Introduction to the Superheterodyne Receiver

by Lloyd Butler VK5BR

Radio receivers have developed considerably over the years around a principle first evolved in 1918. Following Is a discussion on the principle of the superheterodyne and factors which affect its design.

Introduction

The subject of this article centres around basic principles of the superheterodyne receiver. In the article, we will discuss the reasons for the use of the superheterodyne and various topics which concern its design, such as the choice of intermediate frequency, the use of its RF stage, oscillator tracking, bandspread tuning and frequency synthesis. Most of the information is standard text book material, but put together as an introductory article, it can provide somewhere to start if you are contemplating building a receiver, or if you are considering examining specifications with an objective to select a receiver for purchase.

TRF Receivers

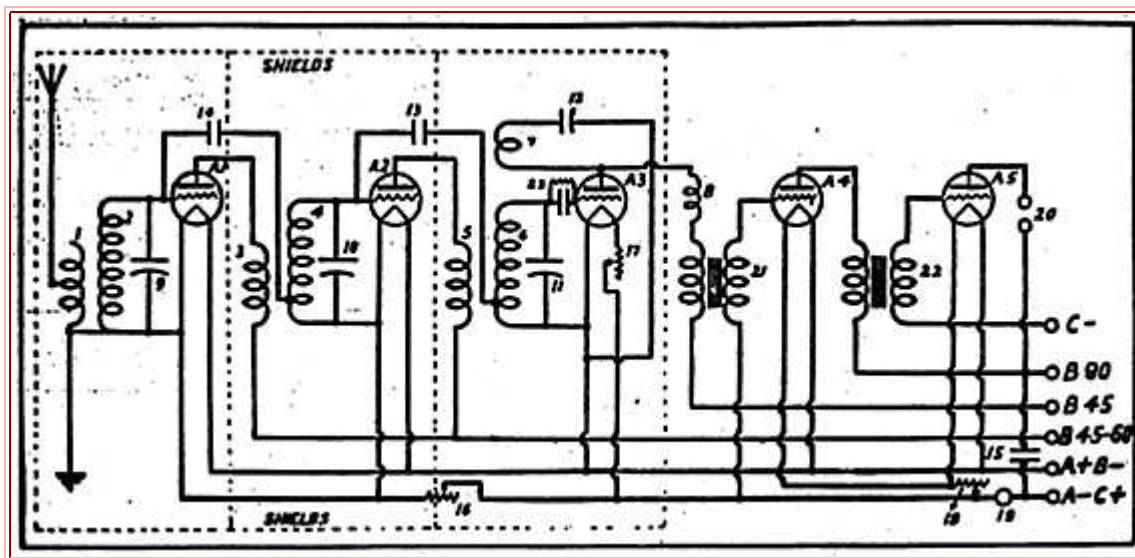**Figure 1 - An Early TRF Receiver. Here there are two neutralised RF stages and a regenerative detector followed by transformer coupled audio stages.**

Early valve radio receivers were of the Tuned Radio Frequency (TRF) type consisting of one or a number of tuned radio frequency stages with individual tuned circuits which provided the selectivity to separate one received signal from the others. A typical receiver copied from a 1929 issue of "The Listener In" is shown in Figure 1. Tuned circuits are separated by the radio frequency (RF) amplifier stages and the last tuned circuit feeds the AM detector stage. This receiver belongs to an era before the introduction of the screen grid valve and it is interesting to observe the grid-plate capacity neutralisation applied to the triode RF amplifiers to maintain amplifier stability. In these early receivers, the individual tuning capacitors were attached to separate tuning dials, as shown in Figure 2, and each of these dials had to be reset each time a different station was selected. Designs evolved for receivers with only one tuning dial, achieved by

various methods of mechanical ganging the tuning capacitors, including the ganged multiple tuning capacitor with a common rotor shaft as used today.
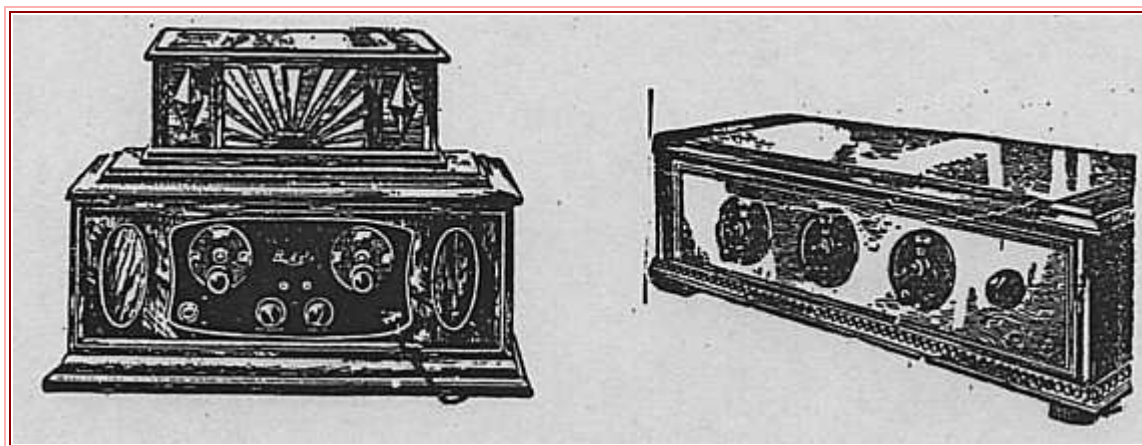

Figure 2: Separate Dials for each Tuned Stags.

The bandwidth of a tuned circuit of given Q is directly proportional to its operational frequency and hence, as higher and higher operating frequencies came into use, it became more difficult to achieve sufficient selectivity using the TRF receiver system.

The superheterodyne principle

The superheterodyne (short for supersonic heterodyne) receiver was first evolved by Major Edwin Howard Armstrong, in 1918. It was introduced to the market place in the late 1920s and gradually phased out the TRF receiver during the 1930s. The circuit of an early superheterodyne, as published in a 1927 issue of "Wireless Weekly", is shown in Figure 3.
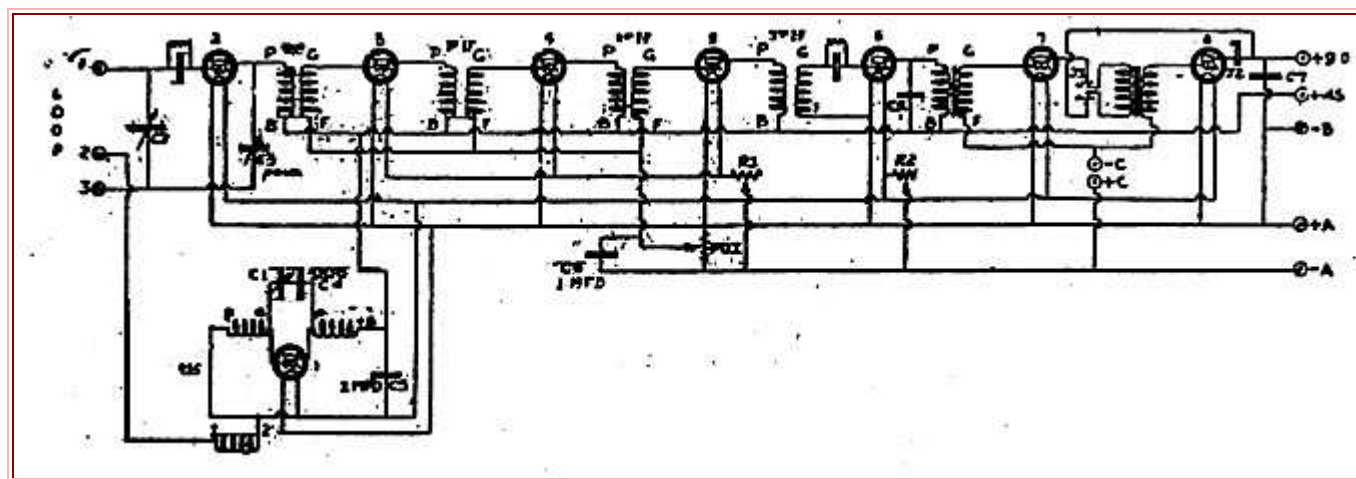

Figure 3 An Early Superheterodyne.

The principle of operation in the superheterodyne is illustrated by the diagram in Figure 4. In this system, the incoming signal is mixed with a local oscillator to produce sum and difference frequency components. The lower frequency difference component called the intermediate frequency (IF), is separated from the other components by fixed tuned amplifier stages set to the intermediate frequency. The tuning of the local oscillator is mechanically ganged to the tuning of the signal circuit or radio frequency (RF) stages so that the difference intermediate frequency is always the same fixed value. Detection takes place at intermediate frequency instead of at radio frequency as in the TRF receiver.
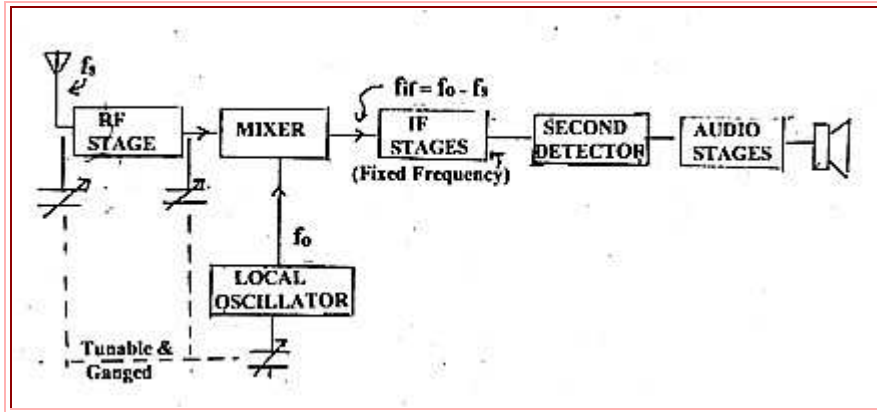
Figure 4: Principle of a Superheterodyne Receiver.

Use of the fixed lower IF channel gives the following advantages:

1. For a given Q factor in the tuned circuits, the bandwidth is lower making it easier to achieve the required selectivity.

2. At lower frequencies, circuit losses are often lower allowing higher Q factors to be achieved and hence, even greater selectivity and higher gain in the tuned circuits.

3. It is easier to control, or shape, the bandwidth characteristic at one fixed frequency. Filters can be easily designed with a desired bandpass characteristic and slope characteristic, an impossible task for circuits which tune over a range of frequencies.

4. Since the receiver selectivity and most of the receiver pre-detection gain, are both controlled by the fixed IF stages, the selectivity and gain of the superheterodyne receiver are more consistent over its tuning range than in the TRF receiver.

Second channel or image frequency

One problem, which has to be contended with in the superheterodyne receiver, is its ability to pick up a second or imago frequency removed from the signal frequency by a value equal to twice the intermediate frequency.

To illustrate the point, refer Figure 5. In this example, we have a signal frequency of 1 MHz which mix to produce an IFof 455kHz. A second or image signal, with a frequency equal to 1 MHz plus (2 x 455) kHz or 1.910 MHz, can also mix with the 1.455 MHz to produce the 455 kHz.
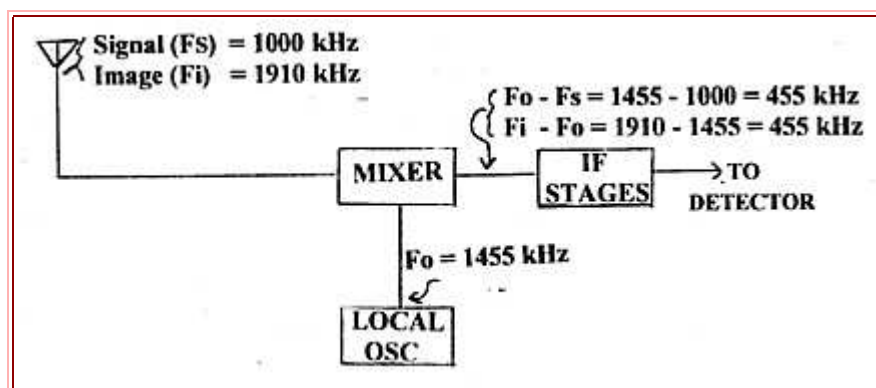

Figure 5: An illustration of how image frequency provides a second mixing product.

Reception of an image signal is obviously undesirable and a function of the RF tuned circuits (ahead of the mixer), is to provide sufficient selectivity to reduce the image sensitivity of the receiver to tolerable levels.

Choice of intermediate frequency

Choosing a suitable intermediate frequency is a matter of compromise. The lower the IF used, the easier it is to achieve a narrow bandwidth to obtain good selectivity in the receiver and the greater the IF stage gain. On the other hand, the higher the IF, the further removed is the image frequency from the signal frequency and hence the better the image rejection. The choice of IF is also affected by the selectivity of the RF end of the receiver. If the receiver has a number of RF stages, it is better able to reject an image signal close to the signal frequency and hence a lower IF channel can be tolerated.

Another factor to be considered is the maximum operating frequency the receiver. Assuming Q to be reasonably constant, bandwidth of a tuned circuit is directly proportional to its resonant frequency and hence, the receiver has its widest RF bandwidth and poorest image rejection at the highest frequency end of its tuning range.

A number of further factors influence the choice of the intermediate frequency:

1. The frequency should be free from radio interference. Standard intermediate frequencies have been established and these are kept dear of signal channel allocation. If possible, one of these standard frequencies should be used.

2. An intermediate frequency which is close to some part of the tuning range of the receiver is avoided as this leads to instability when the receiver is tuned near thefrequency of the IF channel.

3. Ideally, low order harmonics of the intermediate frequency (particularly second and third order) should not fall within the tuning range of the receiver. This requirement cannot always be achieved resulting in possible heterodyne whistles at certain spots within the tuning range.

4. Sometimes, quite a high intermediate frequency is chosen because the channel must pass very wide band signals such as those modulated by 5 MHz video used in television. In this case the wide bandwidth circuits are difficult to achieve unless quite high frequencies are used.

5. For reasons outlined previously, the intermediate frequency is normally lower than the RF or signal frequency. However, there we some applications, such as in tuning the Low Frequency (LF) band, where this situation could be reversed. In this case, there are difficulties in making the local oscillator track with the signal circuits.

Some modern continuous coverage HF receivers make use of the Wadley Loop or a synthesised VFO to achieve a stable first oscillator source and these have a first intermediate frequency above the highest signal frequency. The reasons for this will be discussed later.

Standard intermediate frequencies

Various Intermediate frequencies have been standardised over the years. In the early days of the superheterodyne, 175 kHz was used for broadcast receivers in the USA and Australia. These receivers were notorious for their heterodyne whistles caused by images of broadcast stations other than the one tuned. The 175 kHz IF was soon overtaken by a 465 kHz allocation which gave better image response. Another compromise of 262kHz between 175 and 465 was also used to a lesser extent. The 465 kHz was eventually changed to 455 kHz, still in use today.

In Europe, long wave broadcasting took place within the band of 150 to 350 kHz and a more suitable IF of

110 kHz was utilised for this band.

The IF of 455 kHz is standard for broadcast receivers including many communication receivers. Generally speaking, it leads to poor image response when used above 10 MHz. The widely used World War 2 Kingsley AR7 receiver used an IF of 455 kHz but it also utillised two RF stages to achieve improved RF selectivity and better image response. One commonly used IF for shortwave receivers is 1.600 MHz and this gives a much improved image response for the HF spectrum.

Amateur band SSB HF transceivers have commonly used 9 MHz as a receiver intermediate frequency in common with its use as a transmitter intermediate frequency. This frequency is a little high for ordinary tuned circuits to achieve the narrow bandwidth needed in speech communication, however, the bandwidth in the amateur transceivers is controlled by specially designed ceramic crystal filter networks in the IF channel.

Some recent amateur transceivers use intermediate frequencies slightly below 9 MHz. A frequency of 8.830 MHz can be found in various Kenwood transceivers and a frequency of 8.987.5 MHz in some Yaesu transceivers. This change could possibly be to avoid the second harmonic of the IF falling too near the edge of the more recently allocated 18 MHz WARC band. (The edge of the band is 18.068 MHz).

General coverage receivers using the Wadley Loop, or a synthesised bandset VFO, commonly use first IF channels in the region of 40 to 50 MHz.

An IF standard for VHF FM broadcast receivers is 10.7 MHz. In this case, the FM deviation used is 75 kHz and audio range is 15 kHz. The higher IF is very suitable as the wide bandwidth is easily obtained with good image rejection. A less common IF is 4.300 MHz believed to have been used in receivers tuning the lower end of the VHF spectrum.

As explained earlier, a very high intermediate frequency is necessary to achieve the wide bandwidth needed for television and the standard in Australia is the frequency segment of 30.500 to 30.6.000 MHz.

Multiple Conversion Superheterodyne

In receivers tuning the upper HF and the VHF bands, two (or even more) IF channels are commonly used with two (or more) stages of frequency conversion. The lowest frequency IF channel provides the selectivity or bandwidth control that is needed and the highest frequency IF channel is used to achieve good Image rejection. A typical system used in two metre FM amateur transceivers is shown in Figure 6. In this system, IF channels of 10.7 MHz and 455 kHz are used with double conversion. The requirement Is different to that of the wideband FM broadcasting system as frequency deviation is only 5 kHz with an audio frequency spectrum limited to below 2.5 kHz. Channel spacing is 25 kHz and bandwidth is usually limited to less than 15 kHz so that the narrower bandwidth 455 kHz IF channel is suitable.
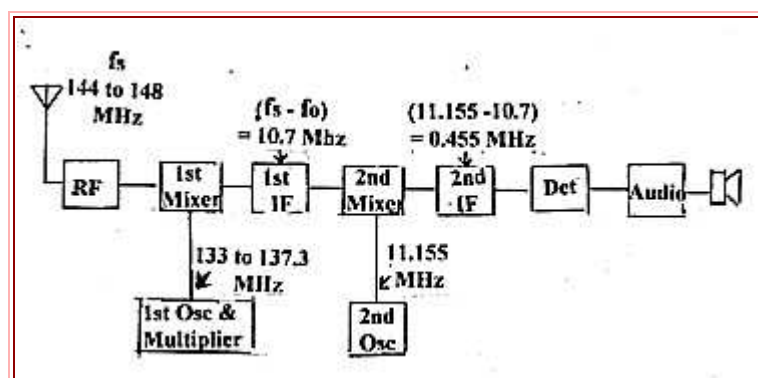

Figure 6: A Two Metre Recelver using Double Conversion.

Some modern HF SSB transceivers use a very high frequency IF channel such as 50 MHz. Combined with this, a last IF channel of 455 KHz is used to provide selectivity and bandwidth control. Where there is such a large difference between the first and last intermediate frequency, three stages of conversion and a middle frequency IF channel are needed. This is necessary to prevent on image problem initiating in the 50 MHz IF channel due to insufficient selectivity in that channel. For satisfactory operation, the writer suggests a rule of thumb that the frequency ratio between the RF channel and the first IF channel, or between subsequent IF channels, should not exceed a value of 10.

The RF amplifier

A good receiver has at least one tuned RF amplifier stage ahead of the first mixer. As discussed earlier, one function of the RF stage is to reduce the image frequency level into the mixer. The RF stage also carries out a number of other useful functions:

1. The noise figure of a receiver is essentially determined by the noise generated in the first stage connected to the aerial system. Mixer stages are inherently more noisy than straight amplifiers and a function of the RF amplifier is to raise the signal level into the mixer so that the signal to noise ratio is determined by the RF amplifier characteristics rather than those of the mixer.

2. There Is generally an optimum signal Input level for mixer stages. If the signal level is increased beyond this optimum point, the levels of intermodulation products steeply increase and these products can cause undesirable effects in the receiver performance. If the signal level is too low, the signal to noise rate will be poor. A function of the RF amplifier is to regulate the signal level into the mixer to maintain a more constant, near optimum, level. To achieve this regulation, the gain of the RF stage is controlled by an automatic gain control system, or a manual gain control system, or both.

3. Because of its non-linear characteristic, the mixer is more prone to cross-modulation from a strong signal on a different frequency than is the RF amplifier. The RF tuned circuits, ahead of the mixer, help to reduce the level of the unwanted signal into the mixer input and hence reduce the susceptibility of the mixer to cross-modulation.

4. If, by chance, a signal exists at or near the IF, the RF tuned circuits provide attenuation to that signal.

5. The RF stage provides isolation to prevent signals from the local oscillator reaching the aerial and causing interference by being radiated.

Oscillator tracking

Whilst the local oscillator circuit tunes over a change in frequency equal to that of the RF circuits, the actual frequency is normally higher to produce the IF frequency difference component and hence less tuning capacity change is needed than in the RF tuned circuits. Where a variable tuning gang capacitor has sections of the same capacitance range used for both RF and oscillator tuning, tracking of the oscillator and RF tuned circuits is achieved by capacitive trimming and padding.

Figure 7 shows a local oscillator tuned circuit (L2,C2) ganged to an RF tuned circuit (Ll,Cl) with Cl and C2 on a common rotor shaft. The values of inductance are set so that at the centre of the tuning range, the oscillator circuit tunes to a frequency equal to RF or signal frequency plus intermediate frequency.
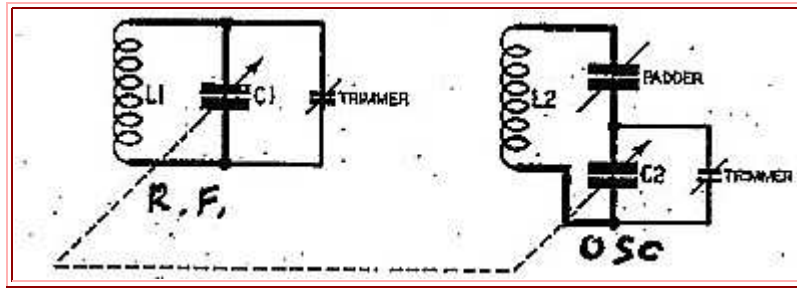
Figure 7: Tracking Circuit

A capacitor called a padder, in series with the oscillator tuned circuit, reduces the maximum capacity in that tuning section so that the circuit tracks with the RF section near the low frequency end of the band.

Small trimming capacitors are connected across both the RF and oscillator tuned circuits to adjust the minimum tuning capacity and affect the high frequency end of the band. The oscillator trimmer is preset with a little more capacity than the RF trimmer so that the oscillator circuit tracks with RF trimmer near the high frequency end of the band.

Figure 8 illustrates the principle. Curve A is the RF tuning range. The solid curve B shows the ideal tuning range required for the oscillator with a constant difference frequency over the whole tuning range. Curve C shows what would happen if no padding or trimming were applied. Dotted curve B shows the correction applied by padding and trimming. Precise tracking is achieved at three points in the tuning range with a tolerable error between these points.
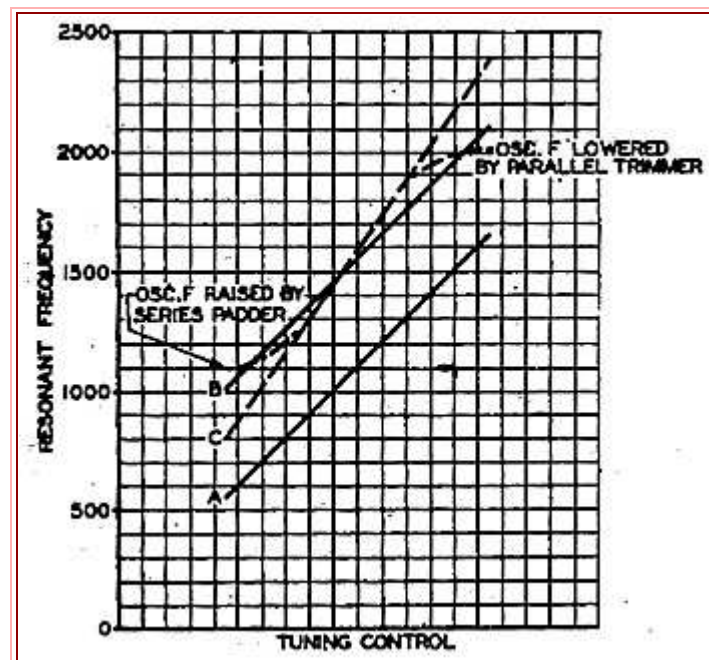

Figure 8: RF and Oscillator Tracking

Where more than one band is tuned, not only are separate inductors required for each band, but also separate trimming and padding capacitors, as the degree of capacitance change correction is different for each band.

The need for a padding capacitor can be eliminated one band by using a tuning gang capacitor with a smaller number of plates in the oscillator section than in the RF sections. If tuning more than one band, the correct choice of capacitance for the oscillator section will not be the same for all bands and padding will still be required on other bands.

Alignment of the tuned circuits can be achieved by providing adjustable trimmers and padders. In these days of adjustable magnetic cores in the inductors, the padding capacitor is likely to be fixed with the lower frequency end of the band essentially set by the adjustable cores.

Oscillator Stability

The higher the input frequency of a receiver, the higher is the first local oscillator frequency and the greater is the need for oscillator stability. A given percentage frequency drift at higher frequencies amounts to a larger percentage drift in IF at the detector. Good stability is particularly important in a single sideband receiver as a small change in signal frequency is very noticeable as a change in the speech quality, more so than would be noticeable in AM or FM systems.

Frequency stability in an oscillator can be improved by care in the way it is designed and built. Some good notes on how to build a stable variable frequency oscillator were prepared by Draw Diamond VK3XU, and published in Amateur Radio, January 1 1998. This an article well worth reading.

One way to stabilise a receiver tuneable oscillator is to use an automatic frequency control (AFC) system. To do this, a frequency discriminator can be operated from the last IF stage and its output fed back via a low pass filter (or long time constant circuit) to a frequency sensitive element in the oscillator. Many of today's receivers and transceivers also make use of phase locked loop techniques to achieve frequency control.

Where there are several stages of frequency conversion and the front end is tuned, the following oscillator stages, associated with later stage conversion, are usually fixed in frequency and can be made stable by quartz crystal control. In this case, receiver frequency stability is set by the first oscillator stability.

One arrangement, which can give better stability, is to crystal lock the first oscillator stage but tune the first IF stage and second oscillator stage as shown in Figure 9. In this case, the RF tuned circuits are sufficiently broadband to cover a limited tuning range (such as an amateur band) but selective enough to attenuate the image frequency and other possible unwanted signals outside the tuning range. This is the method used when a converter Is added to the front end of a HF receiver to tune say the two metre band. The RF circuits in the converter are fixed, the converter oscillator is crystal locked and the HF receiver RF and first oscillator circuits become the tuneable first IF stage and second tuneable oscillator, respectively. Since the HF receiver tuneable oscillator is working at a lower frequency than the first oscillator in the converter, the whole system is inherently more stable than if the converter oscillator were tuned. As stated earlier, the system is restricted to a limited tuning range and this leads to a discussion on bandspread tuning and other systems incorporating such ideas as the Wadley Loop.
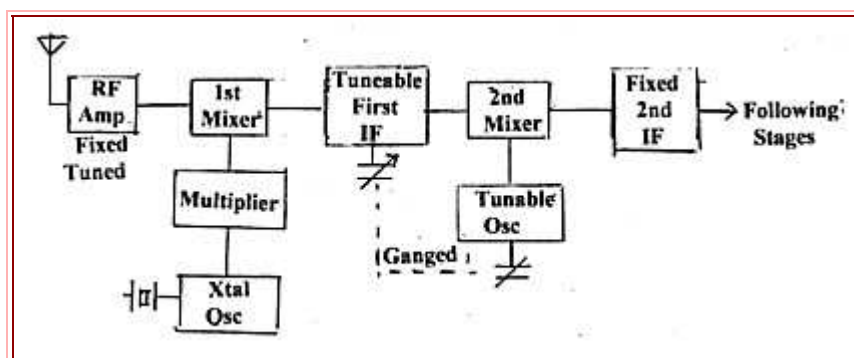

Figure 9: Tuning at the First IF and Second Heterodyne Oscillator Level.

Bandspread tuning

Receivers which tune over a wide frequency range, as one band, generally require some form of fine tuning, or bandspread tuning, to enable easy resolution of the signals. A simple way to do this is to use two tuning gangs connected in parallel, one large to cover the whole range and which can be set affixed bandset points, and one small which provides bandspread tuning around the bandset frequency. The difficulty with the system is in accurately positioning the bandset points. A 100 kHz marker harmonic generator is an essential part of such a receiving system to inject marker signals, at 100 kHz intervals, and provide calibration to set the bandset control accurately.

Many earlier communications receivers, such as the National HRO and Kingsley AR7 (Figure 10) used mechanical bandspread. In these receivers, the tuning capacitors are driven via a high ratio geared dial, quoted as having a range of 500 degrees over an equivalent length of 12 feet.
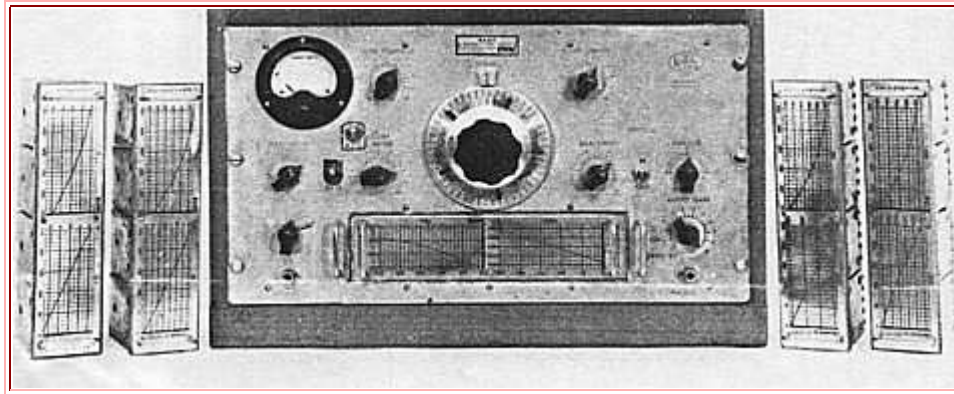

Figure 10: The Kingsley AR7 Receiver.

As discussed earlier, bandspread tuning can be applied with better frequency stability by tuning an IF stage, provided that the source of local signal injected into the first mixer can be frequency stabilised. For the general frequency coverage receiver, the injected source needs to be tuned or preset at fixed frequencies over a wide frequency range. It also needs to be able to be preset accurately and once set, it should maintain frequency stability. These requirements can be achieved with a system incorporating what is called the Wadley Loop which will be discussed in the next paragraph. They can also be achieved by using a frequency synthesis system to be discussed later.

The Wadley Loop

The Wadley is a system used in HF receivers such as the Racel RA-17 and the Yaesu FRG-7. (Figure 11). This system provides bandspread tuning in a lower frequency IF stage combined with a stable and accurate bandsetting arrangement which covers the wide tuning range of 1 to 30 MHz.

Figure 11: The Yaesu FRG-7.

The RF stage of this type of receiver is fixed tuned and broadbanded to cover the full 1 to 30 MHz. A very high first oscillator frequency with a very high first intermediate frequency is used to place the image frequency always well outside the RF passband. In the FRG-7, the first oscillator VFO is tuneable between 55,000 arid 84.5OO MHz and the first IF channel is broad-banded over a frequency range of 54.500 to 55.500 MHz.

Referring to the block diagram, Figure 12, which is based on the FRG-7, the front end stability is controlled by a 1 MHz crystal oscillator D which drives a harmonic generator E. Harmonics of 1 MHz, within the range of 3 to 32 MHz, are fed to the harmonic mixer F and mixed with the signal from the variable first oscillator C.
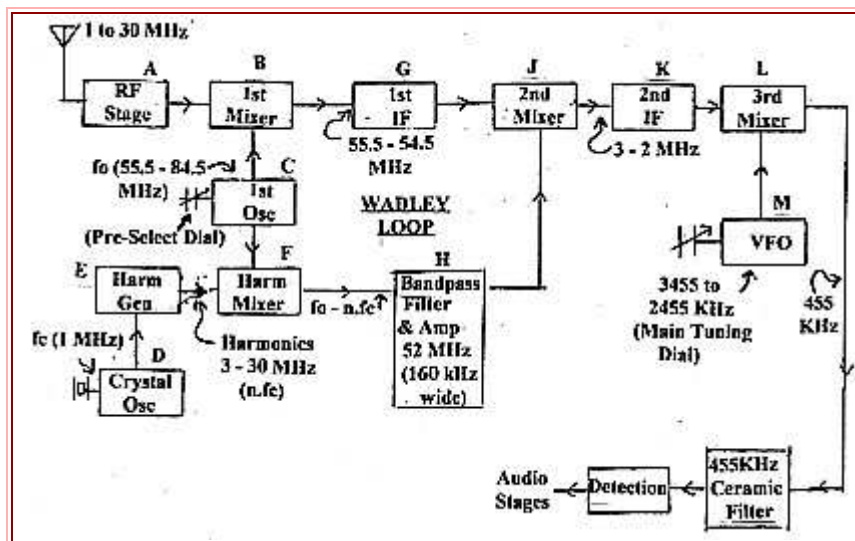

Figure 12: A Receiver using the Wadley Loop.

The first oscillator is the bandsetting stage and this is preset by the operator to any 1 MHz Increment within the 55.500 to 84.500 MHz range with a tolerance of plus or minus 80 kHz of the increment point. Beat components between this oscillator frequency and the harmonic frequencies of the 1 MHz oscillator are produced at the output of mixer F. However, only one of these can pass through the bandpass filter H which has a centre frequency of 52.500 MHz with a bandwidth of 160 kHz.

The first oscillator is also mixed with the incoming signals at B to product a first Intermediate frequency within the 55.500 to 54.500 MHz bandwidth range of the IF channel. The first Intermediate frequency is

then mixed at J with the output of the bandpass filter H to produce a difference output frequency tuned by second IF stage K, within the frequency range of 3 to 2 MHz. Note that the lowest frequency at the RF input A becomes the highest frequency at IF level K and vice versa.

In using such a high frequency tuneable first oscillator C, one could expect frequency instability. However, in the process of double mixing at B and J, using components derived from the same oscillator source, any shift in the first oscillator frequency is cancelled out in the mixed IF output at K. Providing this oscillator is set so that the selected output product at F is within the 160 kHz tolerance of filter H, any given signal frequency at A produces the same IF signal frequency at K, independent of the actual frequency of the first oscillator C. The other frequency determining element, oscillator D, is crystal locked. In practice, the operator need only set the bandset control, coupled to oscillator C, approximately to the 1 MHz increment.

Bandspread tuning over a 1 MHz range is achieved by tuning variable frequency oscillator M, the output of which is mixed with the signal from the 3 to 2 MHz second IF channel to produce third IF of 455kHz. A 455 kHz ceramic filter in this IF channel then sets the signal bandwidth of the receiver. The 2 to 3 MHz IF stage must either be broad-banded over the 1 MHz range or tuned and ganged to the bandspread VFO tuning.

The Wadley Loop is a system which has bean generally applied to receivers tuning the HF bands. Roger Harrison VK2ZTB worked out a proposal far its use in the 30 to 100 MHz frequency region. This was published in Amateur Radio, December 1979, but at that stage the idea had not been put into practice.

Frequency Synthesis

Another method of frequency stabilising the bandset VFO is to make use of a phase locked loop (PLL) circuit with a crystal controlled reference oscillator. The VFO frequency is changed by voltage control and in the following discussion we will call it a voltage controlled oscillator (VCO). Figure 13 Illustrates the elements of this type of a circuit. In this circuit, the divided output (Fo/m) of the VCO is compared in a phase comparator with the output (Fr) of a crystal controlled stable oscillator. The phase comparator output is fed via a low pass filter to a frequency sensitive element in the VCO and this controls its frequency so that Fo/m equals Fr. The counter which does the dividing is programmable and its division ratio m is set by some form of control to control the VCO bandset frequency. The values of m are chosen to provide 1 MHz steps in the VCO frequency or whatever steps are desired for bendset spacing.
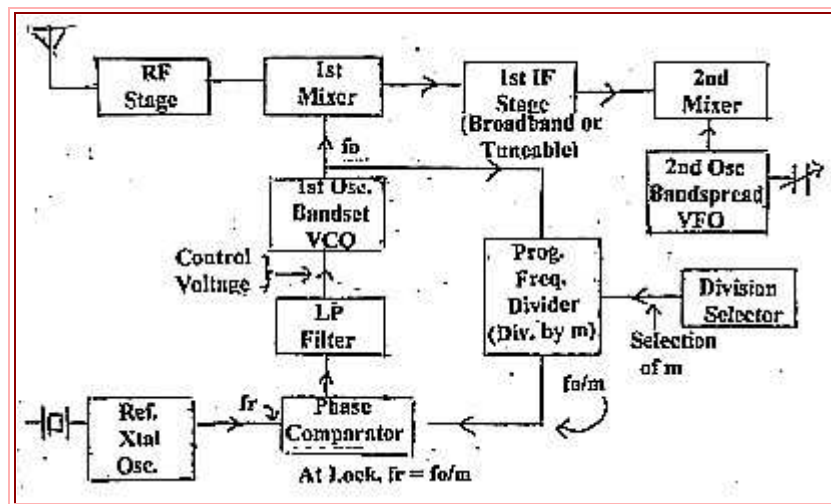

Figure 13: Synthesised Band-Set VFO.

Bandspread is provided by fine tuning a VFO at a second stage of conversion, as described for the Wadley Loop receiver.

An alternative method of providing the bandspread (refer Figure 14), is to insert an extra mixer stage into the reference oscillator circuit and inject bandspread VFO into the mixer. The reference signal into the phase comparator is then either the sum, or the difference, of the crystal controlled reference and the frequency of the bandspread VCO. For this operation, both bandset and bandspread oscillator outputs (Fo and Fb) are divided by the programmed value m and the bandset VCO is locked when (Fo/m) equals (Fr + Fb/m).
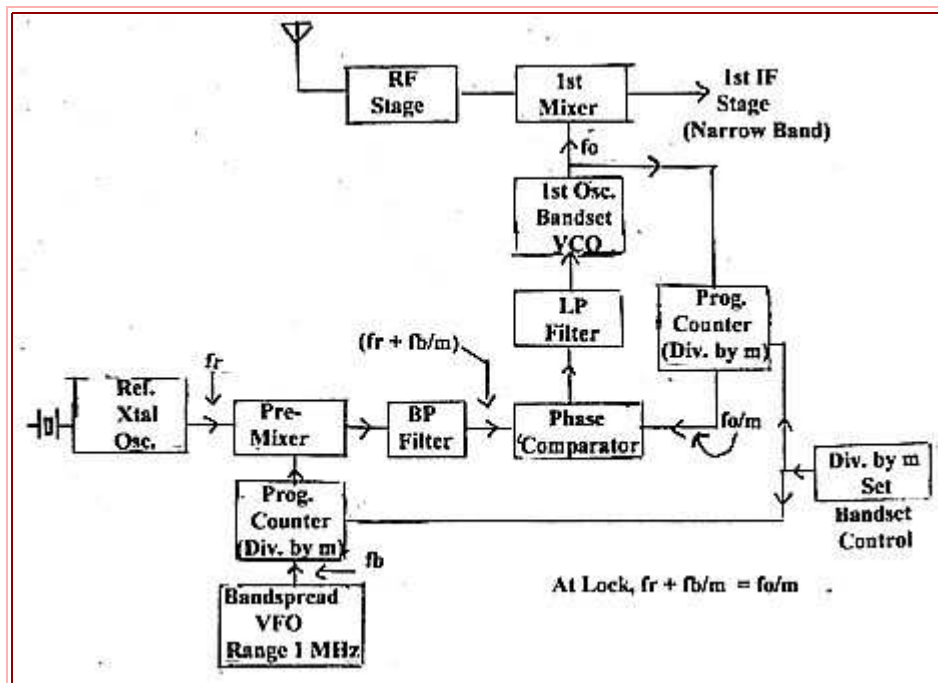

Figure 14: Bandspread combined with Bandset Synthesising Circuit.

As in the previous system, the bandspread VCO tunes a low frequency range (such as 2 to 3 MHz) and is reasonably stable. An advantage of this second system is that a wideband or tuneable following IF stage is not required.

Amateur Band Transceivers

Amateur radio operation in the HF region is limited to a number of bands of restricted frequency range and the bandset oscillator can be crystal controlled with crystals switched to change bands.

A system which has been used on various amateur single sideband transceivers, for a number of years, is shown in Figure 15. A single IF channel of 9 MHz is used with a ceramic crystal filter in that channel. The filter is used to limit the bandwidth of the receiver as well as being used as the sideband filter when the transceiver is switched to transmit. The local frequency source (Fo) to the mixer is generated by premixing a crystal bandset oscillator with a bandspread VFO covering the frequency range of 5 to 5.5 MHz. The frequency stability of the receiver is thus dependent on the stability of the bandspread VFO. It also determines the frequency stability of the transmitter, as on transmit, the whole system works in reverse by generating a 9 MHz SSB signal and beating R with the combined VFO source (Fo) to produce the transmit frequency. As the subject we are discussing is receivers, we will not elaborate further on the transmitter circuit.

The frequency mixing arrangement, as shown for different amateur bands in the table in Figure 15, utilises various combinations of sums and differences in the two mixing operations. The arrangement, which is that used in the Yaesu FT-200 transceiver, is one example of how this type of receiving system is applied. Observe that, on the 3.5 and 14 MHz bands, only one mixing process is applied and the 5 to 5.5 MHz VFO (Fb) is directly mixed with the incoming signal (Fs).
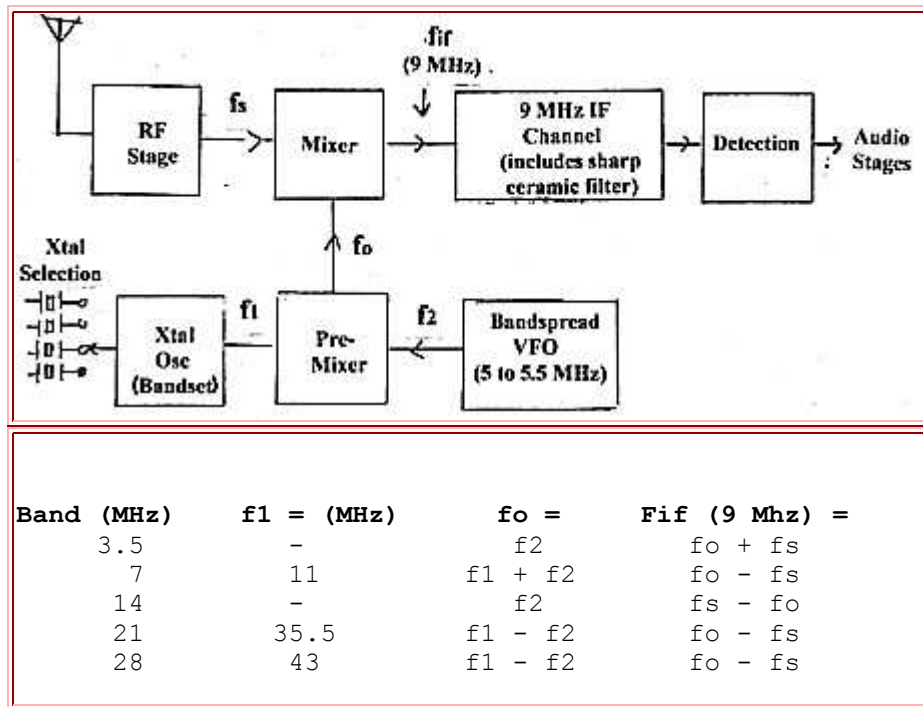
Band (MHz)	f1 = (MHz)	fo =	Fif (9 Mhz) =
3.5	–	f2	fo + fs
7	11	f1 + f2	fo – fs
14	–	f2	fs – fo
21	35.5	f1 – f2	fo – fs
28	43	f1 – f2	fo – fs

Figure 15: Receiving System in Amateur Band Transceiver using 9 MHz IF Channel.

More recent transceivers use the synthesised bandset system with the phase locked loop rather than individual selected crystals. Figure 16 shows the local signal generation system of the Kenwood TS-130. A 10 MHz crystal oscillator, divided down to 500 kHz, is the reference signal source for the phase detector. It is also divided down further to 25 kHz as a marker generator source.
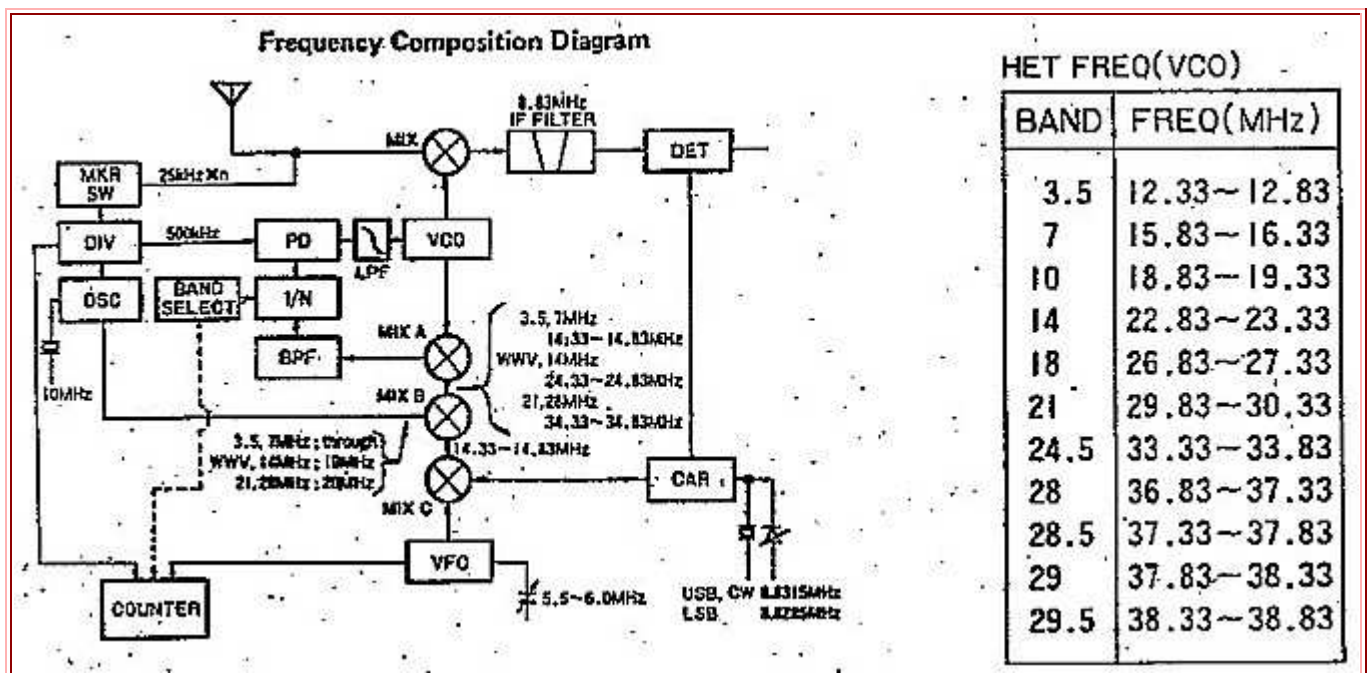

HET FREQ(VCO)	
BAND	FREQ(MHz)
3.5	12.33~12.83
7	15.83~16.33
10	18.83~19.33
14	22.83~23.33
18	26.83~27.33
21	29.83~30.33
24.5	33.33~33.83
28	36.83~37.33
28.5	37.33~37.83
29	37.83~38.33
29.5	38.33~38.83

Figure 16: Receiving System for the Kenwood TS-130.

The output of the voltage controlled oscillator (VCO), in the locked loop chain, is injected into the signal mixer at frequencies, for each of the amateur bands, as listed in the right hand table of Figure 14. The output of the signal mixer produces the intermediate frequency of 8.830 MHz. The slight deviation from the 9 MHz of earlier transceivers was mentioned earlier. The bandspread oscillator (VFO) tunes over a

frequency range of 5.5 to 6 MHz and a derivation of this frequency range, resulting from premixing at mixers C and B, is further mixed with the VCO output at mixer A to produce a second signal, divided at 1/N, to feed the phase detector (PD). At lock, this second signal is the same frequency as the reference 500 kHz at the other phase detector input. Band selection is achieved by controlling the division ration at 1/N.

In a single sideband receiver, it is necessary to reinsert a carrier signal to carry out detection and in Figure 16 the carrier oscillator is shown as the block CAR. Crystal selection for frequencies 1.5 kHz above and 1.5 kHz below the IF centre frequency provides selection of upper or lower sideband operation.

On the amateur bands, it has been the practice to consider the tuned signal frequency for single sideband as the frequency of the suppressed carrier. For transceivers with an installed digital readout, this is the frequency which is displayed. Shifting the carrier oscillator by 3 kHz to change sideband mode, as discussed in the previous paragraph, is therefore considered as a change of 3 kHz in the tuned signal frequency. To correct this shift so that the digital display reads tuned frequency equal to suppressed carrier frequency, the carrier oscillator output is also mixed with the bandspread VFO at mixer C so that a correction of the 3 kHz shift is reflected in the frequency of the VCO and the digital readout. Earlier systems, such as that shown in Figure 13, did not have a digital readout and did not have the correction fitted.

The output frequency range of mixer C is 14.330 to 14.830 MHz and this is mixed further in mixer B, with either the 10 MHz reference frequency or its second harmonic (20 MHz), to obtain various output frequencies for the different bands as shown on the diagram. These output frequencies are mixed at mixer A with the VFO output to feed the phase detector, via the band select divider 1/N as discussed in a previous paragraph. All this might appear a little complicated but if you take each band, one at a time, a frequency conversion map can be worked out.

From an operational point of view in amateur band receivers, there is probably little difference in bandsetting using the locked loop system than in using separate crystals. In the TS-130 there are 11 bands of 500 kHz width and there is probably a cost advantage in using the phase locked loop in preference to 11 crystals.

As far as frequency stability is concerned, the weakest link in the receivers discussed is the manually tuned free running VCO. This can be improved by using a further synthesised system with a phase locked loop to control the VFO. However, the problem with such a system is that it must operate at discrete frequency steps separated by a frequency spacing equal to the reference frequency fed to the comparator. Receiving of SSB, CW and RTTY signals of random frequency on the HF bands demands tuning resolution to within hundreds of Hertz. This places a very stringent requirement on the number of discrete steps needed in the programmable divider to provide increments of a few hundred Hertz.

Synthesis on the VHF bands is not such a problem. One reason for this is that a large amount of communication utilises the "not-so frequency-sensitive" FM mode. A second reason is that frequency channels have been established at a precise frequency separation. (On two-metres it is 5 kHz). As an example, a typical two metre transceiver might have a synthesised tuning system with 10 kHz steps covering the whole 144 to 148 MHz band. The intermediate 5 kHz points are further selected by switching in a 5 kHz offset to the locked loop. A third reason is that most VHF transceivers are restricted to the one band making tuning less complicated than if more than one band has to be covered.

Bandwidth Control

Ideally, the bandwidth of a communications receiver should be only just sufficient to pass the signal information with high rejection outside the band range. A bandwidth wider than necessary just admits more noise and adjacent channel interference. The bandwidth of the superheterodyne receiver is set by the bandwidth of the lowest frequency IF channel. Ideal bandwidths are several hundred Hertz for CW to 2.5 kHz for speech SSB, 4 to 5 kHz for speech AM and 14 kHz for 5 kHz deviation speech FM.

Most HF communication receivers have some form of bandwidth control in the last IF channel to select narrow band for CW or wide band for speech. The Kenwood TS-820S amateur band transceiver has a continuously variable bandwidth control together with a sharp notch to tune out an interfering signal close in frequency. Figure 17 illustrates this principle.
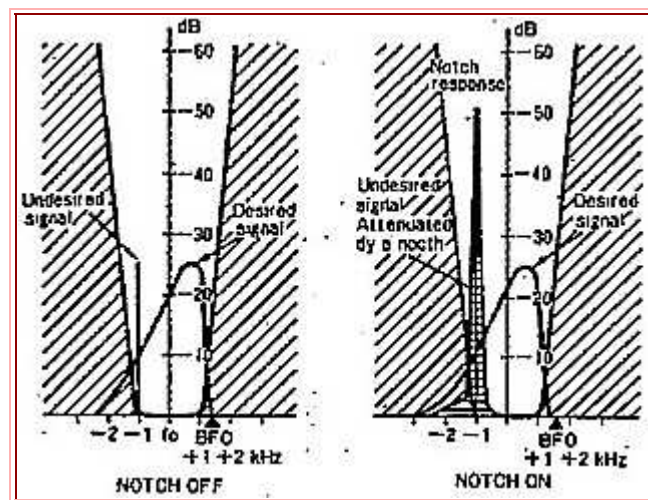

Figure 17: IF Notch In the Kenwood TS-820 Transceiver showing how the IF Notch works.

Comments on some modem trends

Some of the modern trends in receiver design tend to contradict basic theory outlined earlier. One trend is to use wildeband RF amplification at the front end of the receiver. This is in order providing the design is such that the image frequency on any part of the tuning range, falls outside the passband of the RF amplifier. This is achieved in general coverage receivers, such as those using the Wadley Loop, by operating a first IF above the maximum frequency of the R F tuning range. On the negative side, one could well expect that the broadband RF stage would be more prone to cross modulation from strong signals in the range, than an RF stage which was selectively tuned.
\
There have been various suggestions heard by the writer that, as modern MOSFET mixers have noise figures almost as good as straight amplifiers, the RF stage can be dispensed with. Whilst this argument might have some validity, it does overlook the other functions of the RF stage in reducing incoming signal level at the image frequency, reducing signal level at the intermediate frequency, reducing cross modulation and regulating the signal level into the mixer for optimum performance.

Another area of change is the use of single conversion with an intermediate frequency higher than that previously considered suitable to achieve the desired selectivity. An example is the 9 MHz IF channel used in many amateur band transceivers. This has all changed because of the wide use of crystal filters which can be made with a controlled bandwidth characteristic and high out of band rejection. Earlier receivers relied on ordinary L and C tuning components which had insufficient Q to achieve the required selectivity at these higher frequencies.

Modern receivers and transceivers make use of digital techniques including the use of micro-processors to provide synthesis of VFO tuning, provision of memory to recall operator preselected frequencies, provision of digital frequency displays, provision of automatic scanning over fixed frequency steps and many other useful functions. This opens up a complete new area of discussion not specifically related to the principle of the superheterodyne and a little beyond the scope of this article. It might be prudent to comment that all these features make operating a dream at a price (in terms of money). However, they have nothing to do with receiver performance in terms of sensitivity, selectivity, signal-to-noise ratio, image performance, cross modulation and, in fact, the ability to resolve one weak signal from another, or

to read it in the presence of noise. So think about that before you spend your fortune!

Summary

To summarise the material, we have looked at the basic superheterodyne receiver and various factors which must be considered in its design such as, the choice of intermediate frequency, the function of the RF amplifier, oscillator tracking and tuning stability. We have discussed methods of bandsetting and bandspreading including the Wadley Loop and frequency synthesis. We have discussed multiple conversion and application of the superheterodyne receiver in various amateur band transceivers.

As an introductory article, circuit detail and mathematical treatment have been avoided. As it stands, the article should provide some ground work for other more specialised topics on receivers. One topic which the writer feels should follow is the specification of receiver performance and what specific performance figures define a good receiver. A further topic could examine how the well known amateur band receivers and transceivers all shape up against these figures. The second topic would be quite a task and clearly a job for someone more familiar with the wide range of different amateur equipment than is the writer.

References

1. BUTLER, Lloyd, VK5BR. A Discussion on Mixers, Amateur Radio, April 1988.

2. LANGFORD SMITH, F. Radiotron Designers Handbook, Chapter 25 Section 3 - Superheterodyne Tracking.

3. KIRKPATRICK, C.B. Three Point Tracking Formulae, IRE Proceedings, July 1947.

4. DIAMOND, Drew, VK3XU Some Practical Tips on VFO Construction, Amateur Radio, January 1988.

5. A New Receiver Tuning Principle, Amateur Radio, July 1958.

6. Collectors Corner No 2 - The Yaesu FRG-7, Amateur Radio, August 1980.

7. HARRISON, Roger VK2ZTB. Considerations for the Wadley Loop VHF Receiver Front End, Amateur Radio, December 1979.

8. POULTNEY, A.E.J. Trends in HF Communications Receiver Design, The Plessey Company.

Author's Footnote

Early in this article, reference was made to Major Edwin Armstrong as evolving the superheterodyne receiver in 1918. According to the publication Australian Radio - The Technical Story, by Winston T. Muscio, there were two patents filed on the supersonic heterodyne principle, one a French patent in 1917 by Lucian Levy of Paris and another in 1918 also in France by Major Armstrong. A further US patent was filed by Major Armstrong in 1919 and issued in 1920.

Whilst most publications give Major Armstrong the credit for the invention of the superheterodyne, there seems to be some question concerning this history!