HIGH-PASS FILTER

The figure 5 circuit is a high quality high-pass filter that could be used on the back of a TV set to block the low HF transmission from an amateur station and allow the higher VHF or UHF TV signals to pass. Although this is a more complex circuit, you should still be able to work out that it is a high-pass filter.
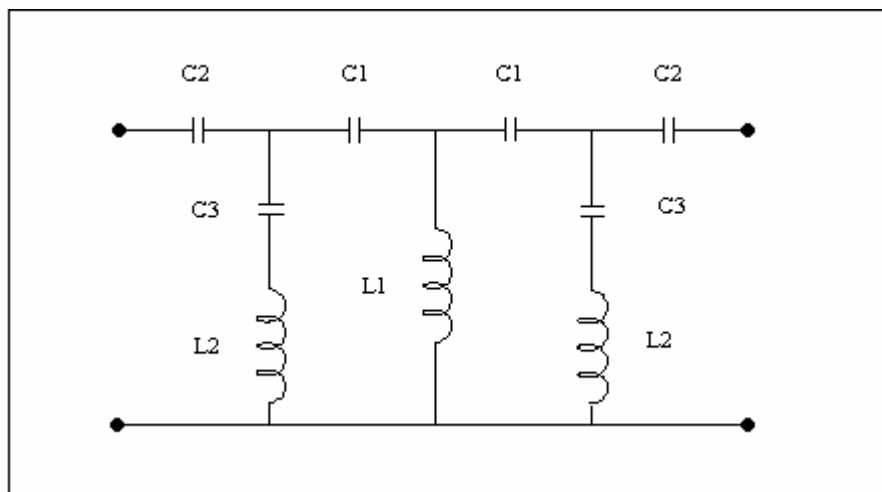

Figure 5 – High-Pass Filter.

INSERTION LOSS

Ideally, on the band or range of frequencies that a filter is supposed to pass unimpeded, the loss should be zero dB. In practice, LC circuits have some insertion loss. An insertion loss of less than 0.5 dB is good, though some more complex filters may have insertion losses as high as 2 dB. Remember, insertion loss is undesirable attenuation to the *wanted* signal.

The best way to identify the function of a filter is to remember the behaviour of X_L and X_C and, impedance of series and parallel circuits. This is the method I much prefer you to use. Having said that, if you have trouble identifying the electrical function of a filter you may use the following straight memory method:

    a) Low-pass filters - inductance in series, capacitance in shunt.
    b) High-pass filters - capacitance in series, inductance in shunt.
    c) Band-pass - series tuned circuits in series and parallel tuned circuits in shunt.
    d) Band-stop - parallel tuned circuits in series and series tuned circuits in shunt.

CONSTANT K

If the values of inductance and capacitance are chosen correctly, any change of reactance of either one (due to a changing frequency) will be exactly offset by an equal and opposite change in the other. Therefore, the product of the reactances will always be constant. This product is known as the 'constant K'. This type of filter is called a Constant K.

CRYSTAL FILTER

We learnt in an earlier reading that a quartz crystal has two resonant frequencies. A series resonant frequency, and a parallel resonant frequency. A quartz crystal operating on its parallel resonant frequency behaves just like a parallel LC circuit, it has high impedance at this frequency and this frequency only. A quartz crystal operating on its series resonant frequency behaves just like a series LC circuit, it has low impedance at this frequency and this frequency only. The practical advantage of quartz crystal is that it has an extremely high Q and therefore makes an excellent high selectivity filter. They are far more expensive than LC circuits and cannot handle the same amount of power.
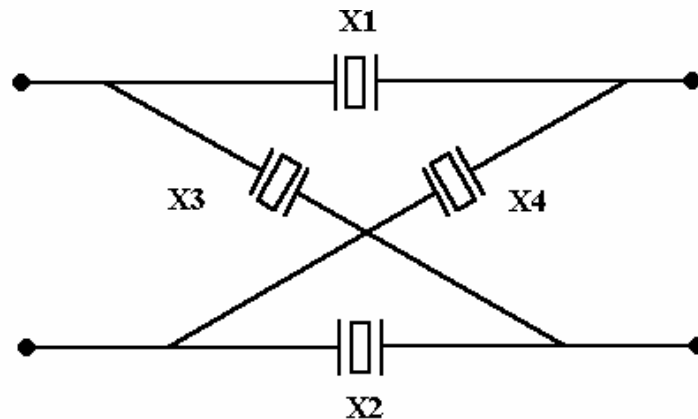
Crystal lattice filter
Sharp Band-pass (eg SSB filter)
Figure 6.

One of the most obvious applications of a crystal filter that we have discussed earlier, is the crystal filter in an SSB receiver. This filter is a band-pass filter about 2.8 kHz wide and very sharp (selective). It is asking a lot of a band-pass filter to remove a single sideband and reject the other - the best way to do this is with a quartz crystal filter. An arrangement of quartz crystals connected to form a filter is often called a crystal lattice filter network.

The crystal lattice filter shown in figure 6 is a band-pass filter, suitable for use as a sideband filter in an SSB transmitter receiver or transmitter. X1 and X2 are series resonant at the centre of the required sideband, while X3 and X4 are parallel resonant at the same frequency.

For a discussion of the two resonant frequencies of a quartz crystal, please refer to 'Reading 27 – Oscillators' on this topic. In the diagram of the crystal filter (figure 6), X1 and X2 being series resonant, behave as a series LC circuit. They have low impedance to the desired signals and exhibit increasing opposition to signals removed from their series resonant frequency. Also, X3 and X4 being parallel resonant, behave like parallel tuned circuits in shunt with the signal path. A high impedance in shunt with the signal path will not affect signal frequencies, but will provide a low impedance path for signals away from the pass band centre frequency, effectively short-circuiting them.

FILTER CURVES

A filter curve or selectivity curve is just a way of graphically describing how a filter works. These curves can actually be produced when testing a filter, using a spectrum analyser and a tracking generator. You may need to be able to identify one of the four basic filter curves.
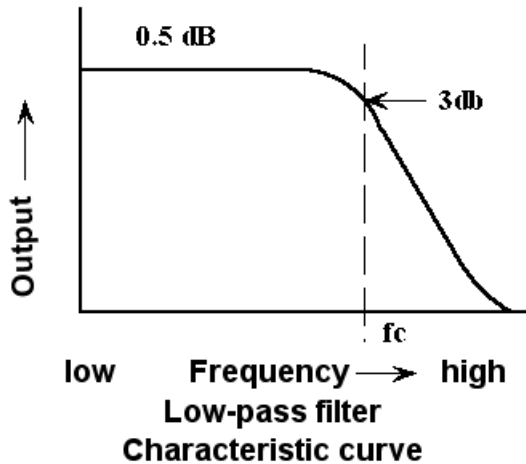

Figure 7.

The selectivity curve of a low-pass filter is shown in figure 7. This filter will pass all frequencies with minimum attenuation (the insertion loss of 0.5 dB) up to the cutoff frequency (fc), which for a typical HF transmitter would be around 35 MHz. Beyond the cutoff frequency the filter begins to attenuate or block signals quickly. At about 50 MHz a low-pass filter of this type could attenuate signals by as much as 70 dB.

It is a trap to assume that a low-pass filter is only used at low frequencies such as the HF radio band. A low-pass filter could have a cutoff frequency of 112 MHz for use with say a FM broadcast station. Such a filter would still pass all frequencies up to 112 MHz.

The selectivity or characteristic curve of a high-pass filter is shown in figure 8. A typical high-pass filter may be used on the back of a TV set where the antenna leads connects to the set or the video. The high-pass filter will pass the high TV signals (with the insertion loss of 0.5 dB shown) and attenuate all frequencies below the cutoff (fc) to give the TV extra protection from say a nearby HF radio transmitter.
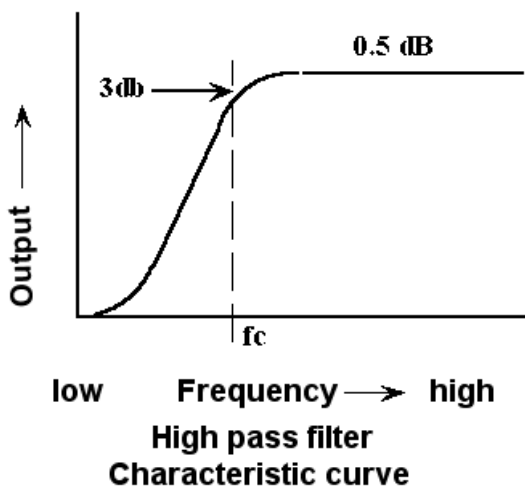

Figure 8.

There are many other applications for a high-pass filter besides this one. The important thing is that you understand and can identify the curve. Output of the filter is high for frequencies above cutoff and low for frequencies below cutoff (fc). I have not shown specific frequencies on the horizontal scale as the frequency range can be anything. In practice, the vertical axis would be marked in actual decibels and the horizontal axis in actual megahertz or kilohertz.

The band-pass curve in figure 9 shows that all frequencies between two cutoffs, f1 and f2, will be passed. Signals outside that band will be significantly attenuated.
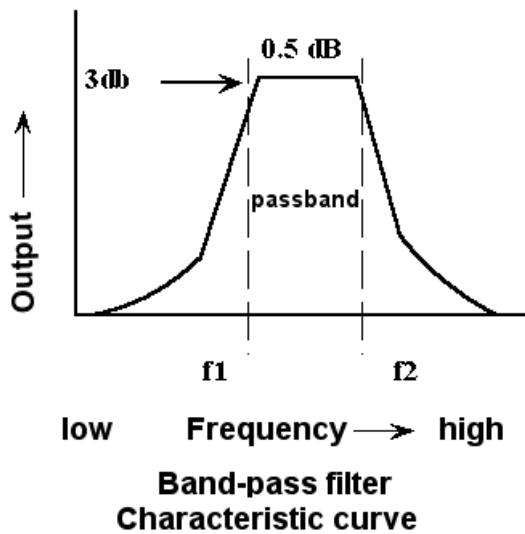

Band-pass filter Characteristic curve

Figure 9.

Most textbooks show band-pass filter curves nice and symmetrical. In practice they often aren't, as my brilliant artwork illustrates!

The curve of a band-stop or notch filter in figure 10 looks a bit strange to begin with.

You may have a broadcast FM station nearby that is overloading one of your receivers. The broadcast FM band is from 88-108 MHz. Therefore, a notch filter for FM broadcast would have an f1 of 88 MHz and an f2 of 108 MHz - or at least somewhere in that band.
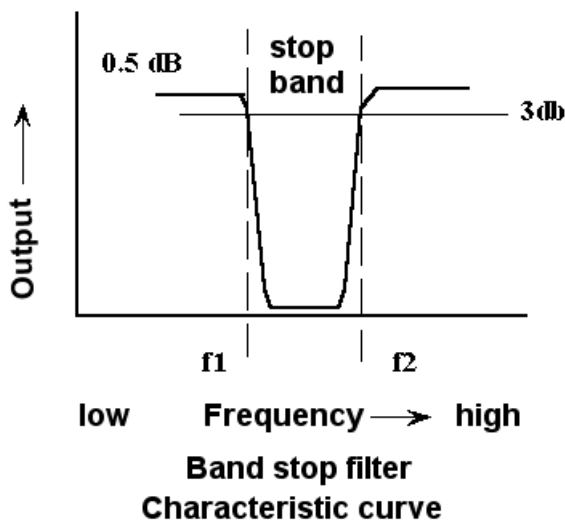

Band stop filter Characteristic curve
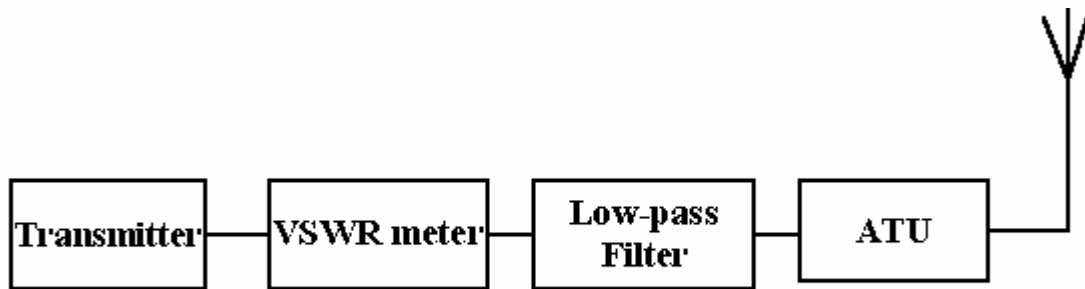
Figure 10.

Again, it is important you can recognise the curve. I suppose I should point out that the examiner could get cunning and change the axis. For example "Output" could be shown increasing downward, instead of as I have shown it. My method is the conventional way - I don't think the examiner would deviate from this, but then you never know, and it should not matter if you learn to read the axis before looking at the curve.

PLACEMENT OF A LOW-PASS FILTER

Probably one of the most useful and most commonly found filters at amateur and HF CB radio stations is the low-pass HF filter. The idea of placing a low-pass filter at the output of a HF transmitter is to make doubly sure that all emissions (and they do exist at all stations) above the HF band are attenuated even further, to reduce greatly the potential for interference. As an inspector for many years I was often astonished at the controversy of where the low-pass filter should be placed.

There is an important rule with all filters, irrespective of their type and frequency range: Filters are made with a specific input and output impedance which is usually the same, and is 50 ohms.

If you do not place a filter into a system which matches its impedance, then it will simply not work as it is intended. In a radio system, the degree of impedance match or mismatch is normally determined by measuring the VSWR, with a VSWR meter (to be discussed in full later). If you have 50 ohm coaxial cable, it will only behave like 50 ohm coaxial cable if the VSWR is 1:1. If you are going to insert a 50 ohm low-pass filter into a 50 ohm coaxial line then there must not be significant VSWR on the line, otherwise the filter may not work or may even cause interference.


A low-pass filter fitted to a HF transmiter

Figure 11.

In the diagram of a HF radio system in figure 11, the low-pass filter is placed last, but before the Antenna Tuning Unit. If there was no ATU then the low-pass filter would be last, but the VSWR must be near to 1:1. In the arrangement above, you should not swap the positions of the VSWR meter and the low-pass filter. A VSWR meter can actually produce harmonics (interference) and these can only be stopped by a low-pass filter placed after it. So, a low-pass filter should be connected into a line that matches its impedance, and it should be the last device in a transmission line with the exception of an ATU and antenna.

A MAINS FILTER

A 240-volt household power line filter is more commonly called a mains filter. The purpose of a mains filter is usually to prevent radio frequency energy from going into the mains network and causing interference to other devices in your (or nearby) household(s). Alternatively, a mains filter can be used to protect a device from radio frequency interference coming via the mains.
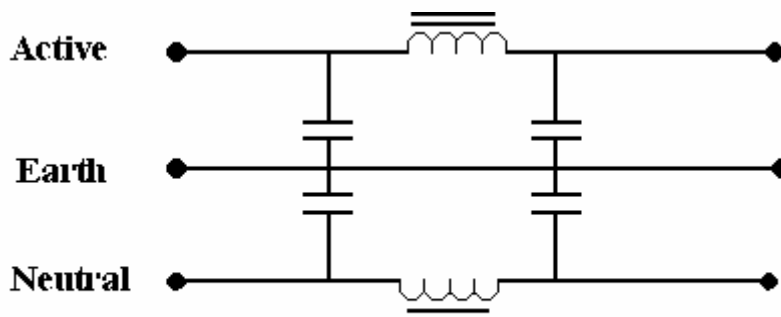
A Mains Filter

Figure 12.

If you can imagine your house being invisible with only the electrical wiring remaining in place, then you can start to imagine the large antenna system your household wiring is.

The diagram of the mains filter is a configuration called double Pi type. A mains filter is a low-pass filter, passing the mains frequency and blocking the higher radio frequencies. Notice the iron core inductors - these are a good indicator of large inductance and low frequency operation. Ceramic capacitors are normally used to obtain the necessary high voltage rating, which is typically 2kV. The high voltage rating is necessary to prevent damage from possible high voltage line transients (voltage spikes). This type of filter could be placed in the mains lead of a TV receiver, to prevent RF energy entering the receiver after being picked up by the household wiring. The filter may also be useful in preventing power tools from interfering with radio and television reception, provided the interference is conducted from the power tool to the effected device via the mains lead. A mains filter will not be of assistance where the interference is being radiated, and *not* conducted by household wiring.

CAVITY FILTERS

Cavity filters are used in amateur radio quite a lot. Amateur repeater stations nearly always use cavity filters. Cavity filters can be made to act as band-pass or band-stop (notch) filters. The principle of operation is similar to that of transmission line filters - which we will discuss in a separate reading called 'Transmission lines'.

The advantage of cavity filters is that they are very high Q, but not as high as a crystal filter, however they have the advantage of being able to handle high power levels. You will find cavity filters, or combinations of them, at the output of receivers and transmitters, even very high power ones.

Figure 13.

A repeater station is a receiver connected to a transmitter. Whatever is received on the receiver is retransmitted on the transmitter, relaying the amateur or CB'ers message. The repeater is usually placed in a prime location to give extended coverage and may run at high power. The problem is keeping the repeaters transmitters from interfering with its own receiver, which may only be a few hundred kilohertz away. A combination of band-pass and notch-filters made from cavities can easily achieve the amount of receiver-transmitter isolation (in decibels). By the way, the receiver and transmitter of a repeater often share the one antenna, though they do not have to.

Cavity filters are rarely used below 30 MHz as below this frequency they are physically too large. The arrangement of 6 cavity filters shown in figure 13 is called a diplexer. A diplexer is just a system of cavities as notch and band-pass filters, to enable a transmitter and receiver on close frequencies to share a single antenna.

The cavities shown in figure 13 are about 300mm in diameter and about 600mm long, and operate in the VHF band. The most common shape of a cavity filter is that of a cylinder as shown, however at higher frequencies any shape can be used such as squares or

rectangles for example.

STRIPLINE FILTERS

At UHF frequencies and above, normal filter components like capacitors and inductors would become too small physically and in value, to be stable. From UHF and beyond a common filter used inside communications equipment is the stripline. I am not going to go into the operation of these filters here as their principle of operation requires some knowledge of transmission line theory, as this is how these filters operate. Suffice to know for now that ordinary capacitors and inductors cause problems in filter construction for UHF frequencies and above, and an alternative is the stripline filter, with its operation to be covered in the reading on transmission lines.

Some pictures of actual filters:

Figure 14 is a bandpass filter for the FM broadcast band. The cylindrical filters below it are 'notch' or 'band stop' filters, also for the FM broadcast band
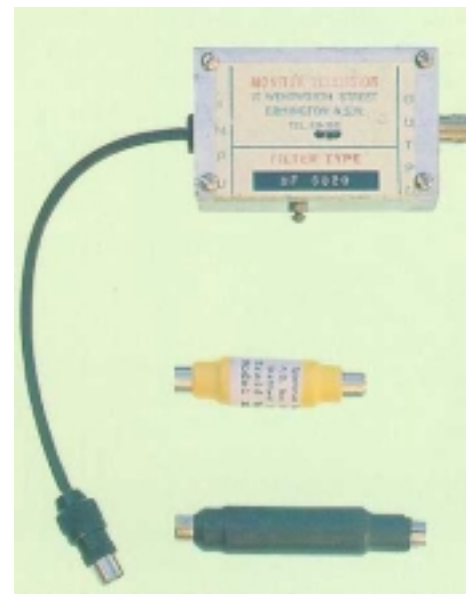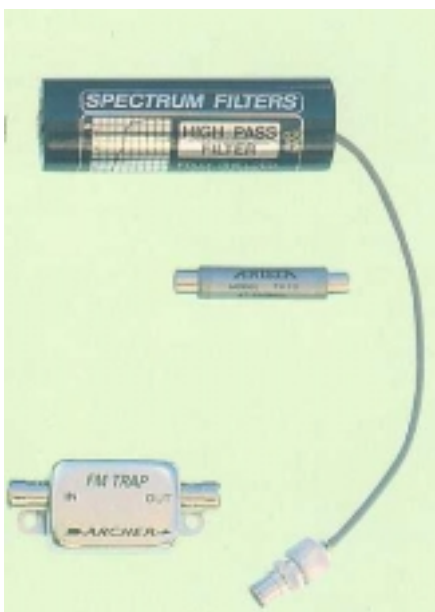

Figure 14.

Figure 15.

Figure 15 (spectrum filters) is a high-pass TVI filter designed by the author.

A high pass filter suitable for a television receiver (as shown) will cure the majority of interference problems between a HF (0-30 MHz) amateur radio station and a TV set which is being overload. Good filters of this type can be expensive – read later how a very cheap transmission line notch will often quickly, simply and cheaply do the same job.

As a matter of interest, over 80% (in the authors opinion) of television and radio interference involves a problem at the receiver. In the majority of cases, interference cannot be cured at the transmitter, presuming the transmitter is operated correctly.

Figure 16.

Figure 16 shows a high-pass TVI (television interference) filter fitted to the back of a TV receiver. These types of filters are extremely effective but expensive. Stub filters are not as good, but are quick and cheap, and discussed in the reading on transmission lines.

The next reading will cover types of interference. Now that you are armed with knowledge of how filters work, we will go on to describe the types of interference that you need to know about for the exam and to enjoy your hobby more. We will also discuss how to cure the interference.

One of the examiners main concerns, shown by previous exam questions, is that you have a good knowledge of types of interference and their identification.

End of Reading 32
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