

'Technical Shorts'

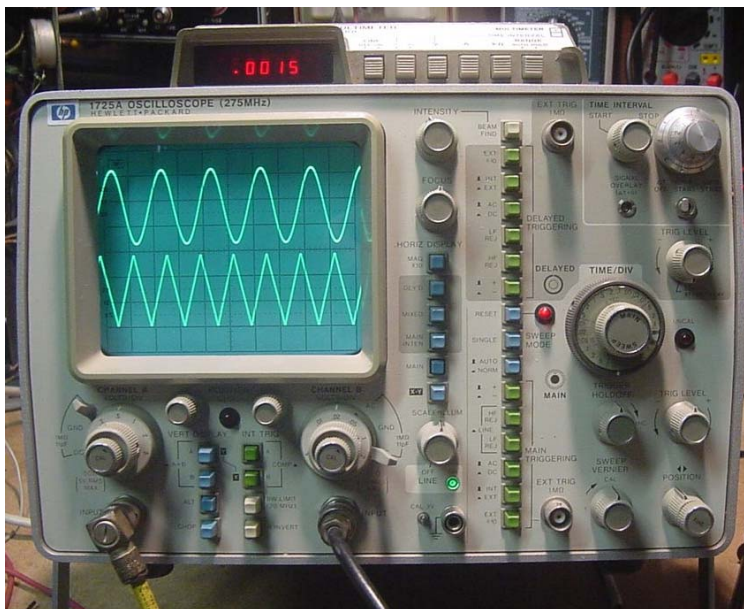
by Gerry O'Hara, VE7GUH/G8GUH

'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.

Oscilloscopes in Radio Servicing

Introduction

When I was a lad, I always wanted an oscilloscope ('scope) – they just looked so cool, at least in an electro-geeky sort of way – all those knobs to twiddle, sockets to plug things into, buttons to push, technical-sounding markings on the panel and, most importantly, a real-time display that apparently showed exactly what was happening in the piece of kit you were fixing such that diagnosing the most complicated problem would become a doddle...



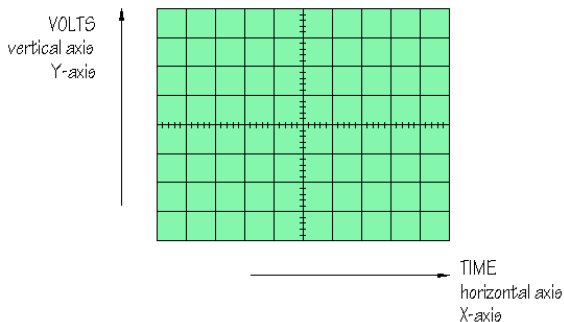
or so I thought. I eventually bought my first 'scope in the 1970's – a rack-mounted, single-trace Telequipment valve job from 'AH Supplies' in Sheffield (model 'S32R' I think) – for the princely sum of £10. After fixing the HT circuit (new EHT rectifiers and caps – replacements supplied, along with a schematic *gratis* by Telequipment, together with a nice letter – I was most impressed!) and a faulty time-base (leaky capacitors), I had a workshop 'scope that I could finally cut my teeth on. Admittedly, it was a bit limited in terms of bandwidth and it was not the most stable of 'scopes, however, it did me proud for my outlay of £10 for many years and was only disposed-of when I emigrated to

Canada in 1997 (by my dad at a car-boot sale in the Northwest of England somewhere) – I think it was still working at the time.

The 'scope is one of those workshop tools that you can actually 'get-by' without most of the time, and if you have never used one, you may wonder what people see in them (electrons?), apart from the techno-glamour and workshop 'eye-candy' aspects mentioned above. I am sure that many 'scopes sit idle in workshops because their owners either don't know how to use them, are intimidated by their apparent complexity, or have become so used to getting-by without (especially if their 'scope is a large old dinosaur and it is such a physical effort) that they almost forget they have it. So, do I use a 'scope much? and if so, what for? The answer is that I do use a 'scope fairly regularly, usually for troubleshooting purposes in AC circuitry, but generally only after techniques using other workshop tools (VOM, VTVM, DFM, etc) have failed to diagnose a problem quickly, or when I know a 'scope is the tool to reach for first from previous experience.

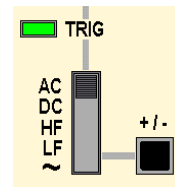
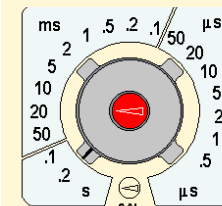
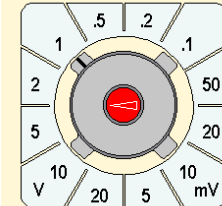
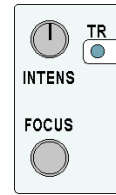
Oscilloscope Basics

A 'scope is a voltmeter - rather a sophisticated one, granted, but still a voltmeter. It can measure DC and AC voltages throughout its bandwidth and sensitivity specifications, and usually has a high input impedance, like a valve (vacuum tube) voltmeter (VTVM), so loading on the circuit being measured is minimal. Its big trick, however, and its primary advantage over a VTVM, is to introduce another dimension into the measurement process: time. By doing this, AC waveforms can be displayed on a voltage/time graph format, a facility that allows the user to 'see' what is happening in a circuit carrying AC signals much more clearly than the surrogates of simple voltage measurement and listening to the output of a receiver for example. It also allows time-related measurements to be made, eg. frequency or interval between two events - not as important a facility in the age of low-cost digital frequency meters (DFMs), but still useful – especially for complex waveforms that can confuse a DFM. Dual-trace 'scopes are able to display two voltage/time graphs at the same time, though usually with the same time-base setting. This facility allows waveforms from two areas of the circuit under test to be displayed simultaneously and compared directly – very useful in certain circumstances. Other, more specialist 'scopes are available, eg. digital storage and sampling 'scopes' that store the applied waveform in digital memory for subsequent analysis or comparison. Digitizing the signal in this way also allows the application of software processing algorithms, however, the need for such complexity (and expense) is hardly justified for the radio hobbyist (some of these gadgets can go to over 30GHz and cost tens of thousands of hard-earned shirts...).



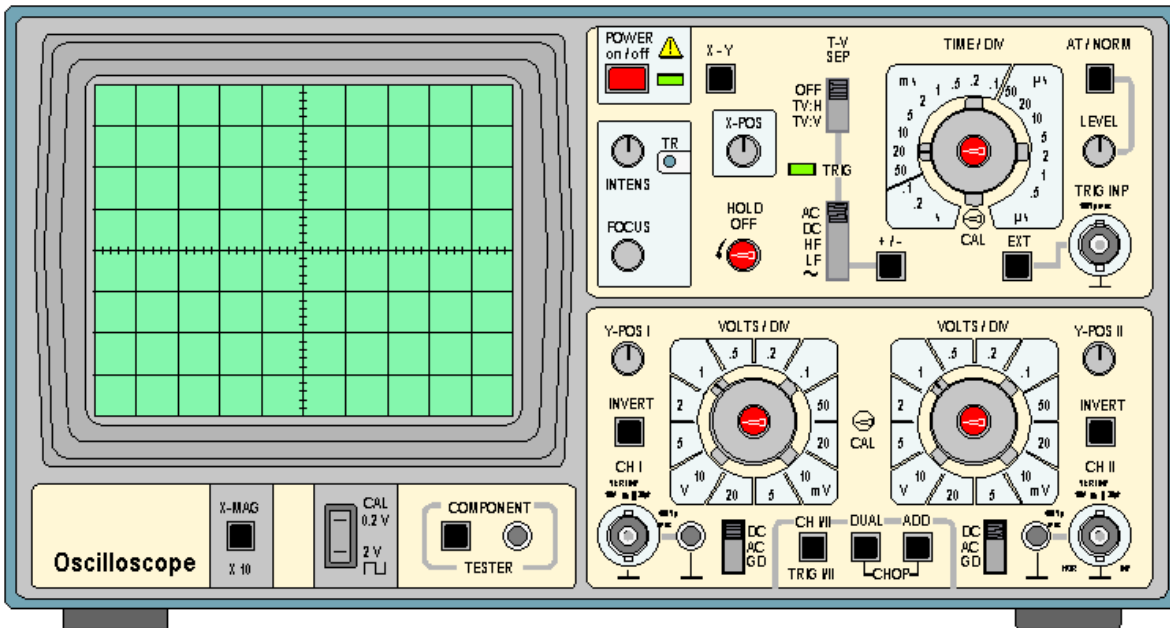
The controls on any simple analogue 'scope can be grouped into three primary sections, as those controlling the:

- display parameters: these are normally brightness ('intensity'), focus, beam width and beam positioning (X-centre, Y-centre). Things to remember when setting-up are not to have the 'brightness' set too high (can 'burn' the phosphor coating on the tube) – instead, set it appropriately for the room's brightness and then adjust the focus. The beam width, X and Y position control functions are self-evident, however, these may need re-adjustment to obtain the best display or to align with the screen graticule for measurement purposes;
- amplitude of the displayed signal: primarily the X (if present) and Y gain controls. These are usually calibrated in Volts (V) and millivolts (mV) per division of the screen graticule (usually a centimetre grid), the more expensive 'scopes tending to have more ranges available. Sometimes a x2, x5 or x10 function is provide for greater sensitivity, along with a variable (non-calibrated) gain control; and
- time-base: interval (time/scale division) and triggering-related functions. The time it takes for the electron beam to complete a scan of each screen division in seconds (given in ms or μ s). The fixed time interval settings are accurately calibrated, so that the graticule can be used for measurement of frequency. Sometimes a variable (non-calibrated) time-base setting is also provided. The triggering can usually be set to synchronize on the positive or negative half-cycle of an AC waveform on one or other of the Y-inputs, to an external source or to mains frequency (50Hz in UK, 60Hz in North America). More sophisticated 'scopes have special filters and delay circuitry installed that allow accurate triggering on more complex waveforms, such as found in TV set circuits.



Once you think of the control grouping in this way, making sense and navigation of the controls becomes much easier. In addition, most 'scopes have a calibration facility (often a square wave of fixed peak-to-peak (p-p) amplitude at 50Hz or 60Hz, depending on the mains frequency. Dual-trace 'scopes, which most are these days, have supplementary controls that allow switching between the two inputs or to display both simultaneously, and which input (if any) is used for triggering to synchronize the display. More sophisticated 'scopes can include many additional controls, but almost all will be related in some way to the above functions, eg. selecting filtering or delay circuits for the triggering.

If you want to explore these functions in some detail, check out <http://hyperphysics.phy-astr.gsu.edu/Hbase/Electronic/scopec.html>, <http://www.kpsec.freeuk.com/cro.htm>, <http://en.wikipedia.org/wiki/Oscilloscope>, or <http://www.doctrionics.co.uk/scope.htm> (some of the graphics used here are reproduced from this site).



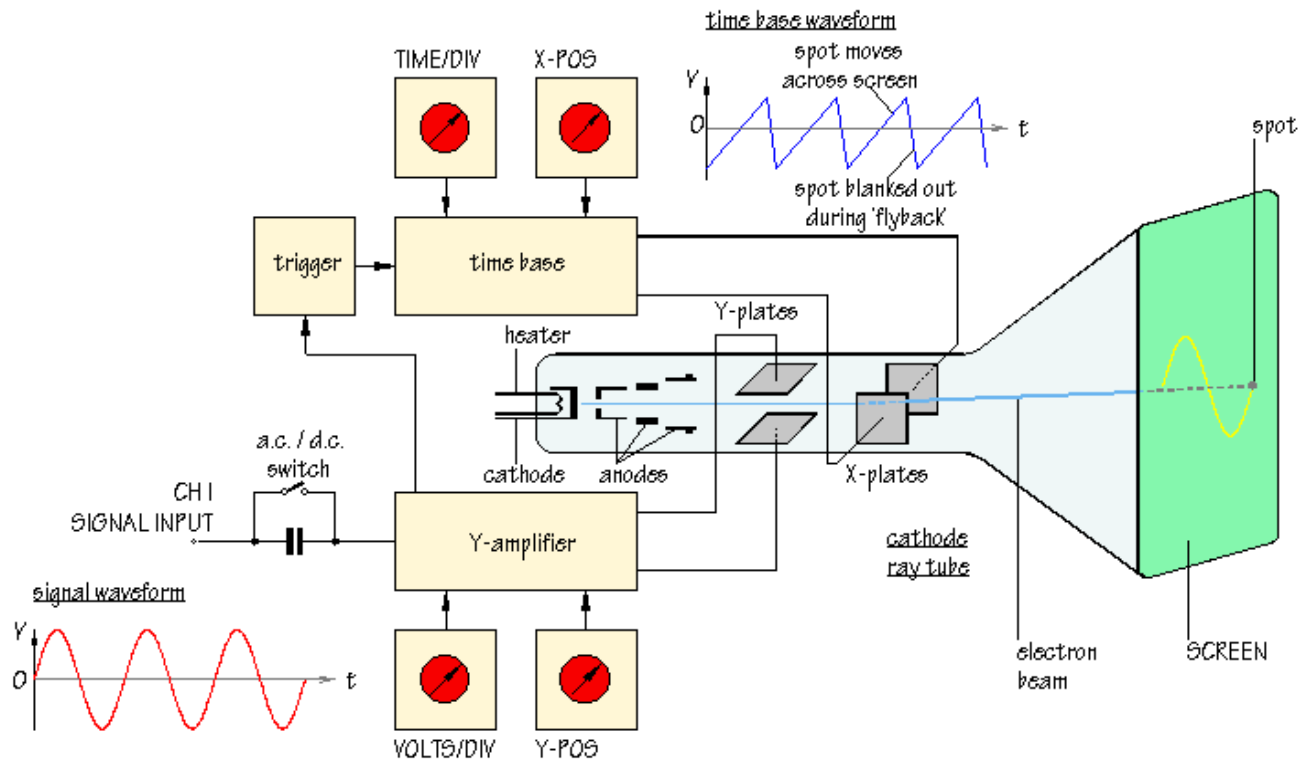
How Does it Work?

The display in a 'scope is usually a cathode-ray tube (CRT), although more recent models use plasma, LED or LCD technology. Display technology apart, the principals of how the display is generated are similar. For description purposes here I will deal only with analogue CRT technology. In the CRT, an electron beam is generated at the cathode of the tube and is accelerated towards the screen where it excites luminescent phosphors to create a visible image. The electron beam is accelerated and focussed by one or more anodes and can be deflected by voltages applied to two sets of plates set at 90 degrees to each other in the neck of the CRT. The horizontal deflection plates produce side-to-side movement and the vertical deflection plates up and down movement of the electron beam. The horizontal deflection plates are usually coupled to the time-base circuit which produces a saw-tooth waveform that sweeps the beam back and forth across the screen at a known rate, set by the time/scale division control as described above, the display being automatically blanked-out during the rapid return part of the sweep.

The signal(s) to be displayed is usually connected to the Y-input(s). There is normally an option to include a DC blocking capacitor if needed (by the AC/DC switch) on each Y input. The signal(s) is then amplified by the Y-amplifier(s) by an amount set by the Y-gain control as appropriate to obtain the desired display amplitude for a given input signal level. The output of the Y-amplifier is applied to the vertical deflection plates.

The trigger circuit is set to synchronise the time-base waveform such that the same section of input signal is displayed on the screen for each cycle (or set of cycles) of the time-base in order to provide a stable waveform on the display. The display can usually be synchronized with an internal (signal) source or external source.

The figure below illustrates the main circuit components in a typical 'scope.



Buying a 'Scope

I currently own two 'scopes, both analogue solid-state models: the simplest of these is a Hitachi Model V-212 20MHz dual-trace one that is some 15 years old (pictured on the following page). It sits on my workbench (as it has a reasonably small footprint) and is used the most because it is handy, simple to use and is adequate for 95% of what I need a scope to do. My second scope is an early-1980's HP model 1725A, a 275MHz bandwidth dual-trace 'scope with an integrated DMM 'clamshell' and some fancy triggering/delayed-time-base features (pictured at the beginning of this article). The Hitachi was bought on Ebay for \$90 and the HP was received *gratis* for the cost of shipping from an Ebay seller in California who I became friends with (he had serviced it before dispatch and he also sent me a box of spare circuit boards), but the 1725A, or similar, can be bought for a reasonable price (<\$500 or so). To be honest though, I am not sure that buying a 'scope off Ebay (or other internet source) is the best way of acquiring one, as 'scopes can get damaged in transit and may have hard-to-fix faults that may not show-up until you are using a certain sensitivity, time-base setting or particular facility (which may be the reason the vendor is selling anyway). For example, my Hitachi 'scope arrived with a peculiar fault – a trace that bent upwards at the left side of the screen that could not be corrected with any of the controls (photo, next page). The vendor was contacted, and although he denied that there was a problem when he was using it (which I now believe to be the case), he did offer a refund if I was not satisfied. Even so, I was a bit miffed, but the issue was not so serious that I could not use the

'scope, so I did not return it as the return shipping was half the cost of the 'scope. I checked the circuitry around the CRT – all seemed in order, and the outer case, nuts and bolts, CRT fittings, etc. were checked for

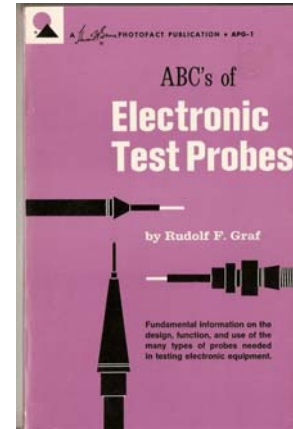


magnetism – nothing found. It was only when I used the 'scope with the outer case removed while fitting a ramp-output socket to it for my wobulator (over 3 years after I bought the 'scope) that I finally discovered what the problem was – a spring-steel strip hidden in the plastic carrying handle had become strongly magnetized (maybe in transit during scanning at an airport en-route to my house). So, I would be cautious of 'arms-length' purchases and would recommend buying from somewhere you can try the 'scope out before buying and also where you could return it to at low-cost should there be a problem. I would not even consider looking at a valve-based unit – these being too unreliable (notwithstanding my comments on the Telequipment unit above), specially in view of their age, numbers of valves and aging-capacitors/resistors present, and the much-higher sensitivity 'scope circuitry has to changing component values compared with a receiver. Good, second-hand, high-quality Tektronix and HP (Agilent) 'scopes that cost thousands when new can be bought at reasonable cost (as per the 1725A), however, these are usually complex and, as such, can be prone to problems – though many faults often result from dirty switch contacts and loose/tarnished circuit-board connectors. Also, these 'scopes probably contain circuitry and facilities that you will likely never use (I use only a fraction of those in my HP unit, which I normally turn to only because of its much wider bandwidth and flexible triggering facilities compared to my Hitachi unit). When shopping-around, bear in mind that new 20MHz 'scopes can be bought for as little as \$400 and 100MHz ones for less than \$1,000. There are also several handheld LCD screen 'scopes now on the market – however, I have only tried one of these out and was not too impressed. Also available are computer-based 'scopes and software – I downloaded some free software for my PC once that allowed the sound card to be used as a simple 'scope for audio frequencies (not too impressive). Much more sophisticated hardware/software-based computer solutions are available, with costs ranging upwards of \$150 or so (eg. see www.taomore.com). These may be worth checking-out if you already have a computer near the workbench.

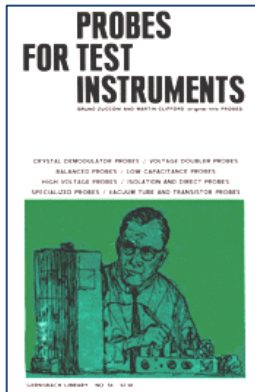
Probes

Of course you need leads of some description to go from the 'scope's input to the circuit under test: all but the oldest 'scopes have BNC sockets fitted, so the test leads used will likely be screened and have one of these fitted on one end, the other end possibly being fitted with an insulated croc clip for a chassis connection and a hooked probe on the signal lead. Such a simple arrangement ('direct probe') is ok for DC and low frequency

circuits and those having reasonably-high signal-level voltages present, however, at higher frequencies, the leads can add undesirable capacitance and inductance to the circuit under test, that can significantly affect the observed waveform – the typical shunt capacitance added by direct probes is in the 50pF to 150pF range, depending on the length of test lead used and capacitance per unit length. In order to minimize disturbance of the circuit under test, the probe should have an input impedance of at least ten times higher than the source (circuit) impedance. Thus a direct probe could be used in low source-impedance applications, eg. in a power supply circuit, or for cathode circuit measurements, but not in a grid circuit in a valve amplifier or the tuned circuit of an oscillator. Also, while a direct probe arrangement allows the maximum sensitivity of the 'scope to be used, it also means that the probe should not contact any circuit element that could apply more than the 'scope's maximum allowable input voltage, possibly damaging the vertical amplifier (at least in a solid-state 'scope). Another undesirable effect that can occur when using a direct probe is the introduction of a feedback loop between the receiver, the 'scope's input circuitry/amplifier and the power line, which can introduce undesired (and confusing) oscillation that is observed on the 'scope trace.



To mitigate the issues mentioned above, most 'scopes are also supplied with a simple 'x10 probe' – here an attenuator (resistor network suited to the 'scope's input impedance) is fitted in the probe body that reduces the 'scope's sensitivity by a factor of 10, but also provides isolation between the circuit under test and the capacitance/inductance of the test lead, as well as some protection of the 'scope's input circuitry. Such a probe is normally fitted with a small trimmer capacitor in the plug end to allow some compensating adjustments to be made for remnant undesirable lead effects. When correctly set up, a simple x10 probe can have an effective shunt capacitance of around 1pF, with consequently minimal effect on most circuits (check-out the YouTube video at <http://www.youtube.com/watch?v=uOAzRIhrnYE&feature=related>).



Many other types of probe are made for 'scopes, including high-voltage probes having higher values of resistor cartridge/improved insulation, 'low-capacitance' probes (variation on the simple 'x10' probe), RF/demodulator probes (with a detector diode in the probe) similar to those used for RF measurements in VTVMs, as well as several active probe types, eg. having an in-built amplifier, buffer amplifier (cathode, emitter or source-follower) or active filtering within the probe. Whole books have been written on the subject of probes – but for general workshop use, a direct probe, a simple x10 probe and an RF probe will normally suffice.

So, I Bought a 'Scope, Now, What Can I do With It?

The short answer is 'lots' – and limited only by your own ingenuity. Many books have been written on this subject and there are many, many web sites that cover various uses,

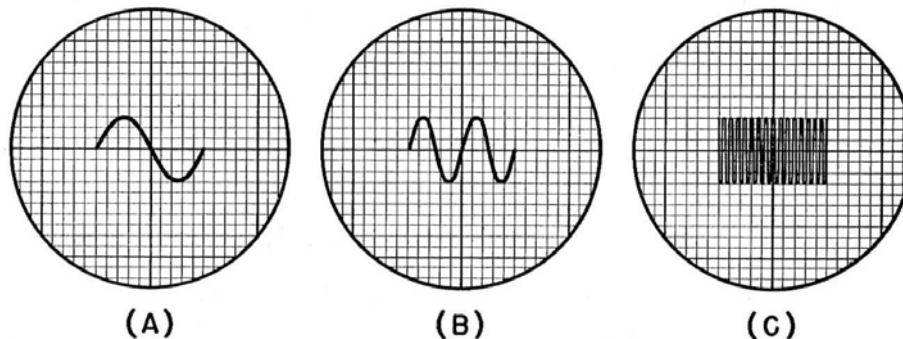
some general, and some very specialized. What I cover below are some of the more common uses on the radio-restorers/repairers workbench. 'Scopes can be used for many other purposes in the radio field, eg. for analysing the modulation of a transmitter, however, I have not covered these here and the reader should refer to some of the referenced articles if interested in these non-receiver type applications.

Setting-Up the 'Scope

The 'Oscilloscope Basics' section above provides enough information to understand the function of the basic controls on a 'scope. The next thing you need to do is to familiarize yourself with their operation and how to set them up to make meaningful measurements on a radio receiver. For step-by-step set-up, check out the YouTube video on 'scope basics at <http://www.youtube.com/watch?v=rC8HBcsNm2g>. In summary:

- Trace controls (brightness, focus, sweep width, X and Y position) – adjust to obtain a sharp, clear but not-to bright trace, centred on the screen area;
- AC/DC: select as needed for the type of measurement being made – on 'AC' a capacitor is introduced, blocking DC and thus adding a level of protection against high DC voltages being applied inadvertently to the 'scope input;
- Time-base: in general, the lower settings of the time-base (5ms/div to 20 μ s/div) are useful for audio frequencies, whereas 5 μ s/div to 0.2 μ s/div are best for displaying IF frequencies and intervals below 0.2 μ s/div for RF frequencies;
- Triggering ('sync'): usually set for 'auto' and for internal triggering, negative or positive slope triggering;
- Y-Gain (sensitivity): most 'scopes will have sensitivities that can be adjusted from a few mV/div through to several Volts/div. Remember that if you are using a x10 probe, these settings will be reduced by a factor of 10, eg. the 50mV/div setting will become 500mV/div when using this probe. Most signals being measured in a receiver will be in the millivolts to hundreds of millivolts range – if you are uncertain of the signal voltage amplitude, it is best to set the Y gain for something like 200mV/div and then increase the sensitivity if needed.

The figure below illustrates 'scope patterns useful in testing receivers. Traces (A) and (B) are obtained by adjusting the sweep frequency to a value equal to and twice the input frequency respectively – these traces are useful for observing distortion on the signal (see section on distortion, below). Trace (C) is obtained by using a sweep frequency much lower than the input frequency – this type of trace is useful for observing gain and output measurements.



DC and AC voltage Measurements

This is the most straightforward use for a 'scope. The time-base can be left on or off for such measurements. For DC voltage measurements, set the sensitivity control to the highest setting, connect the voltage to be measured to the 'scopes Y-input with the input set to 'DC' and then adjust the sensitivity to an appropriate setting to be able to measure the vertical deflection on the screen when the voltage is applied. Then multiply the number of divisions deflection (or part thereof) by the sensitivity to obtain the DC voltage. For example, if the sensitivity is set to 0.5V/div and the applied voltage causes a deflection of 3.7 divisions on the graticule, the voltage being applied is 1.85V. For AC voltages, the AC/DC switch can usually be left at the DC setting unless a large DC offset voltage is present on the AC voltage – if so, set the switch to AC to avoid the trace jumping off the screen. Set the sensitivity control as per the DC voltage measurement procedure until the full deflection can be observed on the screen. The display seen for measurement is the peak-to-peak (p-p) AC voltage. The RMS voltage of a sine wave (as would be displayed on a meter) can be calculated by dividing the p-p voltage by 2 and multiplying this by 0.707. If the time-base is switched-off for the measurements, the electron beam will appear as a spot on the screen and as a moving spot or line if left switched on (depending on the time/div setting of the time-base).

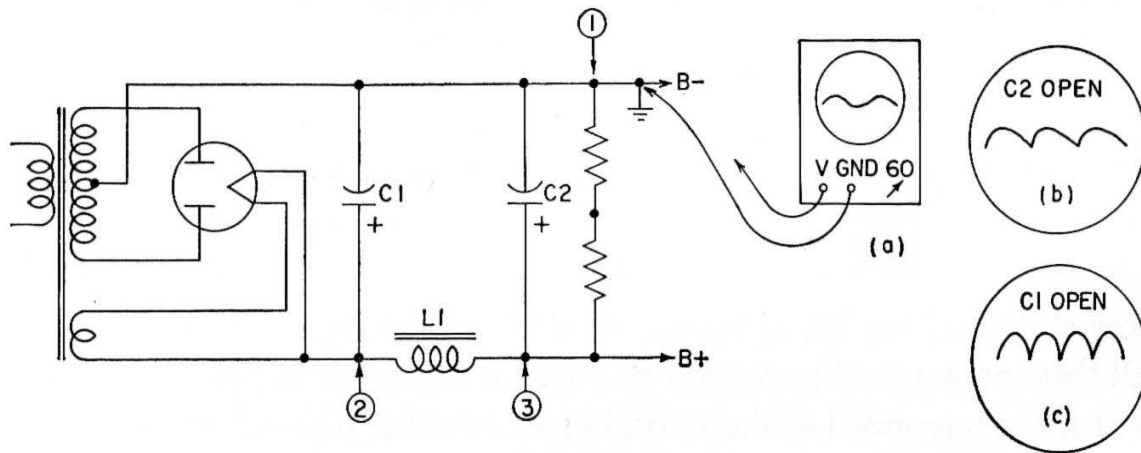
If an AC voltage is applied to the Y input(s) and the time-base and trigger controls are adjusted appropriately, a display of the applied AC waveform(s) can be obtained – this is the usual mode of operation of a 'scope for observing AC signals.

Hum Tracing

A 'scope can be very usefully deployed in tracing hum problems in receivers. For example, ripple present on the HT line can be quantified (check that the 'scope's input is switched to AC and that the 'scope can safely cope with the maximum HT voltage to be applied). If in doubt, use an external isolating capacitor (say 0.25uF) of 20% higher working voltage than the maximum HT voltage. If the AC ripple observed on the HT line is more than a few millivolts, then suspect that one of the electrolytic filter caps in the receiver's power supply is weak or non-functioning.

More diagnostic testing is possible, eg. to identify which of the (typically) two power supply filter capacitors is not performing as it should. Referring to the figure below of a typical power supply in a valve receiver, set the 'scope to the 50Hz trigger position (or 60Hz in North America) and connect the ground probe to point 1 in the power supply under test (usually ground in Eddystone receivers) and the other probe to point 3. If the input filter capacitor (C1) and choke are in working order, but C2 is significantly low in value or open-circuit, the waveform shown in (b) will be observed. If C1 is open-circuit/low capacitance, and the choke and C2 are in good condition, a waveform similar to (c) will be observed. If all filter components are working well, a 'scope trace similar to that shown in (a) will be seen – the faint residual hum present after filtering. The amplitude of traces (b) and (c) will be much larger than (a). It is useful to undertake these

checks on a known good receiver power supply to get a 'feel' for the waveforms and amplitudes to be expected at each test point.



Of course, the presence of undesirable levels of hum on the HT line can be observed at other points through the receiver circuit. Areas that are particularly susceptible to this defect are the AM detector and first audio stages – often an additional electrolytic filter capacitor is included in the anode supply circuit of the first audio stage and this is a good point to check and compare residual hum levels with that on the main HT line (it should be much less at the first audio anode supply filter capacitor).

To check for other sources/causes of hum in the first AF stage, it is necessary to first silence the stages ahead of the stage under test, eg. by shorting-out the grid of the last IF valve. Set the 'scopes time-base and trigger such that a single 50Hz (60Hz) cycle is displayed on the screen and the Y gain is a few tens of millivolts/div. Connect the ground test probe to receiver ground (the ground terminal of the AF gain control is usually a good connection for this), and proceed as follows, observing the 'scope trace for any signs of hum (adjusted to a few millivolts sensitivity) – touch the other test probe to:

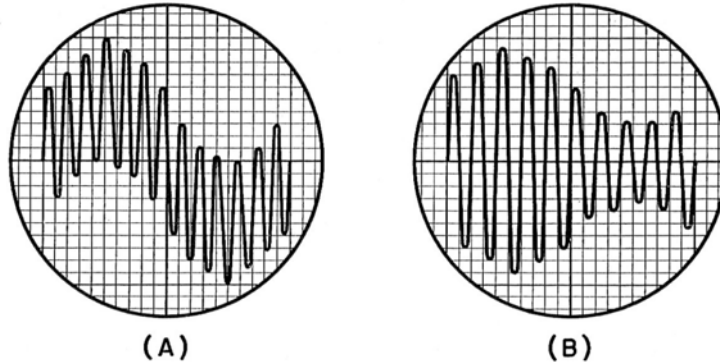
- AF gain control wiper (hum present here could indicate poor ground connection to the AF gain control or screened AF leads, or heater leads dressed too close to the control or nearby signal path leads);
- Control grid of first AF stage (hum present here could indicate poor ground connection to the screened AF leads or poorly-dressed heater leads);
- Cathode of first AF stage (hum present here could indicate heater to cathode leakage in the first AF amplifier valve or faulty cathode by-pass capacitor);
- Anode of first AF stage (hum present here could indicate open circuit or low-value first AF stage HT line filter capacitor or dropper resistor);
- Cathode of output stage (hum present here could indicate heater to cathode leakage in the output stage valve);
- Anode of the output stage (hum present here could indicate open circuit or low-value HT line filter capacitor); and
- Speaker voice coil (hum present here could be induced from nearby inductors (eg. poorly positioned replacement power transformer or choke).

The moment you touch a point in the circuit with a hum voltage present, a single cycle will appear on the 'scope if this is 50Hz (60Hz) or 2 cycles if 100Hz (120Hz) – note though that there is always a small (tolerable) level of hum present on most valve circuits.

Modulation hum is the term applied to a hum that occurs while tuning a station in – this can be present when tuning through either sideband and/or when the station is fully tuned-in, but is not present when a signal is not being received. This form of hum should not be confused with that

discussed above, and if observed, the cause is usually heater-cathode leakage in an RF or Mixer stage. Other causes are open (or poorly grounded) grid circuits, high resistance contacts (eg. on wavechange switches), defective by-pass capacitors (including those

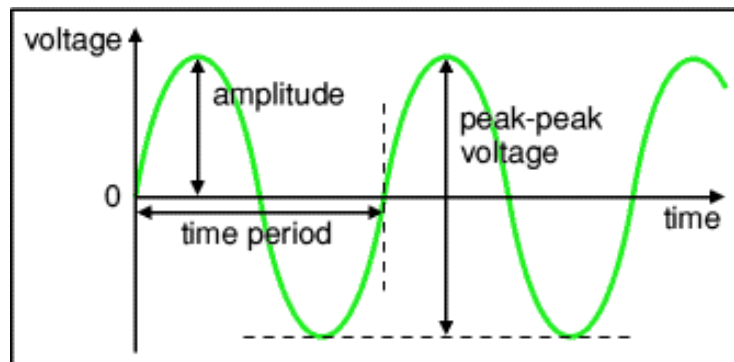
on the HT supply to the RF and mixer stages, and also any mains RF filter capacitors), dry joints, poor lead dressing and poor shielding (including valve shields). The figure above illustrates the audio waveform that may be observed when addition of hum and signal is present (A), which is the more common, as arises from poor HT filtering, whereas that shown in (B) illustrates where the signal and the hum have passed through a nonlinear circuit (eg. mixer stage) and the hum has modulated the signal.



Frequency Measurement

Maybe not used as much these days with the advent of cheap DFM's, a 'scope can still be used for this purpose. I have found it to be of real value when more than one frequency is present in the waveform being analysed, or when the signal frequency is varying somewhat – these conditions can 'confuse' a DFM unless

filtering is employed. To measure a frequency (defined as $1/\text{time period}$) using a 'scope, simply obtain a display of the waveform using the controls as described above, and then position the trace such that the same point on two separate cycles of the waveform can be aligned with the scale graticule (figure, above). The interval on the screen for one complete cycle of the waveform is measured and the frequency calculated by dividing the reciprocal of this measurement by the time/div setting of the time-base control. For

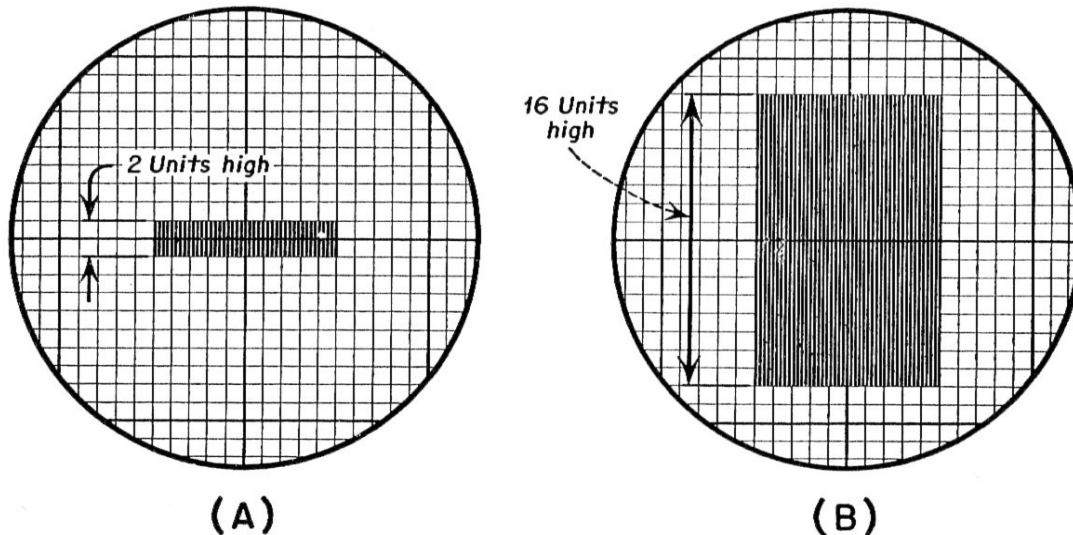


example, if the waveform being measured occupies 9 horizontal screen division and the time-base is set at 0.2mS, the signal frequency is (approximately) 555Hz. Likewise, if one complete cycle occupies 2.7 divisions and the time-base is set at 0.5 μ S, the signal frequency is (approximately) 740.74KHz.

Check-out http://www.wisc-online.com/objects/index_tj.asp?objID=ACE3503 for a step-by-step guide on how to set up the 'scope controls and make the measurement.

Gain Measurements

This is an easy measurement with a 'scope: simply measure the AC voltage at the input to an amplifier stage and compare to that measured at the output (ratio). The input of the 'scope should be switched to AC in order to block DC voltage and, preferably a x10 probe should be used to prevent significant interference with the circuit under test. For example, with the 'scope's vertical amplifier set for 50mV/div, if an AF amplifier stage has 100mV p-p signal at its grid, as in (A) in the figure below, and 800mV p-p at its anode, as in (B), the stage (voltage) gain is x8. Be mindful of the purpose of the stage under test, such that a sensible signal level is applied to the input to avoid overloading the stage (see section on distortion observations below) and the 'scope has sufficient bandwidth for its Y amplifier to operate linearly at the frequency used.



Local Oscillator Operation

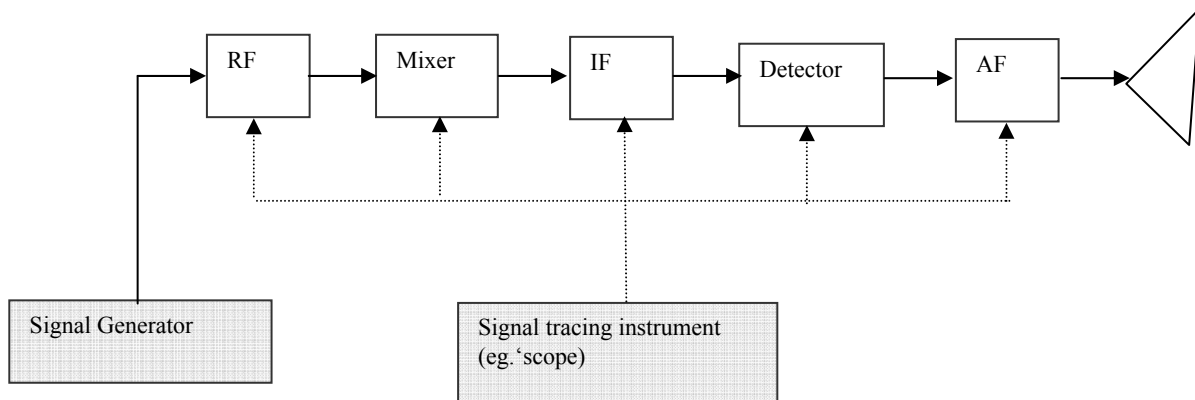
When the RF section of a set appears 'dead', one of the first things to check is whether the local oscillator is actually oscillating. Almost any 'scope fitted with a x10 or an RF probe can quickly ascertain this, and a well-calibrated, higher bandwidth 'scope can even check if it is oscillating in the correct frequency range (see section on frequency measurement above).

With the 'scope set for 'AC' and the x10 probe fitted, connect the probe ground to a ground point near the local oscillator stage. Then touch the x10 probe tip onto the anode

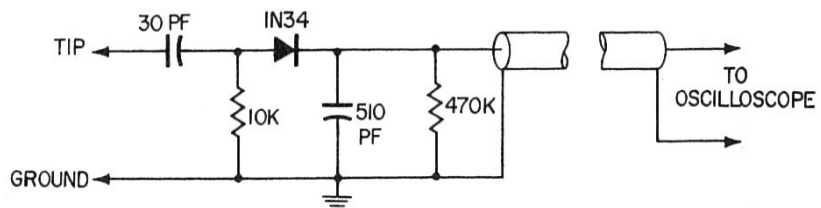
of the local oscillator valve (if the local oscillator is a separate stage to the mixer), or to the stator of the local oscillator tuning capacitor if it is part of a frequency converter stage. Additional isolation may be needed to avoid damping or de-tuning the oscillator – if so, try using a $\sim 20\text{pF}$ capacitor between the $\times 10$ probe and the point in the circuit you are investigating.

Signal Tracing

Again, a really simple thing to do with 'scope. Apply an AM-modulated RF signal to the aerial connection and tune it in on the receiver under test. If your 'scope has a bandwidth that can cope with the RF and/or IF frequencies, you can use the $\times 10$ probe and attempt to observe the signal directly as it passes through the circuit (see figure below), working from the aerial connection through the RF, Mixer, IF, detector and audio stages, adjusting the 'scope time-base, triggering and sensitivity controls as you proceed to suit the changing frequency and amplitude of the signal. Otherwise the technique is similar to that of signal-tracing using a VTVM with an RF probe. Check out the step-by-step YouTube video at <http://www.youtube.com/watch?v=B44wHjb8jMY&feature=related> for an example using a simple 'All-American-Five' AC/DC set, and various waveforms to be encountered.



If the 'scope being used has insufficient bandwidth to operate satisfactorily at RF and IF frequencies, then a simple demodulator RF probe (envelope detector) can be fabricated from a diode and a couple of capacitors and resistors (see figure below) and used in place of the $\times 10$ probe for investigating the RF, Mixer and IF stages. The 1N34 (or 1N34A) diode can be replaced with most small-signal diodes, preferably germanium, eg OA90, and the values of the passive components are not too critical within 25% or so of the values shown.



The circuit must be enclosed in a screened container, eg. a cigar tube. Using a probe like this, the 'scope will display the demodulated AF signal, not the RF or IF signal, however, it is still a useful indication as to where the signal stops/weakens on its passage through the circuit.

Filter Response

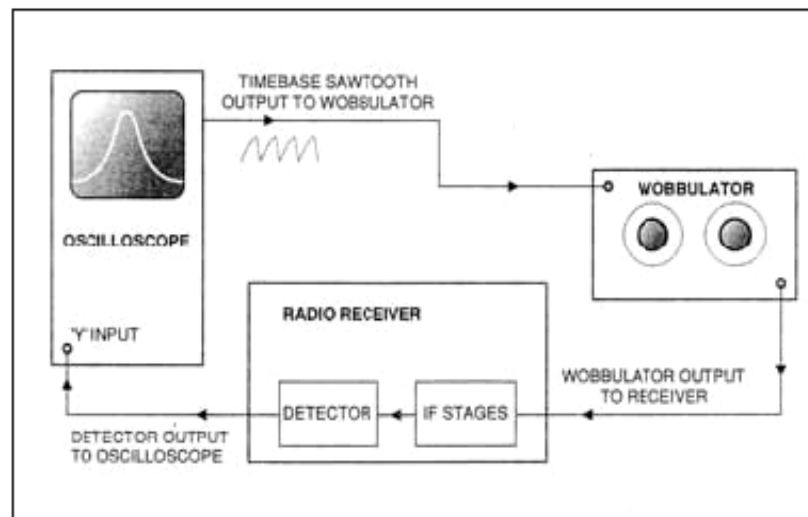
A 'scope can be used to measure the response of a filter when used in conjunction with a signal generator. To do this, connect the signal generator to the input of the filter and the 'scope to the output. Bear in mind that presenting an incorrect impedance to the filter (input and output) can affect the filter performance and distort the response, so if known, use shunt resistors of the correct value to simulate the input/output impedances and use the loosest coupling that can be made to the generator and the 'scope and still make a confident observation of the response.

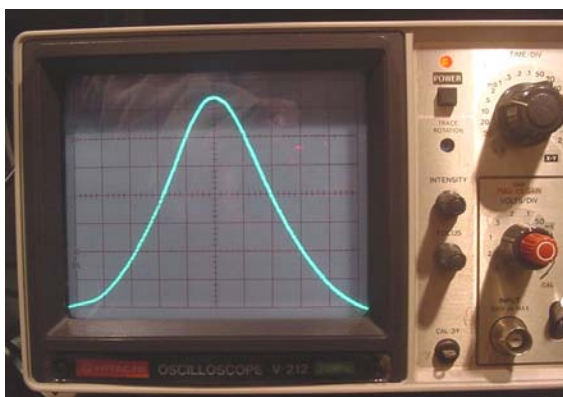
For an AF filter, first check the output characteristics of your variable-frequency AF signal generator by observing the output on the 'scope while sweeping the frequency through the AF range - say 50Hz through 10KHz: observe the amplitude of the signal on the 'scope across the swept range. Note down if the level remains sensibly constant across this range or varies (and by how much). This done, the filter can be tested by connecting the 'scope across the filter output and connecting the AF signal generator across the filter input, observing correct termination arrangements as noted above. Starting with an AF signal around 1KHz, adjust the 'scope to observe the signal. Then sweep the AF generator through the entire audio range and compare the amplitude on the 'scope with the signal passing through the filter with that noted when testing the generator output directly. Any deviation in amplitude of the observed response is noted, and can be plotted against frequency to provide a record of the filter response. A similar process can be followed at RF and IF frequencies if your 'scope has a large-enough bandwidth to accommodate the higher frequencies, however, input and output matching is even more of an issue at these frequencies – to mitigate this, try to undertake the test with the filter in circuit, feeding the input signal into the preceding stage. Also, use a x10 probe on the 'scope to minimize circuit disturbance.

IF Alignment

This is a particular type of filter response measurement. In order to use a 'scope correctly for IF alignment purposes, it must be used in conjunction with a 'wobbulator'. A wobbulator is a special form of signal generator that can be made to sweep its output

frequency repeatedly across the IF bandwidth of the set under test. The sweep is synchronized to the 'scope trace, usually by using the 'scope's time-base ramp signal to control the frequency. The basic set-up for such measurements is shown in the figure above.

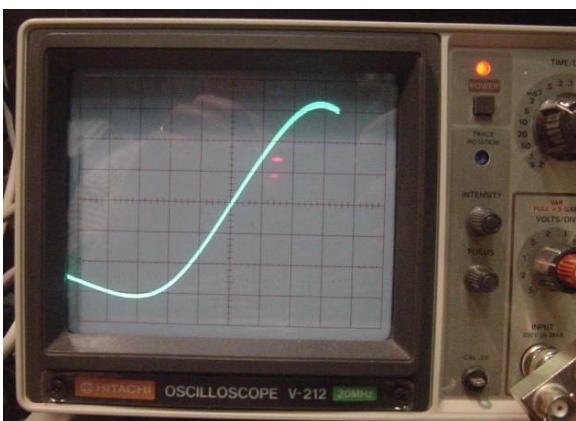
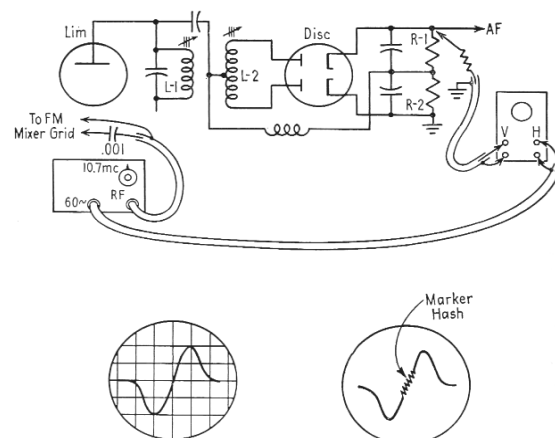




The Technical Short on using a wobbulator for receiver alignment covers this procedure and should be referred to for further information on how to set-up and use a 'scope for this purpose. I tend to use visual alignment methods as a supporting tool to the standard methods described in the Technical Short on receiver alignment – this is especially useful for sets with variable selectivity. A typical receiver IF response curve is shown in the photo, left, here for an Eddystone EC10 receiver.

FM Discriminator Alignment

As for IF alignment, a 'scope must be used in conjunction with a 'wobbulator' for checking the alignment of a Foster-Seeley discriminator. The basic set-up for making such a measurement is shown in the figure, right, and the trace obtained for a properly set-up discriminator is illustrated below (here for an Eddystone S770U). The Technical Short on using a wobbulator for



receiver alignment covers this procedure and should be referred to for further information. The AM rejection of a ratio detector may be checked by applying a square wave-modulated signal to the receiver limiter stage (say at 100mV amplitude) and checking for the square wave signal at the output of the ratio detector – when the detector is adjusted properly, there should be little or no square wave visible.

Automatic Gain Control

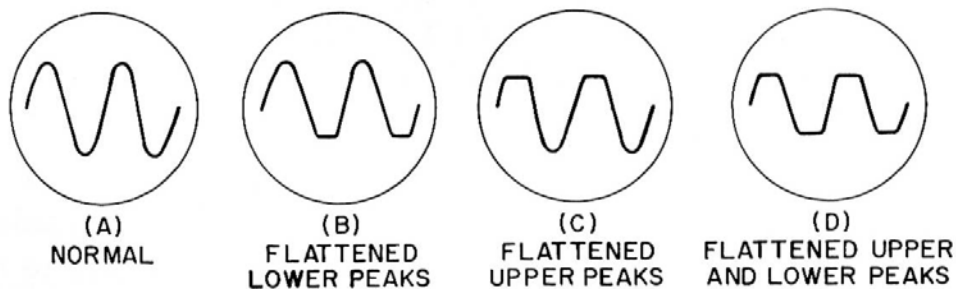
The receiver AGC action can be checked using a 'scope. Apply a fairly low-level (say 10 μ V) AM-modulated RF signal to the aerial connection and tune it in on the receiver under test. Connect the ground probe of the 'scope to the AGC bus (the grid return of an IF stage is an easy point in the circuit to locate for this) and the other (x10 probe) to the 'hot' end of the AF gain control, thus placing the 'scope input across the AGC load resistor (which may actually be formed from several resistors, including the AF gain control). Adjust the 'scope to observe the AF modulation frequency (usually 400Hz).

Increase the output of the signal generator and observe the amplitude of the observed waveform on the 'scope – the trace should increase in the vertical direction to a point and should then remain sensibly constant for further increase in RF signal level, showing good AGC performance. Any distortion of the observed waveform is indicative of a defect in the AGC capacitor(s).

Distortion Assessment

A 'scope can be a very useful tool for investigating distortion issues. The technique is to observe and compare waveforms at the input and output of the stage under examination.

Various forms of distortion can occur in a receiver, eg. harmonic, inter-modulation and crossover distortion in the AF stages, and frequency distortion in either the IF and AF stages. Most often, audible distortion occurs in the AF stages and observing the audio waveform can indicate where the distortion is originating from and its cause. This is very straightforward: with the receiver tuned away from a station (or the local oscillator disabled by shorting the local oscillator section of the tuning gang), inject a low-level audio tone (sine wave) at 400Hz or 1kHz onto the 'hot' end of the AF gain control and adjust the AF gain to a comfortable listening level. Connect the ground 'scope probe to a local ground connection (eg' 'cold' end of the AF gain control). Next, check that the input waveform (from the signal generator) is not distorted by touching the other probe (use a x10 probe) to the slider of the AF gain control, noting the purity of the waveform – adjusting the 'scope controls until a stable waveform showing a couple of cycles of the input tone can be seen on the screen. The waveform should be similar to (A) in the figure below. With the 'scope set to 'AC', work through the audio path (eg. grid of first AF stage, anode of the first AF stage etc), reducing the 'scope gain to accommodate the increasing signal level through the AF stages, observing the waveform. The defective stage has been located when the waveform observed at the output is considerably different to that present at the input. Some examples are given below – the waveforms shown in (B) and (C) would result from a valve where the bias is set too high or too low (trace C), too low an anode or screen voltage is present (trace B), or weak emission. A trace similar to (D), where both negative and positive peaks are clipped, indicates an overloaded amplifier stage (try reducing the input signal level to see if that eliminates this effect), or incorrect grid bias and either the screen or anode voltage is low. In a push-pull output stage, measurement on either of the output valve grids would indicate clipping of half the waveform - of course this is normal, as when the output of the two valves is combined in the output transformer the clipping should disappear. If it does not, or a 'dislocation' of the sine wave occurs at the zero-voltage point on the trace when observing the stage output, this indicates crossover distortion, resulting from a fault in the



phase-splitter stage or incorrect biasing of the output valves. Other forms of distortion can also be observed visually – just check to see if the output waveform bears a close likeness to the input waveform in each stage. Some (small level) distortion is normal – especially in lower-cost receivers, so don't be concerned if this is observed and the set sounds ok. Try checking a known good set to see what can be expected.

If distortion cannot be traced to the AF stages, then an investigation of the preceding stages is warranted. Apply an AM-modulated RF signal to the aerial connection and tune it in on the receiver under test. Connect the 'scope Y input across the AF gain control and adjust the 'scope's controls to observe 2 cycles of the modulated tone. If distortion is observed, and this is known not to be present in the modulated input signal, try injecting the RF signal onto the signal grid of the mixer. If the observed waveform is now not distorted, the defect lies between the aerial and the mixer stage (ie. in the RF amplifier(s)). If the waveform is still distorted, feed a modulated signal at the IF frequency into the signal grid of the first IF amplifier valve (adjusting the 'scope time-base and gain as necessary), if the observed waveform is not distorted, the fault is in the mixer stage (be careful not to overload the stages as this will likely cause distortion). If the waveform remains distorted, repeat for the next IF stage(s) through to the detector anode, until the stage where unacceptable distortion is occurring is identified.

As noted above, frequency distortion can occur in RF, IF or AF stages. The effect is normally to limit higher or lower audio frequencies (or both). First, check the output characteristics of your variable-frequency AF signal generator by observing the output on the 'scope while sweeping the frequency through the AF range - say 50Hz through 10KHz - and observe the amplitude of the signal on the 'scope. Note if the level remains sensibly constant across this range or varies (and by how much). This done, the AF stages can be tested by connecting the 'scope across the speaker and connecting the AF signal generator across the AF gain control. Starting with an AF signal around 1KHz, adjust the 'scope to observe the signal. Then sweep the AF generator through the audio range and compare the amplitude on the 'scope with that noted when testing the generator output. If any deviation in amplitude is noted, some level of frequency distortion is being observed in the AF stages – this could be normal if only minor in the range 150Hz to 5kHz in an AM receiver, however, a sharp roll-off in response could indicate a faulty coupling or by-pass capacitor in the AF stages. A similar test run with a variable-frequency modulated RF signal applied to the aerial of the set could indicate misalignment in the RF or IF stages, or faulty coupling or by-pass capacitors in the RF, IF or detector stages. If this is suspect, refer to the Technical Shorts on receiver alignment, use of a wobulator and fault-finding.



Conclusions

You can certainly 'get-by' without a 'scope in your workshop, however, they can provide some very useful ancillary information and insight into what is happening in a circuit, and for some of the more sophisticated fault-finding and adjustment techniques they are a necessity. For analogue use alone (which is what most Eddystone receiver maintainers, fixers and restorers are interested in), a 'scope can be used as a VTVM for DC and AC voltage measurements, can measure frequency/compare frequencies (especially useful for complex waveforms, low-level signals and where multiple frequencies may be present), measure time intervals between events, look at phase differences, measure frequency response of filters and tuned-circuits, provide a qualitative idea of distortion levels, check the IF response of a receiver, check discriminator characteristics and many other useful things. For the limited outlay needed for a 'scope specification that will suit most folks needs, the decision to buy one seems like a 'no-brainer'. Once you have one, the trick then is to use it and experiment with it – don't fiddle with it for a day or two and then place it on a shelf out of the way to collect dust. There are many good web references, videos on YouTube and books on setting-up and using a 'scope, some listed below, and I encourage you to check them out and apply the knowledge gained.

Gerry O'Hara, VE7GUH/G8GUH, Vancouver, BC, Canada, October, 2009

Some Useful References

- *ABC's of Electronic Test Probes*, Rudolph F. Graf, Sams Photofact Pubs. 2nd Ed. 1966 (very good and informative guide to various simple test probes for 'scope and VTVM use)
- *The Cathode-Ray Tube at Work*, John Rider, 1935 (considering the age of this book it is very useful – it contains one of the best reference sections on using a wobulator I have seen and has some good oscillographs representing various receiver fault conditions)
- *101 Ways to Use Your Oscilloscope*, Robert Middleton, Sams, 1966 (mainly focusing on TV servicing, not as good as the title would have you believe)
- *Profitable Radio Troubleshooting*, William Marcus and Alex Levy, McGraw-Hill, 1956 (excellent all-round fault-finding guide. Chapter 13 covers 'scope uses in radio servicing – some figures in this article are from this book)
- *Elements of Radio Servicing*, William Marcus and Alex Levy, 2nd Ed. 1955, (Chapter 26, provides a useful description of using a 'scope to set up FM receiver IF stages and the discriminator)
- *Latest Instruments for Servicing Radio-Television*, Coyne Electrical, Radio and Television School, 1956 (Chapter 11 covers the use of 'scopes in radio servicing – some good oscillographs representing various receiver fault conditions)
- *Radio and Television Receiver Troubleshooting and Repair*, Alfred Ghirardi and Richard Johnson, 1952
- Some web-based articles/resources on subjects covered in this article include:
 - http://www.wisc-online.com/objects/index_tj.asp?objID=ACE3503
 - <http://oscilloscope-tutorials.com/>

- <http://www.williamson-labs.com/scope-main.htm>
- <http://www.kpsec.freeuk.com/cro.htm>
- <http://www.tone-lizard.com/Oscilloscopes.htm> (idiots guide)
- <http://www.doctrionics.co.uk/scope.htm> (some illustrations from this site are used in this article)
- http://www.radio-electronics.com/info/t_and_m/oscilloscope/using-oscilloscope-scope.php
- And some YouTube videos worth a look:
 - <http://www.youtube.com/watch?v=rC8HBcsNm2g> (a useful video for 'scope beginners)
 - <http://www.youtube.com/watch?v=vFqxn6VGYC0> ('scope basics and set-up)
 - <http://www.youtube.com/watch?v=VWodjUSkYVE&feature=related> (how to measure a voltage without a ground connection)
 - <http://www.youtube.com/watch?v=MmU9kRMDURw&feature=related> (University of Utah video tutorial – heaven help the students. But hey, they have the same model Wavetek function generator as me!)
 - <http://www.youtube.com/watch?v=zQDuZ3a6HAE&feature=related> (basic signal measurements explained)
 - <http://www.youtube.com/watch?v=uOAzRlhrnYE&feature=related> (x10 probe compensation)
 - <http://www.youtube.com/watch?v=B44wHjb8jMY&feature=related> (signal tracing an 'All-American-5' a Baby Champ)
 - http://www.youtube.com/watch?v=q_AFL5K1FQA&feature=related (an hour long tutorial by Professor Kent)
 - <http://www.youtube.com/watch?v=KtbQdHKiWIQ&feature=related> (delightful! – even my cat now understands how a 'scope works...)

