USE OF PHASE SHIFT
TO RESOLVE SIGN AMBIGUITY AND IMPROVE ACCURACY
IN THE AD8302 PHASE DETECTOR

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The AD8302 can be used as a VNA phase detector by sending it a reference signal and a phase-shifted version of that signal. The phase shift is caused by a device under test (DUT) by reflection or transmission, and the goal is to determine the exact effect of the DUT.

One unfortunate aspect of the AD8302 is that it provides an output corresponding to 0-180 degrees, but cannot distinguish the sign of the phase. Both -45 degrees and 45 degrees are measured as +45 degrees. Our goal is to use additional phase shifting of the reference signal to resolve the sign of the phase. At the same time, we can use that phase shifting to avoid other inaccuracies in the measurement.

Figure 1 shows a graph of the AD8302 output level for various input phases.

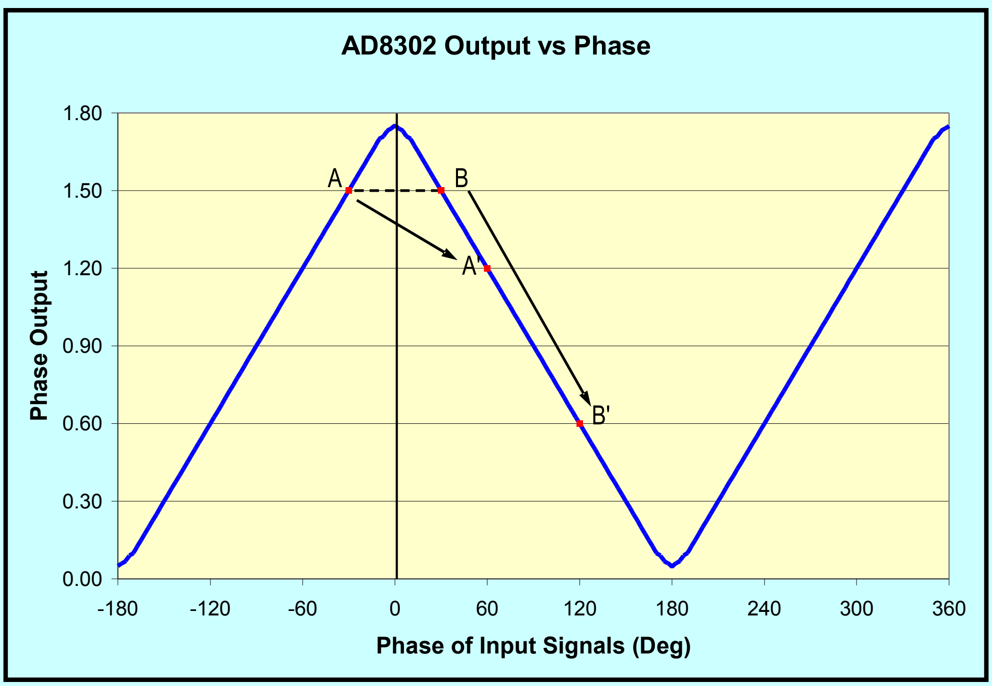


Figure 1—AD8302 Output vs. Signal Input Phase
The measured phase will fall in the range -180 degrees to +180 degrees. The extra range up to 360 degrees is added to assist in determining the effect of phase shifting the reference. Points A and B have opposite phase polarity but the same AD8302 output level. When shifted to the right by 90 degrees, they produce points A' and B'.

Note in Figure 1 that (except for the very high and low peaks) every possible output value can be produced by two different phases, which are negatives of each other. For example, points A and B, representing ±30 degrees, both produce an output of 1.5. So if all you know is that the output is 1.5, you know the phase is at point A or B, but you can't tell which.

Resolving the Sign of the Angle by Making a Shift

Now suppose you shift the reference phase by -90 degrees, which has the effect of increasing the measured phase of the DUT signal by +90 degrees. If you were originally at point A, you will move as shown by the arrow to 60 degrees. If you were originally at point B, you will move as shown by the arrow to 120 degrees. When you make the phase measurement after the shift, there will be "ambiguity" as to whether A' is at +60 or -60, but you know a +90 degree shift from -30 degrees will be in the neighborhood of +60. Likewise for B'. So ultimately there is no ambiguity.

By observing what actually happens when you make the shift, you can determine whether you were originally at point A or point B, and the job is done. If the shift produces a phase of +70, you know you started at A, and the 10 degree discrepancy is partly the result of measurement error and partly the result of your phase shift not being exactly 90 degrees. But despite the uncertainty in the amount of the shift, you can still determine whether you started at A or B.

If the original measured phase is P_M (a positive number) then the actual phase P_A is either – P_M or + P_M. The measured shifted phase will be P_S, whose sign is readily determined as describe above, so it will be the actual signed phase. Ideally, P_S will equal either $S-P_M$ or $S+P_M$, where S is the amount of the shift (S=90 in Figure 1). To allow for measurement and shift errors, we make the decision as follows:

1. Note that S is the midpoint between the two possible shifted values.
2. If $P_S > S$ then $P_A = P_M$
3. Otherwise $P_A = -P_M$

Uncertainty near the peaks

This method works fine when we can clearly determine which side of S P_S falls on. But what if P_S is close to S? If there is uncertainty of $\pm U_S$ in knowing the value of S, then if P_S falls within U_S of S we can't really be sure whether P_S is above or below the "true" S.

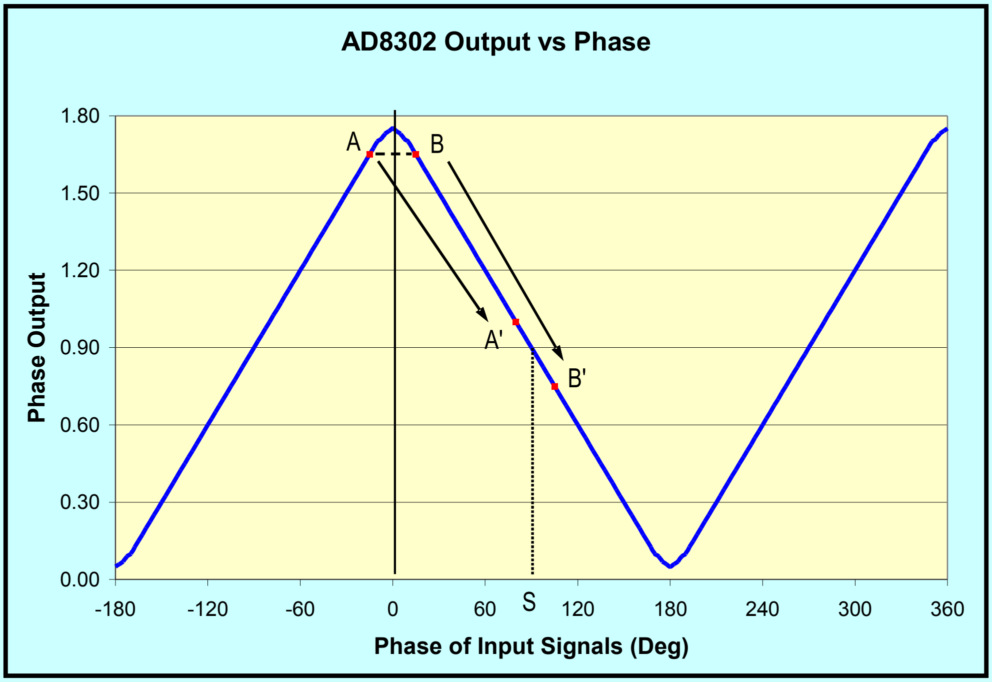


Figure 2—The Area of Uncertainty

When A and B are very near the peak, their shifted values, like their original values, will be close together. Here A=-15, B=15, A'=75, B'=105. The shift value S=90. If the uncertainty in S is greater than 15 degrees, and the shift results in point A', we can't be sure the original point was A.

This issue of uncertainty will only arise when the original measurement falls within U_S of the positive or negative peak. U_S originates with the basic measurement uncertainty of the instrument, discussed further below. If we can make measurements accurate within 1 degree, then U_S will be 1 degree and will make us unable to distinguish between +1 and -1 degrees by the shift method. The net effect is that the measurement uncertainty approximately doubles when very close to the peaks. That is a reason to stay away from the peaks. But as we will see below, there are other reasons to stay much further from the peaks. And if we do so, the effect of U_S will become irrelevant.

The Bigger Problem with Peaks

Many phase detectors have large inaccuracies near 0 and ±180 degrees, and the AD8302 is no exception. Errors in those inaccurate zones can reach 8 degrees. But if you can stay 10 degrees from the upper and lower peaks in the AD8302 response, you can greatly reduce the error. And if you can stay 20 degrees away, you can eliminate it almost entirely. This problem dwarfs any issue of uncertainty in the amount of the phase shift.

The Ultimate Procedure
Where we are going with this is that if we can provide the ability to shift the reference signal by 0 degrees and 40 degrees, we can follow this procedure to both resolve the sign ambiguity and get an accurate measurement:

1. Measure with zero degree shift and 40 degree shift.
2. Use the above procedure to resolve the sign ambiguity.
3. If the resulting measurement at zero degree shift is not within 20 degrees of the peak, then use it.
4. Otherwise, use the measurement with the 40 degree shift and subtract 40 to get the final phase. Note that if actual phase is -10 degrees, then the 40 degree shift will result in an angle of 30 degrees, an angle three times as far from the peak as the original. The worst case is that the actual angle is -20 degrees, so the shift results in +20 degrees, and we have not moved away from the peak. But in any case we will be able to make all measurements at least 20 degrees from a peak. Measurements at the boundary of that ±20 degree zone will be the least accurate, but the accuracy will still be good.

In reality, any phase shift method will produce different phase shifts at different frequencies. We just need to be sure that we can always shift by at least 40 degrees. We also don't want to shift more than 140 degrees, because we then move away from one peak but close to another.

An Actual Phase Shifting Circuit
The circuit shown in Appendix uses an all-pass filter to accomplish the shifts, which are graphed in Appendix B. (Thanks to Gerd Koetter (DO1MGK) for the all-pass idea). The "zero shift" setting actually causes a significant shift due to parasitics, but that is not a problem; it just becomes the base level for measuring the other shifts. The other two possible shifts actually exceed -140 degrees at some points, but the important value is the difference between their shifts and the base "zero" shift.

The net LF and HF shifts (i.e. the shift amount minus the zero shift amount) are shown in Appendix C. The LF Shift works well at the lower frequencies, giving a net shift between -40 degrees and -135 degrees between 750 kHz and 4.7 MHz. The HF shift works well at the higher frequencies, giving a net shift from -37 degrees at 3.2 MHz to –130 degrees at 30 MHz and back down to –65 at 200 MHz. This allows for phase shifts of between -40 degrees and -140 degrees for the range 1

MHz to 200 MHz. The shifting mechanism also creates some magnitude change when a shift is made, which can be taken into account by calibration. The magnitude effect is less than 1db at all frequencies.

It actually may be possible to accomplish the desired shift range with a single capacitor of 680pf switched in/out of the circuit. But since the switch shown is an SPDT, it is easy to play it conservative and use two capacitors.

One More Thing—How big is the Phase Shift?

It is nice to have a circuit which provides the desired phase shift, but how do we know the actual amount of the phase shift at any given frequency? We can make measurements of any DUT, such as an open circuit, at each phase position and subtract the difference. This may seem to be lifting ourselves by our bootstraps, since the purpose of the phase shift in the first place was to enable us to make accurate measurements and resolve sign ambiguities. But if we can stay away from the peaks on our own, and figure out another way to resolve the sign, we can reliably measure the phase shifts.

Assume for the moment we make raw uncalibrated measurements of a reflection from an open DUT. Starting at a low frequency, the reflection may be near zero. We can move it somewhat below zero by adding a length of unterminated coax.

If we treat the measurement as a negative angle, then as we increase the frequency, the measurement will show a steady decrease in phase angle, though the steadiness depends on the internals of the device. If it starts out by increasing, we are actually starting at a positive value and can add a longer piece of coax to make the measurement negative.

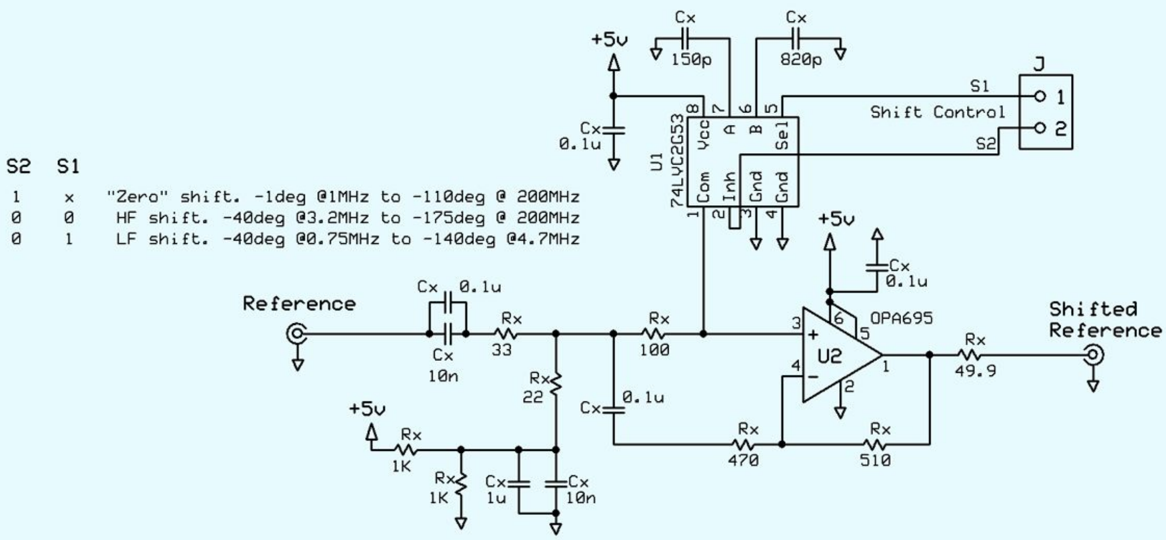
If we measure with the reference shifted and then unshifted, and subtract the second from the first, the result will be the amount of the shift, and should steadily, and nearly linearly, increase with frequency. And the result should be accurate as long as we managed to keep all raw measurements more than 20 degrees from 0 and ±180.

We need to make these measurements at a number of frequencies, but the phase shift normally will turn out to be very linear with frequency, so that it does not take a lot of measurement points to accurately describe the path.

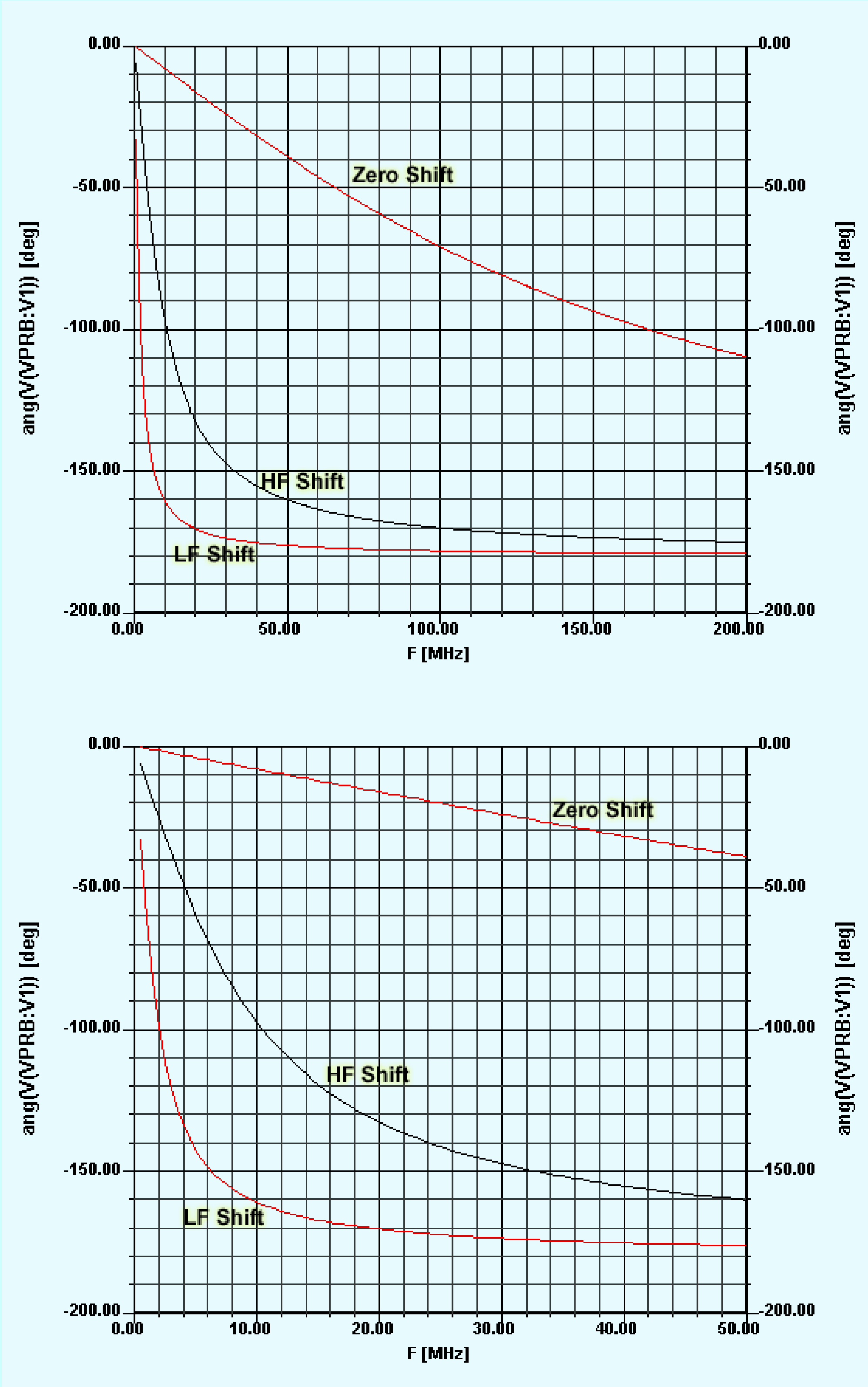
This may sound like an awkward procedure, but it is actually quite straightforward. It only needs to be done once after construction of the device, and maybe repeated occasionally. It does not have to be done every time the instrument is used. Plus, once you have done it, you will know what length coax, if any, is needed to let you do the measurements without going near the peaks.

APPENDIX A--Actual Phase Shifting Circuit for 1 MHz--200 MHz

This circuit is an all-pass filter whose frequency characteristics are determined by a grounded capacitor, for which there are 3 possible values as determined by U1, which can switch one of two capacitors, or be disabled, in which case the relevant capacitance is the parasitic capacitance of the switch (approx. 10 pf).



APPENDIX B—Phase Shifts of Circuit in Appendix A



APPENDIX C—Net Phase Shifts of Circuit in Appendix A
“Zero” shift is subtracted from HF and LF Shift