More Complex Receivers

Limitations of simple receivers — the RF amplifier stage, its operation and use — neutralisation — gain control of TRF receivers — the superheterodyne principle, its operation and advantages — autodyne converters — transistor receivers — more elaborate receivers.

While a beginner may concentrate initially on building small regenerative radio receivers of the type discussed in the last chapter, he must inevitably wonder about the design of larger receivers. In this chapter, we explain the basic idea behind two well-known types of receiver, the "TRF" and the "superheterodyne."

In an explanation of reasonable length, it is not possible to discuss individual circuits in detail — the how and why of every resistor and capacitor. The reader will have achieved something, however, if he can understand the general idea behind these circuits, particularly the superheterodyne.

Having grasped the basic idea, it should be possible to enlarge upon it later by studying the circuit and design information on actual receivers.

The TRF and, later, the modern superheterodyne receiver, came as a natural development from the desire to produce receivers which were more sensitive, more selective and more suitable for use by non-technical members of an ordinary household than regenerative receivers.

The story of the development of these types of receiver is really a continuation of the story told in chapter 11 about small receivers, and it must inevitably read like a piece of radio history.

As we pointed out in the last chapter, a receiver having a regenerative detector followed by two audio stages is capable of receiving a great many stations, both on the broadcast and short-wave bands.

By using a power transistor or valve in the final stage, such a set can operate a loudspeaker at good volume on the stronger stations and, in the early days of radio broadcasting, many domestic receivers were of this general type.

For domestic use, however, such receivers have certain basic limitations.

In the first place, performance depends very largely on proper use of the reaction (regeneration) control. If it is too far advanced, the set oscillates, producing whistles in its own loudspeaker and in neighbouring receivers tuned to the same station. If the reaction control is not sufficiently advanced, perhaps to limit volume, selectivity is likely to suffer to the point where two or more signals are heard together.

While this is no special problem to anyone who understands what the controls are for and how they are supposed to be adjusted, it did prove an embarrassment in the early days for non-technical members of the household. Some less critical arrangement was obviously desirable for general use.

Another difficulty which was experienced with early simple regenerative sets lay in the fact that there was a practical limit to the amount of amplification one could provide following a detector. Thus, while one or two audio stages could be used to usefully increase gain and even selectivity (the latter by roundabout means), anything more than this tended to lead to difficulty.

Slight vibration in the detector valve, causing slight changes in plate current, could be amplified by subsequent staged to produce wnat are known as microphonic effects. Tapping the valve, or even normal vibration, would produce thumps and ringing noises from the loudspeaker.

Then again, noise due to electron flow in the detector itself could be amplified to the point where it produced a continuous background hiss. And in mains-operated receivers, very slight 50Hz or 100Hz voltages, coupled into the detector circuit from the heater and power supply tended to produce an audible hum from the loudspeaker.

Last, but not least, slight variations in high-tension supply voltage, caused by plate current variations in the output valve, could be fed back as a spurious signal to the plate of the detector. If regenerative, this feedback was able to cause an effect called motor-boating, evident as a regular pop-pop-pop noise from the speaker.

While all the problems could be minimised by careful design, they did set a limit beyond which the detector-plus-audio idea became rather impractical.

This limit was reached very early in the history of broadcasting, and designers had to find other means of improving the performance of their receivers. Since additional stages could not be added after the detector, the only alternative was to add stages ahead of the detector and to amplify the incoming signal at its own frequency.

Such stages were known as radio-frequency amplifier stages or simply RF stages.

Now an ordinary valve would not amplify radio frequency signals very effectively if merely coupled to the following stage by a resistance-capacitance network or by some kind of audio transformer. It would give a great deal more amplification if coupled to the following stage by means of a circuit tuned to the incoming signal frequency.

The essential circuit details of a valve-type tuned RF amplifier are shown in figure 1. This is the type of RF amplifier stage used in early receivers, and still used on occasion nowadays.

The incoming signal is fed through a tuned circuit to the grid of the RF amplifier valve. The coil of this tuned circuit is normally referred to as the "aerial coil". It is connected directly to the grid of the valve, without any capacitor or resistor, because the valve is intended to operate as an amplifier rather than as a detector. For the same reason the valve is provided with grid-cathode bias — here by means of a bypassed cathode resistor — to ensure operation as a class-A amplifier.

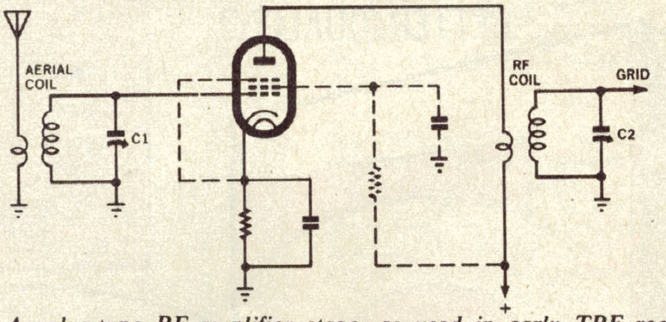


Figure 1: A valve-type RF amplifier stage, as used in early TRF receivers. The additional connections for a pentode are shown dashed.

Amplifier signal output current from the plate circuit flows through the primary winding of a second coil assembly, and is coupled into a tuned secondary winding, the two windings forming what is commonly referred to as an "RF coil" or RF transformer.

The secondary windings of both the input and output tuned circuits, with their associated capacitors, must be capable of tuning over the entire broadcast band. To receive any given station, both tuned circuits should be set to the frequency of that station.

Under these conditions, the signal from the desired station is selected and passed to the RF amplifier grid, in preference to other signals which may be present. It is amplified by the RF amplifier valve and passed through the second tuned circuit, which also favours the desired signal and tends to reject signals on other frequencies.

In other words, the use of a tuned RF

stage not only provides amplification, but also increases selectivity. This was — and is — a most important point.

Since an RF amplifier stage feeds into a circuit tuned to the signal frequency, this is the only frequency which it can amplify properly. Because there is no load resistor in the plate or collector circuit and no audio transformer, it cannot amplify significantly or pass on signals within the audio range. Therefore, it is not nearly as susceptible as an audio stage to hum, hiss, microphony or motor-boating. This, too, is important.

Many early receivers used one triode RF amplifier stage, a regenerative detector and two audio stages. They were the first "TRF" receivers, the letters indicating the use of a tuned radio frequency amplifier stage.

Such receivers were generally better than earlier types without the RF stage. They had better gain and selectivity and therefore relied to a lesser extent on critical setting of the reaction control. And because there was an amplifier stage between the detector and the aerial, the reaction setting was not affected so much by the type of aerial in use.

For all that, the basic problem remained that there was still a reaction control to set, and attempts were made to produce receivers with two RF amplifier stages ahead of the detector, but with no reaction.

Here designers came up against the full measure of a problem which was mentioned in chapter 6. They found that, because plate and grid in a triode were side by side, there was considerable capacitance between them and energy was being fed back from plate to grid as a result.

In detector or audio service it did not matter a great deal, but in RF stages, with both grid and plate circuits tuned to the one frequency, the feedback tended to cause oscillation. One low-gain triode RF stage was practicable (even if barely so) but two such stages were almost unmanageable.

A temporary answer to the problem was found in the so-called "Neutrodyne" principle, which enjoyed some popularity in the late 1920s. The primary winding of the RF coil was centre-tapped so that a signal voltage appeared at the lower end similar to but out-of-phase with the signal voltage at the plate end. A small variable capacitor was connected from the lower end of the primary to grid and adjusted to have the same value as the grid-plate capacitance of the value.

Being connected in this fashion, this so-called neutralising capacitor fed back to the grid a signal equal to and out-of-phase with that fed back from the plate, so that the two cancelled out. As a result, the tendency to oscillation was overcome and two triode RF amplifier stages bacame practical.

The early "Neutrodyne" receivers were, therefore, a special type of TRF receiver, employing the principle of neutralisation.

In point of fact, neutralised TRF receivers did not enjoy a lengthy period of popularity because valve designers came to light with the screen-grid principle. Applied in RF tetrodes and pentode valves, it almost eliminated grid-plate capacitance, and therefore, eliminated the major source of instability in RF stages.

As a result, it became possible to achieve high figures of stage gain, and, further, to use two high-gain stages in sequence. Nor was there any great trouble with instability. By shielding the valves and coils and adopting a layout which kept input and output leads reasonably apart, such a set could remain completely stable, even under full gain conditions.

With such gain available and the selectivity afforded by three tuned circuits, reaction became unnecessary, and the reaction control therefore largely disappeared from sets of the day.

By carefully matching tuning coils and adding small variable trimmer capacitors across each tuned circuit, designers were able to gang together the three tuning capacitors and operate them from a single tuning dial. This done, domestic receivers became really simple to operate for the first time — one dial to select the station and one knob to control the volume.

TRF receivers reached their heyday about 1930 and their general design followed the pattern shown in the block schematic diagram of figure 2.

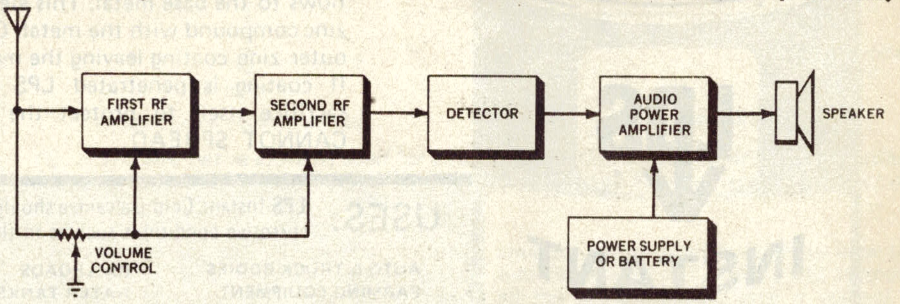


Figure 2: The basic arrangement used in early TRF radio receivers. Such receivers had their heyday in the 1930s.

The incoming signal was fed by the aerial coil to the first RF amplifier stage, then passed to the second RF amplifier stage and thence to the detector. This was followed by a single audio stage, but, using a sensitive pentode valve, which gave high amplification as well as ample power output to operate a loudspeaker.

Power to operate all these stages came, in mains receivers, anyway, from a power supply built on to the same chassis. This included a power transformer, a rectifier, a filter choke of some description and two or more filter capacitors. (More will be said about the operation of this section of the circuit in a later chapter.)

The volume control in such receivers usually took the form of a potentiometer connected at one end to the two RF amplifier cathodes, and at the other to the aerial terminal. The adjustable tapping went to earth. With the moving arm towards the cathode end, the RF amplifier valves operated with minimum bias and maximum gain, while the amount of resistance between aerial and earth was too high to make any real difference to its efficiency. Adjusting the control the other way applied high bias to the RF amplifier cathode and reduced the stage gain; at the same time it shunted the aerial to ground and therefore reduced the signal input.

It might be thought that the evolution of the TRF receiver would have largely halted receiver development in that it provided good gain and selectivity with plenty of acoustic output and simplicity of operation.

But it didn't.

About the same time, many new stations were coming on the air, crowding the broadcast band and ever increasing the demand for selectivity. The limitations of the simple TRF soon became apparent, particularly for the more difficult reception areas.

To add yet another RF stage or yet another tuning circuit gave only limited improvement at the cost of much greater complexity and with the attendant risk of instability. What was more there didn't seem to be any obvious way of making tuned circuits much more efficient. To resort again to reaction as an aid to selectivity was unthinkable to a commercial designer.

As a result, they began to look for other basic methods of receiver design and the one which seemed to hold the greatest promise was the superheterodyne principle.

This was not new, having been developed by Edwin H. Armstrong of Columbia University in New York as early as 1921. It had been used in a limited way for many years, mainly in professional and military short-wave receivers. Could it be adapted for use in domestic radios? Designers soon found that it could.

Designed around the better valves available, and using modern circuit techniques, the superhet receiver quickly established itself in popular favour, and has remained undisputed leader ever since.

But how does the superhet work? At this point, we can drop the semi-historical sort of discussion and settle down to some straight theory. This is appropriate, because the superhet principle does not yet belong to history. Practically every modern broadcast, communications and television receiver uses the principle.

As the name suggests the superheterodyne receiver utilises a method of heterodyning or beating two signals together. Let's explain this.

It has been found that, when two signals are fed into a non-linear circuit, they combine to produce signal voltages at frequencies additional to and distinct from either of the original input frequencies. Further, that these new frequencies are equal to the sum and the difference of the original frequencies.

Consider, for example, two frequencies which we shall designate as f1 and f2. If fed into a non-linear amplifying stage, it would be possible to detect output voltages, as expected, having the original frequencies f1 and f2. But, in addition, we would find that output voltages were present at frequencies equal to f1-plus-f2, and f1-minus-f2 (assuming f1 to be the higher numerical value).

Taking an actual case, we may feed

signal voltages at, say, 2,000 and 1,500 kilo hertz into a non-linear stage. Both original signal frequencies would be present in the output, plus additional frequencies of 3,500 kHz (2,000 plus 1,500) and 500 (2,000 minus, 1,500).

In actual fact, there may be other frequency components in the output, due to the presence or generation of harmonics, but we can afford to neglect these as being incidental to the main effect.

As we already know, stations on the broadcast band transmit on allotted frequencies, between the limits of 550 and 1600 kHz. To tune and amplify them on a TRF receiver involves the use of a ganged capacitor tuning two or three matched coils.

There are difficulties in the way of tuning more than about three coils in this way, so that the performance of a TRF receiver is largely limited by the selectivity and gain which can be achieved with three variable tuned circuits.

But, in the superheterodyne, the designers utilise the heterodyne principle to change the frequency of any and every desired incoming signal to a new, pre-arranged and fixed frequency. This is passed to and amplified in a section of the receiver, which can employ any desired number of fixed tuned circuits.

The new frequency is usually lower than the signal frequency but still well above the audio spectrum, which is perhaps the reason why it is commonly referred to as the "Intermediate" frequency — usually shortened to "IF."

The particular intermediate frequency is selected by the designer to suit his requirements. If high gain and extreme selectivity is the object, he may choose an intermediate frequency of about 200 kHz. But, with such a low frequency, great care has to be exercised to avoid receiving the same signal at two points on the dial — called "two-spotting" — owing to unwanted heterodyne effects.

An intermediate frequency of more like 2,000 kHz minimises double-spotting, but requires greater attention to the design of the tuned circuits, if gain and selectivity are not to be sacrificed.

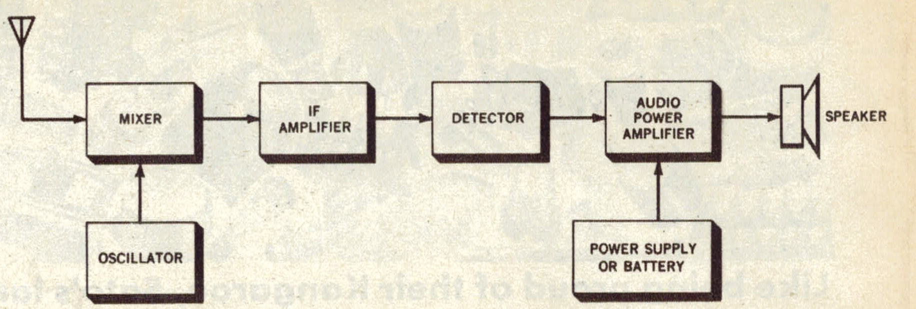


Figure 3: The basic arrangement of a single-conversion superheterodyne receiver. Most modern receivers are of this type.

A compromise figure, which is widely employed in this country, is an intermediate frequency of 455kHz or thereabouts.

Assume that a desired signal is on 1,000 kHz. The first obvious requirement then, is for the tuned aerial input circuit to be resonated to this figure. This is accomplished by tuning the aerial input coil with a variable capacitor, exactly as in an ordinary TRF receiver.

The desired 1,000 kHz signal is then fed into the "mixer" or "frequency changer." In the output, remember one desires a frequency equal to the selected intermediate frequency, which one may assume to be 455kHz.

Essential for the frequency change is an oscillator, which delivers a locally generated signal voltage to the mixer stage. To obtain the desired result, the oscillator would be tuned to 1,455 kHz coming signal frequency by just 455 kHz.

It could alternatively be tuned to (1000-455) or 545 kHz, but the higher oscillator frequency is normally used.

At the output of the mixer stage, one would expect frequency components of 1,000, 1,455, 2,455 and 455 kHz. But the mixer invariably feeds directly into a tuned circuit, which would be resonated permanently at 455 kHz. This one frequency is, therefore, selected and passed on, while the first three mentioned above, together with all other incidental harmonic frequencies, are suppressed.

If the desired signal were on 1,020 kHz, then it would be necessary to increase the local oscillator frequency by another 20 kHz to ensure that the IF output remained at 455 kHz.

Thus, in a simple superhet, there are two variable tuned circuits. One gives intitial selection at the signal frequency, and the other adjusts the local oscillator frequency to a figure which differs from the signal frequency by the selected intermediate frequency.

In the earliest "superhets" the aerial and oscillator circuits were controlled by separate capacitors and tuning dials. But, in all modern sets, the coils are accurately adjusted and the oscillator tuned circuit arranged so that it maintains the required frequency difference automatically. This is called "tracking."

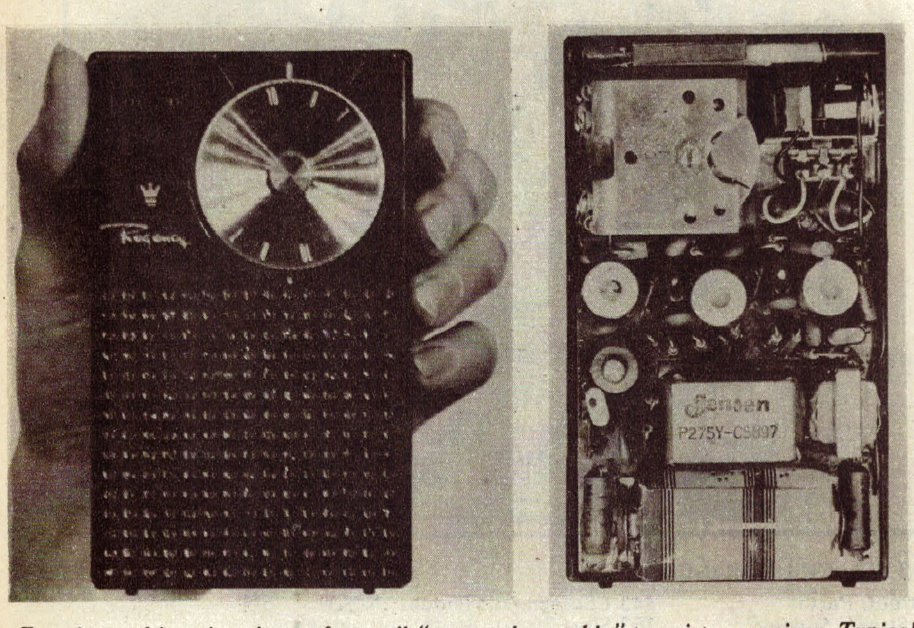
In most modern receivers this is arranged by means of a so-called "padderless gang", a two-gang variable capacitor in which one of the sections has smaller and specially-shaped plates. An alternative technique, and that generally used for short-wave receivers, is to use a conventional tuning capacitor with a so-called "padder" capacitor connected in series with the section used to tune the oscillator. The padder may be made variable to ensure that the oscillator frequency may be adjusted for optimum tracking.

The intermediate frequency generated from the received RF carrier retains the original modulation, so that it can be amplified and passed on to the detector in the usual way.

It is here that the advantage of the superheterodyne principle becomes evident. Since each selected signal is automatically transformed to a constant frequency (which we have assumed to be 455kHz), the IF amplifier channel may be provided with any desired number of circuits, permanently tuned to the selected intermediate frequency.

Coupling coils between valves may have both primary and secondary tuned, instead of the secondaries only, as in ordinary TRF practice. No variable tuning gang is necessary for this purpose, and the coils may be designed for compactness and efficiency, and thoroughly shielded for stability.

Intermediate frequency (IF) tuning circuits were frequently resonated in the past by means of small compression type



Exterior and interior views of a small "personal portable" transistor receiver. Typical small receivers of this type use the superheterodyne principle, and have from six to eight transistors.

mica trimmers, adjusted with a screwdriver. Alternative and common practice nowadays is to have a fixed mica or ceramic tuning capacitor and to vary the inductance of the coil by a small adjustable iron core.

Most ordinary superhets employ one stage of IF amplification, involving two IF transformers, Larger sets may use two IF amplifier valves or transistors with three IF transformers.

These tuned circuits in the IF channel are fully effective in discriminating against unwanted signals.

For example the desired signal may be on 1,000 kHz with an adjacent and interfering signal of 1,010. The single tuned circuit ahead of the mixer valve could not discriminate effectively against a signal only 10 kHz removed from the desired one, so that a substantial 1,010 kHz signal may reach the input of the mixer valve.

In the output of the latter, there would, therefore, be the desired heterodyne frequency of 455 kHz, plus another heterodyne produced by the unwanted carrier at 445 kHz. But, with four or more circuits to negotiate, all tuned to 455 kHz the signal on 445 kHz would have little chance of reaching the detector at troublesome level.

Thus, even though the average domestic superhet uses only a two-gang tuning capacitor, there are generally something like four or five tuned circuits to discriminate against unwanted signals — as against two tuned circuits provided by a two-gang capacitor in the TRF arrangement.

Another reason for improved selectivity in the superhet is the basic fact that the frequency is changed to a lower value. As shown in the example above, the difference in frequency between the wanted and unwanted station — 10kHz in this case — is retained when the frequency is changed. However, relative to 455 kHz, 10 kHz is a greater change, in terms of percentage, than the same change relative to 1000 kHz.

Thus, assuming tuned circuits of equivalent "Q", the one at 455 kHz will be better able to reject the unwanted signal than the one at 1000 kHz. It will also be understood why some circuits use even lower frequencies, 175 kHz and even 50 kHz being employed where very high selectivity is required.

The output from the IF amplifier stage ultimately feeds into a detector, which may be any one of several varieties. The output and power supply arrangements are exactly as for a TRF receiver.

Figure 3 shows the sequence of stages in a typical superhet in block schematic form. The aerial input signal is fed to the mixer or frequency changing stage, where it is mixed with a signal generated by the in-built oscillator.

The resultant or intermediate frequency is then amplified in the IF stage and passed on to the detector, where the audio component is extracted. This is amplified in the audio stage and applied to the loudspeaker.

At first, the functions of mixer and oscillator were entirely separate, as indicated.

The mixer was normally operated under very high bias conditions, as employed for a detector. Hence, the mixer valve in these early superhets was commonly referred to as the "first detector." The normal detector for demodulation naturally gained the title of "second detector."

In the inevitable trend to simplification, it was found possible to obviate the separate oscillator valve, and the first detector was made simultaneously to fulfil the function of oscillator by connecting it to the oscillator tuned circuit.

This arrangement, employing generally the 57 or 6C6 pentode, was widely used around 1932. Known as the "autodyne" circuit, it proved quite efficient and adequate until the demand for dual-wave sets emphasised its non-suitability for such receivers.

Ultimately, the trend to superhet circuits, the popularity of dual-wave receivers and adoption of automatic volume control, led to the evolution of special valves for use as frequency changers. These varied a good deal in structure from one type to the next, but normally had a triode oscillator and a screen-grid mixer section within the one envelope.

With the advent of transistors, the autodyne principle has been revived with the first transistor acting as both local oscillator and mixer.

In fact a modern "pocket portable" transistor radio illustrates very well how the superhet has been developed and simplified. Typical receivers of this type use only six transistors: one as an autodyne mixer, one as an IF amplifier, and the remaining four in the audio amplifier. The "second detector" function is generally performed by a germanium diode.

Receivers intended for specialised communications work invariably use the superhet principle, because of the high gain and selectivity which it offers. In many of these receivers more than one intermediate frequency is used, with a number of mixers used to change the frequency of the signals from one to the other. Thus one can have a "double-conversion" receiver, a "triple-conversion" receiver, and so on.

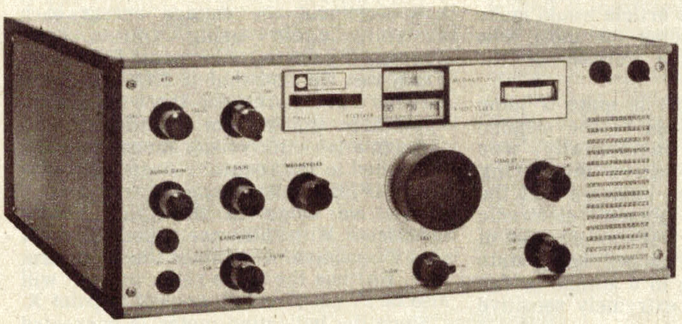
Many such receivers use special filter units in their IF amplifiers, to achieve either a very sharp selectivity response or a carefully adjusted wider response. There are a variety of such filter units available with names such as "crystal filter", "mechanical filter", and "ceramic band-pass filter".

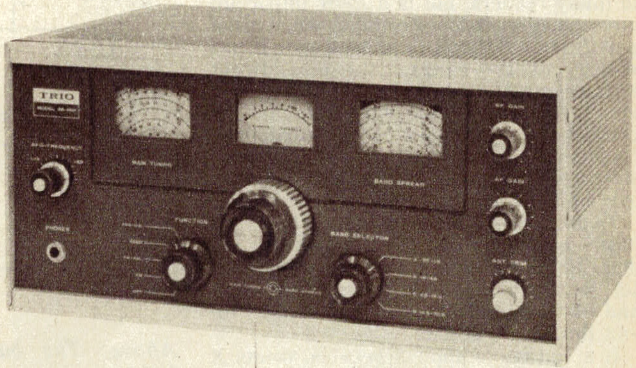
The provision of these and other facilities at the fixed intermediate frequency is something which could not reasonably be duplicated in any TRF design.

At the same time, most high performance superhet receivers do use at least one RF amplifier stage ahead of the frequency changer. An RF stage ahead of a superhet circuit makes a minor contribution to gain and selectivity and also helps exclude from the frequency changer strong signals at frequencies remote from the desired station. In special circumstances such signals may cause spurious beats with harmonics of the local oscillator and penetrate the IF channel.

An RF stage also tends to have a lower inherent noise level than a mixer. By amplifying the incoming signal somewhat before its frequency is changed, a more favourable signal-to-noise ratio can be obtained.

Modern television receivers also use the superhet principle. The problem in this case is not to get extreme selectivity but a specific amount of selectivity — no more and no less. To meet this requirement in the variable tuned circuits of a TRF would be very difficult but in the IF channel of a superhet it can be provided without any specially difficulty. Five or six tuned circuits are often used for this purpose.





Examples of more elaborate receivers. These are generally double or triple conversion superhets, with a variety of additional features.