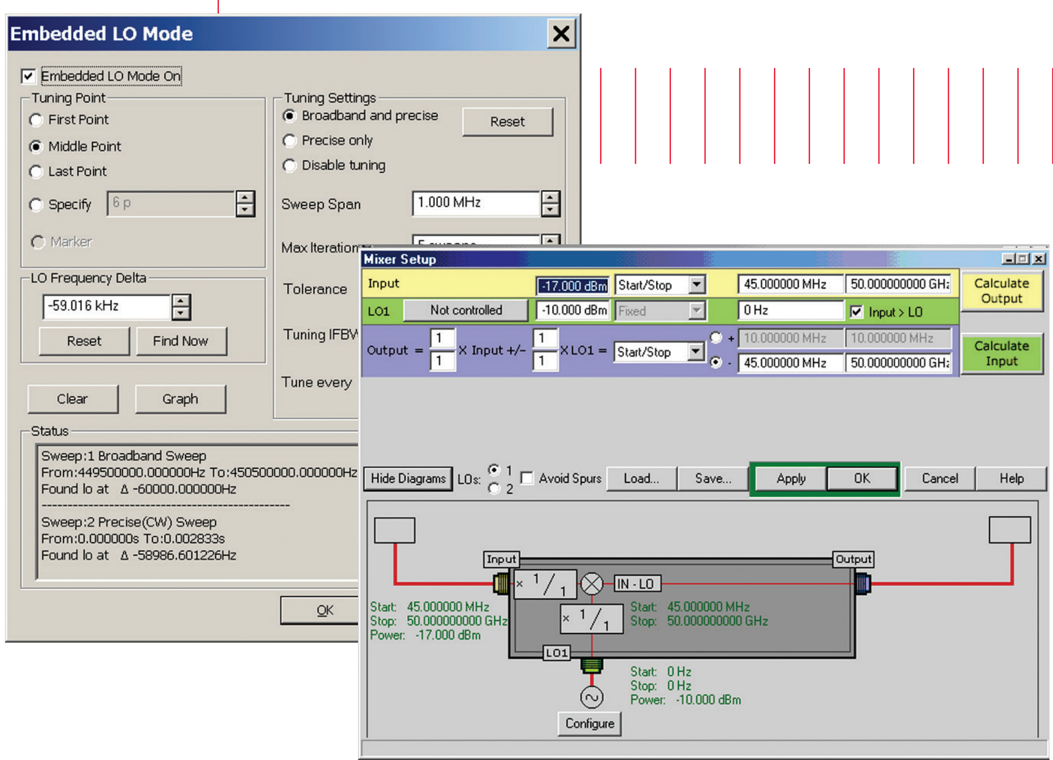
Keysight Technologies

Measuring Group Delay of Frequency Converters with Embedded Local Oscillators

Application Note



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Introduction

Mixers and frequency converters lie at the heart of wireless and satellite communications systems. The requirements on the frequency response and phase linearity of these frequency converters, particularly those used in satellite systems, are increasing. A key measurement that is becoming required is the relative and/or absolute group delay for the frequency converter. However, attributes of these systems require new techniques, and one key attribute is that the Local Oscillator (LO) is not, in any way, accessible. Furthermore, there is not even a common reference frequency signal (typically 10 MHz) that is available to lock the embedded LO with external signal generators.

This application note describes how to make measurements using a new technique to test the frequency converter with an embedded LO source, and without direct access to a common reference signal. The key aspect of this new technique is the tracking frequency of the IF of the DUT such that the frequency of the external LO used for the reference channel mixer can be adjusted to accommodate an offset and drift in the DUT embedded LO. Furthermore, the phase of the IF of the DUT is also tracked to accommodate phase shift or slight frequency error (less than 1 Hz offset is required to avoid difficulties in the delay measurement). This frequency tracking is done through software techniques that do not require additional phase-locking hardware.

The new measurement technique, Embedded LO Measurements (PNA and PNA-X option 084) requires the Frequency Converter Application (FCA, option 083) option. The measurement accuracy depends on the embedded LO's frequency stability (see Appendix A).

Details of the Measurement System

The calibration and measurement systems are shown in Figures 1 and 2. The calibration of the measurement system proceeds as described in the *Application Note 1408-3 (Improving Measurement and Calibration Accuracy using the Frequency Converter Application*, Literature number 5988-9642EN). During the calibration process, the reference and calibration mixer shares the same LO source. The PNA-X has an option for a second source and the standard PNA uses an external source for reference and calibration mixer LO source.

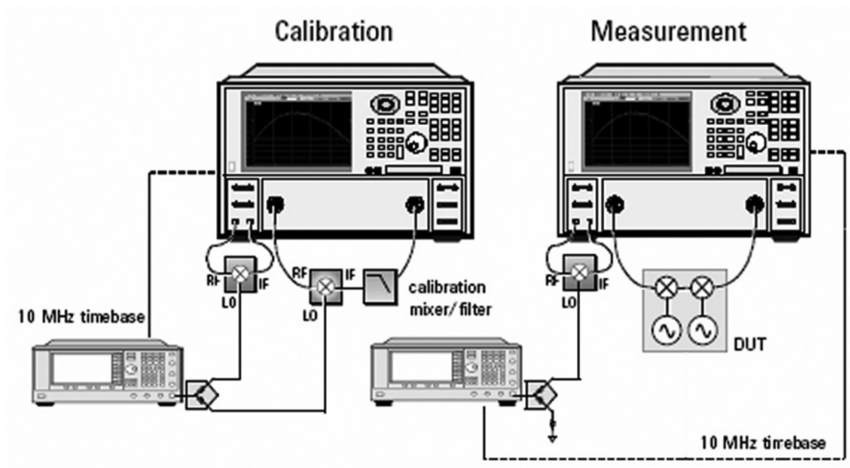
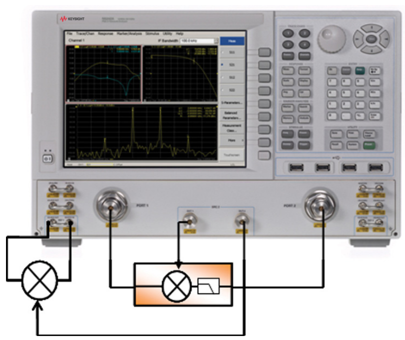


Figure 1a. PNA calibration

Figure 1b. Measurement



Figures 2a (Calibration)

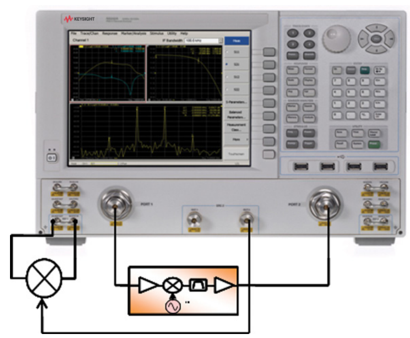


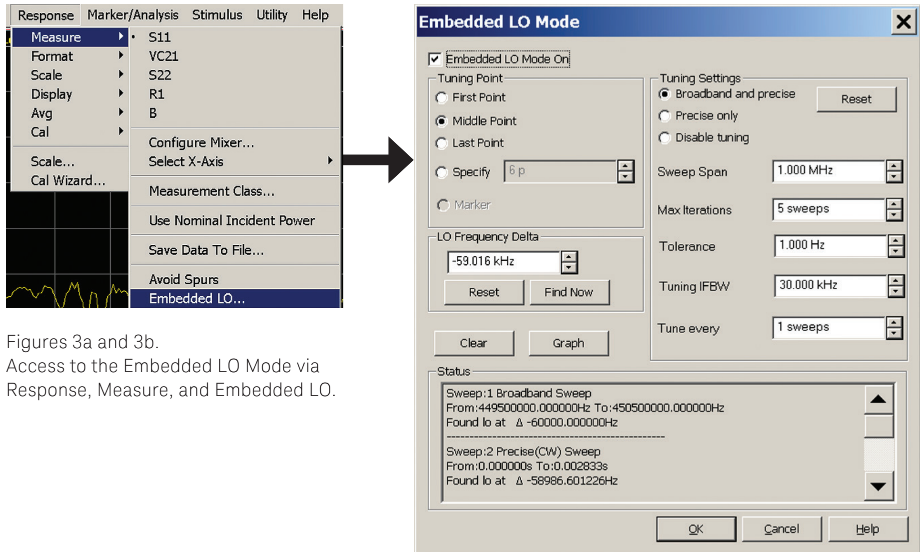
Figure 2b (Measurement).
PNA-X calibration and measurement setup.

During the measurement of the DUT, the LO of the DUT is used instead of an external LO. It is assumed that the approximate frequency of the LO is already known. There are two ways in which the LO frequency is determined.

- Broadband sweep – A rough measurement of the embedded LO frequency is made around a selectable data point over a selectable frequency span. The input signal to the DUT is constant. The reference mixer is not used. The B receiver is used to measure the DUT output. The resolution of this sweep is approximately 1/3 the selected Tuning IF Bandwidth for the precise mode portion.
- Precise sweep – The reference mixer LO and the PNA receivers are first offset according to the result of the broadband sweep. A phase versus time sweep is performed to determine the precise reference mixer external LO frequency. VC21 is measured at the selectable data point. Measurements are not made until the tolerance value or maximum iteration is met (shown in Figure 3).

Before each DUT measurement sweep, background sweeps (Appendix B) are made to determine the frequency of the embedded LO to a configurable degree of accuracy (Max Iteration or Tolerance). The DUT LO frequency is used to set the reference mixer LO frequency and PNA receivers for the VMC measurements.

The Embedded LO Measurement User Interface



Figures 3a and 3b.
Access to the Embedded LO Mode via Response, Measure, and Embedded LO.

Embedded LO Mode On

Check to enable Embedded LO measurements.

Tuning Point

Select or specify the data point in the mixer sweep that will be used to find the embedded LO frequency. If a marker is enabled, that data point can be used. Choose a point in the mixer sweep where noise is least likely to be found. This is generally the center of a sweep or the center of a filter, if used.

LO Frequency Delta

The difference between the measured embedded LO frequency and the LO setting that is entered in the mixer setup dialog. This value is updated each time the embedded LO frequency is measured. Entering a value is a way to change the LO frequency on the mixer setup without invalidating the calibration. If the embedded LO changes frequency too fast, it may be necessary to reset this value to reestablish a lock to the LO frequency. This is sometimes necessary if the DUT is removed and there is no signal to be detected.

Reset

Set the LO Frequency Delta back to 0 Hz.

Find Now

The PNA finds and measures the actual LO frequency using the current dialog settings. The data is displayed in the Status box. It is good practice to use the “Find Now” function the first time that the DUT is connected to the analyzer (PNA or PNA-X).

Clear

Clear status area

Graph

Display tuning graphs. See Appendix B.

Tuning Settings

These settings determine the amount of time spent versus the degree of accuracy to which the LO Frequency is measured. Both Broadband and Precise Only settings do the entire tuning process for each background sweep.

Broadband and Precise

Perform the entire tuning process for each background sweep. A rough measurement of the embedded LO frequency is made around a selectable data point over a selectable frequency span. The input frequency to the DUT is constant. The reference mixer is not used. The B receiver is used to measure the DUT output and the reference mixer LO is tuned to the result of the broadband measurement, and then a precise method is used (as described below). VMC measurements are not made until the tolerance value or Max iteration is met.

Precise Only

The reference mixer LO is tuned to current LO frequency delta (which may have been found by the broadband tuning, or may be directly entered). VMC measurements are not made until the tolerance value or Max Iterations is met. It does not perform broadband tuning on each sweep. Use when the embedded LO is stable, recommended for Embedded LO drift less than 1/3 of the Tuning IFBW.

Reset

Set all Tuning Settings back to the defaults.

Disable Tuning

Only the previously measured LO Frequency Delta is applied to the reference mixer LO and PNA receivers.

Sweep Span

It is for the broadband sweep. Narrowing the sweep span limits the number of data points that are measured in the broadband sweep and makes the measurement faster.

Max Iterations

The maximum number of Precise sweeps to make. When this number is reached, the final measurement is used.

Tolerance

When two consecutive precise measurements are made within this value, the final measurement is used. If this is not achieved within the Max Iterations value, then the last measurement is used. This is the best of the 'Tunings settings' to change for improved accuracy. Typically, less then 1 Hz should be used. Noise will limit the accuracy to which the frequency can be measured, with accuracies better than 0.02 Hz being very difficult to achieve. A good starting value is 1 Hz (default), but 0.3 Hz has shown to give good results with stable embedded LO.

Tuning IFBW

IF Bandwidth used for broadband and precise tuning sweeps. The larger the IFBW, the faster the sweep, but the signal may not be found.

Tune Every

Set the interval at which tuning is performed before a measurement sweep. 'Tune every 3 sweeps' means that every third measurement sweep is preceded by tuning sweeps. If the embedded LO drifts or if regularly changing DUTs, use 'Tune every 1 sweep.'

Measurement Example

The following measurements are for example only. For other Vector Network Analyzers and Frequency Converters (DUT), the actual measurement steps, frequency, and power may not be same as described in this paper.

Setup

Legend [Hard Keys], Soft/Dialog Keys

Connect reference mixer as shown on Figure 1a or 2a for calibration.

1. Press [Preset], [Meas], Measurement Class..., Vector Mixer/Converter, Next, choose Delete.
2. Press [Freq], Input, and fill in frequency of the DUT as shown in Figure 4 (This is DUT frequency and power requirement) OK.
3. [Avg], IF Bandwidth, enter 1 KHz (suggested value for optimize trace noise and speed).

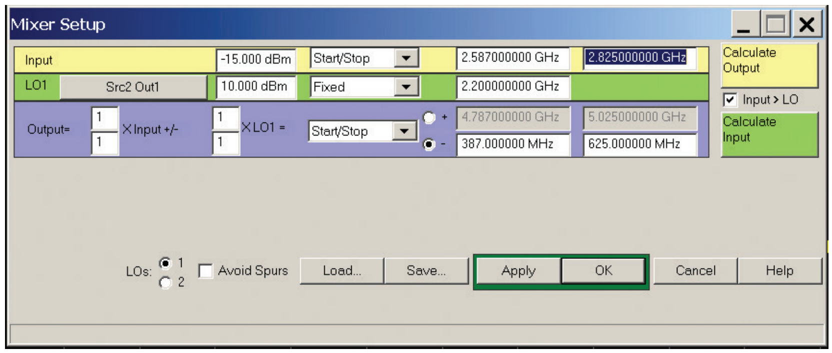
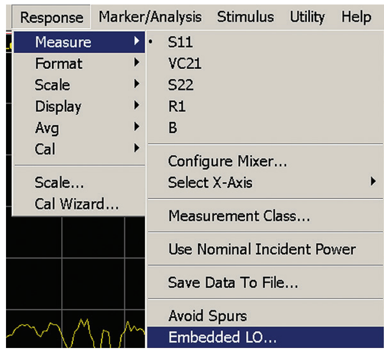
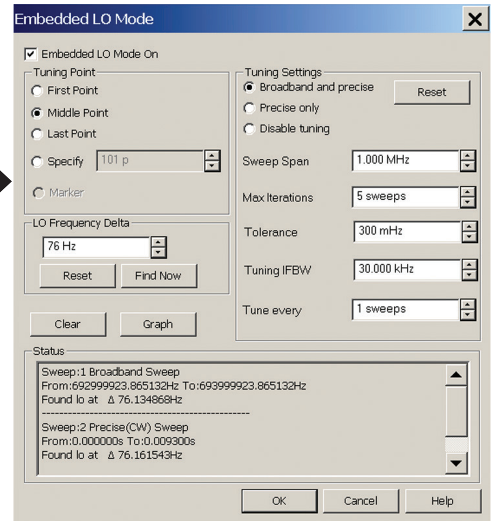


Figure 4. Frequency and power requirement inputs.

4. [Cal], Start Cal, Cal wizard, next. Choose one of the Mixer characterization choices.
   - Perform characterization (requires reference mixer) recommended.
   - Load characterization from file.
5. Choose DUT connector and Cal kit (recommend ECal if available), Next, and follow the calibration guide. This step does two-port calibrations.
6. Connect Cal-Mixer/Filter pair as diagram shows on the PNA/PNA-X, press Measure, and follow the calibration guide. This step is Cal-Mixer/Filter pair characterization.
7. Choose Save mixer characterization data for future use or Not Save (Next). As you just experienced from the above step, the Cal Mixer/Filter pair characterization is fast and simple. Saving data is optional.
8. Connect Cal-Mixer/Filter pair output to port-2 as diagram shows on the PNA/PNA-X
9. Press Measure, Next, Finished.
10. Disconnect Cal-Mixer/Filter pair then connect DUT.

11. Access to the Embedded LO menu/Window.





Figures 5a and 5b. Embedded LO Mode window.

12. In the Set Tuning point area, set the Tuning point to Middle point or linear phase response area, then click Reset. Note: Click on Reset before clicking on Find Now (tuning).
13. In the Tuning Settings area, set the Tuning Setting to Broad and Precise (Use Precise only mode if embedded LO source drift less than 1/3 of Tuning IFBW).
14. Set Tolerance to the desired value. This value will set the trace noise and accuracy of the measurement.
15. Other settings can be left as defaults.
16. Click OK.

Figure 6 is the comparison between using the new measurement technique (Embedded LO Measurement Option) to the DUT embedded LO locked to the reference mixer LO source.

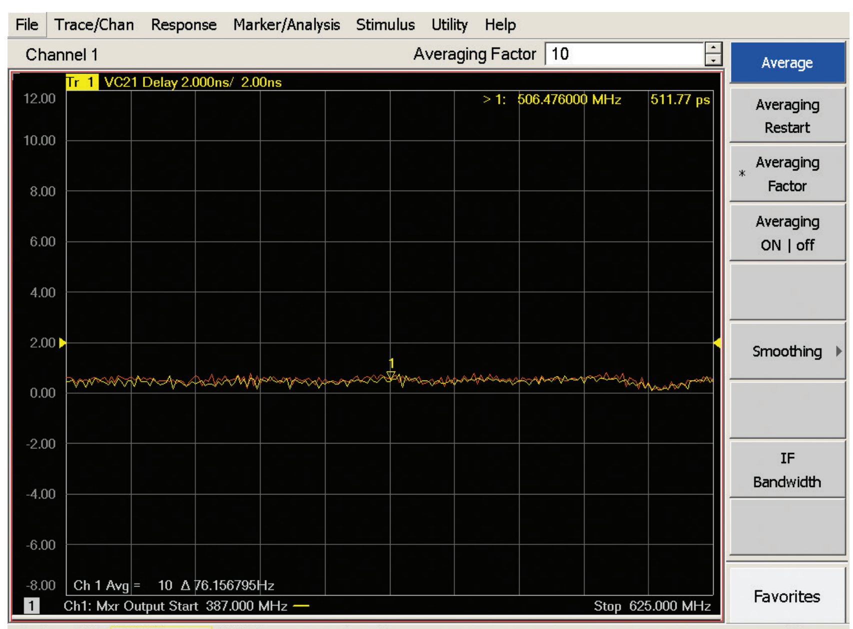


Figure 6. Orange trace = DUT embedded LO locked to reference mixer LO source.
Yellow trace = Using Embedded LO Measurement Option (option 084).

Improving Measurement Noise

The LO phase noise will directly translate to the IF phase. Narrowing the normal network analyzer IFBW will not reduce this noise because the phase noise of the embedded LO and the reference mixer LO combine to create noise in the delayed measurement response, as any frequency error causes a sweep-to-sweep offset in the phase of the output.

To understand why narrowing the IFBW does not remove the delay noise in the measurement, one must understand that this noise is related to the phase noise of the LO at each mixer. The phase noise can be thought of as frequency shifting, and the IF filter has a phase versus frequency response which is proportional to the IFBW, and the reduction in noise is also proportional to IFBW. Thus, the resulting phase deviation is essentially flat with respect to IFBW. That is, reducing the IFBW reduces the effective frequency deviation in direct proportion to the IFBW, but the narrower filter has a steeper phase slope with frequency so the same phase deviation occurs. However, using vector averaging allows a noise reduction without narrowing the IF BW, so improved delay noise can be achieved.

For best measurement results, we see in Figure 7 that at 20 kHz, IFBW provides the minimum delay noise at a fairly fast speed, so this is the recommended setting. The best choice for IFBW may depend upon the particular phase noise characteristics of the embedded LO.

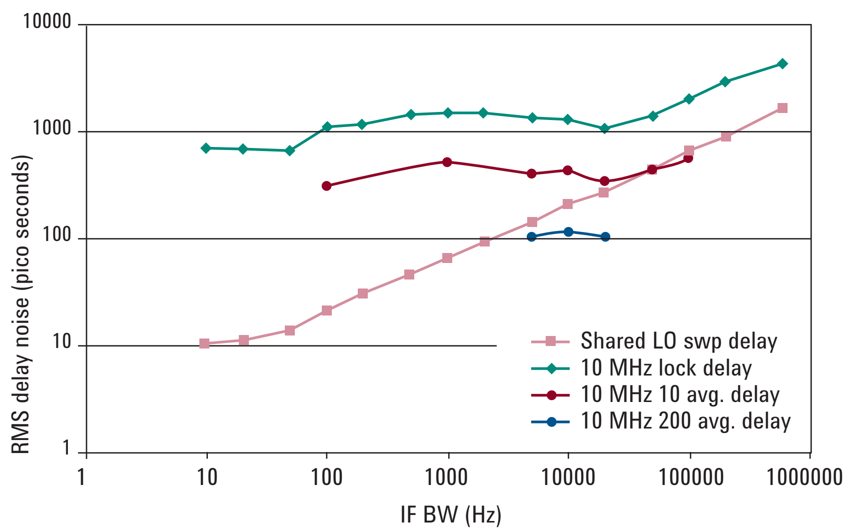


Figure 7. Delay noise versus speed.

Conclusions

This application note shows that the results from the new method of measuring the group delay of a frequency converter are the same as locking the DUT embedded LO source to the reference mixer LO. The key to this new technique is software phase tracking the embedded LO on the back group sweeps, and compensating for frequency drift error over the measurement aperture before applying the averaging required to reduce noise to an acceptable level. This new method may be used with arbitrarily narrow bandwidth devices, which precludes some other methods requiring amplitude or complex modulation.

Appendix A

The quality of the group delay measurement is limited by the phase noise of each LO. Thus, the converter (DUT) embedded LO requires a certain level of frequency stability to obtain an adequate measurement accuracy. The following describes the frequency drift that affects measurements. Most of the embedded LO frequency is known and meets
this requirement.

Frequency Drift Data rates for the embedded LO:

- For frequency drifts of 1 Hz/Sec: No effect on any measurements.
- For frequency drifts of 10 Hz/Sec: Small (100 ps) effect on Absolute delay, no effect on relative group delay measurements.
- For frequency drifts of 100 Hz/Sec: Small effect on relative delay measurement (approximately 10-20% more trace noise on delay trace), no effect on frequency tracking.
- For frequency drifts up to 10 kHz/Sec: Frequency tracking with no problem, but not usable for group delay measurements.

Appendix B

Graph displays for the background sweeps (example only).

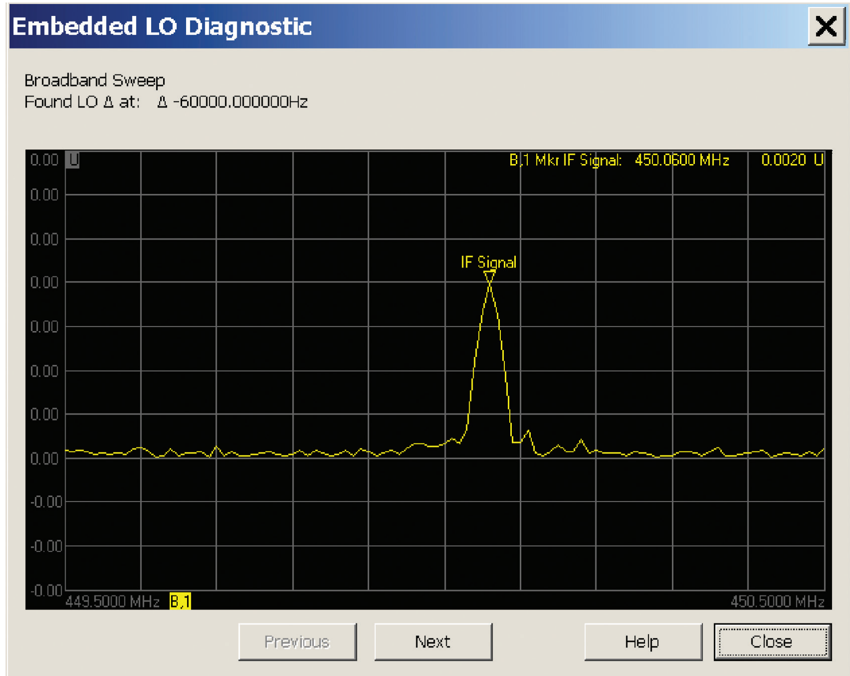


Figure 8. Finding the embedded LO frequency uses two methods, a frequency sweep method to detect the approximate IF frequency (broadband) and a phase versus time method (precise).

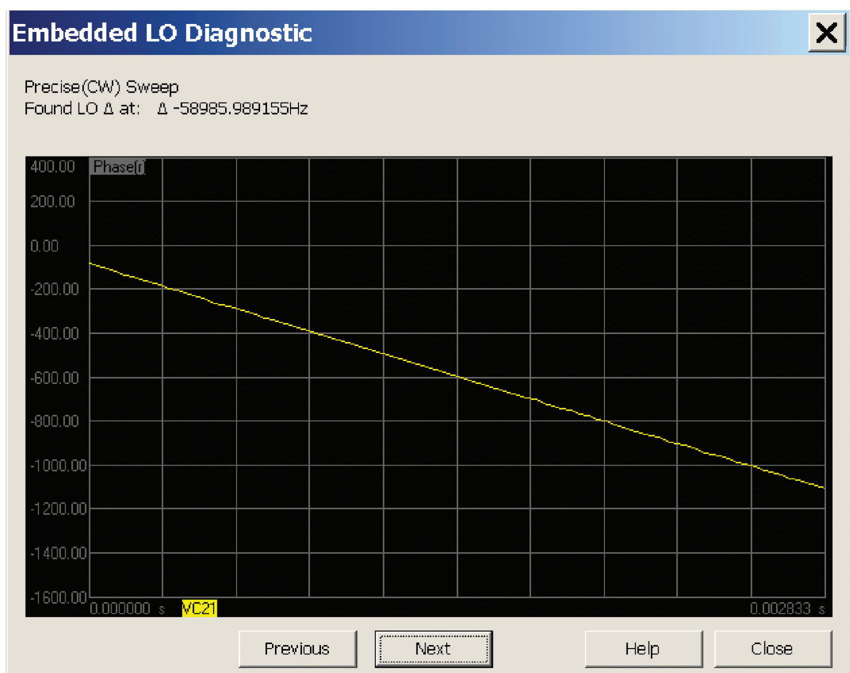


Figure 9. This shows the first phase versus time result comparing the reference channel to the DUT channel. This phase (scale is 200 degrees per division) change shows that the estimated DUT LO frequency is off by about 1000 Hz.

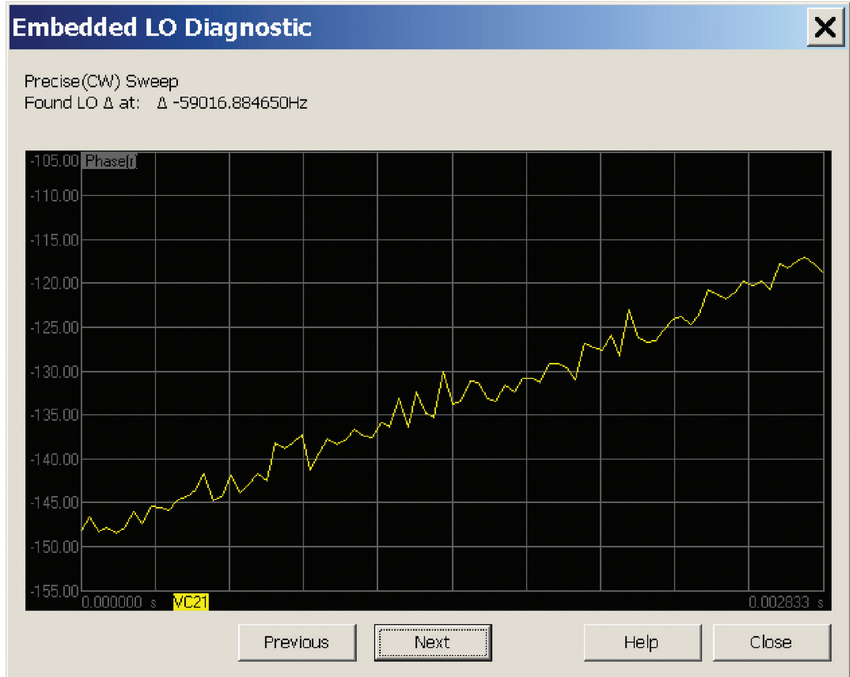


Figure 10. After updating the Reference LO, the phase change shows that the estimated DUT LO frequency is still off by about 30 Hz. At this scale, the effects of phase noise can be seen on the phase trace.

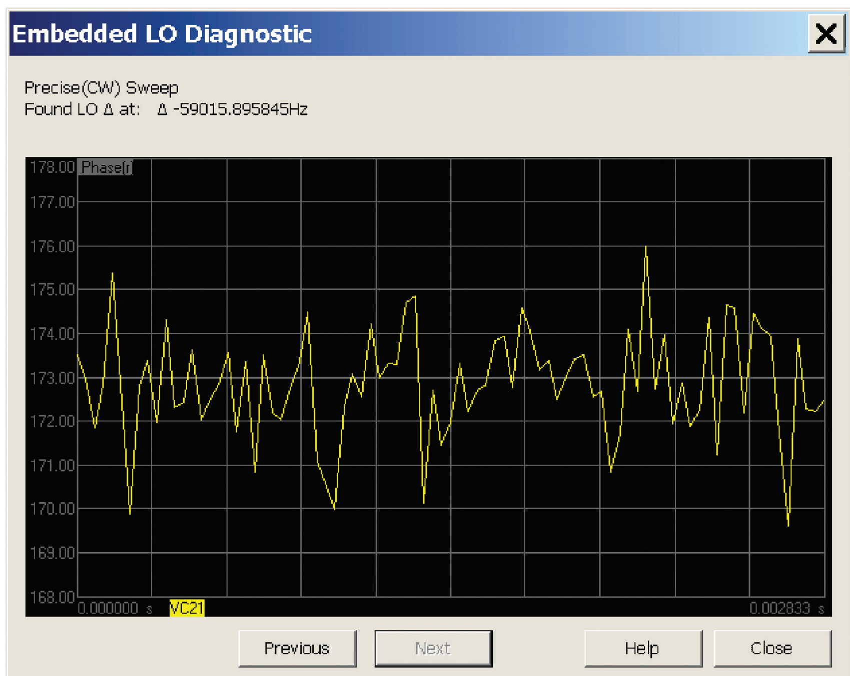


Figure 11. After updating the reference LO, the phase change shows that the estimated DUT LO frequency is still off by about 1 Hz (default tolerance). Perform VMC at this reference LO frequency.

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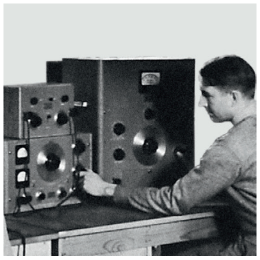
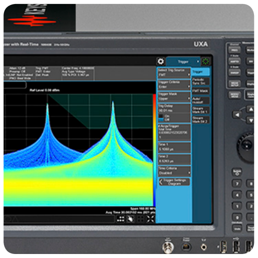


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