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Application Note 2-90

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Microwave Oscillator Testing Using The CCMT

Summary

This note describes a number of practical, fast and easy to employ tests for evaluation and design of microwave oscillations using the Computer Controlled Microwave Tuner (CCMT). These tests include Power, Frequency and Harmonic Pulling as well as Load Sensitivity Analysis of typical stable oscillators such as DRO, CSO and XSO and to some extend also VCO (*). The results of the automatic measurements, when plotted as 3D surfaces or contours over the Load Reflection Factor, provide valuable insight for the characterization, understanding and design improvements of the microwave sources.

(*) DRO : Dielectric resonator oscillator
CSO : Cavity stabilized oscillator
XSO : Crystal stabilized oscillator
VCO : Voltage controlled oscillator

1. Introduction

Among the various measurements on microwave sources which are necessary for design or performance verification the most tedious are those dealing with the variation of the source's parameters with load conditions. The diagram of **Rieke** contains very useful information concerning power and frequency sensitivity on the load, but it is extremely difficult to measure in practice.

The **General Load Pull**, is a practical method to generate Rieke diagrams using the CCMT and consists in systematical scanning of the whole load reflection factor plane with a fine grid of points, measuring frequency, power, harmonic content or spectral purity of oscillators and then graphically processing the data to Rieke-type contours. This method is described in section 2.

The standard **Load Pull Test** of microwave oscillators provides very important specifications such as the maximum variation in frequency and power for a constant VSWR of the load at all phases. The way this method is commonly used however bears systematic errors due to the dependance of the coupling factor on load impedance of the couplers used to measure the oscillator power. A specific **Load Pull** routine, developed around the CCMT and described in section 3 of this note delivers more reliable results.

Finally the **Load Sensitivity** test method is described which is a fully new application routine and measures the differential frequency and power variations of an oscillator as a function of **real** and **imaginary** part of the load separately. This technique is described in section 4.

For the purpose of this note we applied these test methods using CCMT models 1816 (1.6 - 18GHz) and 4026 (25 - 41GHz) on dielectric resonator stabilized oscillators (DRO), voltage controlled oscillators (VCO) and YIG tuned oscillators (YTO) at different frequencies from 8 to 35 GHz.

2. General Load Pull Measurements

2.1 Power and Frequency Load Pull (Rieke diagrams)

Figure 1 shows the basic frequency / power load pull test setup for generation of microwave oscillator load pull diagrams. The requested microwave quantity such as power, frequency, harmonics or spectral purity is measured using the appropriate GPIB programmable instruments via the IEEE 488 bus for a great number of reflection factor points uniformly

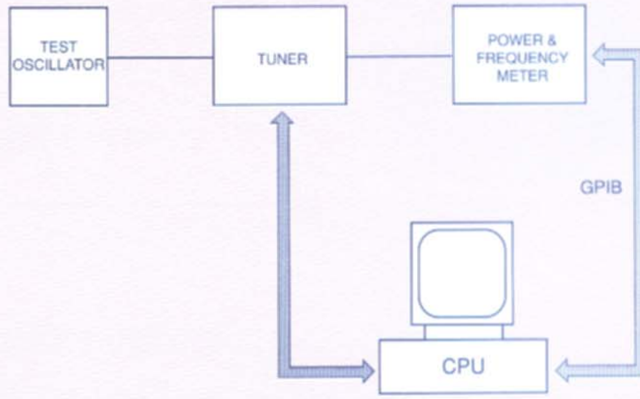

Fig. 1: Setup for oscillator Power and frequency Load Pull

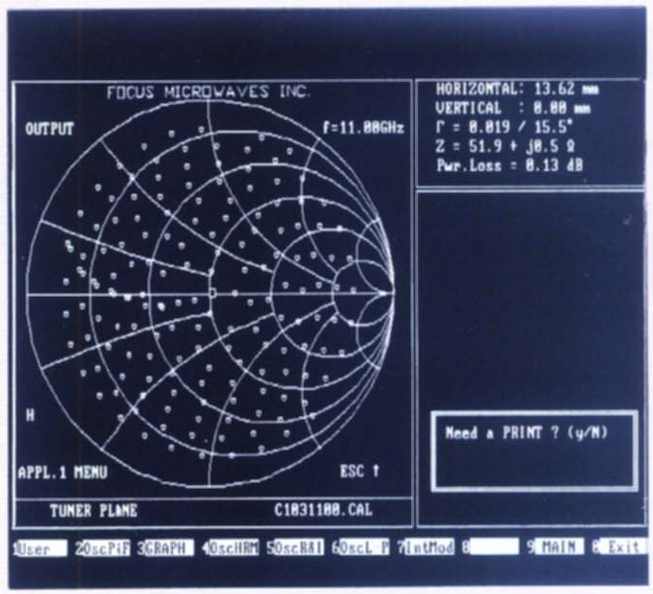

Fig. 2: Distribution of Impedances for Load Pull measurement

distributed over the Smith Chart (figure 2). In this case the use of a frequency counter with power option like HP 5342A or EIP 575 together with a CCMT system to control the load at the fundamental frequency is fully sufficient. A combination of a frequency counter with an analog or GPIB programmable power meter is also possible (see section 6 for instruments supported). A low pass filter inserted between tuner and counter will improve accuracy if the harmonic content of the test oscillator is above -20 dBc.

The number of measurement points can be selected by the user to any fraction of the number of calibration points i.e. between roughly 45 and 360. In order to be able to extract the measured contours with sufficient

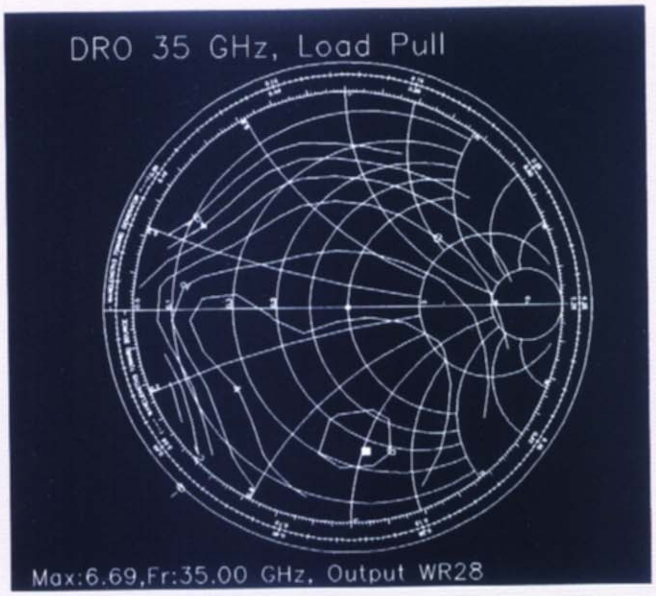

Fig. 3: Power Load Contours of a 35 GHz FET DRO, measured using the 4026 mmWave Tuner

precision it was found that at least 95 points are required. In case of device behaviour showing abrupt changes the number of points used should be at least 180 (see cover picture). All the results in this section have been measured using 181 load impedance points per frequency.

.Figures 4 and 5 represent simultaneous measurements of power and frequency of a YTO at 8.5 GHz. Figure 3 shows **constant power** contours and figure 4 **constant frequency shift** contours as a function of the complex load reflection factor. Both contours together represent the **Rieke** diagram of this oscillator

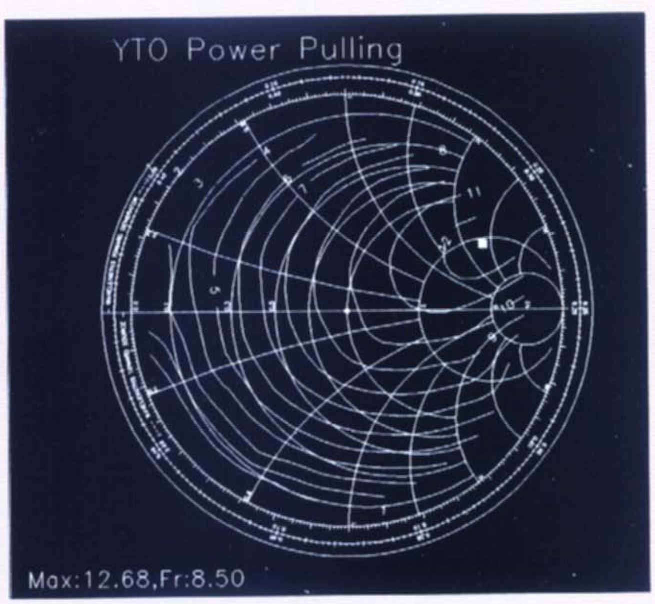

Fig. 4: Constant Power Contour YTO.

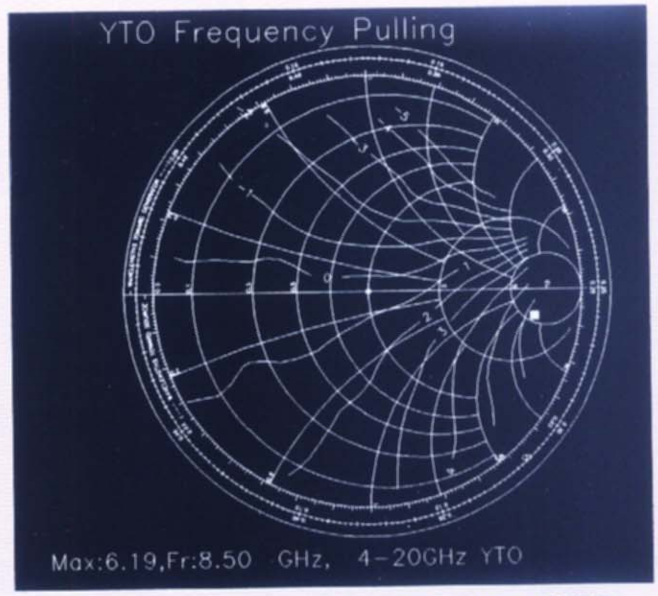

Fig. 5: Constant Frequency Pulling Contour of YTO.

and can be generated by the CCMT system within 3 to 6 minutes depending on the operation frequency.

The cover picture shows the dependence of the output power of a 10.4 GHz reflection type DRO on load conditions. This image which has been generated also from measurements at 180 impedance points uses the **3D surfacing** capability of the CCMT software and demonstrates the real analytic potential of the CCMT system and its Graphics processing capability. This particular DRO ceases oscillating at load impedance around 30-j.30 Ohm but restarts at load impedances lower than 5 Ohm which is unusual and very hard to detect under normal conditions only employing ordinary load pull tests.

2.2 Harmonic Level Load Pull

The setup of figure 6 permits to measure the harmonic content in the oscillator signal as a function of the microwave load at the fundamental frequency. In this case a spectrum analyzer (see section 6) can be used as a selective receiver to pick up a specific harmonic component. The results shown in figure 7 represent the 22 GHz first harmonic component of a 11 GHz DRO. Again these load pull tests represent an efficient, fast and fully documented approach for characterising microwave sources for harmonic content. Simultaneous control of the load at the harmonic itself is also possible but only using a frequency diplexer and a second tuner calibrated at the harmonic frequency. This though limits the bandwidth and increases the complexity of the setup.

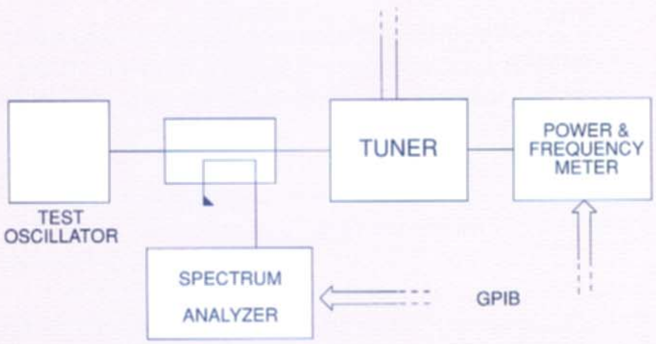

Fig. 6: Setup for Harmonic Level Load Pull

Fig. 7: Harmonic Level of 11 GHz DRO

3. Load Pull Test

The **Load pull test** is a method that permits to measure the maximum power and frequency pulling of microwave oscillators for all phases at a given Load VSWR or reflection factor. The test setup used is shown in figure 8. However the evaluation of measurements is based on the **assumption** that the **coupling factor C** of the coupler is **constant** with changing $\varnothing_L$ of the load. This assumption is not correct firstly because the coupling factor is specified under 50 Ohm load conditions at all ports of the coupler and secondly because directivity effects cause a change of C with Γ_L. The measured Power P at the coupler should therefore be corrected at any load impedance using 3 port "S" parameters of the coupler. This approach is quite impractical and is never being used in reality.

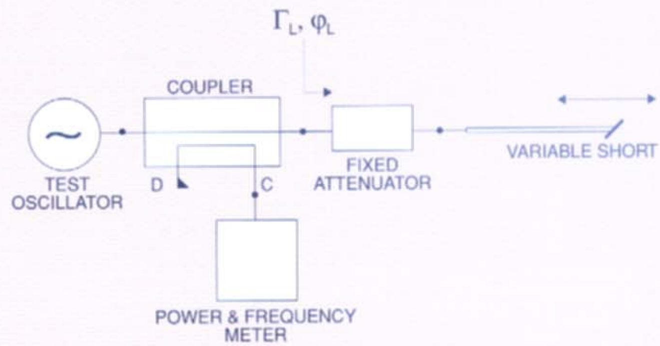

Fig.8: Actually used setup for oscillator Load Pull

The CCMT eliminates this systematic error. A simpler setup as shown in fig. 1 permits to measure power at the output of the tuner and then calculate it back to the output port of the oscillator, since the actual loss of the tuner is known at any impedance point. The impedance synthesis capability of the CCMT permits to tune to a selectable, practically unlimited number of points with $|\Gamma_L|$ = const and change $\varnothing_L$ from 0 to 360° in equal steps. Fig. 9 shows such a measurement pattern.

At each tuned point output power and frequency are measured and corrected to the oscillator output port level. At the end the output VSWR of the oscillator is calculated using the relation (1) which is an important figure of merit for microwave sources. Figure 10 gives an example of a measurement protocol and the associated tuning precision and resolution produced during this test. [1]

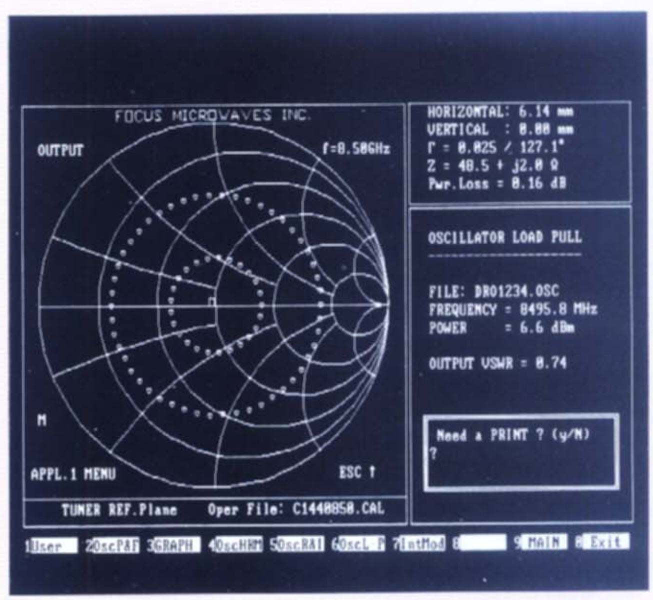

Fig. 9: Measurement Pattern for oscillator Load Pull Test using the CCMT.

$$\text{Output VSWR} = \frac{1 + |\rho_o|}{1 - |\rho_o|} \quad \text{where} \qquad (1)$$

$$\rho_o = \frac{4 \cdot (10^{\Delta p/20} - 1)}{10^{\Delta p/20} - 1}$$

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FREQ = 8.50 GHz , DRO #12-34

OSCILLATOR LOAD PULL, Fo = 8501.260 MHz, Po = -1.44 dBm

Γ	Ø	FREQ.PULL(MHz),	POWER PULL (dB)
0.300	0.0 °	0.000	0.00
0.299	7.2 °	-0.094	0.16
0.300	14.4 °	-0.196	0.33
0.300	21.6 °	-0.328	0.53
0.300	28.8 °	-0.459	0.70
0.297	36.5 °	-0.603	0.94
0.300	43.2 °	-0.732	1.15
0.300	50.4 °	-0.894	1.45
0.300	57.6 °	-1.072	1.94
0.300	64.8 °	-1.203	2.32
0.300	72.0 °	-1.324	2.67
0.300	79.2 °	-1.391	2.96
0.300	86.4 °	-1.426	3.22
0.300	93.6 °	-1.423	3.43
0.300	100.9 °	-1.367	3.51
0.300	108.0 °	-1.293	3.53
0.301	115.2 °	-1.191	3.47
0.301	122.4 °	-1.077	3.35
0.301	129.6 °	-0.906	3.19
0.301	136.8 °	-0.775	2.99
0.301	144.0 °	-0.645	2.77
0.301	151.2 °	-0.517	2.52
0.300	158.4 °	-0.392	2.27
0.301	165.4 °	-0.284	2.01
0.301	172.8 °	-0.198	1.79
0.301	-180.0 °	-0.105	1.54
0.300	-172.8 °	-0.022	1.29
0.299	-165.4 °	0.059	1.08
0.300	-158.4 °	0.114	0.90
0.300	-151.2 °	0.176	0.67
0.300	-144.0 °	0.231	0.46
0.300	-136.8 °	0.275	0.30
0.300	-129.6 °	0.319	0.11
0.300	-122.4 °	0.352	-0.03
0.301	-115.2 °	0.383	-0.17
0.300	-108.0 °	0.413	-0.30
0.300	-100.8 °	0.438	-0.40
0.299	-93.0 °	0.456	-0.49
0.300	-86.3 °	0.468	-0.57
0.300	-79.2 °	0.465	-0.55
0.300	-71.9 °	0.469	-0.59
0.300	-64.8 °	0.464	-0.61
0.300	-57.6 °	0.456	-0.63
0.300	-50.4 °	0.441	-0.61
0.300	-43.2 °	0.417	-0.57
0.300	-36.0 °	0.386	-0.51
0.300	-28.8 °	0.340	-0.43
0.300	-21.5 °	0.289	-0.33
0.301	-14.4 °	0.224	-0.21
0.300	-7.2 °	0.148	-0.08
0.300	0.0 °	0.049	0.11

Fig. 10: Measurement Protocol of a DRO Load Pull Test.

4. Load Sensitivity Measurements

The CCMT system software includes an **Impedance Synthesis** routine which permits it to tune fast to any arbitrary complex impedance and measure microwave quantities at this point.

This capability of the CCMT is used to measure the differential power and frequency sensitivity of oscillators by changing Real and Imaginary parts of the load by ±10% separately around a starting point. This starting point is then systematically moved all over the complex Load reflection factor plane and the corresponding differential frequency and power pulling factors are measured and displayed on the screen. The frequency and power pulling factors are defined as

$$\text{Frequency pulling factor} = \left.\frac{\Delta f}{\Delta X}\right|_{R=\text{const}} \quad \left[\frac{\text{MHz}}{\Omega}\right] \quad (2)$$

$$\text{Power pulling factor} = \left.\frac{\Delta P}{\Delta R}\right|_{X=\text{const}} \quad \left[\frac{\text{dB}}{\Omega}\right] \quad (3)$$

Best performance is obtained from a microwave source if both frequency and power pulling factors are minimum. It has also been found that a low df / dx corresponds to low phase noise near to the carrier.

The automatic test routine of the CCMT applications software marks these results at different points on the Smith Chart and gives this way the possibility to the oscillator designer to optimize his circuit by tuning it to the right area of the complex load. Figure 11 shows an example of this type of measurement.

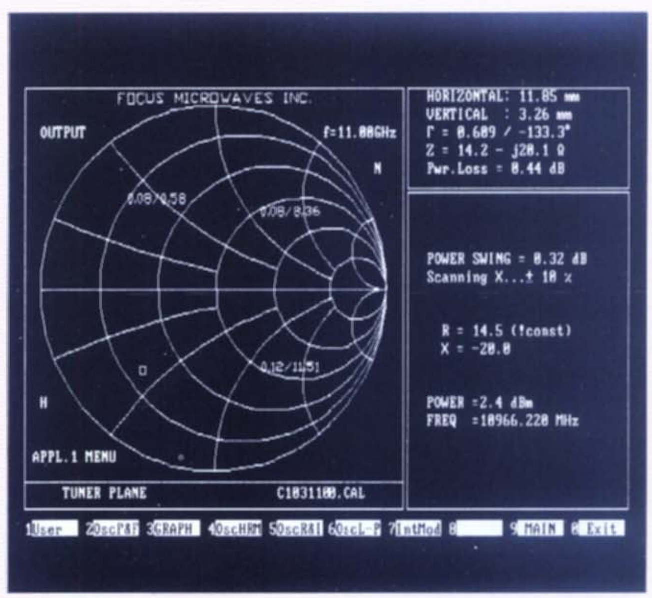

Fig. 11: Load Sensitivity Measurement

5. Measurement Errors

The possible measurement errors in this type of oscillator tests can be divided in two families

a. Random errors
b. Systematic errors

The random errors are due to imprecision in S-parameter measurement of the building blocks of the setup and the tuner during calibration, the reproductibility of RF connectors and RF resettability of the tuner. The last one represents probably the most important contribution though still of the order of 40 dB (± 0.005 reflection factor units). The systematic errors are due to frequency pulling during the measurement and the associated error in calibration data of the tuner. Since the CCMT tuners are inherently very wideband devices this error is exclusively a phase error. This phase error of the reflection factor can be estimated to

$$\Delta\varphi = (f_{cal} - f_{mes}) = \frac{4\pi \cdot l}{Co} \quad (4)$$

In the case of a tuner of serie 1800 (1.6 to 18 GHz) the phase error can be calculated by

$$\Delta\varphi\,[deg] = 0.19 \cdot \Delta f\,[MHz] \quad (5)$$

which is acceptable for microwave sources where the maximum frequency pulling does not exceed 10 or 20 MHz. Consequently the methods described in this note are most accurate when applied to high Q sources like DRO, CSO, YTO or XSO and uses wideband tuners, like the CCMT, because this way the systematic error in load impedance, due to frequency pulling, is sufficient small during the scanning of the entire Smith Chart. Tests on VCO should be applied under precautions in order to stay within a low frequency pulling.

6. Instrument Support

The CCMT application software supports most of the commonly used GPIB programmable microwave test instruments. It has also the capability of reading analog test instruments with a DC recorder output. The following GPIB instruments are actually supported:

1. **Network Analyzers** (for tuner calibration) : HP 8510, Wiltron 360, HP 8720 and HP 86160A millimeterwave kit.
2. **Frequency Counters**: HP 5342 and 5343 with and w/o power options, HP 5351, EIP 545 and 575 and Systron Donner 6530.
3. **Power Meters**: HP 436, 437 A and B and HP 438 as well as the frequency counters of 2. with power option.
4. **Spectrum Analyzers**: HP 8569, HP 8562 and HP 70000.

7. Conclusion

The **Computer Controlled Microwave Tuner (CCMT)** system proves very useful in testing microwave oscillators. It permits easy generation of **Frequency, Power and Harmonic Load Pull contours** ('Rieke' Diagrams), **eliminates systematic error** (constant VSWR Load Pull test) and gives **insight** in **fundamental behaviour** of the microwave sources such as their Frequency/Power sensitivity on Real/Imag part of the load.

Measurement examples on DRO, VCO and YTO at frequencies between 8 and 35 GHz are presented.

Acknowledgement

The contribution of Dr. A.P.S. Khanna from Avantek Inc. should be emphasized for his suggestions in the development of some of the routines described and who also provided the Ka-band DRO's tested. The mmWave Tuner model 4026 has been calibrated using the 360 network analyzer of Wiltron Co.

References

[1] Specifying a DRO, Avantek, Application Note AN-M004, 1990

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