# DIRECT MEASUREMENT OF THE NONLINEAR M.I.C. OSCILLATOR CHARACTERISTICS USING INJECTION LOCKING POLAR DIAGRAM. -

A.P.S. KHANNA
GIGA INSTRUMENTATION
Immeuble ATLAS - Av. Baltique
Z.A. Courtaboeuf Les Ulis
91941 FRANCE
(now with Frequency Sources, Inc., Lanham, MD 20706)

J.OBREGON
Laboratoire Electronique Microondes
Université de LIMOGES
123, rue A. Thomas - 97060 LIMOGES
FRANCE

## Abstract :

Direct measurement of principal characteristics of a negative resistance nonlinear M.I.C. Oscillator using a network analyser is presented. Theoretical considerations and experimental results are shown for the injection locking polar diagram obtained by placing the oscillator directly at the unknown port without the use of a circulator.

## Introduction

The measurement of the microwave oscillators have always been either cumbersome or incomplete. The use of a network analyser has so far been little known. The only oscillator measurements proposed till now using a network analyser have used the injection locked oscillator through a circulator (1). A new measurement is proposed without circulator. We present here simple ways for visualisation and measurement of principal characteristics of an oscillator : for example, injection locked gain and bandwidth external quality factor, oscillator nonlinear constants, output matching circuit characteristics; frequency jumps etc... in addition to output power using a single setup. The principle of the measurement is based on injection locking the oscillator under test, with the signal available at the unknown port of the network analyser (Fig.3) without using a circulator, and presenting the reflection or transmission injection locking polar diagram on the polar display. Use is made of the capability of the network analyser to measure the magnitude and phase of the injection gain under locked condition. The visualisation of the injection gain on the polar display is thus made similar to passive impedance measurement. The theoretical considerations and experimental results are presented. The importance of the approach for rapid characterisation and realisation of the quality oscillators is explained.

## Theory

The equivalent circuit of an injection locked oscillator is shown in figure 1. The reflection coefficient "a" and the injection gain G which can be assumed to be constant (2) are given by:

$$G = \frac{1}{a} = \frac{b_1}{a_1} = |G|\, e^{j\theta g} \qquad (1)$$

For the known value of injection gain G the corresponding perturbed load conductance $\Delta g$ and susceptance $\Delta b$ are given by :

$$\Delta g = \frac{2\,(G\cos\theta g - 1)}{G^2 + 1 - 2G\cos\theta g} \qquad (2)$$

$$\Delta b = \frac{-2G\sin\theta g}{G^2 + 1 - 2G\cos\theta g} \qquad (3)$$

The change in oscillator frequency $\Delta\omega$ is given by[3] :

$$\Delta\omega = K\alpha\,\Delta g - \Delta b \qquad (4)$$

where K and $\alpha$ are the nonlinear constants of the oscillator.

Using (2) and (3) in (4) :

$$\Delta\omega = \frac{2K\,\{\alpha\,(G\cos\theta - 1) + G\sin\theta g\}}{G^2 + 1 - 2G\cos\theta g} \qquad (5)$$

Now

when $\theta g = 0$

$$\Delta\omega_o = \frac{2K\alpha}{G - 1} \qquad (6)$$

when $\Delta\omega = 0$ the relation (5) gives :

$$\alpha = \frac{G\sin\theta_o}{1 - G\cos\theta_o} \qquad (7)$$

Again from (5) the injection phases $\theta g_1$ and $\theta g_2$ corresponding to $\Delta\omega$ maximum and $\Delta\omega$ minimum can be calculated by putting $\frac{d\,\Delta\omega}{d\,\theta} = 0$

This gives us :

$$\theta g_1 = 2\tan^{-1}\frac{G-1}{G+1}\left\{-\alpha - \sqrt{\alpha^2 + 1}\right\} \qquad (8)$$

$$\theta g_2 = 2\tan^{-1}\frac{G-1}{G+1}\left\{-\alpha + \sqrt{\alpha^2 + 1}\right\} \qquad (9)$$

and

$$\tan\frac{\theta g_1 - \theta g_2}{2} = \frac{G^2 - 1}{2G}\sqrt{\alpha^2 + 1} \qquad (10)$$

Using (8) and (9) in (5) the corresponding frequency deviations can be calculated to be :

$$\Delta \omega_1 = \frac{2K \{ \alpha(G \cos \theta g_1 - 1) + G \sin \theta g_1 \}}{G^2 + 1 - 2G \cos \theta g_1} \quad (11)$$

$$\Delta \omega_2 = \frac{2K \{ \alpha (G \cos \theta g_2 - 1) + G \sin \theta g_2 \}}{G^2 + 1 - 2G \cos \theta g_2} \quad (12)$$

All the above quantities are clearly shown in a typical polar injection gain diagram. (Fig.2)

Measurement setup :

For the oscillator measurements described in this paper HP network analyser 8410 was used. Fig.3 a represents the setup for the oscillators having an RF output up to 10 dBm while the setup of Fig.3 b can be used for oscillators with power output up to 30 dBm. In Fig.3 a the attenuators of 30 db in the test channel and 3 db in the reference channel are added to increase the gain measurement dynamic range 4 and to safeguard the sensitive harmonic frequency converter. The limits for the R.F. power at the reference channel input of the Harmonic frequency converter being - 16 to -44 dBm (5) a signal generator having a power output of -10 to 17 dBm covers the complete range of possible power variation for the setup.
For example, for an oscillator with 0 dBm output power, this setup can be used to measure the injection gain range of 3 to 30 db.

Calibration

The set up can be calibrated for transmission and reflection coefficient modulus using a through line and a short circuit , while the phase can be calibrated under injection locked condition with a very high injection gain ( 30 dB). With this it can be easily assumed that the phase difference between the locked and the locking source at the center frequency is zero at the parallel tuned circuit oscillator plane or 180° at the series tuned circuit oscillator plane. The reference adjustable transmission line is adjusted to bring the polar injection locking diagram in its desired plane (Fig.4a)

Measurements

Once the calibration is complete the injection locking polar diagram (I.L.P.D.) can be obtained on the polar display for different values of injection again using the Test channel gain control, signal generator sweep bandwidth and output power Fig.4a . Using the test channel gain control the point on the ILPD corresponding to $\theta g = 0$ is brought to the outer edge of the polar display. The oscillator power output can now be determined to the accuracy of the signal generator controls without using a powermeter, oscillator power for the case of measurements setup shown in Fig.3 a, at any frequency $f_i$ being given by :

$$P_{osc.} = P_{sig.gen.} - 20 \text{ dB} + \text{Injection Gain at } f_i$$

The injection gain and bandwidth from the ILPD as shown in Fig.2 without needing a spectrum analyser .

The external quality factor can now be calculated from :

$$Q_{ext} = \frac{2f_o}{\Delta f} \cdot \frac{1}{\sqrt{G}}$$

where G represents the power injection gain and f the injection bandwidth.

The nonlinearity constants $\alpha$ and K can be determined , from the measured values of G, $\Delta\omega_o$ and $\theta_o$ (Fig.2), with the help of equations (6) and (7). The approach provides a rapid means of determining $\alpha$ and K and visualising the effects of the parameters like biasing voltage variation on their values. The assymetry of the locking range which is a function of $\alpha$ as shown in equations (8) to (12) as well as the elliptical power variation in the injection locked fquency range can be easily verified from the directly displayed Injection Locking Polar Diagram.

Directly displayed ILPD also gives a quick information about the oscillator output circuit. The frequency jumps due to improper tuning of the output circuit can be easily visualised as shown in Fig.5 thus a rapid means of testing and aligning the output load circuit.

In the case of two or more (6) output ports oscillators, the transmission injection locking polar diagram can be obtained Fig.4 (b) in the same way and can be compared to the reflection ILPD at each port rapidly.

CONCLUSION

A direct oscillator measurement technique has been presented using Injection locking polar diagram. This allows rapid testing and alignment of the MIC oscillators. All the principal characteristics can be measured from the directly displayed transmission and reflection characteristics of the oscillator in the form of injection locking polar diagram on the polar display of the network analyser.

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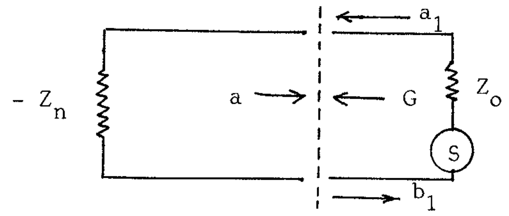
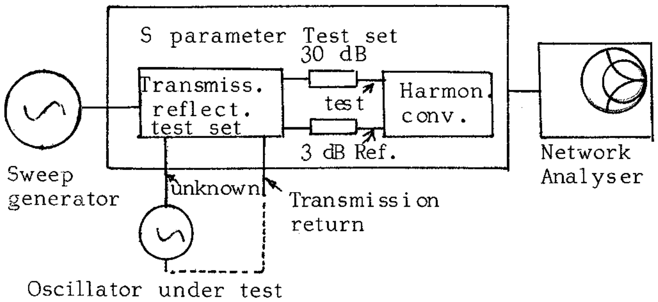



Fig. 1   Injection locked oscillator



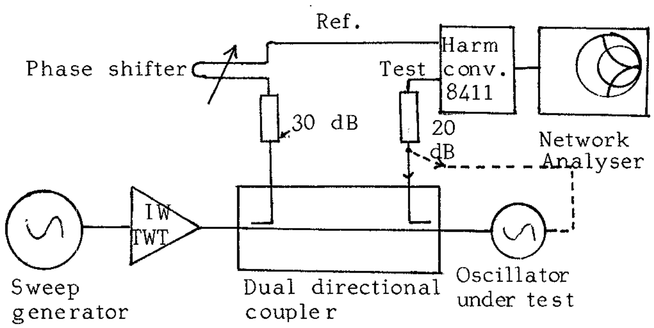




Fig. 3   Measurement set up

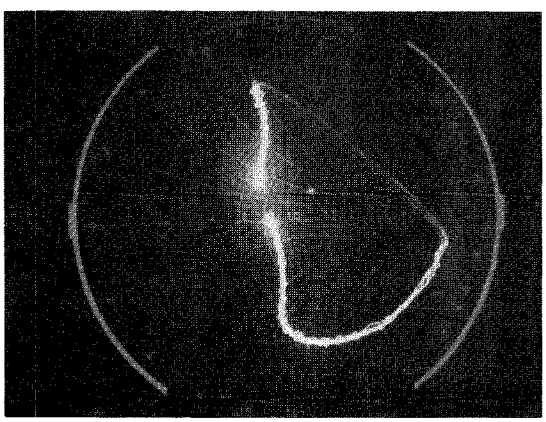


Fig.5   Typical frequency jumping

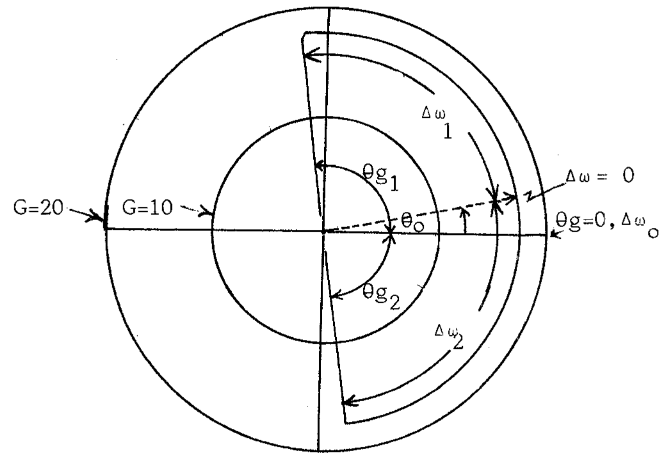
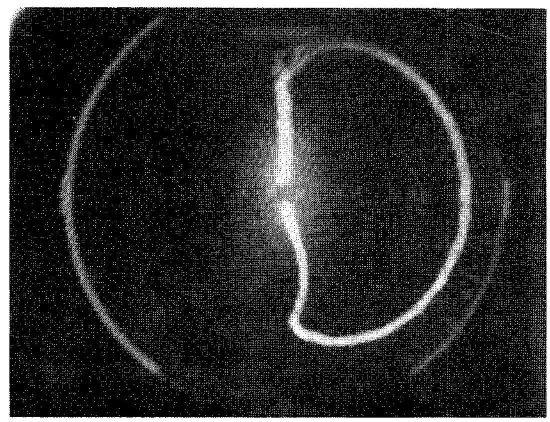
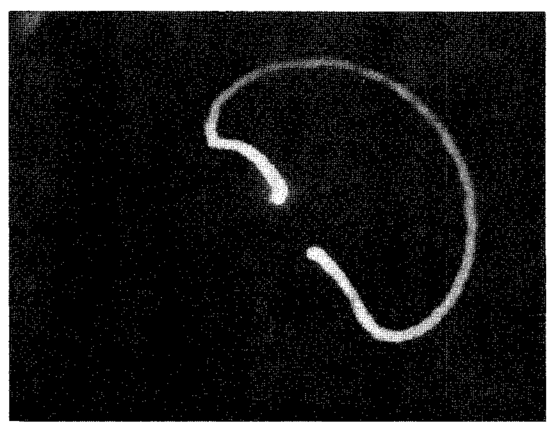



Fig.2 Typical injection locking polar Diagram



4 (a) Reflection
G = 26 dB   $\Delta\omega$ = 1.2 MHz



4 (b) Transmission
G = 26 dB   $\Delta\ \omega$ = 2.3 MHz

Fig.4 Injection locking polar diagrams of a dielectric resonator oscillator at 9.5 GHz