

# Network analyzer doubles as oscillator diagnostician

Normally used with filters and amplifiers, the network analyzer can also characterize microwave oscillators efficiently.

**A.P.S. Khanna**, Senior Member, Technical Staff, Advanced Technical Laboratories, Loral Corp., 5001-G Forbes Blvd., Lanham, MD 20706; and **J. Obregon**, Professor LCOM, UER des Sciences, University of Limoges, France

**C**OMPLET E characterization of microwave oscillators normally requires a bench loaded with expensive laboratory equipment. It doesn't have to, however. You can recruit your old reliable network analyzer to serve double duty and, in conjunction with a signal generator, reveal the major performance characteristics of a microwave oscillator.

Network analyzers are normally used to characterize filters, amplifiers, and similar microwave devices. However, the network analyzer can also be profitably employed to test microwave oscillators using the principle of injection locking.<sup>1</sup> By connecting the oscillator under test to the "unknown" port of your network analyzer, a reflection or transmission injection locking polar diagram (ILPD) is developed. The parameters displayed were previously obtainable only with a spectrum analyzer, a frequency counter, a power meter, a sliding short, a variable attenuator, a circulator, and a signal generator. But now, using your network analyzer and signal generator, you can accurately measure frequency, frequency jumps, power output, harmonic level, injection-locked gain and bandwidth, external quality factor,

nonlinear constants, and output circuit matching characteristics.

The network analyzer is used to measure the magnitude and phase of the injection gain when the oscillator under test is injection-locked, with the signal available at the unknown port. The resulting ILPD resembles ordinary impedance measurements. Moreover, the ILPD can be used to optimize key oscillator operating parameters in a manner analogous to using the network analyzer in its conventional role involving filters and amplifiers.

## Analyzing the theory

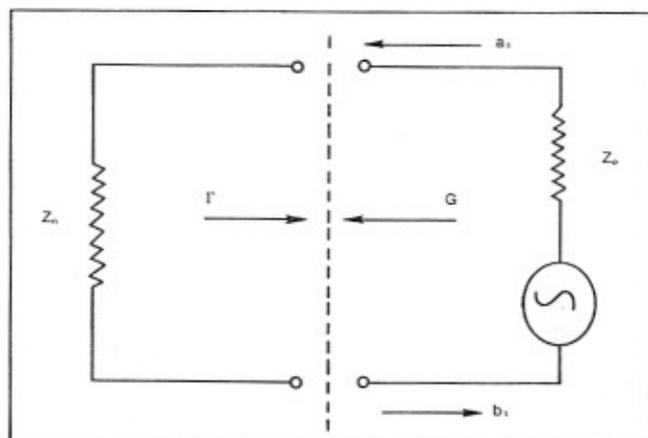
Figure 1 shows the equivalent circuit of an injection-locked oscillator. The reflection coefficient,  $\Gamma$ , and the injection gain,  $G$ , can be assumed constant<sup>2</sup> and defined as

$$G = \frac{1}{\Gamma} = \frac{b_1}{a_1} = |G| e^{j\theta_g}$$

where  $a_1$  and  $b_1$  are the normalized amplitudes of the electric field associated with the incident phase-locking wave and the reflected or output wave, respectively.

An injection-locked oscillator can be treated as a free-running oscillator with the output admittance perturbed by an amount equal to that sufficient to cause the observed frequency

(continued on p. 108)



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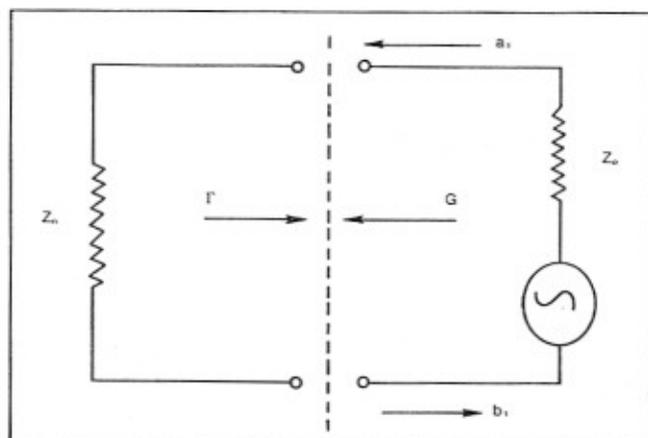
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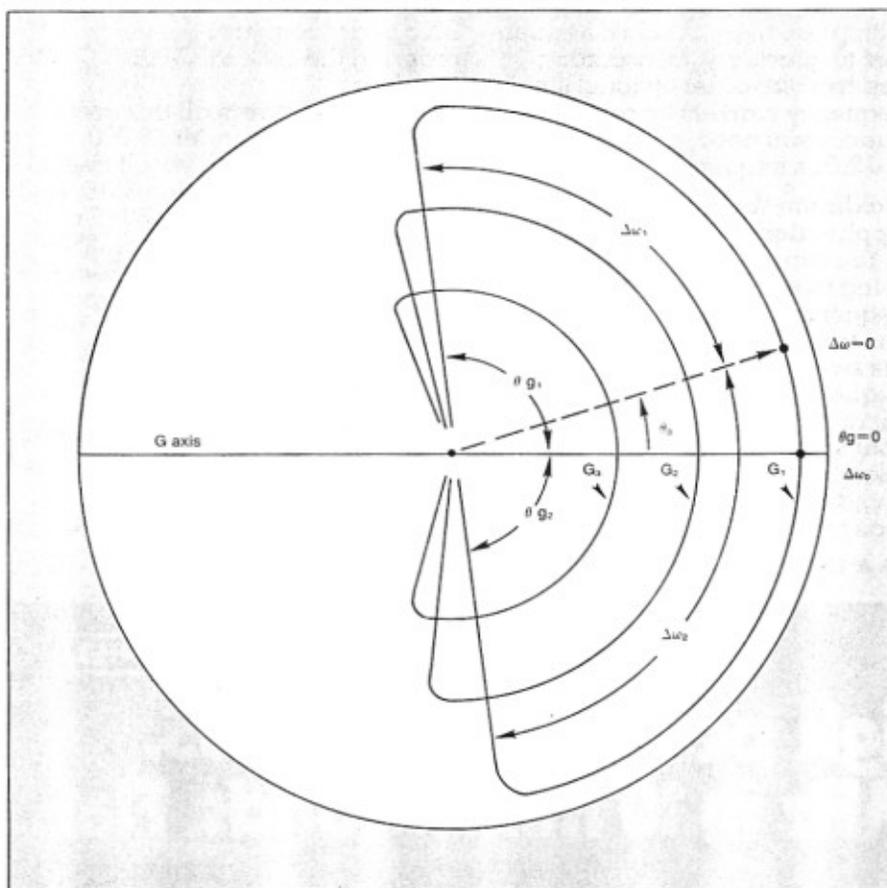
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(continued on p. 108)



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2. A typical injection-locking polar diagram for different injection gains ( $G_1$ ,  $G_2$ , and  $G_3$ ) corresponding to different values of sweep generator power levels ( $P_1$ ,  $P_2$ , and  $P_3$ ).

change. The frequency change of an oscillator,  $\Delta\omega$ , for a known value of  $G$  and  $\theta_g$  is

$$\Delta\omega = \frac{2K\alpha (G\cos\theta_g - 1) + G\sin\theta_g}{G^2 + 1 - 2G\cos\theta_g}$$

where  $K$  and  $\alpha$  are nonlinear oscillator constants that reflect the effect of changes in signal amplitude and frequency on the device's admittance.<sup>1</sup> In Eq. 2 we set  $\theta_g = 0$  and get

$$\Delta\omega_0 = \frac{2K\alpha}{G - 1}$$

Thus, when  $\Delta\omega = 0$ ,

$$\alpha = \frac{G\sin\theta_0}{1 - G\cos\theta_0}$$

Referring again to Eq. 2, the injection gain phases,  $\theta_{g1}$  and  $\theta_{g2}$ , corresponding to the maximum frequency deviations,  $\Delta\omega_1$  and  $\Delta\omega_2$ , can be determined by setting  $d(\Delta\omega)/d\theta = 0$ , which yields

$$\theta_{g1} = 2 \tan^{-1} \frac{G-1}{G+1} (-\alpha \pm \sqrt{\alpha^2 + 1})$$

The corresponding frequency deviations are then calculated from Eq. 2:

$$\Delta\omega_1 = \frac{2K[\alpha(G\cos\theta_{g1} - 1) + G\sin\theta_{g1}]}{G^2 + 1 - 2G\cos\theta_{g1}}$$

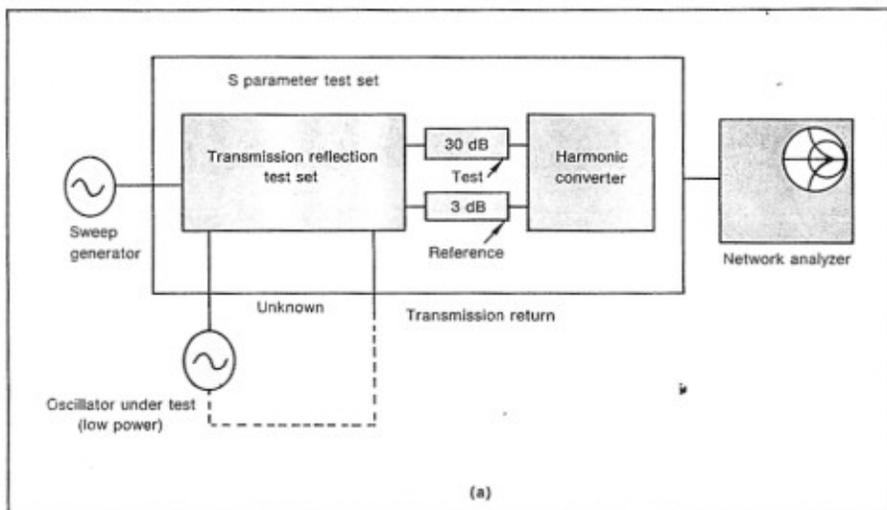
The typical ILPD shown in Fig. 2 shows all the measurable quantities in Eqs. 3 to 6.

**Equipment configuration**

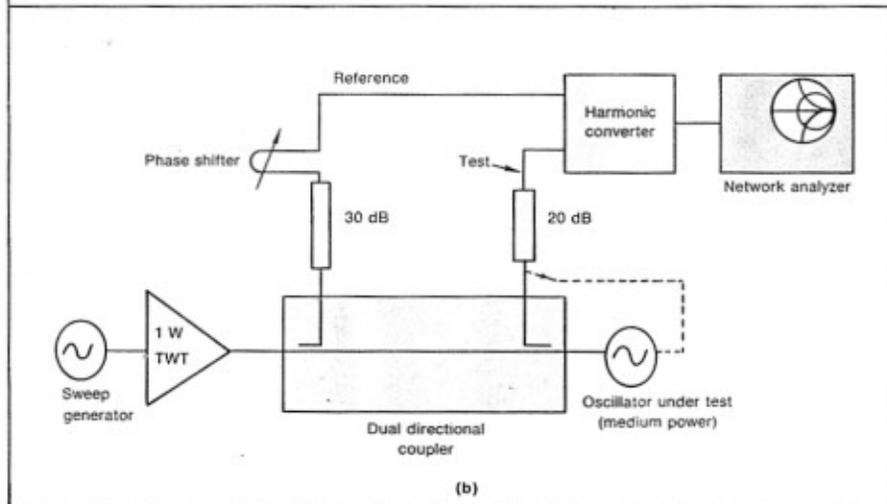
The Hewlett-Packard HP 8410 network analyzer was used for the system described here. For low-power oscillators (up to about +10 dBm), the configuration shown in Fig. 3a was used. Figure 3b shows a higher-power configuration that is useful up to about a 30-dBm output. To increase the gain measurement dynamic range<sup>4</sup> and to protect the sensitive harmonic converter from inadvertent overload, attenuators of 30 dB and 3 dB are inserted in the test channel and reference channel, respectively.

With a range of RF power of from -16 to -43 dBm at the reference channel input of the harmonic frequency converters, the use of a signal generator with a power output of from -10 to +17 dBm allows complete cov-

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(a)



(b)

3. For low-power oscillators, the measurement set-up in (a) was used; the configuration in (b) was used for high-power tests.

erage of the range of possible power variations encountered. For example, using an oscillator having a +10-dBm output, one can measure an injection gain range of from 13 to 40 dB (Fig. 3a configuration).

The equipment can be calibrated for either a transmission or a reflection coefficient mode using a through-line and a short circuit. The phase calibration can be accomplished with the circuit injection-locked with very-high injection gain (> 30 dB). In this case the phase difference between the locked signal and locking source at the center frequency can be assumed to be zero at the parallel tuned-circuit oscillator plane. The reference plane extension control is adjusted to bring the polar injection-locking diagram into the desired plane. The oscillator free-running frequency is measured using a counter to locate the  $\theta_0$  (when  $\Delta\omega = 0$ ) point on the injection-locking diagram.

With the oscillator connected to the S-parameter test set's unknown port, and the sweep generator set to sweep

across about 10 percent of the known oscillator's frequency, noise can be observed on both the polar and rectangular display. This noise is in addition to the desired signal peak on the rectangular display and the ILPD on the polar display. Figure 4 shows a typical rectangular display of a test oscillator.

Next, the sweep band is gradually reduced, and the sweep generator power and the test channel gain are adjusted to obtain the desired ILPD on the polar display for various values of injection gain. The injection gain is thus directly measurable:

Reducing the sweep bandwidth to a usable minimum helps eliminate the noise and improves the ILPD. Figure 2 shows the ILPD for different values of sweep generator power output and hence the injection gain. Figure 5 is an ILPD of a FET DRO operating at 9.5 GHz.

For RF power measurements the test channel gain is set to correspond to an injection gain of >20 dB. Using the signal generator output power level control, the  $\theta_g = 0$  point on the ILPD

is moved to the polar display's outer edge. The oscillator power can then be determined to the accuracy of the signal generator output controls without using a power meter. For the low-power test configuration of Fig. 3a, the oscillator output power is equal to the signal generator output power.

Having established the injection gain,  $G$ , on the ILPD, the remaining parameters can be easily measured. Injection bandwidth,  $\Delta\omega$ , is given by  $|\Delta\omega_1| + |\Delta\omega_2|$ , and the external quality factor,  $Q_{ext}$ , can be determined from

$$Q_{ext} = \left( \frac{2\omega_0}{\Delta\omega} \right) \left( \frac{1}{\sqrt{G}} \right)$$

Significantly, this measurement is made *without* a spectrum analyzer, circulator, directional coupler, and power meter, which are usually required. Moreover, the display presented by the network analyzer is generally more informative than that obtained from a spectrum analyzer because it also gives the injection gain phase information. This is not available from a spectrum analyzer.

The nonlinear constants  $\alpha K$  can now be determined from the measured values of  $\Delta\omega_0$ ,  $\theta_0$ , and  $G$  using Eqs. 3 and 4:

$$\alpha = \frac{dB/dv}{dG/dv}$$

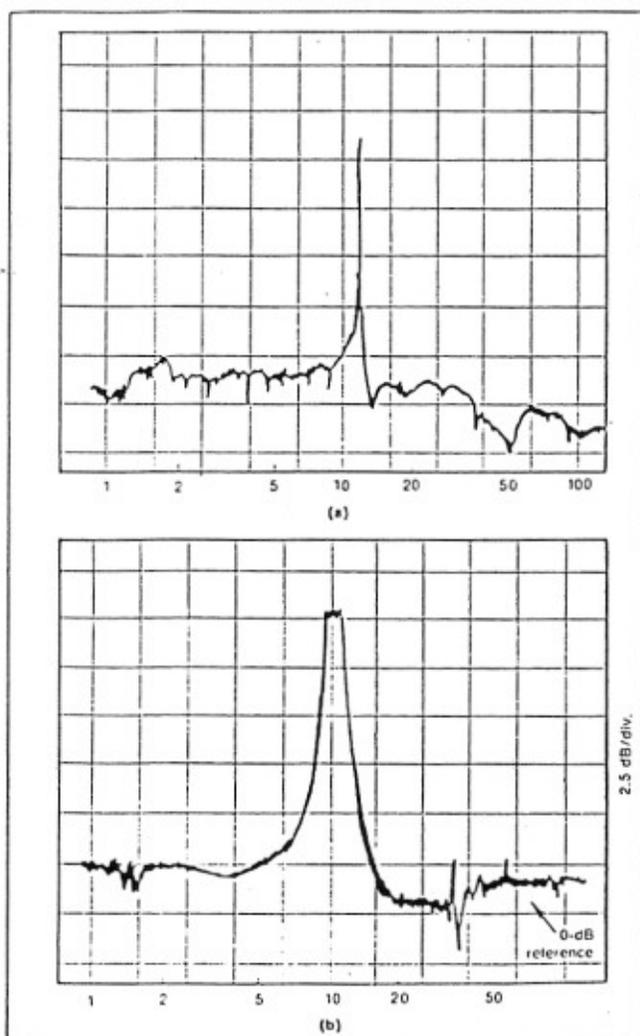
$$K = \frac{dG/dv}{\frac{dG}{dv} \cdot \frac{dB}{d\omega} - \frac{dG}{d\omega} \cdot \frac{dB}{dv}}$$

This approach provides a rapid means of determining  $\alpha$  and  $K$  and graphically depicting the effects of parameters such as biasing voltage on these nonlinear constants. For low values of injection gain the elliptical power variation in the injection-locked frequency range as well as in the locking-range asymmetry (which is a function of  $\alpha^3$ ) can be read directly from the ILPD (Fig. 6).

#### Harmonic measurement

Oscillator harmonic levels can be measured with the network analyzer if the harmonic lies within the analyzer's range. The signal generator is swept over a narrow band of frequencies that must include the harmonic frequency. The harmonic amplitude can then be measured in the same manner as the fundamental frequency power as explained above. To compare the amplitude of the harmonic to that of the fundamental, the injection gain at

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4. Noise in a typical test oscillator was observed when sweeping over about 10 percent of the oscillator frequency. In this case,  $F_0$  is 7.5 GHz, sweep bandwidth is 1 GHz (a) and 100 MHz (b). Power output is 10 dBm, and injection gain is 15 dB.

each of the two frequencies is measured. The signal generator output power must be set at identical levels for each measurement, of course. To ensure accuracy, the injection gain,  $G$ , should be at least 20 dB.

When two or more oscillators are to be evaluated,<sup>6</sup> the transmission ILPD can be obtained using a similar configuration and by connecting the second oscillator port to the transmission return port of the S-parameter test set (Fig. 3). In some cases the transmission ILPD is preferred to the reflection ILPD.<sup>7</sup> For example, occasionally the transmission ILPD can retain higher gain within a given locking range and does not require a circulator to isolate the input and output ports. Using the approach described here, the transmission ILPD can be promptly displayed and readily compared to the reflection ILPD.

The ILPD yields valuable insight into the oscillator output matching circuit as well. Frequency and phase jumps within the locking range are readily displayed and recognized (Fig. 7). The network analyzer thus provides a valuable tool for testing and aligning the output load circuit. Since the injection gain represents oscillator power output (for constant oscillator signal input), the oscillator can easily be tuned for the desired power output. The method employed is comparable to using a network analyzer for tuning a filter or amplifier. This results from the comprehensive display that imme-

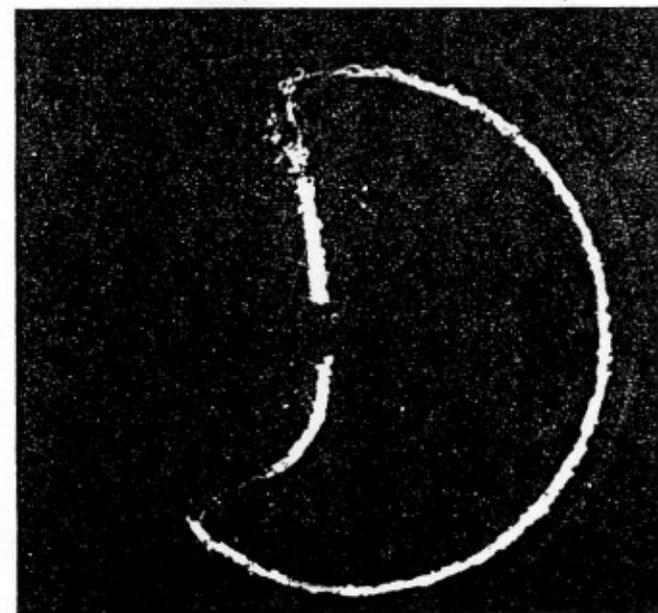
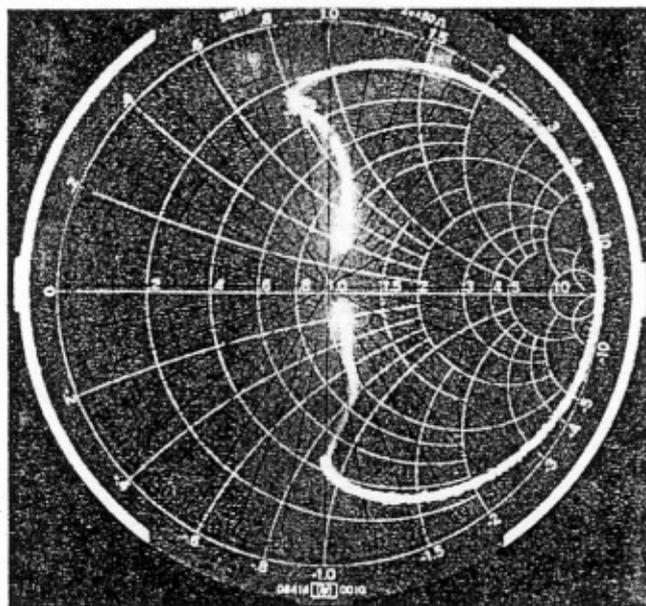
diately shows the effect of changes to load or circuit impedances.

VCO characteristics can also be rapidly characterized using the automatic network analyzer. Tests over a wider range of frequencies should also be possible with the newer HP 8510. Higher dynamic range in the new S-parameter test set allows measurements over a wider range of injection gain too. The time domain analysis mode is expected to help in making new oscillator measurements. ♦♦

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**5. Reducing sweep bandwidth helps reduce noise and improves the injection-locking polar diagram. Power output is 10 dBm,  $F_o$  is 7.5 GHz, injection gain is 26 dB, and  $\Delta\omega$  is 1.5 MHz.**



**6. The asymmetrical locking range of a FET oscillator can be read directly, and clearly shows nonlinearity.**

**7. The ILPD shows the frequency jump of the FET DRO.**