Loop-Gain Measurement and Feedback Oscillator Design

Bahman Meskoob, *Student Member, IEEE*, and Sheila Prasad, *Senior Member, IEEE*

Abstract— **The feasibility of a technique for the design of feedback oscillators is reported. An intermediate step is presented during which the loop gain of oscillators can be measured and tuned. Results for an oscillator operating at 6 GHz demonstrate that the output frequency and power of feedback oscillators can be predicted with sufficient accuracy using small signal loop-gain measurements together with an empirical equation given by Johnson.**

I. Introduction

Designing and analyzing the performance of oscillators in terms of output power and frequency is not straightforward. Large signal oscillator design has been discussed by Johnson [1]. The disadvantage of Johnson's method is that it requires a knowledge of the large-signal S-parameters. More recently, harmonic-balance based methods have become popular. With the exception of the method of Filicori *et al.* [2], such methods require a large-signal transistor model. Development of large-signal transistor models is, however, a very time consuming process. Recently, feedback oscillators consisting of a FET amplifier and a microstrip coupler were investigated [3]. It was demonstrated that such oscillators exhibit larger locking bandwidths than reflection type oscillators.

Here, as a design aid, we propose the measurement of the loop gain of feedback oscillators. This measurement can be incorporated within the fabrication process with little additional effort. The loop-gain measurement of a prototype oscillator operating at 6 GHz is presented together with a discussion of its accuracy and use. The loop-gain measurement 1) allows for the convenient tuning of the output frequency, 2) shows the existence of any undesirable oscillatory conditions, and 3) includes the effects of the bias network. In addition, when operated as an injection locked oscillator, the loop-gain measurement can be used to estimate the locking bandwidth. As for the output power of such oscillators, an equation developed by Johnson provides sufficient accuracy [1].

II. Procedure

Fig. 1 shows the schematic of the feedback oscillator. It was fabricated on a ceramic-PTFE substrate with a thickness of 0.635 mm and dielectric constant of 10.2. The oscillator is composed of an amplifier with a nominal gain of 7 dB, a microstrip coupler with a coupling factor of 5.7 dB, and a

Manuscript received June 1, 1992. This work was supported in part by NSF Grant ECS-9005837.

The authors are with the Department of Electrical and Computer Engineering, Northeastern University, Boston, MA 02115.

IEEE Log Number 9202827.

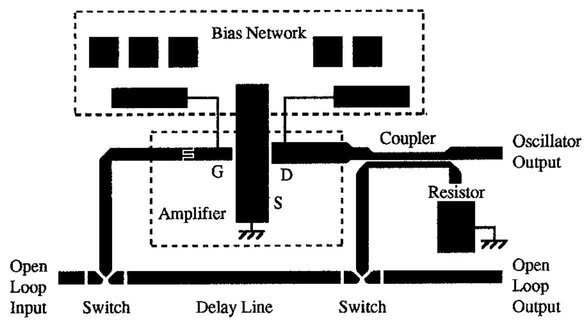

Fig. 1. Schematic diagram of the feedback oscillator.

delay line. The coupler/delay line combination feeds 27% of the amplifier's output power back into the input. The condition for stable oscillation is *unity* loop-gain amplitude and *zero* phase. The length of the delay line is chosen for zero phase while the amplifier gain and the coupler loss are chosen for a loop-gain amplitude of slightly greater than unity.

The amplifier uses a Fujitsu MESFET with a saturation power of 1 W. The capacitor used in the gate matching network is a 0.21 pF four-finger interdigital capacitor. In order to check their performance, a prototype coupler and interdigital capacitor were measured separately prior to oscillator fabrication. To measure the loop-gain, patterns similar to a gap capacitor are used as switches (Fig. 1). Switching action is provided by shorting the gaps. This was done using removable conductive paint; however, more reliable methods are preferable [4].

In order to measure the loop-gain, switches are set such that the circuit acts as a linear amplifier composed of the amplifier, the coupler, and a length of line equal to the delay line. The output of the oscillator is terminated and a calibrated microstrip fixture is used to measure the small signal gain of this "open-loop amplifier."

III. Results and Discussion

Fig. 2 shows the measured loop gain of the feedback oscillator. Both magnitude and phase are displayed. Measurements were performed as discussed in the preceding section from 2 to 12 GHz. For comparison, Fig. 3 shows a Touchstone simulation of the "open-loop amplifier." It should be noted that both the open-loop measurement and simulation include an extra 1.27 mm length of delay line (26° at 6 GHz) as compared to the closed-loop case. There is good agreement between the simulated and measured response throughout the band. This shows the feasibility and accuracy of the measurement. It should be noted that the open-loop measurement requires

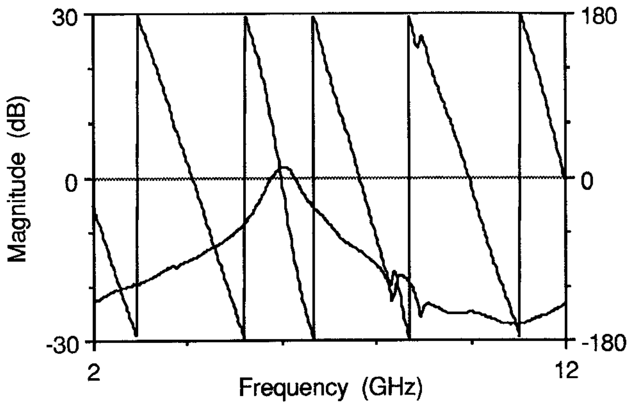

Fig. 2. Measurement of oscillator open-loop gain.

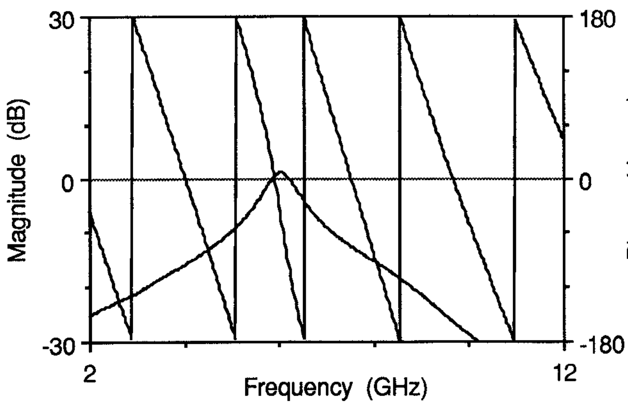

Fig. 3. Simulation of oscillator open-loop gain.

little extra fabrication effort and measurements are those of the final oscillator, not a prototype. All the necessary tuning can be performed during the open-loop measurement. Note that tuning at this stage differs from the tuning of an oscillator in that the "open-loop amplifier" is a linear circuit. Hence, linear simulations provide valuable information. In addition, there can be no hysteresis at this stage and the effects of tuning are easily detectable. The open-loop measurement also indicates any unusual responses due to the bias network such as inductor resonance or drain-to-gate leakage. In addition, a broad-band open-loop measurement shows the possibility of out of band oscillations. Once the loop is closed, the information provided by the open-loop measurement is difficult if not impossible to obtain.

Fig. 4 shows a close-up of the measured response. As mentioned earlier, the open-loop response has an additional 26° of phase compared to the closed-loop response. From the open-loop measurement one can estimate an oscillation frequency of 6.075 GHz. On closing the loop, the oscillator stabilized at 6.05 GHz which is within 1% of the estimated value. The spectrum of the output signal was observed to be clean and free of secondary effects.

To maximize the output power of the oscillator, the transistor bias and the output resistance presented to the transistor were chosen for maximum low-frequency I-V swing. Output power of the oscillator was measured to be 26 dBm. Johnson has developed the following empirical equation for the output

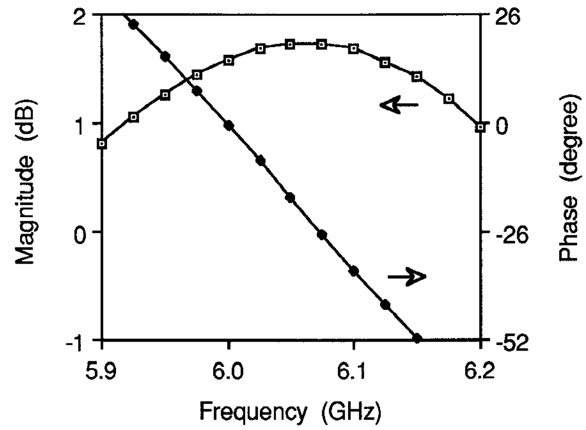

Fig. 4. Close-up of the measured open-loop gain including the additional 26° of phase shift.

power of oscillators [1]

$$P_{\text{osc}}(\max) = P_{\text{sat}}\left(1 - \frac{1}{G} - \frac{\ln G}{G}\right), \tag{1}$$

where P_{sat} is the saturated output power (1 W) and G is the small signal gain of the amplifier (7 dB). Using this equation, the estimated maximum output power of the oscillator is 26.8 dBm. The close agreement between the estimated and measured value indicates that Johnson's equation is well suited for prediction of the output power of feedback oscillators.

The open-loop measurement can also be used to estimate the locking bandwidth of such oscillators. As shown in [3], the fourth port of the coupler can serve as an injection port with the locking bandwidth $\Delta\omega$ given by

$$\Delta\omega = \frac{2(1 - C^2)a_i}{ACa_o}, \tag{2}$$

where C is the voltage coupling coefficient, a_i, the amplitude of the injection signal, a_o, the amplitude of the output signal, and $A = d\phi/d\omega$ where ϕ is the phase of the loop gain. Given the measured phase of the loop gain, the factor A and therefore, the locking bandwidth can be calculated. For the oscillator of Fig. 1, with an injection signal of 5 dBm, the locking bandwidth is calculated to be 42 MHz.

IV. Conclusion

A method for measuring the loop gain of feedback oscillators using two switches is presented. Results for an oscillator operating at 6 GHz show close agreement between the simulated and measured loop gain. The oscillation frequency predicted by the loop-gain measurement (6.075 GHz) and the output power predicted by Johnson's equation (26.8 dBm) agree very well with measured values (6.05 GHz, 26 dBm). The loop-gain measurement allows for the tuning of the oscillator while operating in a linear mode, shows the effect of the bias network and the out-of-band responses, is descriptive of the final circuit, not a prototype, and requires little additional fabrication effort. In addition, it can be used for estimation of the locking bandwidth of feedback oscillators.

ACKNOWLEDGMENT

The authors would like to thank Prof. C. G. Fonstad of M.I.T. and R. Halquist, S. Dicacio, and K. Warner of Northeastern University for sharing their facilities and helpful discussions throughout this and other projects.

REFERENCES

[1] K. M. Johnson, "Large signal GaAs MESFET oscillator design," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-27, pp. 217–227, 1979.
[2] F. Filicori, V. A. Monaco, and G. Vannini, "A harmonic-balance-oriented modeling approach for microwave electron devices," *IEEE Int. Electron Devices Mtg. Tech. Dig.*, 1991, pp. 345–348.
[3] J. Birkeland and T. Itoh, "Two-port FET oscillators with applications to active arrays," *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 112–113, May 1991.
[4] R. S. Bischof, R. C. Blanc, P. B. Harper, "New technology in synthesized sweeper microcircuits," *Hewlett-Packard J.*, vol. 42, pp. 36–46, Apr. 1991.