‘TECHNICAL SHORTS’

by Gerry O’Hara, G8GUH

‘TECHNICAL SHORTS’ is a series of (fairly) short articles prepared for the Eddystone User Group (EUG) website, each focussing on a technical issue of relevance in repairing, restoring or using Eddystone valve radios. However, much of the content is also applicable to non-Eddystone valve receivers. The articles are the author’s personal opinion, based on his experience and are meant to be of interest or help to the novice or hobbyist – they are not meant to be a definitive or exhaustive treatise on the topic under discussion…. References are provided for those wishing to explore the subjects discussed in more depth. The author encourages feedback and discussion on any topic covered through the EUG forum.

AGC

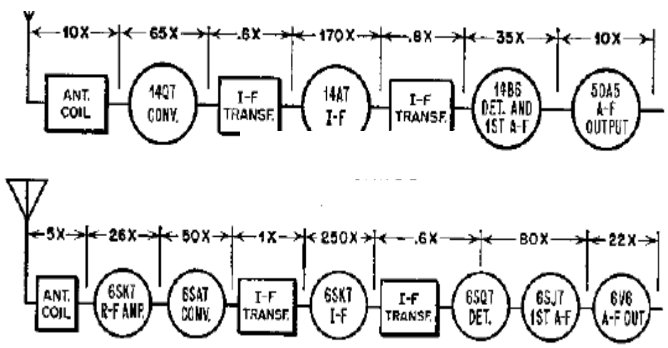
Introduction

Although most radio receivers were still of the ‘tuned radio frequency’ (TRF) type in the late-1920’s, advances in valve design, in particular the introduction of the screen-grid valve (tetrode), and improved inter-stage screening and decoupling, meant that they could attain high levels of gain while remaining stable. However, this high sensitivity, when coupled with more numerous and higher power broadcast stations coming on the air, began to cause several undesirable effects to manifest: cross-modulation, overloading (in many stages of the receiver), distortion, and large changes in output volume as the receiver was tuned through different stations – very disconcerting and annoying. Almost all receivers were fitted with a manual gain control of some description: in these early sets, this could be as simple as a rheostat in the heater supply to one or more valves, as in my King-Hinners Model 25 ‘Neutrodyne’ TRF from 1924 – photo, below, (using 01A triodes), or a potentiometer in the aerial circuit, as in the Atwater Kent Model 37 TRF from 1926 (#226A triodes in RF stages), and this method coupled with variable bias, as in my late-1920’s Philco Model 77 ‘Highboy’ console TRF from 1929 (#24 tetrodes in the RF stages) – see illustrative circuits at the end of this article. However, this was not ideal, especially when listening to more distant station subject to fading, an issue that became more important when shortwave bands started to become popular and reception of very long distance stations became possible, along with more ‘serious’ fading due to atmospheric effects.

This caused circuit designers to develop means of controlling the gain of the receiver automatically, essentially by using methods of variable negative feedback, ie. the gain of the set would vary inversely proportional to the level of the signal strength received. This type of circuit was initially used in the last generation of TRF sets, but the use of such ‘automatic volume control’ (AVC[1]) really took hold when superhet circuits became commonplace in the early-mid 1930’s and with the advent of variable-mu valves (see sidebar, right), such as the #58 in the US.

Receiver Gain

The distribution of gain within typical (broadcast) radio receivers with and without an RF stage is illustrated in the following figure:



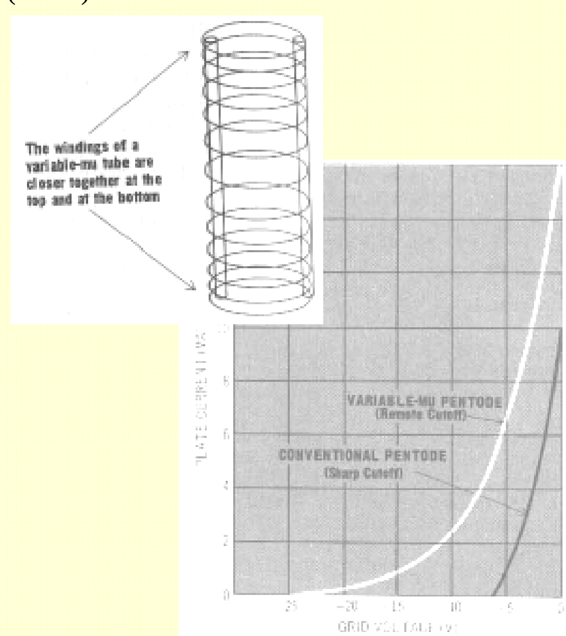
As can be seen, the largest gain factors are those of the RF/mixer and IF stages combined. In communications receivers with multiple RF and IF stages, the available gain may be significantly more.

Controlling Gain in a Receiver

As noted above, the gain of a receiver takes place in several stages: RF (including any mixer stage gain), IF and AF. Adjustment of the gain in each of these stages has different effects on receiver performance and warrants some

Variable-Mu Valves

The amplification factor (mu) of a valve depends on the geometry of the valve electrodes and is generally fairly constant across the operating parameters of the valve. The value of mu determines the negative control grid voltage (bias) that will cut off the electron flow in the valve at a given anode voltage. Low values of mu mean that high values of bias can be applied before the valve is cut off and vice-verse. Pentodes generally have high values of mu, however, it is sometimes desirable to operate a pentode with a large negative bias so that a large input signal can be accommodated. This cannot be done with conventional pentode, but is possible with pentodes having a control grid that has varying spacing along its length (closer together near the ends than at the centre), such construction being known as a ‘variable-mu pentode’. The mu of this type of valve depends on the value of the negative control grid voltage: when small, the mu is high, when large, the mu decreases: as the grid voltage becomes more negative, its repelling effect on electron flow increases, this effect being greatest at the top and bottom of the grid, where the grid spacings are closest together, the electron flow being cut of first in this area. As the grid becomes more negative, the centre portion of the grid that still allows electron flow reduces, until the flow is eventually cut off. The variable-mu valve is often termed a ‘remote cut-off’ valve due to its characteristic curve (below).



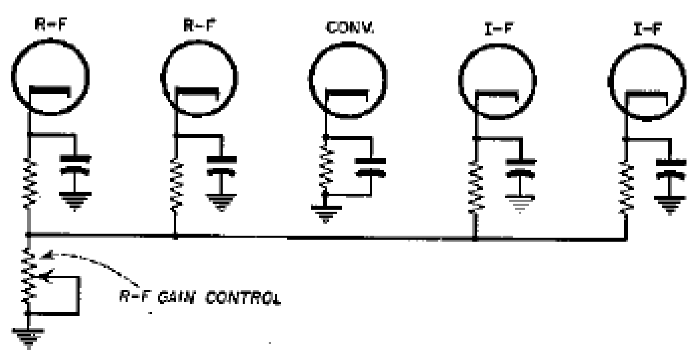
[1] note: in my opinion, the correct term for such control of the receiver’s gain is ‘automatic gain control’, or AGC, which is in widespread usage in the industry, although Eddystone tended to use the term AVC. I will use ‘AGC’ in this article as being synonymous with ‘AVC’.

explanation here. The effects of such gain adjustments are also important in understanding how AGC is derived and applied, together with when it is/is not appropriate to use AGC (also see the Tech Short on Receiver Operation).

RF Gain

Gain in the RF stages is desirable to receive weak signals by improving the set's signal to noise ratio and overcoming losses in the RF tuned circuits present to improve selectivity and reduce image interference in superhets. However, high levels of RF gain when a strong signal is encountered can result in undesirable effects as noted in the introduction, namely non-linearity causing inter-modulation, overload, distortion and even 'blocking', when the RF and/or subsequent stages becomes so sever that the affected stage(s) cannot work within normal parameters. The ability to adjust the gain of the RF stage(s) is therefore very useful in being able to cope with a wide variety of signal strengths.

Adjusting the level of the signal being fed to the RF stages is certainly one method of mitigating the above undesirable effects, and indeed some receivers to the present day incorporate an attenuator for this purpose. However, from the early to mid-1930's, and the advent of variable-mu valves, manual control of the RF stages became almost universally effected by adjusting the grid bias to the RF stage(s) and sometimes the mixer, varying the self-bias conditions by placing a potentiometer in the cathode grounding circuit (diagram, below). The range of operation of this control was sometimes enhanced by applying a positive bias, derived from the HT line, to the control, eg. in some Eddystone sets, such as the S.830/4, where up to -45v of grid bias is available.



The ability to reduce the RF gain of a receiver is also important for certain reception modes, in particular CW and SSB, whereby optimum operation of the BFO/detector can be attained, usually by reducing the RF gain and increasing post-detector gain using the AF gain (volume) control. Reducing only the RF gain, however, has an undesirable effect, in that some RF stage noise and all the mixer and IF stage noise is retained.

IF Gain

The need for the ability to vary the gain of one or more of the IF stages is similar to the reasons given for the RF stages, however, such adjustment of the IF gain on its own will not prevent overload of the RF and mixer stages. Reduction of the IF gain does allow the signal to noise ratio of the RF/mixer stages to be maintained and lowers the noise input from the IF stages. Careful adjustment of this in combination with the RF and AF gains can help to 'winkle out' a weak signal. In many sets, however, the IF gain is coupled electrically to the RF gain, as in the Eddystone S.640 and S.940, where the same potentiometer controls the bias on the RF and IF stages. Other sets in the Eddystone range, usually the more 'professional' models, have independent RF and IF gain controls, eg. the S.750 and S.830 series, where the bias conditions of the RF and IF stage valves is adjusted by separate potentiometers.

AF Gain

Often referred to as the 'volume control', the AF gain control is usually located between the detector(s) and the first AF stage, normally comprising a potentiometer varying the AF signal level applied to the subsequent stages.

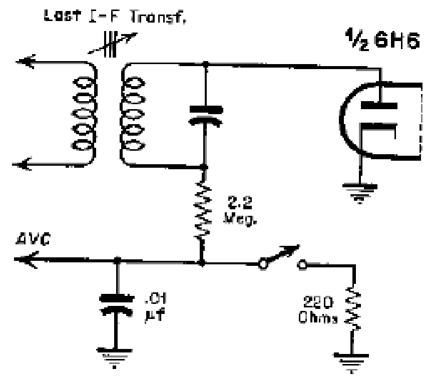
It is therefore evident that adjusting a receiver's gain is not that straightforward under all signal conditions and reception modes, and generally, the more sophisticated the receiver, the more flexibility is incorporated into the circuit design to allow the operator to utilize the available receiver gain to its optimum use. Even so, for many conditions, an ability to control the gain of the receiver automatically is desirable. As such, almost all communications receivers will allow the ability to vary the gain of different stages manually and allow the AGC to be switched in or out, and, in some sets, even its characteristics to be adjusted (see below).

An 'ideal' AGC system would hold all signals at a constant level, however, this is not achievable in practice. A typical AGC system will typically hold the audio level within 9dB when the received signal level changes by 100dB.

Methods of Deriving AGC

As mentioned earlier, the basic principle behind AGC is that a form of negative feedback is incorporated into the circuit: the stronger the received signal, the lower the gain of the receiver is made. This feedback is usually derived by arranging for the DC grid bias of the RF and IF stage(s), and sometimes the mixer stage, to be varied by a voltage derived from the detector stage, or, as in Eddystone receivers, derived from a separate, dedicated

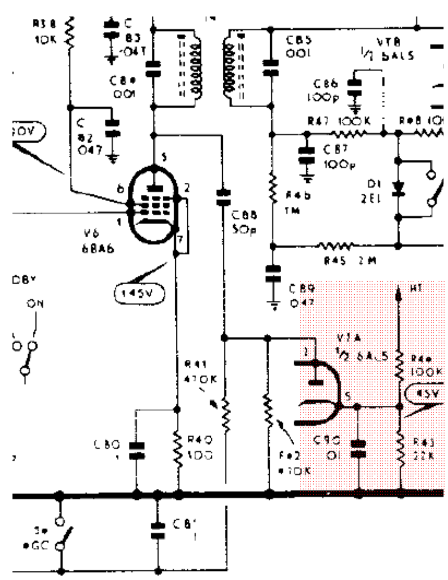
AGC detector diode. The use of separate diodes for detection and AGC gives better performance, particularly when receiving weaker stations, than when a single diode is used for both. The detector diode is arranged such that this ‘AGC voltage’ is negative with respect to ground (circuit below, right): thus, a stronger signal will produce more (negative) AGC voltage, and if this is connected to the RF/IF/Mixer stage grids, will reduce their gain proportionally. The connection to each of the valve grids is usually via a high-value resistor (270k to 1Mohm) and the AGC ‘line (or ‘bus’) is ‘smoothed’ and decoupled at RF and AF frequencies to ground via one or more capacitors to mitigate the possibility of unwanted (positive) feedback between the stages. The actual AGC voltage range varies with the design of the set, valve types etc, but can vary up to around -10volts or so under strong signal conditions.



Whereas the audio signal detector is placed after the secondary of the final IF transformer, the AGC signal is frequently taken from the anode of the final IF valve via a small-value capacitor. This provides a slightly broader action of the AGC when tuning through stations as well as mitigating the effects of the BFO when deployed (see below).

Simple and Delayed AGC

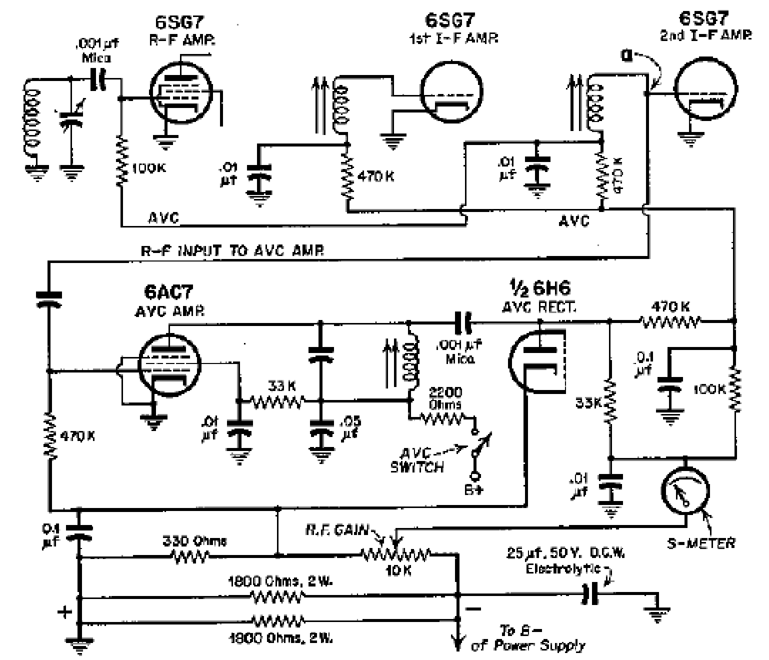
The above ‘simple’ AGC system works remarkably well, however, some refinements are normally incorporated to improve performance of the system when dealing with low signal levels, different fading rates and reception modes. The first improvement is that of introducing a ‘delay’. We normally think of a ‘delay’ in temporal terms, however, in the case of AGC, this means arranging the circuit such that a pre-determined minimum signal level is needed before the AGC action starts to have an effect, ie. *the onset of the AGC action is delayed until a pre-determined minimum signal level is reached*. The reason for this is to prevent the receiver gain being reduced even on very small signals, where it could reduce an already weak signal to a level beneath the RF/mixer/IF stage noise level and/or provide insufficient volume from the set, even with the AF gain fully on.



The AGC delay voltage is often obtained by placing a resistor in the cathode circuit of the AGC diode, or an alternative bias method, eg. via a voltage divider from the HT line, as in the S.940 (circuit, above), thus giving a pre-determined positive voltage on the AGC diode cathode. The AGC voltage will therefore remain at zero until sufficient signal is received to overcome the cathode offset voltage. Resistors in the cathodes of the mixer-oscillator and IF amplifier valves ensure that they are correctly biased for optimal small-signal gain when the AGC voltage is zero.

Amplified AGC

The problem of obtaining satisfactory AGC action when the BFO is operating, in particular during CW reception, may be mitigated by amplifying the AGC signal in a separate amplifier. The National NC-57 includes such a circuit: the IF signal is taken from the grid of the last IF amplifier valve via a small-value capacitor and fed to the grid of the pentode section of a 6AC7 pentode, ie. it is taken ahead of the location where the BFO signal is injected. The amplified IF signal is then rectified by a dedicated diode (half of a 6H6), is decoupled to ground, and is then used to bias the RF and IF stages in the conventional way. The benefit of this arrangement is that little of the BFO voltage, applied to the signal detector diode, returns through the IF amplifier stages or through the AGC amplifier, thus allowing the AGC to remain operational along with the BFO without the receiver sensitivity being adversely affected by the BFO signal generating AGC bias. Amplified AGC may also be used to provide an increased range of gain control than can be provided by the rectified IF signal alone.

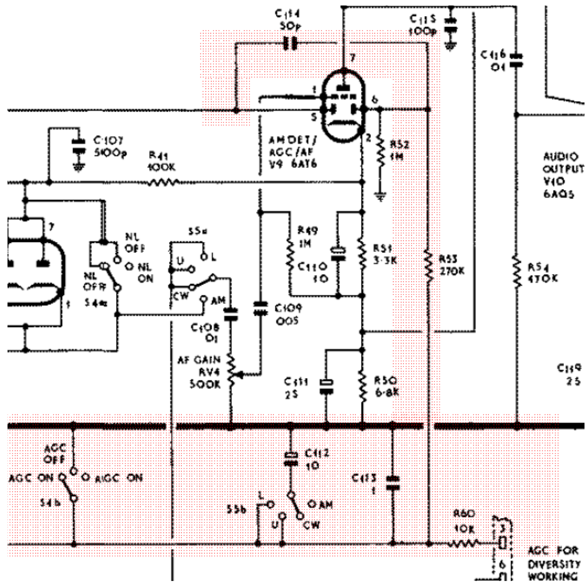


The davc circuit of the National Model NC-57 receiver. With this arrangement, the i-f signal used for automatic volume control is tapped off at point *a* and amplified in a separate amplifier before rectification. This isolates the avc system from the beat-frequency oscillator, coupled to the main i-f amplifier after the avc i-f signal is tapped off.

The only receiver I have in my collection having amplified AGC is my National NC-46: in this circuit the IF signal is taken from the same point in the circuit (audio detector) where the BFO signal is injected and fed to the grid of the pentode section of a 6SF7 diode-pentode. The amplified IF signal from this valve is then rectified by the diode section of the same valve, is decoupled to ground, and then used to bias the converter and two IF stages in the conventional way. Therefore, the above-noted benefits of not allowing the BFO signal to generate AGC voltage is missing – a strange piece of design.

One day I must try modifying the set by changing the IF take-off point to be from the grid of the second IF stage as in the NC-57 to see if this improves things…

AGC 'Hang'



As noted above, the AGC bus is decoupled to ground using one or more capacitors (0.01uf to 0.1uf is typical). As the AGC bus is at high impedance, the value of the decoupling capacitor(s) and any associated series resistor in the AGC line can be selected to provide an appropriate 'time constant', or 'hang', maintaining the AGC voltage (and thus the gain condition of the set) during rapid fluctuations in received signal, eg. when rapid 'flutter' of the signal is present, or during SSB reception (although many operators prefer to keep the receiver gain under manual control only for receiving SSB). The instantaneous sympathetic variation in receiver gain under these conditions with a 'normal', relatively fast time constant, typically 100ms to 250ms, can be very annoying, with strong 'bursts' of background noise appearing during gaps in transmission. Thus, a slower time constant (eg. 1 to 10 seconds), which maintains the receiver gain at a mean level over that period, may be preferred by the operator, or may even be switched into the circuit automatically during SSB reception, as in the Eddystone S.830 series, circuit above, where a 10uf capacitor is added in parallel with the 'standard' 0.1uf capacitor when in SSB mode.

'Quiet' AGC

The term 'QAVC' (Quiet Automatic Volume Control) was used to describe a system of silencing the receiver when signals below a set threshold were received. This system was popular in many sets of the mid-1930's, eg. models by Philco, EMI and Ekco. The general principle relied on biasing the detector diode negatively so that it would respond only to strong signals and the set would remain quiet whilst tuning between such stations. This was effectively what would normally be called a 'squelch' circuit in modern parlance, generally now only applied to frequency modulated (FM) signals.

'Forward' AGC

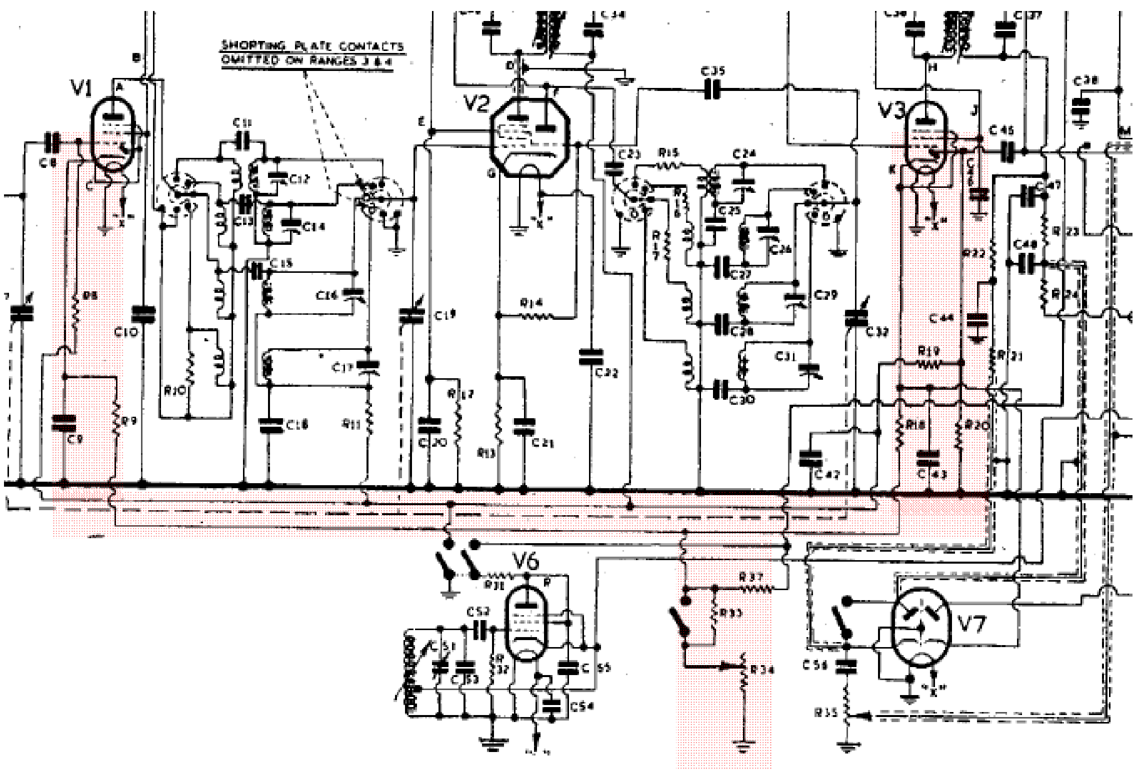
This term is sometimes used for an alternative form of adjusting the bias conditions of an IF amplifier stage, particularly in solid state circuits, in which some of the IF signal is rectified by a dedicated diode(s) and applied as a positive voltage to the first IF stage (transistor base), preventing an increase in collector current and hence limiting gain. Another form of 'forward' AGC is used in the Eddystone EC10, where a diode is acts as a switch when the signal level exceeds its forward bias and thereafter dampens the primary of the first IF transformer, thus acting to enhance the set's normal AGC action.

Typical Eddystone Manual and AGC Circuits

Post WWII Eddystone HF valve sets generally adopted conventional manual and AGC arrangements as described above. The VHF and UHF sets (S.770R and S.770U series) also incorporated a squelch circuit. Examples are provided below from some sets in my collection to illustrate typical manual and AGC arrangements in Eddystone receivers.

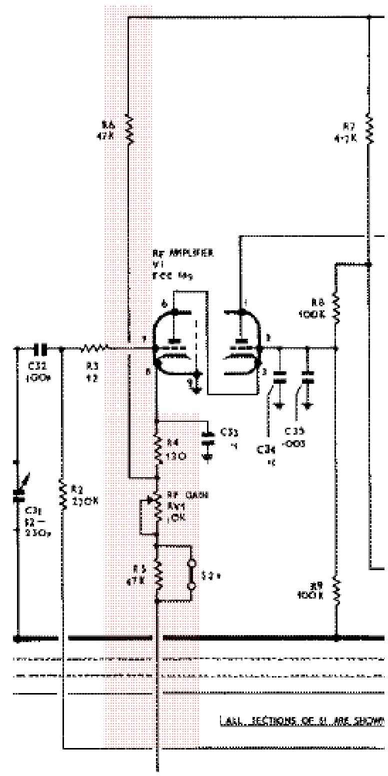
Model S.740

This set has a combined RF/IF gain control (labelled 'RF Gain' on the front panel). This control is effected by a 10kohm pot used in the conventional way to adjust the DC bias conditions of these stages (circuit, below). The AGC circuit is also conventional, using the diode section of the diode-pentode EAF42 IF amplifier stage to rectify the IF signal derived from the secondary of the last IF



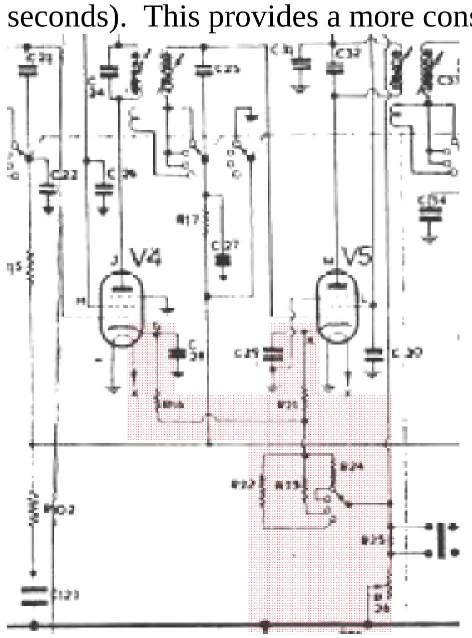
transformer. The AGC is automatically disabled (the bus is shorted to earth) when the BFO is switched on and cannot otherwise be disabled. This arrangement works well for general, relatively strong signal, broadcast reception on the SW and MW bands, but provides only limited control for more 'serious' DX'ing. A 'standby' switch is provided which increases the bias level on the AGC line, thus desensitizing the receiver during transmission.

Model S.830



Separate RF and IF manual gain controls are provided via a concentric control: control of the RF gain is by a 10kohm potentiometer in the cathode circuit of the first triode of the cascode RF stage (circuit, right). The range of this control is extended by the provision of a small bleed current from the HT line. Control of the IF gain is effected by varying the bias conditions of the 1st 100kHz IF amplifier stage, again using a 10kohm potentiometer in the cathode circuit, its control range also being extended by a small bleed current from the HT line. A 'standby' switch is provided which increases the bias level on the RF and first 100kHz IF stages, thus desensitizing the receiver during transmission.

The AGC circuit is considerably more refined than that in the S.740, as befits a high-grade communications receiver (see circuit extract presented in the AGC 'Hang' section above): the IF signal for the AGC circuit is derived from the secondary of the final IF transformer, with delayed AGC provided by a biasing arrangement on the AGC detector diode (part of a 6AT6 duo-diode triode), the amount of the delay being reduced automatically when the set is switched to SSB mode. This maintains an efficient AGC action with the reduced average sideband power available for the production of AGC voltage on SSB signals. In addition, as noted above, the time constant of the AGC circuit is increased automatically on switching to SSB reception (from 150ms to 10 seconds). This provides a more constant gain level for the set under this reception mode and prevents 'noise bursts' between pauses in (speech) transmission. The AGC is applied to the cascode RF amplifier, 1st mixer and the two 100kHz IF amplifiers. The AGC bus is also made available to a connection on the rear of the receiver for use in diversity (multiple receiver) operation. The AGC bus is shorted to ground when the set is switched to manual gain control.



Model S.770R

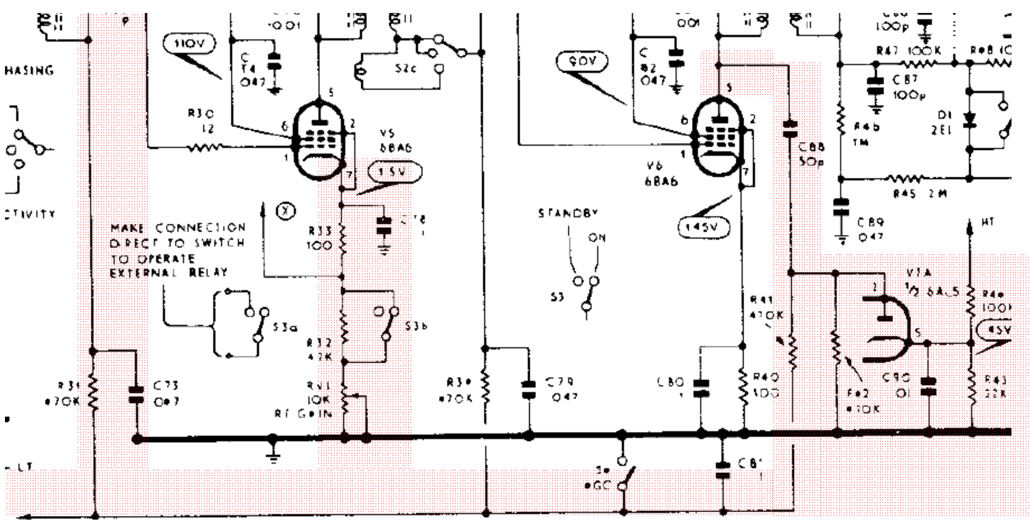
In the S.770R, the RF amplifier stage operates at full gain at all times, however, gain of the IF stages (circuit, left) can be controlled manually by a 10kohm potentiometer in the cathode circuit of the first two IF stages, its control range being extended by a small bleed current from the HT line. A refinement is provided by automatically adjusting the IF gain to predetermined levels for each of the reception modes, ie. CW, AM, NBFM and WBFM (the same level of gain is used for CW and AM), this being effected by switching different cathode resistors into the circuit of these stages. A 'standby' switch is provided which increases the bias level on the first two IF stage, thus desensitizing the receiver during transmission.

The AGC arrangement utilizes one half of a (6AL5) duo-diode valve, the IF input signal being derived from the anode of the final IF amplifier valve, ie before the limiter stage. A delayed AGC action is derived from biasing the cathode of the diode using a voltage derived from the output stage cathode circuit. The AGC voltage is fed to the RF stage and the first three IF stages. AGC action is automatically switched out by shorting the AGC bus to earth when the mode switch is set to CW.

The S.770R is also fitted with a 'muting' (squelch) circuit that silences the receiver when the input signal is below a predetermined threshold.

Model S.940

A combined RF/IF manual gain control is provided in this circuit, effected by



varying the bias on the first triode of the cascode RF stage, the pentode second RF stage and 1st IF stage. This is implemented by a 10kohm potentiometer to ground, again with a small bleed current from the HT line being provided to increase its range of control. A 'standby' switch is provided which increases the bias level on the two RF stages and first IF stage, thus desensitizing the receiver during transmission. The AGC arrangement utilizes one half of a (6AL5) duo-diode valve, the IF input signal being derived from the anode of the final IF amplifier valve. A delayed AGC action is derived from biasing the cathode of the diode using a voltage divider from the HT line (circuit, above). The AGC voltage is fed to the two RF stages, mixer and both IF stages (note: several sources have suggested removing the AGC from the mixer stage to improve receiver stability – I have not tried this modification in my S.940). The AGC action may be switched off by shorting the AGC bus to earth.

AGC Faults

The AGC voltage bus is at a very high impedance. Thus even the slightest leakage in the AGC decoupling capacitor(s) will reduce the AGC voltage level. The result of this condition will be excessive gain for the signal level received (similar to switching the AGC off), resulting in distortion and/or instability. For this reason, many folks recommend replacing the AGC decoupling capacitor(s) in elderly sets as a matter of routine, and certainly if the capacitor(s) have any measurable leakage (several hundred Mohms). Other components that can give problems, though more rarely, include the delay bias resistors and the AGC detector diode itself, and very rarely, the high-value resistors connecting the AGC bus to the controlled valve grids.

Due to the high impedance of the circuit, a very high impedance meter, eg. a VTVM or DVM, must be used to measure the AGC voltage, otherwise the loading on the circuit due to the presence of the meter will significantly affect the AGC action when it is connected between the AGC bus and ground.

Conclusions

AGC provides a very useful function in all receivers, however, whether it is used when receiving CW or SSB signals depends on the signal level, band conditions, the receiver design (type/level of sophistication of the AGC circuit, available manual gain controls and their range), as well as the preference of the operator. One final note – the AGC should normally be turned off during any re-alignment work to avoid it influencing the gain of the receiver during these adjustments.

Gerry O’Hara, G8GUH, Vancouver, BC, Canada, January, 2007

Some Useful References

- Radiotron Designers Handbook, 1941, 3rd Ed., Ch. 19
- 1928 Radio Troubleshooting, E Haan, Popular Mechanics Mag., (reprinted, 1989)
- Old Time Radios! Restoration and Repair, J Carr, 1991
- Most Often Needed 1926-1938 Radio Diagrams, M Beitman, 1941
- Modern Radio Servicing, A Ghirardi, 1935, Ch. 14
- Wireless Servicing Manual, W Cocker, 1945, 7th Ed. Ch. 16

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- Radio Servicing: Theory and Practice, A. Marcus, 1948 (Ch. 10)
- Radio and Television Receiver Troubleshooting and Repair, Ghirardi & Johnson, 1952, (Ch.s 4 & 9)
- Radio and Television Receiver Circuitry and Operation, Ghirardi & Johnson, 1951 (Chapter 5)
- Radio Receiver Servicing and Maintenance, E Lewis, 1944, 3rd Ed. Ch. 3
- Practical Radio Servicing, W Marcus and A Levy, 1955, Ch. 22
- Principals and Practice of Radio Servicing, H Hicks, 1943, 2nd Ed., Ch. 9
- Electronics One-Seven, H Mileaf, 1967, Ch.s 2, 5 & 7
- Radio Servicing, L Butterworth, 1969, Ch. 18
- Transistor Radio Servicing Course, W Lemons, 1977, 2nd Ed.
- Various sections of Eddystone manuals downloaded from the EUG web site and specific articles in Lighthouse including:

- Some web-based articles/resources on subjects covered in this article include:
    - http://www.mattmccool.com/radio/tech/avc3.shtml
    - http://www.kbapps.com/audio/tubemanual/040.html
    - http://pw2.netcom.com/~wa2ise/radios/aa5h.html
    - http://mailman.listserve.com/archives/collins/2002-05/msg00047.html
    - http://www.vk2bv.org/radio/parry1.htm
    - http://www.archive.org/details/Elements_Of_Radio_Servicing

Curves illustrating the effect that delayed AGC has on receiver response (from Radiotron Designer's Handbook, 3rd Ed.)

Curve A is the "No Control" characteristic and is the curve which would be followed, with A.V.C. removed from the receiver, up to the point at which overloading commences. This curve is a straight line with a slope of 20 db. per 10 times voltage.

Curve B is the A.V.C. Characteristic for a delay of —9 volts. From 3 to 18 μV. the experimental curve follows the "no control" line exactly, and then deviates sharply at inputs above 18 μV. From 18 to 500,000 μV. the curve follows an approximately straight course with an average slope of 3.25 db. per 10 times voltage. Above 500,000 μV. the curve tends sharply upward, indicating severe modulation rise.

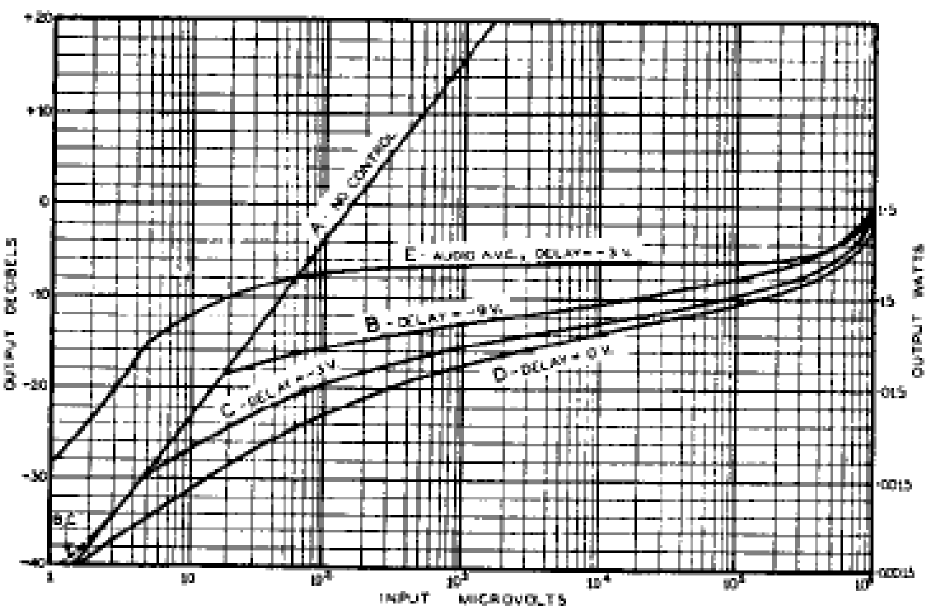
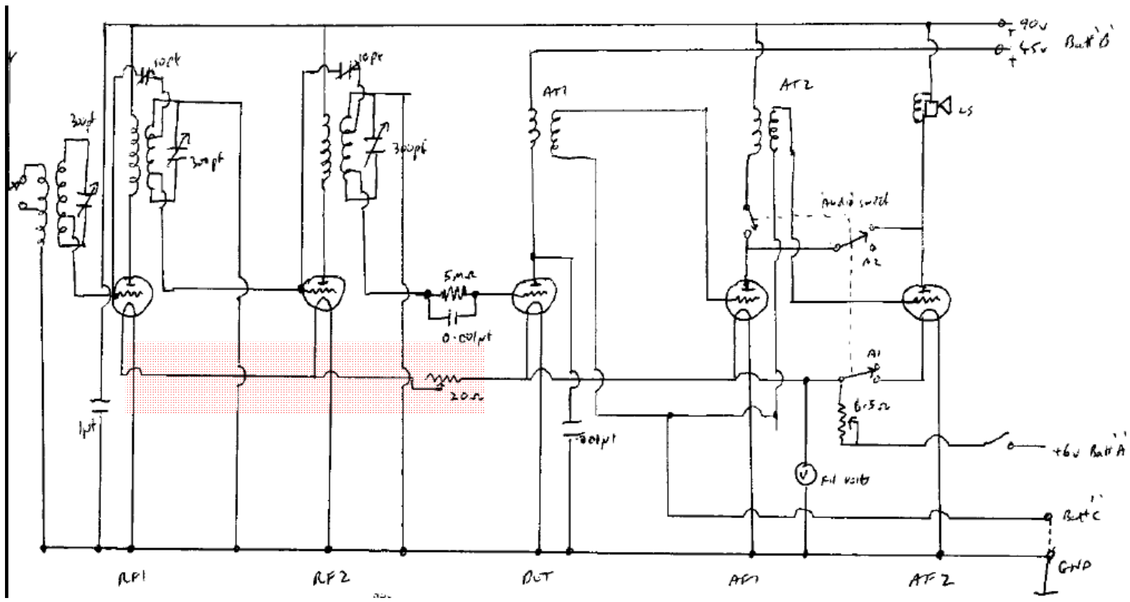


Figure 8

Curve C is the A.V.C. Characteristic for a delay of —3 volts. The A.V.C. comes into operation at a lower input voltage, and the average slope is steeper than for the higher delay voltage. In both cases, however, the "knee" of the curve as it leaves the no control line is very sharp and clearly defined.

Curve D is the A.V.C. Characteristic for a delay of zero voltage, with due compensation for the effect of contact potential on the standing bias of the controlled valves.

Curve E is the Characteristic obtained with a typical Audio A.V.C. System. Over the range from 100 to 500,000 μV. the total rise is only 3 db.



Some Early Receiver Gain Control Methods

Above: gain control in 1924 King-Hinners Model 25 TRF – a rheostat in the RF stage heater supply (directly-heated cathodes)

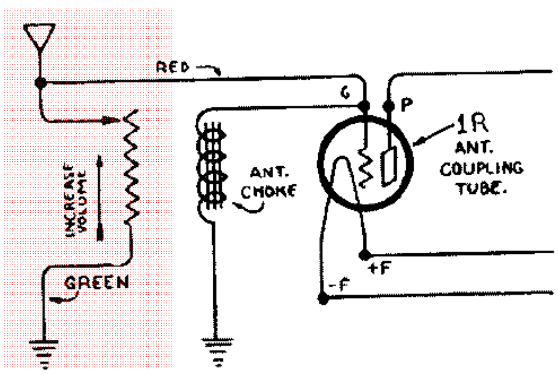


FIG. 60. SCHEMATIC DIAGRAM OF VOLUME CONTROL IN MODELS 37 AND 38.

Left: gain control in 1926 Atwater Kent Model 37 TRF – a potentiometer in the aerial circuit

Below: gain control in 1929 Philco Model 77 – both a potentiometer in the aerial circuit and variable bias on the RF stages (indirectly-heated cathodes) – points E&F go to a DC bias supply