VINTAGE RADIO

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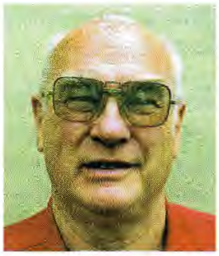


Intermediate Frequency (IF) Amplifiers; Pt.1

The IF stage is an important circuit section in all superheterodyne radio receivers. Here's a look at how the IF stage evolved in early broadcast-band AM radio receivers and the problems that were overcome along the way.

In a superheterodyne receiver, the IF amplifier has a number of tasks to accomplish. First, it sets the selectivity of a receiver (ie, the ability to separate stations), whether tuned to 30MHz (megahertz) or 550kHz (kilohertz).

If you've ever tuned an Astor "Football", a tuned radio frequency (TRF) set, you will notice that the selectivity is good at 550kHz but is quite broad at 1600kHz. At 1600kHz, stations up to 30kHz away from the designated tuned frequency can be heard in addition to the desired station. However, this is not usually a serious problem, as stations are allocated channels at least 100kHz apart in any particular area.

The IF amplifier stage also provides most of the radio frequency (RF) amplification in a superheterodyne receiver. This means that fewer stages are required to obtain the same performance compared to a TRF set. It is also much easier to set up, with just a few screwdriver adjustments required for alignment, and is often the only stage in a receiver that has automatic gain control (AGC/AVC) voltages applied to it.

Finally, some IF amplifier valves include detector and AGC diodes. So the IF amplifier stage is a very important part of a superhet radio receiver.

The frequencies used

Over the years, manufacturers have used many different intermediate frequencies (IFs) in their receivers. For example, in very early Australian domestic sets, the IFs were in the order of 30, 45, 50 and 60kHz. However, once superheterodyne receivers be-

This photo show a selection of several large-size IF transformers.

This large IF transformer includes a top-cap grid connection lead.

came properly established, the common IFs used were as follows: 173kHz, 175kHz, 181.5kHz, 182.5kHz, 200kHz, 210kHz, 212.5kHz, 220kHz, 226kHz, 250kHz, 252kHz, 252.5kHz, 262.5kHz, 390kHz, 445kHz, 446kHz, 450kHz, 452kHz, 453kHz, 453.5kHz, 455kHz, 456kHz, 457.5kHz, 458kHz, 460kHz, 462.5kHz, 465kHz, 469kHz, 472.5kHz, 475kHz, 550kHz and 595kHz.

That's quite a list and covers 36 different frequencies that were used by various manufacturers in Australia over the period that domestic superheterodyne radio receivers have been around. Both 550kHz and 595kHz appear to have been used by some sets when tuned to shortwave, or in shortwave converters. On the other hand, high-fidelity AM tuners often used 1900kHz and some earlier communications receivers used 1600kHz or 1650kHz.

Later high-frequency (HF) communications and other specialised receivers used a number of other frequencies, including frequencies around 45MHz and 70MHz in the VHF range. However, we are not interested in those in this article.

The next question to ask is which IF frequency is the "best"? The answer is that there is no "best". They all have their good and bad points. Initially, superhets used very low IF frequencies, as mentioned above. These low IFs (30-60kHz) enabled triode valves to be used with no neutralisation and provided quite high selectivity. However, their big disadvantage was that they suffered intolerable "double-spotting".

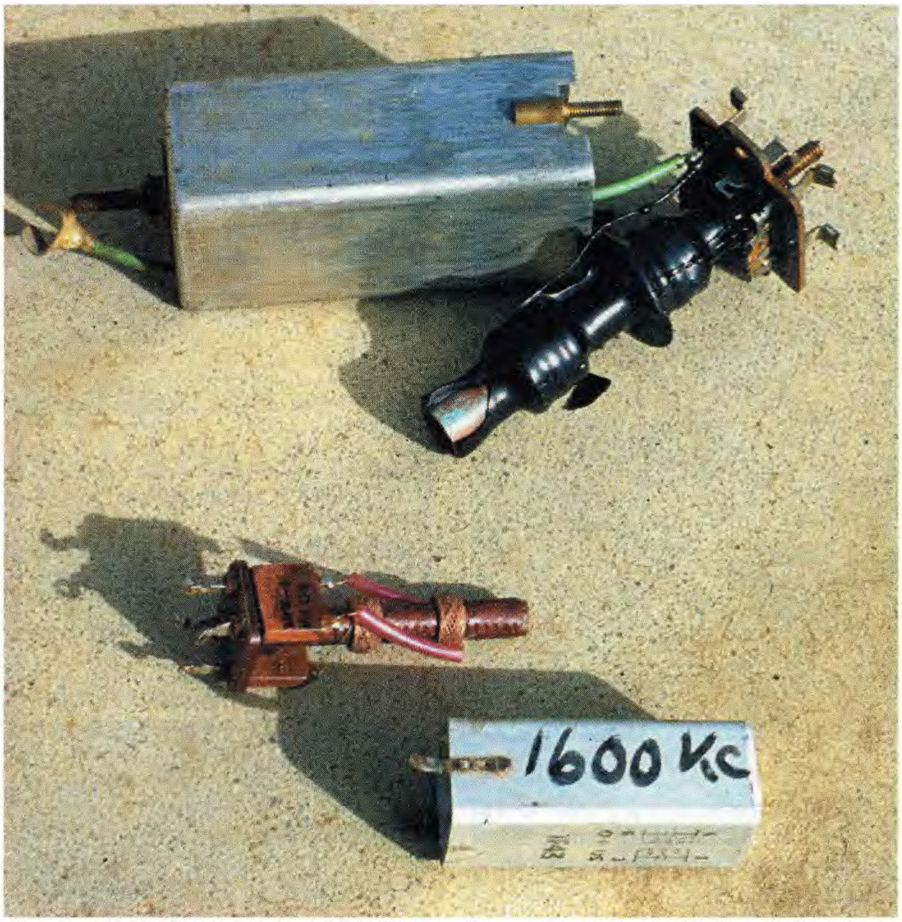
Double-spotting

"Double-spotting" is a term that means that the wanted station is tuned in at two spots on the dial. These spots would be just 60kHz apart if an IF of 30kHz is used. So how does this occur?

In a superhet receiver, the local oscillator frequency is offset from the wanted station by the frequency of the IF amplifier. For example, let's say that the wanted station is on 800kHz and the IF is 30kHz. This means that the local oscillator (which is usually higher in frequency than the tuned station) will be on 800 + 30 = 830kHz.

However, if the selectivity of the RF stage is quite poor, a station on 860kHz will also give a 30kHz IF output when mixed with the local oscillator (on 830kHz). As a result, two stations – one on 800kHz and one on 860kHz – will be received at the same time.

If the receiver is now tuned to 740kHz the oscillator will be on 770kHz. However, this will also give a 30kHz IF output from the 800kHz station. This means that the 800kHz sta-



These 455kHz (top) and 1600kHz IF transformers have been dismantled to show the windings. The windings are secured inside the metal cans for protection and shielding.

tion is heard at both the 800kHz and 740kHz positions on the dial.

Indeed, it was virtually impossible to stop double-spotting on these early sets with very low IFs, as the selectivity of the aerial and RF tuned circuits was quite poor. But even today, with much higher quality materials, double-spotting would still be a major problem using such a low IF.

Double-spotting (or more correctly, the "image") was a real annoyance and so designers set about solving this problem. As a result, triode valves were used for only a short time in superhets, being quickly replaced by the tetrodes and pentodes that were being developed during this time. The latter valve types had greater gain at RF compared to triodes and so generally didn't require neutralisation. And that in turn made it possible to select a higher IF to help overcome the image problem.

The next frequency selected was around 175kHz. This meant that the image frequency was now 350kHz (ie, 2 x 175kHz) away from the desired frequency (instead of being just 60kHz away). This meant that the image was rarely observed on those receivers that featured an RF stage – at least on the broadcast band.

However, if the receiver had no RF stage, it only had the selectivity of the aerial coil to rely on. Unfortunately, this was insufficient to provide image rejection and so the image was still quite evident – although further away. To overcome this problem, some sets used a bandpass double-tuned aerial coil network. However, this still involved using a 3-gang tuning capacitor, despite the absence of an RF amplifier stage.

A growing problem

In the 1920s, there weren't many radio stations and so the image didn't really present a problem. However, as the 1930s progressed, more and more radio stations commenced operation and they were becoming more powerful too. This meant that the gain of an RF stage was not needed on the broadcast band but due to the strength of many stations, the image problem was becoming quite noticeable again. This was particularly evident where stations were about 350kHz apart.

The move to a 455kHz IF

Fortunately, the materials used to make RF coils and transformers had improved during this period, as had the pentode valves used for RF amplification. As a result, a move to a higher intermediate frequency was investigated in the early to mid-1930s. This step also involved the Postmaster General's Department (PMG), as will soon be evident.

To overcome image problems, an IF in the frequency band just below the broadcast band was sought. However, the frequency band from 405-513kHz had been used by large ships and coastal radio stations since the beginning of the 20th century. This meant that the new IF had to be carefully selected, otherwise marine radio stations could break through into broadcast receivers on the IF frequency.

Obviously, having Morse code transmissions on top of the news or the current popular radio serial would not be well accepted. What's more, it would not be possible to tune the interference out.

The PMG allocated all frequencies for radio transmission services but had not allocated any marine frequencies around 455kHz. As a result, Australia fell into line with the USA which had already adopted 455kHz as the favoured IF frequency.

A number of manufacturers put a series tuned IF trap (455kHz) across the aerial and earth terminals to make doubly sure that interference problems would not occur. At the same time, the gain of the IF amplifiers increased as better low-loss materials became available for constructing IF transformers.

Initially, some IF stages used air-cored coils which were tuned by fixed and adjustable capacitors in parallel with one another. Later on, the capacitors were fixed and the inductance was varied by placing moveable iron-dust slugs into the centres of the coil formers. And later again, the two windings in most IF transformers were encased in an iron-dust or ferrite pot core type assembly which improved the performance even more.

With the IF at 455 kHz, the image was now 910kHz away. This meant

Photo Gallery: STC Model 5017A & STC Model 5017

The STC Model 5017A used the same chassis as the more compact 5017 shown at right but was housed in a different cabinet style. It featured an attractive illuminated dial that was oval in shape. The example shown here was produced in Sydney in 1936. It covered the medium-wave broadcast band only and used the following valve line-up: 6A7 frequency changer; 6D6 IF amplifier; 6B7 1st audio/detector/AVC amplifier; a 42 output stage; and an 80 rectifier. (Photo and information courtesy Historical Radio Society Of Australia).

Produced by STC (Sydney) in 1937, the Model 5017 was housed in a stylish wooden cabinet that was more upright than the cabinet used for the 5017A. It carried the same illuminated oval-shaped dial and also covered the medium-wave broadcast band. Its valve line-up was identical to that used in the 5017A, ie: 6A7 frequency changer; 6D6 IF amplifier; 6B7 1st audio/detector/AVC amplifier; a 42 output stage; and an 80 rectifier. (Photo and information courtesy Historical Radio Society Of Australia).

that a set tuned to 600kHz would have an image response at 1510kHz – nearly off the end of the broadcast band. The frequency difference had now become so great that the selectivity of a single tuned circuit in the aerial was adequate to reject almost all signals on the image frequency.

With the profusion of IF frequencies around 455kHz (445-475kHz), marine radio stations could be still amplified by the IF amplifier in those receivers not tuned to 455kHz. In Europe, for example, 465kHz and 475kHz were common IF frequencies, as the marine radio stations were allocated different frequencies to those used in Australia and New Zealand.

Substituting IF transformers

Anyone aiming to keep a supply of IF transformers to tune to every one of these frequencies is going to need a rather large box to store them all. Scrutiny of the range of frequencies will reveal that they fall into a few general frequency ranges such as 173-182.5kHz, 200-226kHz, 250-262.5kHz and 446-475kHz – with 390kHz, 550kHz and 595kHz being the odd ones out.

As an example, let's say that you have a set with an IF of 475kHz in which an IF transformer becomes faulty. So where can you get a replacement 475kHz IF transformer in Australia? The answer is you probably can't get one but fortunately, most 455kHz units can be adjusted to 475kHz.

In fact, most IF transformers have a frequency adjustment range of 110-115%. Therefore, it isn't necessary to keep a wide range of transformers. Most 175kHz transformers will cover from 173-182.5kHz and most 455kHz transformers will cover from 445-475kHz (these are the two most popular frequencies used). IF transformers in the 200kHz and 250kHz range were less common, with only a few receivers using them.

Modifying IF transformers

If a direct replacement can't be found, it's also possible to modify IF transformers to operate at different frequencies. Note, however, that their performance may be slightly inferior to the ideal replacement.

For example, I have an AWA AR8 receiver which has an IF of about 750kHz. One IF transformer winding went open circuit in the middle of the winding and replacements definitely are not readily available.

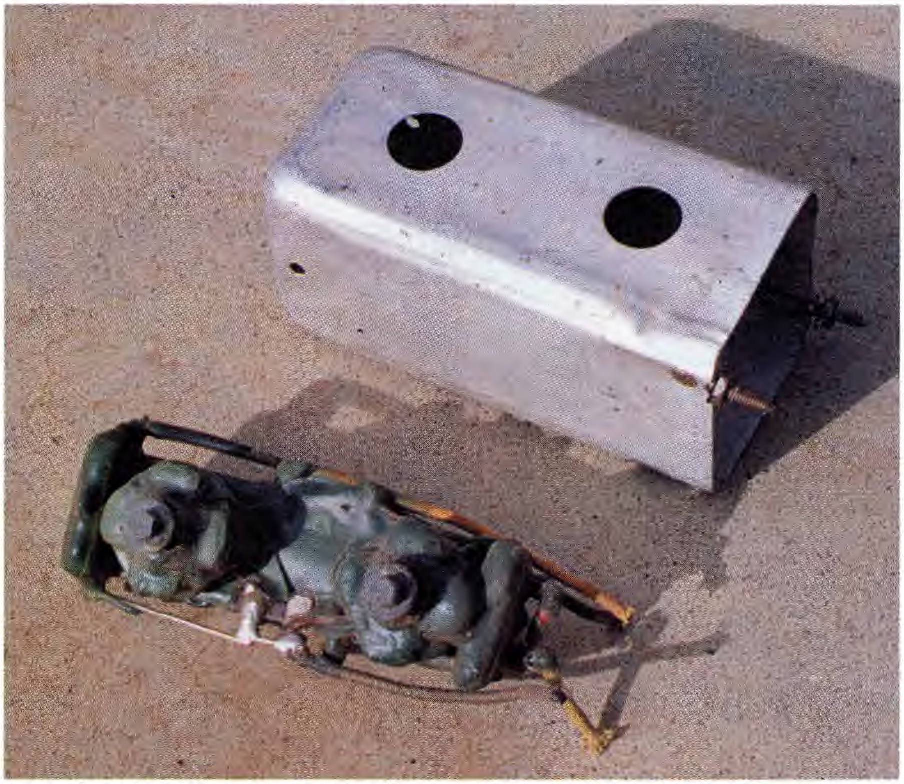
To solve this problem, I opened up an AWA 455kHz IF transformer of the same general size and reduced the value of the two fixed mica tuning capacitors (from 400pF to 100pF). This enabled the IF transformer to be tuned to 750kHz and the set worked just as well as it did with the original.

This is a useful trick to remember if you need to adjust an IF transformer to an odd-ball frequency that's outside its original tuning range.

Of course, new replacement IF transformers are no longer available but old derelict receivers are a good source. So never throw a derelict receiver away until you've stripped it of everything that's likely to be useful.

Standardised IF frequencies

In the domestic arena today, there are two main IF frequencies used on the AM bands: 455kHz and 450kHz. The latter is commonly used in synthesised receivers, since this frequency is very convenient where the set has



An early side-adjustment IF transformer, shown here out of its metal can. The holes in the side of the can provide access to the adjustment slugs.

to be able to tune in either 9kHz steps or 10kHz steps. That's because there are no complicated division ratios as there would be if 455kHz were used.

IF & detector radiation

During operation, all receivers radiate some signals from the IF amplifier and detector stages. These signals are radiated on 455kHz and also on the second harmonic at 910kHz. That's because the detector is a non-linear device and generates harmonics of the intermediate frequency.

For this reason, no radio station was allocated 910kHz when stations were 10kHz apart. Nor is 909kHz used now that 9kHz station spacing is used. If a station had been allocated 910kHz or 909kHz, there could have been considerable interference from the receiver itself and this would have caused "whistles" on that station.

As a matter of interest, I had an amateur-band receiver that tuned from 1800-1875kHz and it picked up the fourth harmonic radiation of the IF on 1820kHz. So it certainly can and does occur. A well-shielded radio receiver will radiate very little IF or IF harmonic energy but most domestic receivers are not shielded so these signals are radiated.

AM signal transmissions

As can be imagined, the signal emitted from AM broadcast transmitters determines the design parameters of IF amplifier stages. So let's take a closer look at AM broadcast signals.

The transmitted signal consists of three components: the carrier frequency (eg, 600kHz) plus upper and lower sidebands which convey the audio signal. These upper and lower sidebands are identical and they extend either side away from the carrier by an amount that's equal to the highest audio frequency used to modulate the transmitter.

For example, if there is a 10kHz audio frequency present, the sidebands are ±10kHz either side of the carrier frequency. This means that if the carrier is on 600kHz, for example, then the sidebands are at 590kHz and 610kHz, so that the whole signal is 20kHz wide. When that signal is converted to the IF, the actual receiver IF channel passband would need to pass all signals from 445kHz to 465kHz.

However, the IF amplifier passband shape is not perfect and signals are not amplified uniformly within the passband. In addition, the frequency response of the IF transformers does not drop dramatically outside of the wanted passband. Hence frequencies further than 10kHz from the centre frequency (455kHz) will also be amplified but to a lesser extent, as you can see from the IF response graph in Fig.1.

AM broadcast transmitters did transmit audio frequencies up to 10kHz and beyond before the introduction of 9kHz station spacing, although I suspect that they now restrict themselves to 9kHz. Shortwave AM radio transmitters such as Radio Australia only transmit audio frequencies as high as 4.5kHz.

For this reason, a 20kHz IF bandwidth is not always necessary. In the case of Radio Australia, for example, a 9kHz bandwidth would be quite adequate, particularly so when shortwave radio stations are allocated channels 5kHz apart. And although AM radio stations do transmit signals as high as 9kHz, very few run-of-the-mill receivers can reproduce frequencies that high.

The IF bandwidth of older receivers was probably of the order of 10kHz, which allowed frequencies up to 5kHz to pass through. However, the latest imported transistor sets may only have an IF bandwidth of just 7kHz which means that audio frequencies up to only about 3.5kHz will be reproduced. And that's not taking into account the limited response of the 50mm speakers used in many sets!

Why so many IFs?

According to the Australian Official Radio Service Manuals (AORSM) and other sources, 16 IF centre frequencies ranging between 445kHz and 475kHz were used. Many of these varied by just a kilohertz or so from an adjoining intermediate frequency.

It might be thought that manufacturers had some good reason why a particular IF centre frequency was used. However, with only a few exceptions, I can find no reason why this should be so. If a 455kHz IF channel is 20kHz wide, it would amplify all the frequencies/channels from

445kHz to 465kHz as mentioned at the beginning of the article, although not equally and with considerable sideband cutting and distortion in many cases.

In the 1930s and 1940s, many of the smaller manufacturers did not have accurate signal generators and may have relied on crystal oscillators to set the IF centre frequency. Crystals were not cheap so if they had one on a slightly different frequency to 455kHz, that would not have worried them. However, I do know why one frequency other than 455kHz was used in the days of 10kHz spacing between stations.

With a 455kHz IF, the image frequency is 910kHz higher. If a receiver was tuned to 600kHz (for example), the image would be on 1510 kHz. If there was a strong station on 1510 kHz and the station on 600kHz was weak, a whistle may have been heard on the weaker station due to the image response.

A clever scheme

To overcome this, HMV used an IF centre frequency of 457.5kHz. The image frequency in this case was 915kHz higher, so a receiver tuned to a 600kHz station would have an image frequency of 1515kHz, which is 5kHz away from the carrier frequency of broadcast stations on either 1510kHz or 1520kHz. This meant that, in an ideal world, the whistle was 5kHz and by adjusting the tone control it would not be evident.

This was a nifty idea by HMV and it worked quite well, provided that the IF was accurately aligned. And, of course, it also relied on the owner tuning the set accurately!

Next month we'll look at variable selectivity IF amplifiers, neutralisation, the effects of unintended IF radiation, problems with the AGC system and alignment. **SC**

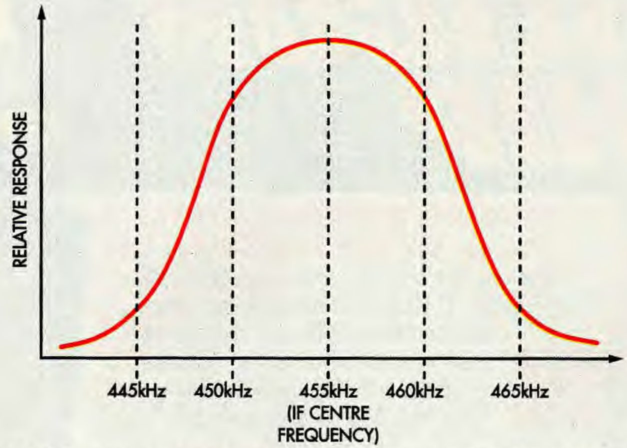


Fig.1: typical frequency response of an IF stage centred on 455kHz. Note that the response is not perfect since not all signals in the passband are amplified uniformly.

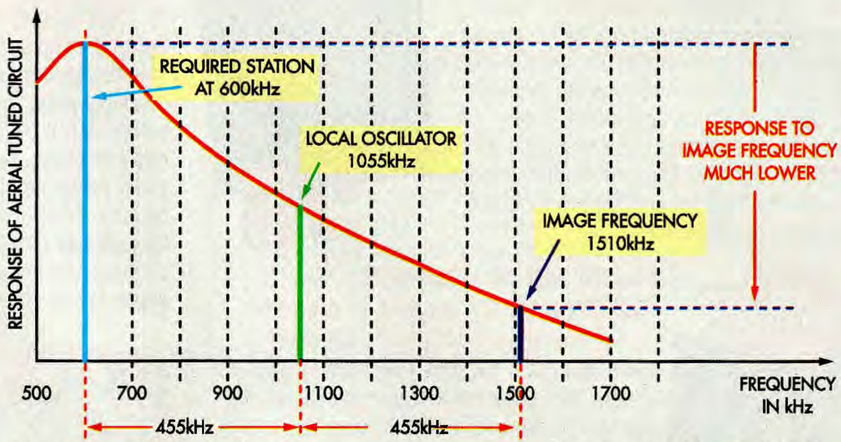


Fig.2: this diagram shows the relative response of the aerial tuned circuit to (1) a tuned radio station on 600kHz, (2) the local oscillator frequency on 1055kHz and (3) the image frequency at 1510kHz.