BASIC DESCRIPTION, CALIBRATION AND CONTROLS

NOTE: This is a text version of an article appearing in the Summer 1997 issue of "QRPp." The article contains numerous illustrations and photos of oscilloscopes displays, which unfortunately can not be included in a text file.

GENERAL O-SCOPE DESCRIPTION.
THE VERTICAL INPUT is applied to the vertical input amplifier, which is quite sensitive, designed for a 25-50mV input. For larger inputs, the signal is routed through attenuators comprised of simple voltage dividers. These attenuator dividers is what forms the VERTICAL SENSITIVITY, calibrated in mV/division or V/div. An INPUT COUPLING switch selects DC or AC coupling, and sometimes a GROUND position. The output of the vertical input amplifiers is a differential signal, amplified up to high voltages and applied to the CRT (cathode ray tube) vertical plates for deflecting the beam in the vertical axis.

THE HORIZONTAL AMPLIFIERS are driven by an internal sweep generator, amplified to a high voltage and applied to the CRT horizontal plates for deflecting the beam in the horizontal axis ... that is, the sweep that moves the beam from left-to-right.

Thus, for a proper oscope display, such as displaying a sinewave, it is a combination of moving the trace from left to right to show TIME, and up-and-down to show MAGNITUDE.

THE SWEEP GENERATOR is a constant current source charging a capacitor to make a linear sawtooth waveform. The value of the capacitor will determine the time is takes to eventually move the beam across the screen, and is selected by the HORIZONTAL SWEEP control, calibrated in seconds, mS, uS (or nS) per division. The faster the beam moves across the screen, the higher the frequency that can be displayed. An important task of a scope is to display a stable waveform, which is done by starting the sawtooth sweep at exactly the same time in respect to the input signal. A switch labelled TRIGGER SOURCE determines what initiates the sweep. In the INTERNAL position, a sample of the input signal from the vertical amplifiers is used, and when it reaches a certain level, WOOSH, the sweep occurs. In the AUTO mode, the sweep is free running and not necessarily synchronized with the input signal. In LINE position, the sweep is triggered off of 60-Hz from the power supply (useful for synchronizing to TV/VCR signals), and EXTERNAL the sweep is triggered from an external input applied to a BNC (on the front or the back of the scope).

OTHER FEATURES your scope may have are:
* Two vertical input channels for dual-trace operation
* Two separate time bases for delayed sweep operation
* Various modes to display the input signals (alternate, chopped, A+B added, invert B, A intensified by B, etc.)
* Built in calibrators

CALIBRATING YOUR SCOPE.
Likely, you obtained your scope from a hamfest, the company junk bin, etc. The first thing you should do upon acquiring a scope is to check its calibration.

THE VERTICAL AMPLIFIERS can be checked with a known voltage source, such as a 9v battery. Measure the battery output with an accurate voltmeter. Let's say it's exactly 9v. Set the input coupling to the GND position (0v) and move the trace to the bottom division. Switch the input coupling to DC and set the attenuators to 2v or 5v/div. To give a nearly full scale deflection. For example, if your scope has four vertical divisions, setting the attenuators to 2v/div. would be 8V full scale deflection, and at 5v/div., full-scale would be 20V. With the 9v battery applied, the DC deflection should be 1.8 divisions at 5v/div. Switching to 10v/div., the deflection should be just a bit less than one division. Internal to the scope (or perhaps accessible from the outside) are adjustments for the VERTICAL AMPLIFIER GAIN. Adjust this pot for the proper deflection described above. The procedure can be repeated with a 1.5v battery for the lower sensitivity ranges (which you'll be using more of the time anyway).

Also note that when you adjust the Vertical Amplifier Gain adjustment, the 0v (ground) reference on the bottom division may also shift. So after each adjustment, reposition the trace on the bottom division for 0V input, then recheck the trace position for the 9V or other test voltage you are using to calibrate against. It takes a few times going back and forth to get it right.

The horizontal amplifiers should be checked/calibrated using a signal generator. For example, a 1 MHz signal has a period of 1uS per cycle. Setting the SWEEP RATE to 1.0uS/div., a 1 MHz signal should take EXACTLY one division per cycle. Ensure the horizontal WIDTH control is set so the beam starts at the first division and ends on the last one, and the HOR SWEEP VERNIER (fine adjustment) is in the OFF or CAL position. If the sweep rate appears incorrect, an internal SWEEP GAIN Adjustment can be set for proper display of the test signal. This should be repeated at different frequencies, and some scopes will have a separate adjustment for each time base setting. Once the Sweep Gain has been set as above for 1MHz = 1 cycle per division, go to the next faster sweep speed, which should usually be 0.5uS/div. In this case, the 1MHz sinewave should take TWO divisions to display a complete cycle, as shown in the quasi-illustration to the right. Trigger the scope for a stable display so that the zero crossings or the peaks are on the vertical graticle lines. The illustration shows the positive going "zero-crossings" occurring on the vertical at graticles labelled "1" - "3" - "5". For proper zero-crossings, the waveform should be centred between two divisions, also as shown in the illustration.

```
1      2      3      4      5
|--**--|------|--**--|------|
| *  * |      | *  * |      |
|*    *|      |*    *|      |
*----- * -----*------*------*
|      |*    *|      |*    *|
|      | *  * |      | *  * |
|------|--**--|------|--**--|
|             |
|<---1.0uS--->| 1MHz sinewave
 at 0.5uS/div.
```

If you can't find the adjustment to tweak the horizontal gain, you can shrink or stretch out the test signal to the desired divisions using the HORIZONTAL WIDTH control, usually a front panel control. Then you can mark on the front panel where the HOR WIDTH control must be at each SWEEP setting for proper calibration.

Without checking and calibrating the accuracy of your time base sweep, time and frequency measurements performed on your scope may contain significant errors.

If you don't have a signal generator, you might use the audio from a receiver tuned to WWV. The various tones transmitted throughout the minute and hour are listed in various references. And of course, there's always 60-cycles floating around the ham shack somewhere!

MAIN OPERATOR CONTROLS.

INTENSITY - controls the brightness of the beam. Adjust for a clear trace, but not too bright. A very bright trace can cause permanent damage to the CRT, particularly on a well-used scope.

FOCUS - adjusts the beam for the thinnest and sharpest display.

VERT & HOR POSITION controls the vertical and horizontal position of the trace.

VERT VOLTS/DIV - controls the vertical sensitivity of the display, i.e., how may volts or mV per division.

VERT VERNIER - adjust the vertical sensitivity in fine steps. Should be off (or CAL position) for calibrated measurements.

TIME BASE/HOR SWEEP SPEED - sets the horizontal sensitivity, i.e., how many second, mS or uS per division.

HOR VERNIER - adjusts the horizontal sensitivity, or sweep speed, in fine steps. Should be in **OFF** or **CAL** for calibrated measurements.

OTHER ADJUSTMENTS YOU MAY FIND:

ASTIGMATISM - With the scope INTENSITY and FOCUS properly set, this adjustment compensates for the curvature of the CRT tube by making it in-focus across the entire sweep. If your trace is out-of-focus in certain areas, but in-focus elsewhere, the ASTIGMATISM needs to be adjusted.

TRACE ROTATION - is a small coil around the CRT that skews the trace to ensure it is perfectly horizontal. Set the scope to GND, free-run the sweep and adjust the vertical position so the beam is along a graticle (division) line. Adjust the TRACE ROTATION until the beam is perfectly parallel to the horizontal graticles. On scopes without this adjustment, loosening the CRT mounting brackets and physically rotating the CRT tube for a level trace, then re-tightening the CRT brackets perform levelling the trace.

!!! WARNING!!! HIGH VOLTAGE ARE PRESENT AROUND THE CRT TUBE. USE EXTREME CAUTION WHEN PERFORMING THE ABOVE PROCEDURE.

DC BALANCE - is a DC offset in the vertical amplifiers that causes a shift in the trace baseline when changing vertical scales. It is most obvious when displaying AC signals. For example, you are displaying a 10Vpp sine wave, centered on the center graticle at 2v/div. Changing to 5v/div, the sine wave shifts away from the center graticle, up or down ... that is, it assumes a DC bias error in the vertical amplifiers. The DC BAL is adjusted until no shift occurs when changing vertical scales. Admittedly, setting the scope for perfect dc balance on all scales is an exercise in patience! DC BAL is often an internal adjustment, or on the rear panel. On dual trace scopes, there will be one for each channel.

HV ADJUST - is the high voltage that controls the intensity of the trace. Turn up the INTENSITY control to its brightest position, then adjust the HV ADJ for a trace slightly brighter than normal intensity. Return the INTENSITY for normal brightness. The INTENSITY control now has the proper range. On some scopes, it takes a little piddling around to properly set the HV ADJ, intensity and focus for proper operation. The HV ADJ is often an internal adjustment.

!!! If you adjust the HV ADJUST, you may also have to recalibrate the VERTICAL and HORIZONTAL GAINS as described above for proper calibration (V/division and time/division accuracy).

An oscilloscope is an amazing instrument for making voltage, time and frequency measurements ... however, all of these measurements are worthless unless you ensure the vertical and horizontal stages of your scope are reasonably calibrated. The time to calibrate your scope will be worth the ease and reliability of subsequent measurements you will make.

LET'S MAKE SOME MEASUREMENTS - DC voltages, AC voltages, time period and frequency.

NOTE ON LIMITED BANDWIDTH SCOPES.
Today's scopes have 500MHz bandwidths or higher. Likely your scope is much less than that. A limited bandwidth scope is still very useful to the QRPer. Say the bandwidth of your scope is 5MHz. This does not mean you can't see a 7MHz (40M) signal ... it just means that the calibration of the scope is no longer valid. The peak-to-peak value of the display is not correct and much smaller than it really is, and the sweep rate may be in error. But still, you may likely be able to resolve individual cycles higher than the cited bandwidth to a certain degree, and make the gain and phase measurements that follow (since they are based on RATIOS).

Most of the examples in this article explore many regions of a QRP rig without the benefit of any great bandwidth. Experiment with your scope to learn its limitations.

!!! IF POSSIBLE, SPEND THE MONEY TO GET A GOOD SCOPE PROBE AND MAKE MEASUREMENTS WITH A GOOD GROUND CONNECTION TO GET THE MOST OUT OF THE BANDWIDTH YOU HAVE.

BASIC MEASUREMENTS.
It is assumed you have your scope relatively calibrated as described above, and familiar with the front panel controls. For the sake of the following discussions (since illustrations can not be included), it is assumed the scope has 4 vertical and 4 horizontal divisions.

DC VOLTAGES.
Say you want to check the T-R switch (Transmit-Receive) in your QRP rig. Usually this will be a transistor (or inverter gate, such as in the 38-Special). The key line goes to the base, which is pulled HI to some positive voltage (on key UP), and goes LO to ground when the key is DOWN (or closed).

Set up your scope for DC voltage at 2v/div. and a slow sweep speed (say 100mS/div). Set the trace so the bottom graticle (division line) is 0v. Place the scope lead on the T-R switch transistor base. Say the trace deflects two divisions. This would be 4vdc bias on the base. Now close the morse code key. The trace should drop to 0v.

The purpose of the T-R switch is to generate a POSITIVE voltage on key down, which is taken from either the collector or the emitter (depending upon the circuit configuration). Say it comes off the emitter. Move the scope probe to the emitter. Now you should have about 0v with the key UP, and with the key DOWN, the voltage should jump to some positive voltage, often +12v. In this case, the trace will go off the top of the screen. Change the scope to 5v/div. Re-verify that 0v is the bottom graticle. On key DOWN the trace jumps up 2 divisions. The key DOWN voltage is thus +10v. If the emitter is "stuck" at +10v on both key up and down, the transistor is not switching. If the base signal above is correct, then likely the transistor is bad.

While this test could be done with a DVM, the integration time is slow requiring long key downs to get the proper voltage. A scope will also show you how clean the switching is, or if there is an AC voltage (or RF noise) riding on the T-R voltage.

Scopes are thus good DC voltmeters, with about a 5% reading accuracy.

AC VOLTAGES.
Here is where a scope pays for itself by making AC voltage (and frequency) measurements. You must remember that AC voltage displayed on a scope is PEAK-TO-PEAK VOLTAGE, while a voltmeter or DVM measures AC voltage in RMS (root mean square). RMS voltages read on a DVM will be ABOUT 1/3rd the peak-to-peak voltage (Vpp) shown on a scope.
Or specifically,

$V_{rms} = .707 \times V_{peak} = 0.5(.707 \times V_{pp}) = .35 \times V_{pp}$

```
|--**--|------|--**--|------|
| *  * |      | *  * |      |
|*    *|      |*    *|      |
*----- * -----*------*------*
|      |*    *|      |*    *|
|      | *  * |      | *  * |
|------|--**--|------|--**--|
VERT: 2V/DIVISION
```

If the signal on your scope looks like that in the quasi- illustration, at 2V/division, then the signal would be 4V peak-to-peak (4Vpp), or 1.4Vrms if read on a DVM or voltmeter.

For example, let's measure the output voltage and frequency of the sidetone oscillator in your QRP rig. Set up the scope for 1v/div, AC volts, and a sweep speed of 1mS/div. Connect the scope probe to the audio output of your rig and set the volume control on key DOWN so the audio sinewave is 2 division peak-to-peak. This would then be 2Vpp AC, and should look similar to the illustration above.

AC FREQUENCY MEASUREMENT.
With this same waveform, we might as well see what frequency our sidetone or transmit-offset is at. Most operators prefer the side-tone to be about 700Hz. With the same setup as above, trigger the scope for a stable waveform and the time base sweep to display 2 or 3 cycles. Center the waveform on the center horizontal graticle so the sinewave goes one division above, and one division below the center graticle. Now move the HOR POSition so the first "zero crossing" of the sine wave is on the first or second vertical graticle. With this setup, zero-crossing would be where the sine wave crosses the center horizontal graticle. Now measure the time it takes to make one complete sine wave, from one zero-crossing (sine wave going positive) to the next positive going zero crossing. Say one complete sine wave takes one and half horizontal divisions. At 1.0mS/div., this would be 1.5mS per cycle.

Frequency is the reciprocal of time, such that the sidetone frequency is: f = 1/t = 1/1.5mS = 667 Hz.

(Sidetone frequency is the tone heard on key DOWN). This may be a little low to your liking. To raise it to 700Hz, calculate the period of 700Hz, which is t = 1/f = 1/700 = 1.4mS. At 1.0mS/div, you can adjust your XMIT OFFSET on key down until zero-crossings (or the positive peaks) are 1.4 divisions apart. This will be 700 Hz. (The XMIT OFFSET is not adjustable in all rigs ... such as the 38-Special. In this case, it usually requires changing the value of a capacitor on the XMIT MIXER and usually discussed in the instruction manual). QUALITY OF THE WAVEFORM is another feature of a scope that is unsurpassed, since your are "seeing" the waveform in real time. For example, say the audio output from your QRP rig is not a clean sine wave, that is, it has a slant to it, or the rise time takes longer than the fall time. This could be due to improper time constant on the audio amplifier coupling capacitors or improperly biased amplifiers. Or, say the audio output sine wave is flattened at the top, looking sorta like a square wave then a sine wave. This would be a raspy sounding sidetone, and due to the audio power amplifier being overdriven and in gain compression (clipping). You should be able to see this effect by turning the volume control to its maximum level, overloading the output audio amplifier (unless your QRP rig has anaemic audio like some).

The o-scope is an invaluable tool for detecting and diagnosing such distortions and impurities in the signal quality. The audio output of a QRP rig, whether the sidetone or an on-the-air signal, should be a fairly pure sine wave. If not, something is wrong, from a poor product detector action, poor filtering after the product detector, poor coupling capacitors, or severe noise being introduced into the audio at some point.

By tuning in an on-the-air signal and plotting the Vpp at different audio frequencies, you can plot the filter response of your QRP rig. This will be discussed in detail in a later section. You can also adjust your BFO on the product detector for the maximum Vpp of the received signal for centering the signal in the filter passband. Note how these important tests and adjustments (sidetone, filter response and setting the BFO) are a few of the things that can be done on a scope with a very limited bandwidth ... since you're not looking at anything beyond the audio range.

Once you get comfortable making the above voltage, time and frequency measurements, you might want to go through your QRP kit with the schematic and record the various DC and AC voltages and waveforms at pertinent locations in the circuit. This will be a great aid in the future should your rig develop a problem. NOTE however, that signal levels from the receive mixer through the IF crystal filters are VERY weak and can not not be seen on even an excellent scope. The main exception to this would be the local oscillator (LO) drive on pins 6 and 7 on a NE602. They are usually in the order of 100mVpp.

!!! NOTE: You can't hurt anything by probing around the circuit of your QRP rig. The biggest mistake made by beginners is to let the ground lead come loose and drag along the tops of components, which can short out the power supply or damage a component. …
OR when putting the scope probe on an IC pin, to slip and let the probe touch two pins at once. This will short out the two pins, which in some cases, could cause damage to the IC. For example, on a NE602, measuring the Vcc voltage on pin 8. A slip to Pin 7 (the OSC input) could destroy the internal oscillator if the pin 8 to 7 short persisted a second or two.

LET'S MAKE SOME MEASUREMENTS. - Amplifier gain and insertion loss.

AMPLIFIER GAIN

The gain of an amplifier can be measured in terms of VOLTAGE GAIN, which is simply Av = Vout/Vin. For example, if the input to an amplifier is 1Vpp, and the output is 4Vpp, then the amplifier has a VOLTAGE gain of 4.

GAIN IN DB is often more useful and is how the gains of amplifiers are usually expressed. With dB (decibels), every time you DOUBLE the AC voltage, you ADD 6dB of gain. It is the RATIO of output to the input, and this RATIO is easy to measure on a scope, even for signals that exceed the cited bandwidth of your scope to some extent.

Say you just built a single transistor amplifier to boost the audio signal before the final audio amplifier (usually an LM386). It is often easier to start with the OUTPUT for measuring amplifier gain. Inject an audio signal into the amplifier (transistor base). Place the scope lead on the transistor COLLECTOR, and set the scope so the output waveform is exactly 4 divisions peak-to-peak. Do not disturb oscope settings.

Now move the scope leads to the amplifier INPUT, the transistor's base. You will of course have a much smaller signal, and the ratio of the input to the output will be the gain in dB. For example, say the input signal is 2 divisions peak-to-peak. This would be 6dB of gain, since you are DOUBLING the signal in the amplifier. Every time you DOUBLE the voltage, it is 6dB of VOLTAGE gain. If the input signal is 1 division peak-to-peak, then the amplifier gain is 12dB. (With the output still at 4Vpp or 4 divisions). Going from 1 division to 2 division is 6dB gain; going from 2 divisions to 4 divisions is 6dB gain. Therefore going from 1 division to 4 divisions is 12dB (6dB + 6dB).

This illustration shows how 0dB to measure Amplifier GAIN on an oscope. FIRST, adjust the scope so the amplifier 3dB OUTPUT is 4 DIVISIONS peak-to-peak. THEN, switch to the INPUT, and position the 6dB waveform so the NEGATIVE peaks are on the bottom division, as shown. Where 12dB the POSITIVE peaks of the 18dB input occur will be the GAIN in dB by reading the scale on the left. You may want Amplifier INPUT displayed to make such a scale and attach it to the side of your CRT screen for making quick measurements in dB's.

```
0dB---|------|------|------|------|
      |      |      |      |      |
      |      |      |      |      |
3dB---|----- | -----|------|------|
      |      |      |      |      |
      |      |      |      |      |
6dB---|--**--|------|--**--|------|
      | *  * |      | *  * |      |
      |*    *|      |*    *|      |
12dB--*----- * -----*------*------*
18dB__|      |*    *|      |*    *|
      |      | *  * |      | *  * |
   ---|------|--**--|------|--**--|
        Amplifier INPUT displayed
```

IF YOU WANT TO DO IT MATHEMATICALLY ...
Vout = 4Vpp
Vin = 1Vpp
Therefore, voltage gain Av = Vout/Vin = 4v/1v = 4
and gain in dB is:
dB = 20log(Av) = 20log(4) = 20(0.602) = 12dB.

OR AS SHOWN DIRECTLY ON THE O-SCOPE AS DESCRIBED ABOVE. Since this is a relative measurement (a RATIO), the absolute value of Vin or Vout does not need to be determined.

INSERTION LOSS.
In some circuits, such as filters or attenuators, the LOSS in dB needs to be determined, and this is called the INSERTION LOSS. It is determined the same way as amplifier gain, except the INPUT will be GREATER than the OUTPUT since there is a LOSS involved.

For example, with a signal generator connected to your QRP rig antenna input, you want to measure the insertion loss of your IF crystal filter. At the filter input, you can just barely squeak out 2 divisions of input signal on your scope at its most sensitive setting. (Perhaps due to exceeding the scope's bandwidth). The output from the crystal filter is 1 division, or a 50% reduction. The insertion loss would be 6dB (since if the power were HALF, or 50%, it would be a 6dB LOSS).

OR MATHEMATICALLY USING SCOPE DIVISIONS:

Insertion loss (dB) = 20log(Vin/Vout) = 20log(2 div./1 div.)
= 20log(2) = 20(.30) = 6 dB

If the output were 1.5 divisions,
Insertion loss (dB) = 20log(2 div/1.5 div) = 2.5 dB

Again, you are determining the insertion loss of a circuit element from the RATIO of input to output. You do not need to make absolute measurements. So if the frequency is beyond the bandwidth of your scope, as long as you can get enough vertical deflection to measure it's magnitude in some terms of divisions, and able to see the signal either get smaller or larger, you can estimate the gain or loss in dB fairly accurately. If the signal DOUBLES, it is 6dB; if it is about half of doubling, it is about 3dB; if the change is barely noticeable, it is around 1dB. This is usually sufficient for determining if circuit elements are working properly. For example, using the insertion loss of an IF crystal filter as above, if you determine the loss to be a few dB, the crystal filter loss is acceptable. If it is much more than around 6dB, you may have a problem. And if you can't see any output, you have a real problem. (Loss is about 1 to 1.5 dB per crystal in filter). Same with checking the gain of amplifiers. It's not important if the gain is 6.2 dB or 6.5 dB, but whether the gain is ABOUT what you'd expect. If the output of an amplifier is ABOUT DOUBLE the input, you have 6dB of gain. If the output is just a bit larger than the input (or the same) ... then you've got a problem (no or little gain occurring).

With a little practice on your o-scope, you will learn to recognize approximate gains and losses in dB's very quickly from the oscope display.

You might want to go through your QRP kit with the circuit and measure the gains through different stages. If your rig has an MC1350 IF amplifier, what is it's gain with a strong signal vs. a small signal to see if the AGC is working properly. What is the gain of the LM386 audio output amplifier? With larger bandwidth scopes, check the gains of the RF driver transistor and output PA transistor. Knowing what these gains are could help troubleshoot the circuit later should a problem develop.

MEASURING PHASE SHIFTS - Phase relationships between two signals at the same frequency can be measured with 2-5 degree accuracy with a scope, although more suited for a dual-trace scope. The REFERENCE signal is applied to CH. 1 and the signal to be phase measured to CH. 2. For proper phase measurements, ensure your dual trace display is in the CHOPPED mode, not ALTERNATE mode. (Alternate mode can effect the triggering position for the second, or CH.2 sweep).

There are many methods to do this. One is to stretch out the signal so it takes 4 full divisions, so each division is 90 degrees of phase. By measuring from a common point on one signal to the other (zero crossings or from the peaks), the phase can be measured.

```
       :          :     +117 degree
   --->:          :<--- Phase Shift
       :          :     based on PEAKS
       **-----|------|------|-----**
       |  *   |  :   |      |   *  |
       |    * |  :   |      | *    |
 CH.1- |------*------|------*------|
       |      | *:   |    * |      |
       |      |  :*  |  *   |      |
       |------|-@@@-***-----|------|
       |     @|  : @ |      |      |
       |   @  |     @       |      |
 CH.2- |-@----|------|-@----|------|
       @      |      |   @  |      |
       |      |      |     @|     @|
       |------|------|------|-@@@--|
        DUAL-TRACE PHASE MEASUREMENT
```

For example, say you are making a phased array antenna system, in which one feedline must cause a 90 deg. delay. You calculate the electrical length for a quarter wavelength [L=(246/f) x velocity factor] and cut the coax to that length. You are now working on blind faith that you have exactly 90 degrees. With a scope, you can measure it fairly accurately by injecting a signal into one end with a signal generator (at the frequency of interest) and a 50-ohm load on the other. Connect the scope CH.1 to the coax input (signal generator end) and CH.2 to the load end and measure the phase. Trigger the scope and move the horizontal position and/or the time base vernier so the positive peak of the CH.1 sinewave is on the first vertical graticle line and the second positive peak is on the fourth vertical graticle, as shown in the illustration to the right. Now measure the phase by noting where the first positive peak on CH.2 occurs. Say it occurs about 1.3 divisions to the RIGHT of the CH.1 positive peak. Since one division is 90 degrees, using this method, then 1.3 div. x 90 deg. = 117 deg. YOUR DELAY LINE IS TOO LONG!

Cut off an inch or two at a time until the CH.2 peak is one division from the CH.1 peak (or on the 2nd vertical DUAL-TRACE PHASE MEASUREMENT graticle as shown in the illustration) for precise tuning of the delay line.

```
 0     90 degrees
 :     :
 :     :
 |---**|-----|-----**----|
 |  *  *     |    *|  *  |
 | *   |*    |   * |   * |
 |Z----|-Z---|--Z--|---Z-|
 *     |  *  | *   |    *|
 |     |   * |*    |     *
 |-----|----**-----|-----|
  Z=Zero-crossing points
```

Another method is to make the CH.1 signal to be two divisions high, and center it between the two divisions, such that the zero-crossing points are on the middle graticle line. Where the CH.1 sinewave signal crosses zero going positive is the 0 deg. REFERENCE; the positive peak is 90 deg.; the negative going zero crossing is 180 degrees, etc. For CH.2 to be 0 90 degrees 90 degrees delayed from CH.1, the CH.2 sinewave should cross zero, going positive, right under the 90 degree peak of the CH.1 signal. If the CH.2 zero crossing is farther to the right from the CH.1

positive peak, the phase shift is MORE than 90 degrees. Back to the example of the coaxial delay line, you would cut an inch or two at a time until Z=Zero-crossing points the CH.2 zero crossing is directly underneath the CH.1 positive peak (the 90 degree point).

And still yet another method of comparing the phase between two signals on a dual-trace scope is to accurately measure the period it takes for one complete sine wave on the CH.1 reference channel.

Say it is 140nS (that would be 7.14 MHz, by the way). Now say the CH.2 signal is 50nS delayed from the CH.1 signal. The phase shift would be:

Phase = 50ns/140ns x 360 degrees = 129 degrees

POSITIVE OR NEGATIVE PHASE SHIFT?
One thing you must remember is how to "read" phase shifts on an oscope. When comparing two signals as described above, remember that if the CH.2 signal peak is to the RIGHT of the CH.1 peak, then the CH.2 signal is OCCURING LATER IN TIME than the CH.1 signal, because time is travelling from left to right. If the CH.2 peak is say 90 degrees to the LEFT of the CH.1 peak, then the CH.2 signal occurred in time BEFORE the CH.1 signal. This would then be a –90 degree phase shift, or 270 degrees. Think about this carefully before you start cutting the coax on that delay line!

PHASE MEASUREMENTS ON A SINGLE TRACE SCOPE
Phase measurements can be made on a single trace scope as well. First, connect the REFERENCE signal, using a BNC "T", to both the VERTICAL INPUT to the scope and the EXTERNAL TRIGGER and select EXTERNAL as the trigger SOURCE. Adjust the TRIGGER LEVEL so the zero-crossing occurs at the beginning of the trace on the first vertical graticle. Now remove the reference signal from the scope's vertical input (but NOT the external trigger input) and connect the signal to be phase measured to the vertical input ... WITHOUT altering the time base or trigger level. The sinewave of the signal to be tested should be on the CRT, with the trace being triggered from the external trigger input, or the reference signal.

The sinewave now on the CRT likely will not have it's zero-crossing starting at the first vertical graticle as the reference signal did, but some place else. On the illustration to the right, the zero crossing occurs about 0.3 divisions to the RIGHT. This can now be converted to the phase angle in degrees. In the illustration, one complete cycle takes 2.5 divisions, and the phase delay from the reference is 0.3 div. The phase shift is therefore:

Phase shift
= 0.3 div/2.5 div. x 360
= 0.12 x 360 = 43 degrees.

The SINGLE-TRACE scope method is a little easier to do if you make the sine wave of the reference to be 4 divisions for one cycle, thus making 90 degrees per division. The phase angle can be guestimated a little quicker with the

```
    |----**-----|-----|**---|
    |    *  |*    |      *   *  |
    |  :*   |  *   |    :*|    *  |
    |-*---|--*--|---*-|----*|
    |*:    |    *  |  *:  |      *
    *  :    |     *|  *  :  |      |
    |-----|-----**----|-----|
    :  :                :
 -->:  :<--.3 div.      :
       :<----------->: 2.5 div.
```

SINGLE TRACE SCOPE
PHASE MEASUREMENT

signal to be phase measured.

It is noteworthy to mention that in the above examples, measuring the phase through a delay line at 7 MHz would require an oscope with a 20MHz or higher bandwidth, if for no other reason, then just ensure that the time base is fast enough to display 1 or 2 sinewave cycles on the CRT. If at your fastest sweep speed, the 7MHz signal is displayed as many cycles, then obviously the accuracy that you can determine the phase angle will be highly degraded.

LOW FREQUENCY PHASE SHIFTS ON A LIMITED BANDWIDTH SCOPE.

If your scope has a limited bandwidth of only a few MHz or less, there are still useful phase measurements that can be performed.

One interesting experiment is to measure the phase shift of the audio signal at different frequencies as it travels through the stages in a CW audio filter. This is done by putting the input to the CW audio filter on CH.1 and the output on CH.2. What is the phase shift of the wanted vs. unwanted frequencies? Recall that an audio filter works by cancelling out (180 degree phase shift) the unwanted signals, while re-enforcing (0 degrees) the frequencies you wish to pass. There will only be one audio frequency for which there is a 0 degree phase shift. This will be the "pole frequency" of the active filter, or the frequency you wish to have the maximum gain. For CW QRP rigs, this should be around 700 Hz.

And finally, on a limited bandwidth scope, the phase angles of higher frequencies can be determined by applying the reference signal to the vertical input and the signal to be phase measured on the external horizontal input. This will form a lissajous pattern, the angle or tilt will signify the phase angle.

This is the last part of this series of articles on OSCOPES posted to QRP-L. There will be another series on scope measurements posted in the future (many months) that will include some advanced techniques, such as measuring sideband rejection, tuned circuits, filter responses, group delay, VCO phase noise, etc. This will be the contents of part 2 of the oscope article for the Winter QRPp. I haven't written it yet or made hardcopies of the scope displays. But following publication in QRPp, I will convert it to a text file and post it to QRP-L as I did this one.

PS - making those waveform illustrations really sucked swampwater!

72, Paul Harden, NA5N

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