

# THE HANDYMAN'S GUIDE TO OSCILLOSCOPES (Part 2 of 2)

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## *Making some advanced measurements with your Oscilloscope*

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4 pages  
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*In Part 1, oscilloscope operation was covered for making basic voltage, time and frequency measurements. In this part, we'll continue with some more advanced uses of a scope, and in particular, how to use a scope for testing and troubleshooting ham radio QRP transceivers in the homebrewer's workshop.*

### Receiver Filter Bandwidth.

This procedure uses a scope (a DVM can be used with less accuracy) for determining the overall filter bandwidth (or selectivity) of a receiver. It is basically measured by plotting output voltage vs. audio frequency to construct a picture of the filter response.

Connect scope to the receiver audio output (speaker or phone jack); measurement will be based on peak-to-peak voltages ( $V_{pp}$ ) on a scope, or rms voltage ( $V_{rms}$ ) on a DVM.

Using a signal generator, set the frequency for the band of interest on your radio. For example, on a general coverage shortwave receiver, you might set it for 10 MHz (top end of the 31M band), or perhaps to 7.040 MHz on a 40M ham radio receiver/transceiver. Tune the receiver to the signal generator signal. If you don't have a signal generator, you can also tune to a steady carrier or station to produce a heterodyne audio "pitch." Tune in the signal to the pitch that causes the maximum peak-to-peak display. Adjust the scope and volume control to produce a 2V<sub>pp</sub> display (4 divisions). This is the peak response of the overall filtering stages as shown in **Fig. 13**.

Now determine the audio frequency at this peak response by measuring the time period between cycles and convert to frequency. In the example to the right, the period of one cycle is 1.7mS, which is an audio tone of 750Hz (1/.0017sec). A frequency counter on the output can also be used.

Next, tune the receiver such that the sidetone pitch goes UP in frequency and the peak-to-peak signal will decrease in magnitude. Tune to the point where the signal is exactly 1V<sub>pp</sub> on the scope. See **Fig. 12**.

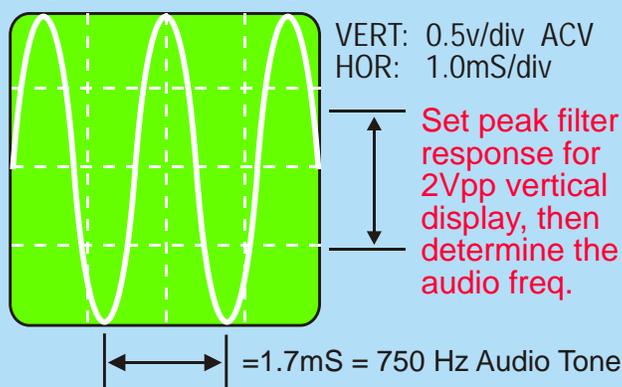
This is the -6dB point of the high end of the filter ( $20\log 1v/2v = -6dB$ ). Determine the frequency of the audio pitch as before. In the example, this is 1100 Hz. Record the data.

From these two data points, the -6dB bandwidth can be estimated. The bandwidth from the filter peak (750 Hz) to the -6dB point (1100 Hz) is 350 Hz. The bandwidth (BW) between the two -6dB points is usually twice this value, or 700 Hz. A filter with a -6dB BW of 700Hz is a mediocre filter for CW reception, and way too narrow for SSB or AM.

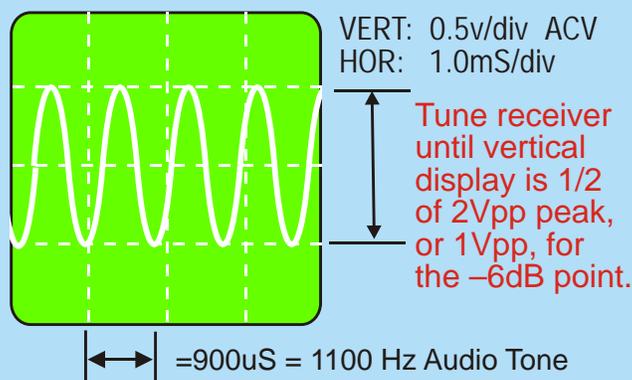
Of course you can determine the exact -6dB BW by tuning the receiver back to the 2V<sub>pp</sub> peak response, and continue tuning DOWNward in frequency until the audio is again exactly 1V<sub>pp</sub>. Determine this frequency and record. In this example, it should occur around 400 Hz if the filter shape is symmetrical.

Plot these three data points on a sheet of graph paper as shown in **Fig. 15** to construct the filter shape. Return to the upper -6dB point (1100Hz in the example) and continue tuning upwards in audio pitch, recording the frequency at 0.5v (-12 dB), 0.25v (-18 dB), 125mV (-24 dB), etc. Everytime you "halve the voltage," it is a 6 dB change. The more points you collect, the more accurate your filter response plot will be.

**Fig. 13 – Displaying Filter Peak Response**



**Fig. 14 – Displaying -6dB Frequency**



Of interest to proper rig alignment is to repeat the above using the output of the product detector. To maximize the effectiveness of the filtering, the receive offset frequency set by the BFO should be adjusted to the same frequency as the peak frequency response of the audio. In this example, with the peak audio response occurring at 750Hz, if your BFO is set for a sidetone frequency of 700 Hz, you are losing 2–3 dB, since this is in your filter skirt. This is shown on the response plot in **Fig. 15** by the dashed lines. By adjusting your BFO for a sidetone frequency of 750 Hz, you will pick up 3-4dB of overall gain in your receiver, plus increase the selectivity a bit as well. Why? Because nearby stations, such as one at 800–900Hz tone, could actually be louder than the 700Hz tone signal you are trying to copy, since the gain of the receiver is greater at those tones than at 700Hz, as shown in the plot.

### Opposite Sideband Rejection

A superhet receiver is supposed to pass just one sideband and reject the other. Poor opposite sideband rejection could indicate the crystals in your IF filter are not well matched or other problems. It is measured almost identical to plotting the filter response just described. First, you tune the receiver to the test signal to find the peak response frequency, or 750Hz in this example. Set the scope display for 2Vpp. Now tune downward in audio pitch, passing zero-beat, and continue tuning and you should hear the test signal, much weaker, now rising again in tone. This is the *opposite sideband*. Measure the peak-to-peak voltage, if you can. For example, say it is 80mVpp, as shown in **Fig. 16**. Calculate the opposite sideband rejection by:

$$\text{rejection} = 20 \log \frac{80\text{mV}}{2.0\text{v}} = \frac{80\text{mV}}{2000\text{mV}} = -28\text{dB}$$

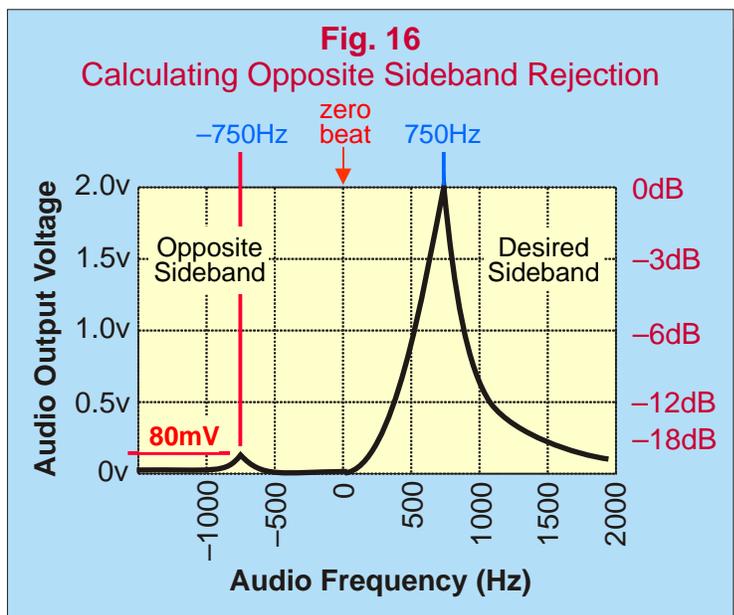
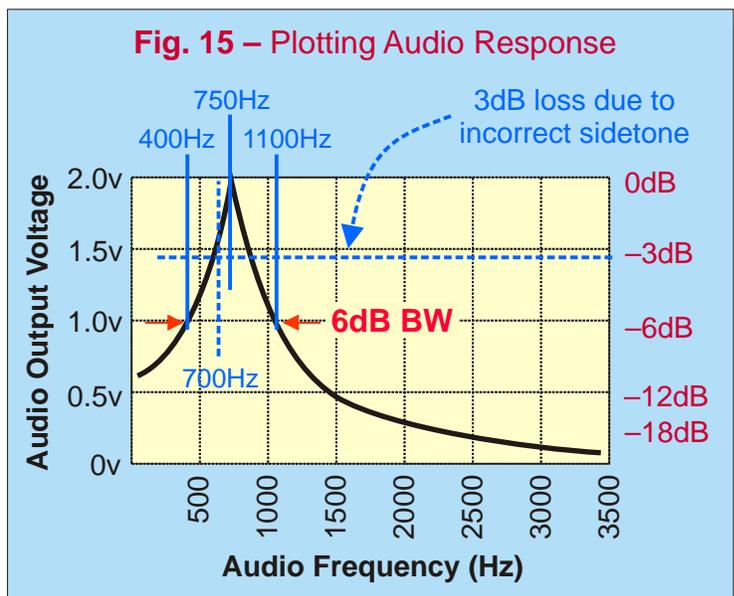
If you can't hear the opposite sideband, then obviously you have excellent filter rejection. If you can just barely hear it, you may have to increase the sensitivity of your scope (set vertical gain to 20 or 50 mV/div). In this example, -28dB rejection of the opposite sideband is quite good. A -30dB rejection means the opposite sideband is only 1/1000th of the desired sideband, a very suitable attenuation of the opposite sideband.

These tests are important to perform on your rig for documenting it's current performance, and repeated periodically to detect unfavorable changes or for troubleshooting when a problem is evident. For homebrewing, these tests can allow you to evaluate different circuits or when experimenting with different components or part values.

### Oscillator Phase Noise

When homebrewing a basic oscillator circuit, such as a VFO, looking at the oscillator output on a scope can reveal several problems. One is to check for excessive phase noise. Phase noise is small variations of the oscillator frequency that causes power in the close-in sidebands, usually measured on laboratory equipment within 100KHz, or even within 10 KHz.

To check for oscillator phase noise, connect the oscilloscope to the oscillator output, loading the output of the oscillator as little possible. Most scopes have sufficiently high input impedances where this shouldn't be a problem, but some cheaper scopes can load an oscillator circuit. If you suspect your scope is loading the oscillator, couple the scope to the circuit with a small value capacitor, less than 20pF.



Display 2–3 cycles of the oscillator output as shown on the scope display shown in **Fig. 17**. Properly focus the scope and carefully observe if the waveform appears in focus at the peaks, but slightly out-of-focus at the zero-crossing points, that is, on the rising and falling edges of the sine wave.

If it appears out-of-focus, this is excessive phase noise jittering the signal and “smearing” the waveform along the time (horizontal) axis. Extreme phase noise may show 2-3 sine waves very close to each other, as shown in the exaggerated waveform to the right — assuming you have your scope properly triggered.

Phase noise is random, instantaneous changes in the oscillator

frequency that smears the display. If you can see this on a scope, the phase noise is excessive! If you can't see it, it doesn't mean the oscillator has no phase noise (all oscillators have some phase noise), it just means it is not excessive enough to see on a scope. A scope is not a good instrument for checking phase noise, but for homebrew circuits, it is a check to ensure you do not have a serious oscillator problem.

Excessive oscillator phase noise in receivers can cause IMD products and noise in the audio range at the output of the mixer(s), including the product detector. In a transmitter, excessive oscillator phase noise will put power in the close-in sidebands of your carrier, not only wasted power for lower transmitter efficiency, but may produce strange sounds (buzzing or chirping) to the receiving station. A few causes of phase noise are excessive current in the oscillator transistor, low-Q coil(s), high dissipation in the tuning caps or poor power supply filtering at the oscillator frequency.

### AM (Amplitude) Noise

Another oscillator problem may be AM noise, or amplitude modulated noise. It is an opposite effect on a scope when displaying the oscillator output — the sine wave appears out-of-focus or thicker at the peaks, and in-focus elsewhere as shown in **Fig. 18**.

If you detect AM noise, slow down the scope's sweep rate to the audio frequencies or slower to see if you can notice a lower frequency component. A common cause of AM oscillator noise is 60 Hz from the power mains leaking into the circuits. This is particularly true if using a power supply off of 120v 60 Hz, or sometimes it can be due to the AC lighting above your head! If the AM noise seems to be at the same frequency as the audio output tone, it means audio is getting into the Vcc bus, likely due to poor bypass filtering at the audio amplifier stages (particular if using an LM386 or similar).

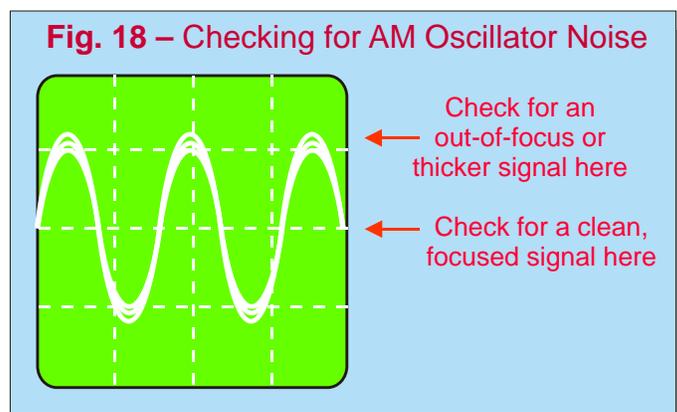
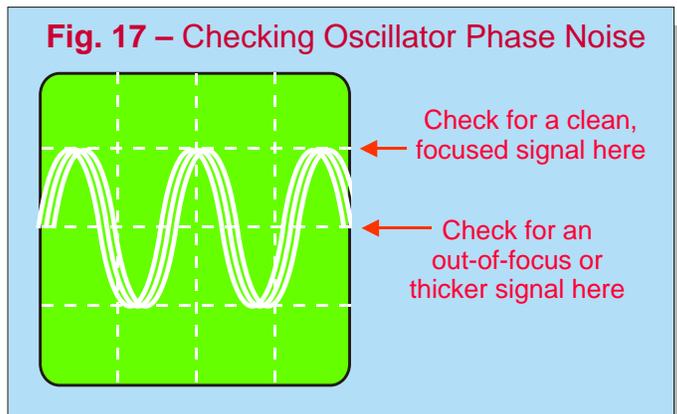
If you can't find a low frequency component, the AM noise may be random, which may indicate poor voltage regulation, a noisy voltage regulator, or perhaps a circuit in VHF oscillation. If the

AM noise seems to occur on key-down only on a transmitter, the transmit current may be loading the power supply, the voltage regulator is under-rated, or just simply loading the oscillator. In the case of loading the power supply or regulator(s), perhaps a separate voltage regulator or zener circuit should be used, dedicated for the oscillator(s). In the case of transmit loading, adding a buffer amplifier or emitter follower to isolate the load from the oscillator may help.

Much of this can be diagnosed also with the scope, by looking at the AC ripple on the DC power lines. You should have less than 50mV of any AC component on the 8-12v DC wiring, whether 60Hz, audio or RF. If >50mV, then additional low or high frequency filtering on the DC power is needed.

### Monitoring Transmitter RF Output

RF Power (in watts) is  $E^2/R$ , where E is in rms and  $R=50W$ . The voltage displayed on the scope (peak-to-peak) must be converted to rms by  $E_{rms}=.707(E_{pp}/2)$ . To measure properly, the transmitter should be on a 50W dummy load using the normal hi-Z scope input. If your scope has a selectable “50W” input, it can be the transmitter dummy load directly, providing it can tolerate the 50Vpp input. (Always know what the maximum p-p input voltage your oscope will tolerate. It is often stated on your scope at the vertical channel inputs. 50Vpp to 100Vpp are typical).



## Measuring Transmitter RF Output Power

**Figure 19** shows how you can use an oscilloscope to fairly accurately measure output power from a low power transmitter (generally 10W or less with a 1X probe and 20-30W with a 10X probe). Connect transmitter output to a 50W dummy load. Connect the scope lead to the transmitter output (after the low pass filters) or directly to the dummy load. Do not connect the scope leads to the collector or drain of the final PA transistor. The displayed voltage in this case will be erroneous.

In the example, the output transmit voltage across the dummy load measures 24Vpp. Convert this voltage to Vrms, then use the equation (Vrms squared divided by the load resistance) to calculate the power in watts. In the example, 24Vpp, the output power is 1.4 watts. A 5W QRP transmitter should produce about 45Vpp.

The accuracy of your power measurements depend upon the condition of your oscilloscope:

- 1) Ensure your scope's vertical sensitivity (volts/division) is properly calibrated (see Part I)
- 2) Ensure your vertical sensitivity is properly calibrated with the 1X or 10X probe you are using.
- 3) Ensure that the transmitter frequency is well within the bandwidth of your scope. A 100 MHz scope should give reliable readings on all HF bands. A 50 MHz scope should be reliable on all HF bands except slight errors at 28MHz.

## Checking Transmitter Purity

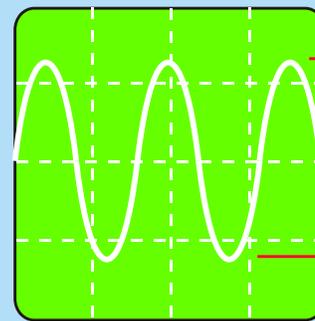
**Phase Noise** of the transmitter is measured identically to the phase noise checks on page 2–3. With the scope properly triggered and focused, you are looking for an out-of-focus “fuzziness” around zero crossing. If it appears phase noise exists, the fault is generally at the beginning of the transmit chain. That is, seldom does the PA transistor add phase noise; it's merely amplifying what it is given. Phase noise on the transmitter output is more likely due to the transmit oscillator, or the transmit mixer if used.

**Harmonic Power** can also be detected on a scope while looking at the transmitter RF output power. In **Fig. 20**, notice the “dips” or the two “peaks” on the top and bottom of each sine wave. This is caused by excessive 2nd harmonic output power. The rule-of-thumb is – if you can see any 2nd harmonic power (a dip or flattening at the peaks), then you are right at or exceeding the –30dBc FCC harmonic specification. A clean sine wave implies FCC compliance, providing the 2nd harmonic is within your scope's bandwidth. Obviously, a spectrum analyzer should be used for accurate harmonic evaluation, but a scope can be used to indicate if you have a problem. If you build your own transmitter, it is your responsibility to ensure it is compliant. An approximate method of estimating 2nd harmonic attenuation is shown.

–30dBc means the 2nd harmonic power is 1/1000th of the fundamental power. For a 5W transmitter, this means the 2nd harmonic power should be 5mW or less, or about 1Vpp. In displaying a 5W signal on a scope (45Vpp), it would be difficult to resolve much less than a 1Vpp dip or ripple.

**Conclusion.** This concludes the NA5N “Handiman’s Guide to Oscilloscopes.” Hopefully, it has helped you to understand your oscilloscope to make simple measurements, and with some practice, perform the more advanced measurements discussed. An oscilloscope is a very powerful tool that is invaluable on the homebrewer’s workbench. If there is a particular measurement you feel I omitted, please let me know and I will add it when time permits.

**Fig. 19 –Oscilloscope as a Power Meter**

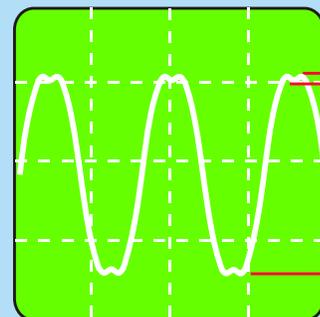


24Vpp  
across  
50W load

1. Measure output voltage. 24Vpp
2. Convert Vpp to Vrms 8.5Vrms
3. Calculate power in watts

$$\frac{V_{rms}^2}{R} = \frac{8.5v^2}{50W} = 1.4W$$

**Fig. 20 –Checking 2nd Harmonic Power**



1Vpp

24Vpp

1. Measure output voltage. 24Vpp
2. Measure ripple voltage. 1Vpp
3. Calculate dBc of 2nd harmonic ripple

$$20\log \frac{V_2}{V_1} = 20\log \frac{1v}{24v} = -27.6 \text{ dBc}$$

or, not quite FCC compliant!