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Translated Frequency Response Measurements Using the HP 89440A

Product Note 89400-6

Phased lock loops, modulators/ demodulators and other systems that translate signals from baseband frequencies to RF push the limits of traditional test equipment. Characterizing the signals in these systems with speed and accuracy requires a distinct set of features brought together for the first time in the HP 89440A vector signal analyzer. This product note examines the challenge of translated frequency response measurements and shows how the unique capabilities of the HP 89440A provide the first true solution to these complex problems.

The Challenge of Translated Frequency Response Measurements

Circuits and devices that convert frequencies from one range to another present some special measurement challenges. In the past this meant getting by as best you could with rough estimates or cumbersome custom-built systems—if you could make the measurements at all. The HP 89440A packs the features and flexibility you need into a single piece of equipment and makes the measurements with a degree of accuracy that you've come to expect from world-class spectrum analyzers. From the four measurement examples described here, you can see how the HP 89440A's translated frequency capabilities can be applied in a wide variety of design and troubleshooting applications.

Many troubleshooting situations involve looking for the source of a particular signal. With its powerful digital signal processing, the HP 89440A gives you the tools you need to track signals through your circuits—even when one frequency is at baseband and the other is at RF. In the first measurement, for instance, you'll see how the coherence function identifies the type and source of a noise component in a phase-locked loop (PLL).

That measurement and the others in this product note also make use of the analyzer's demodulation function, which can measure amplitude, frequency, and phase modulation. Demodulation is an innovative tool both for identifying signal contamination (which often shows up as modulation) and to measure system responses to modulated signals.

The optional dc-10 MHz baseband channel (option AY7) works in conjunction with the DSP functions, demodulation, and the analyzer's source to make the translated frequency response measurements possible. Having this additional channel opens up an entirely new range of test techniques, such as measuring a modulating input signal on one channel and the demodulated output on the other channel.

Locating Noise Sources

How many times have you seen noise or some other component mixed in with your expected signal and wished you had a fast, easy way to locate the source of the unwanted signal? This can be an especially vexing problem in frequency converting systems, where the unwanted signal may originate in an entirely different frequency range from the one you're measuring. The HP 89440A's baseband and RF channels give you the means to measure the two different frequency ranges, and as you'll see, the HP 89440A's coherence function can be used to determine the source of the unwanted signal.

The 442-MHz oscillator in the PLL shown in figure 1 exhibits excessive noise within 50 kHz of the carrier, as shown in figure 2. To identify the type of noise and separate it from the carrier, the HP 89440A's demodulation function is used. A check of both AM and PM in this case, shows the noise to be phase related.

Since the demodulation function provides results in the time domain, it's easy to do a comparison of the PM-demodulated, time-domain signal with the time-domain signals at suspect nodes around the circuit. This measurement approach can be particularly effective when the sidebands are caused by logic signals. If so, the PM-demodulated time results would resemble a digital waveform (or its derivative).

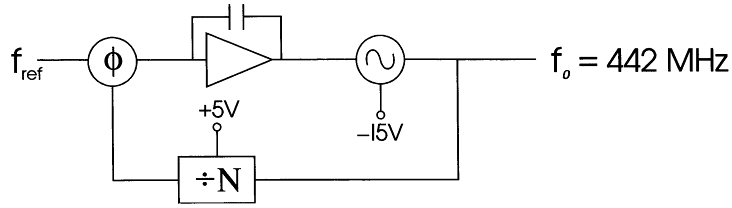


Figure 1. A block diagram of a typical phase lock loop.

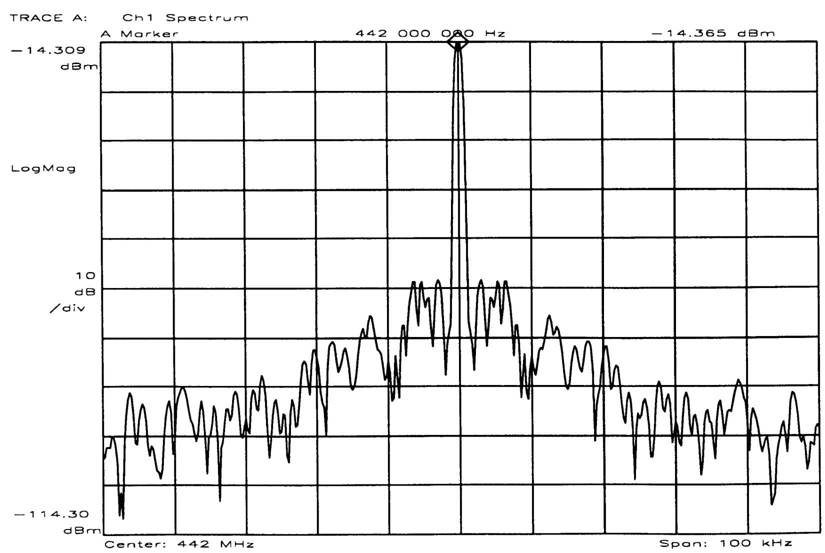


Figure 2. You can see the familiar "noise shoulders" around the carrier at the output of the 442-MHz oscillator.

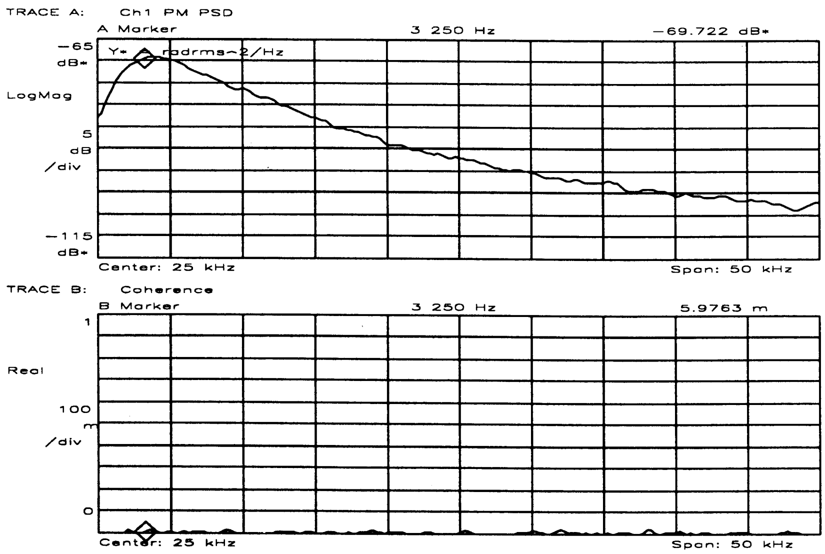


Figure 3. You can see there is almost no coherence between the noise on the +5V supply and the demodulated phase noise.

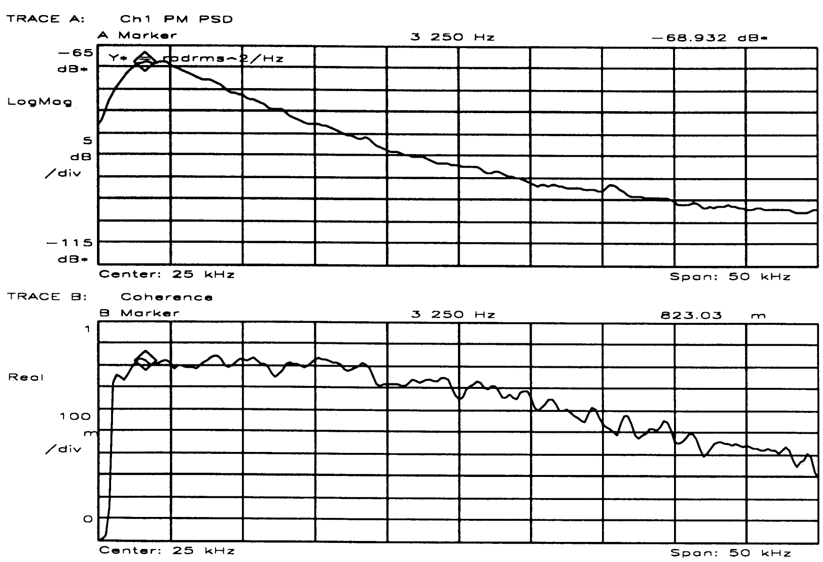


Figure 4. The high coherence between noise on the -15V supply and the output phase noise indicates that this supply probably is part of the problem.

In this particular case, however, a time-domain comparison was inconclusive. Switching to the frequency domain lets you take advantage of the coherence function and gain additional insights into the nature of the problem.

Coherence is a frequency-domain measurement that tells you how much of the power in one signal is related to the power in a second signal. The results are scaled from 0 to 1, where 1 indicates that all of the power in one signal is related to the power in the other signal. If you observe noise sidebands on the output of an oscillator, for instance, you can probe around the circuit looking for a likely source of the problem. When you find a signal that shows coherence close to 1 over a range of frequencies, you've found a likely source of the problem.

The analyzer's baseband channel is used to probe the PLL power supplies. Since the frequency span of the HP 89440A's baseband channel matches the demodulated span, a coherence measurement is possible. Figures 3 and 4 show the coherence checks made on two of the power supplies. The top trace in both cases is the demodulated phase noise measured on the RF channel, and the bottom trace is the coherence function. You can see that the +5V supply isn't the culprit, since its coherence with the phase noise is essentially zero. However, the -15V supply shows a high degree of coherence, indicating that the noise on this supply is a significant contributor to the phase noise problem. Coherence and time-domain displays are just two of many troubleshooting tools that the HP 89440A provides.

Using the Source for Translated Frequency Response Measurements

In many translated frequency response measurements, you'll need to stimulate the device-under-test and analyze response characteristics. The HP 89440A comes standard with a versatile 10-MHz source (Option AY8 converts this up to 1.8 GHz) that provides the signals you need to stimulate a wide variety of circuits and devices. When the RF source upconverter is used, the source's chirp and random noise outputs are available across the same start and stop frequencies as the RF input channel. If the source upconverter is bypassed, the source operates in baseband mode, in which case the periodic chirp and random noise operate from dc to one-half the RF input span. For instance, if the RF input is set from 100 MHz to 106 MHz (a 6-MHz span), the chirp and noise will be available from dc to 3 MHz.

In figure 5, a frequency chirp from the baseband source modulates a 455-MHz carrier. The main RF input is tuned to the modulated carrier while the baseband channel monitors the chirp.

Trace A shows the spectrum of the modulated carrier, complete with sidebands, centered at 455 MHz with a span of 50 kHz. Trace B shows the spectrum of the chirp, measured on the baseband channel from dc to 50 kHz. Note how the baseband channel tracks the span of the RF channel and how the source's chirp output is constrained to 1/2 of the RF input span (50 kHz/2 = 25 kHz). When demod is selected, the span on the baseband input channel is also reduced by half, allowing you to make transfer function measurements between baseband and demodulated RF.

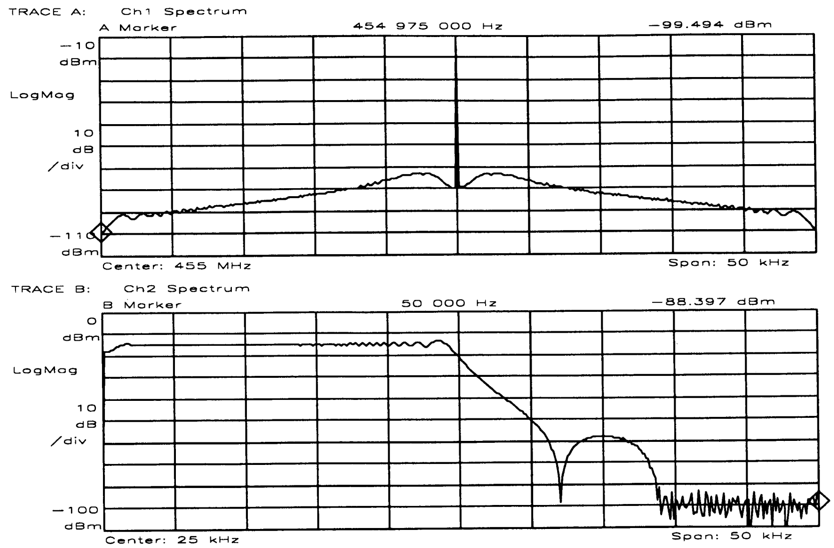
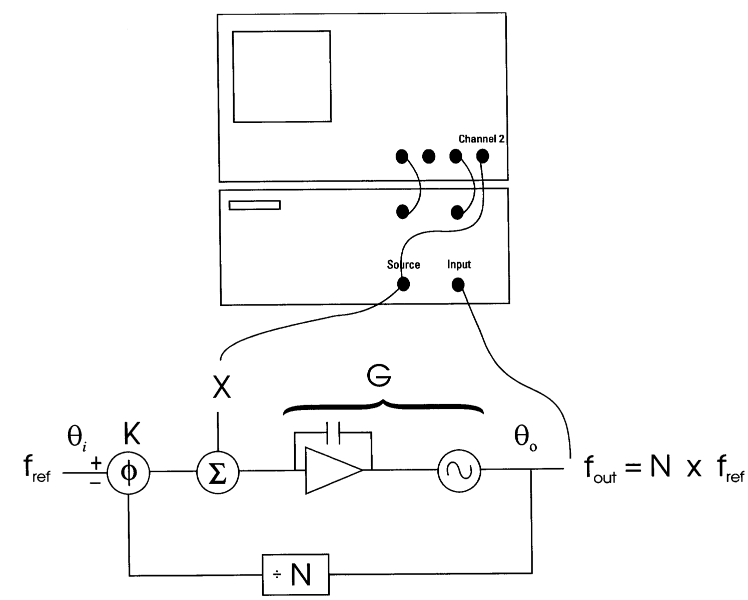


Figure 5. A dc-25 kHz frequency chirp from the HP 89440A's source (bottom trace) modulates a 455-MHz carrier; the resulting signal is shown in the top trace.



$$\theta_o = \theta_i KG + XG - \theta_o \frac{K}{N} G$$

$$\left.\frac{\theta_o}{\theta_i}\right|_{X=0} = \frac{KG}{1 + \frac{K}{N}G} \qquad \left.\frac{\theta_o}{X}\right|_{X \gg \theta_i} = \frac{G}{1 + \frac{K}{N}G}$$

Figure 6. The PLL block diagram shows the additional summing node used to inject a measurement stimulus.

Quick Estimates of PLL Response

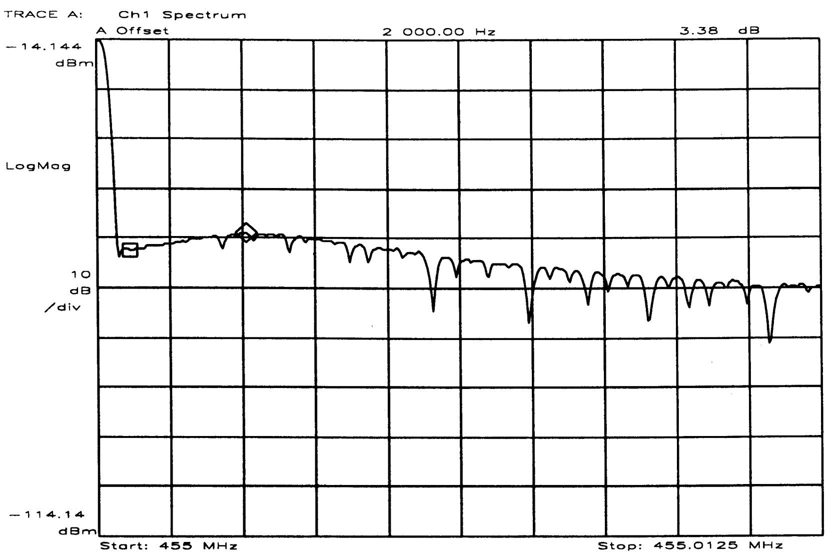


Figure 7. Using an external signal generator and the peak hold function on a traditional spectrum analyzer, you can build up a closed-loop response of the PLL; this provides a quick estimate, but the HP 89440A can provide a much cleaner measurement in less time.

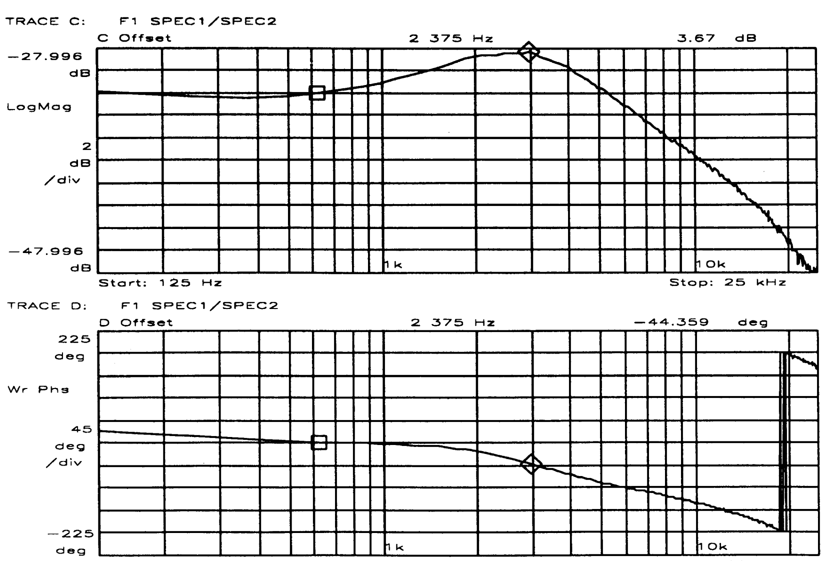


Figure 8. The HP 89440A provides a fast, accurate measurement of the PLL's response, including both phase and magnitude.

For years, engineers have used a traditional spectrum analyzer in conjunction with a signal generator to get quick estimates of the frequency response of PLLs. By injecting a baseband signal into a loop summing node (X in figure 6), and looking at the resulting modulation sidebands at the output of the loop (θ_0), you can quickly view a scaled version of the system's closed-loop response (assuming an ideal phase detector).

With this technique, the peak hold function in the spectrum analyzer builds up a trace as the operator manually steps the signal generator across the frequency span. It is a fairly fast way to estimate system response, but as you can see from figure 7, the results are not easy to interpret. Moreover, you have to assume that the sidebands are the result of phase modulation and not some unanticipated behavior in the system.

The HP 89440A provides this same quick technique, but it is significantly faster and provides better answers. Making this measurement with the HP 89440A is simple and straightforward. The main RF input channel is connected at the output of the VCO, and PM demodulation is activated to measure θ_0. A baseband frequency chirp is injected into the summing node, and the baseband input channel measures this input (X). The baseband channel's frequency span automatically tracks the demodulated span on the RF channel, so the two spectra have the same frequency span. The analyzer's trace math computes the transfer function (θ_0/X), and the offset markers are used to determine the loop peaking. The results, including magnitude and phase, are shown in figure 8.

The HP 89440A's source triggering and time averaging improve the signal-to-noise ratio in the measurement without destroying the phase information. The log-frequency-axis display gives you a better view of key parts of the response. To give you even more confidence in your measurement, the HP 89440A's demodulation feature verifies that the sidebands do in fact result from phase modulation. In addition, you can use the coherence function to verify that the loop response is due to the injected input and not some other factor.

Analyzing Sensitivity to Power Supply Ripple

Synthesizers and other frequency converting systems are often sensitive to power supply ripple, and translated frequency measurements are a great way to test the degree of sensitivity. Looking at the PLL shown in figure 9, for instance, you'd like to know how much supply voltage ripple the VCO can withstand and still operate within its specified limits. Once again, the HP 89440A's baseband channel, demodulation feature, and versatile source provide a quick and accurate answer.

A transformer could be used to inject the ripple onto the supply line. In this case, small resistances (R1 and R2) were added as shown in figure 9. The baseband input channel measures the ripple while the RF input channel demodulates the output of the VCO. The analyzer's trace math is then used to derive the VCO sensitivity to the power supply (radian/volt) by dividing the demodulated PM on

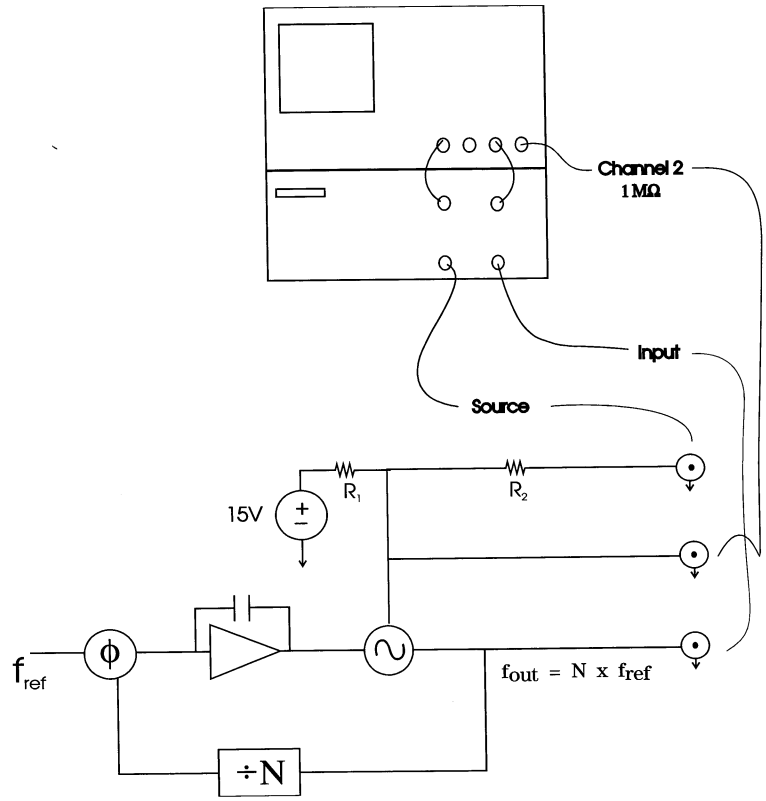


Figure 9. The HP 89440A's source injects a test signal onto the PLL's power supply to measure the PLL's sensitivity to power supply ripple.

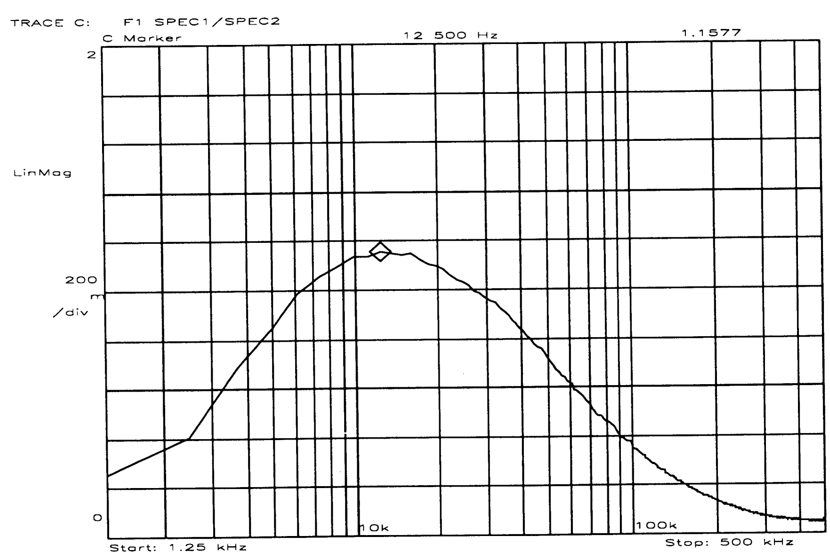
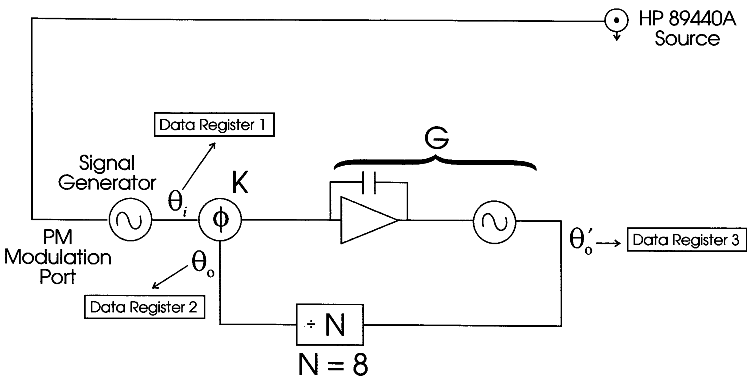


Figure 10. The measurement shows that the PLL's sensitivity peaks near 12.5 kHz.



$$\text{Open-loop response} \quad \frac{\theta_o}{\theta_i} = \frac{KG}{N}$$

$$\text{Closed-loop response} \quad \frac{\theta_o}{\theta_i} = \frac{\frac{KG}{N}}{1 + \frac{KG}{N}} = X$$

$$\text{Solving for } \frac{KG}{N} : \quad \frac{X}{1 - X} = \frac{KG}{N}$$

Figure 11. The HP 89440A's source modulates an external signal generator to provide a signal to test the performance of the PLL control loop. The equations show how to derive the open-loop response.

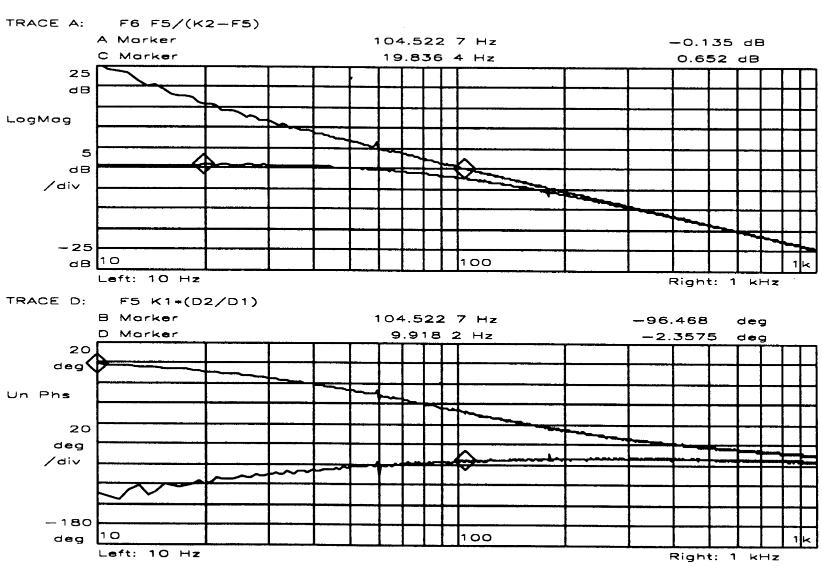


Figure 12. Here are the measured closed-loop response and computed open-loop response (magnitude on top and phase on bottom).

the VCO output by the injected ripple. The result, shown in figure 10, indicates the frequencies at which the VCO is most sensitive to supply ripple.

As you can see, the PLL is most sensitive at 12.5 kHz. Knowing your circuit's sensitivity to power supply ripple allows you to modify either the circuit or the power supply to keep your design within acceptable operating limits.

Characterizing Control-Loop Performance in PLLs

In the fourth example, we measure the frequency response of a PLL control loop. You may be familiar with the technique used in the HP 3562A, 3563A or other dynamic signal analyzers (DSAs), in which you measure the open-loop response then mathematically derive the closed-loop response. However, this technique isn't available when the loop bandwidths are above 100 kHz (the typical maximum range of DSAs) or when you can't gain access to the loop between the phase detector and the VCO input. The HP 89440A has the answer for both situations.

The approach is to measure the closed-loop response by taking the ratio of the phase modulation at the output to the phase modulation at the input. The open-loop is determined mathematically. You end up with both open- and closed-loop responses. This approach has the advantage that the loop was not opened and no additional summing nodes were used. The test circuit in this case is the PLL shown in figure 11.

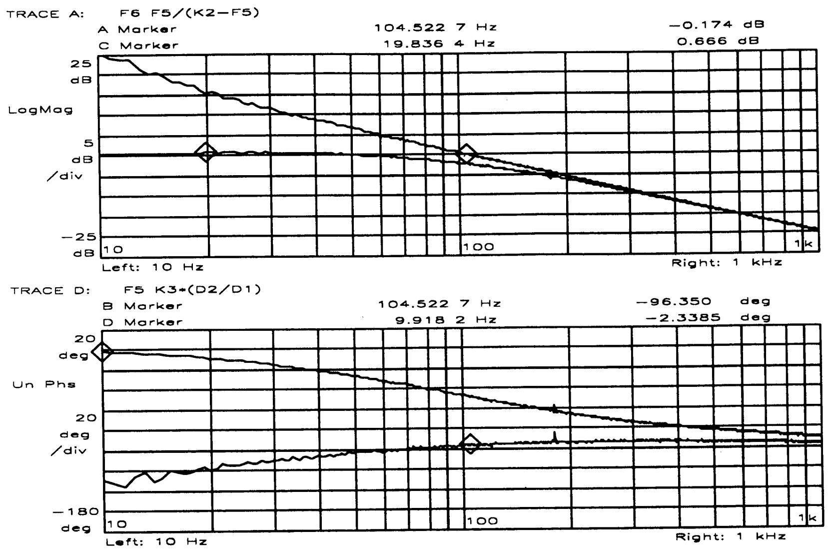


Figure 13. When you can't meaure at the phase detector, you can measure at the VCO output and use trace math to move the response to the phase detector; this result matches the result shown in figure 12.

Figure 11 also lists the equations for the open- and closed-loop responses.

In this example, the analyzer's source phase modulates an external signal generator. The resulting modulated signal is applied as the reference input to the PLL. The spectum of this reference signal's phase modulation, θ_ι, is measured using PM demodulation and stored in the analyzer's first data register (D1). Next, the signal fed back to the phase detector (θ_0) is measured, again with PM demodulation, and stored in data register (D2). The closed-loop transfer function can now be found by dividing D2 by D1.

To compute the open-loop response, the math function F6 was defined as F5/(K2 - F5). The function F5 is the closed-loop response just calculated, and the constant K2 was set to (1 + j0). The open-loop and closed-loop responses are shown in figure 12. The top trace shows the magnitude components of both responses, and the bottom trace shows phase.

To compute a key parameter such as phase margin, for instance, you would simply check the necessary marker readouts on the display. Phase margin is equal to 180 degrees minus the phase at the frequency at which the magnitude of the open-loop response passes through 0 dB. From the marker readouts shown in figure 12, you can see that the phase margin is 83.532 degrees (180 - 96.468).

You won't always have access to the feedback signal θ_0 at the phase detector, but the HP 89440A provides an answer for these situations as well. Referring to the schematic in figure 11, you can measure the output of the VCO instead (θ_0') then use trace math to "shift" this response back to θ_0 at the input of the phase detector. In this example, the VCO output is at 80 MHz, so θ_0' is measured by setting the RF input to 80 MHz, again with PM demodulation enabled. The result is stored in data register D3. The trace math function F5 is then redefined as F5=K3*(D3/D1). In this case K3 is defined as 0.125 +j0, since the frequency divider N equals eight. The results of these operations are shown in figure 13.

With this approach, the phase margin works out to 83.650 degrees, which is in close agreement with the results shown earlier in figure 12.

A Flexible, Versatile Troubleshooting Solution

You can sum up the HP 89440A's advantages for translated frequency measurements by considering the benefits offered by four key features:

1. The optional baseband input channel, which can be coupled to the span of demodulation results on the RF input channel.

2. The flexible source, which can operate at baseband spans while the main input channel measures at RF.

3. The powerful demodulation feature, which helps you identify AM, PM and FM components.

4. The advanced DSP abilities, which extract more information from your measurements.

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