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A New Measurement System for Oscillator Noise Characterization

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ABSTRACT

The prediction of oscillator noise has been one of the more difficult problems in circuit analysis. A new system for measuring modulation (amplitude or phase) transfer and upconversion is presented which allows insight into the causes of oscillator noise. This system can measure modulation at less than -50dbc and accurately predict the oscillator noise spectrum.

INTRODUCTION

The theory of oscillator noise characteristics has been well established [1,2]. In recent years the focus on GaAs FET oscillator noise has focused on the upconversion of 1/f noise through gate capacitance modulation [3,4]. Characterization of oscillator noise must include more than phase noise via upconversion; it must include all noise upconversion mechanisms and crossmodulation effects at the carrier frequency [1,2]. The following measurement technique provides large signal information on upconversion and crossmodulation in a highly accurate manner. The technique uses simple equipment and provides substantial insight into all the noise contributions to the final noise spectrum. Oscillator noise predictions with this equipment proved to be quite accurate. Predictions within 3db of the final noise spectrum were typical, and predictions within a few tenths of a db were not uncommon. While the ultimate goal is to be capable of predicting oscillator noise from device physics and circuit configurations, this measurement technique provides a useful tool for laboratory verification and analysis.

The measurement system consisted of an amplitude/phase modulation (AM/PM) generator and an amplitude/phase modulation detector. This system allowed both upconversion and crossmodulation (AM–PM and PM–AM conversion at the carrier frequency) to be mesured. The system normally used an open loop mode for testing feedback oscillators, but could be configured in a reflection mode suitable for one–port oscillators. The following sections describe the measurement technique and give some sample results.

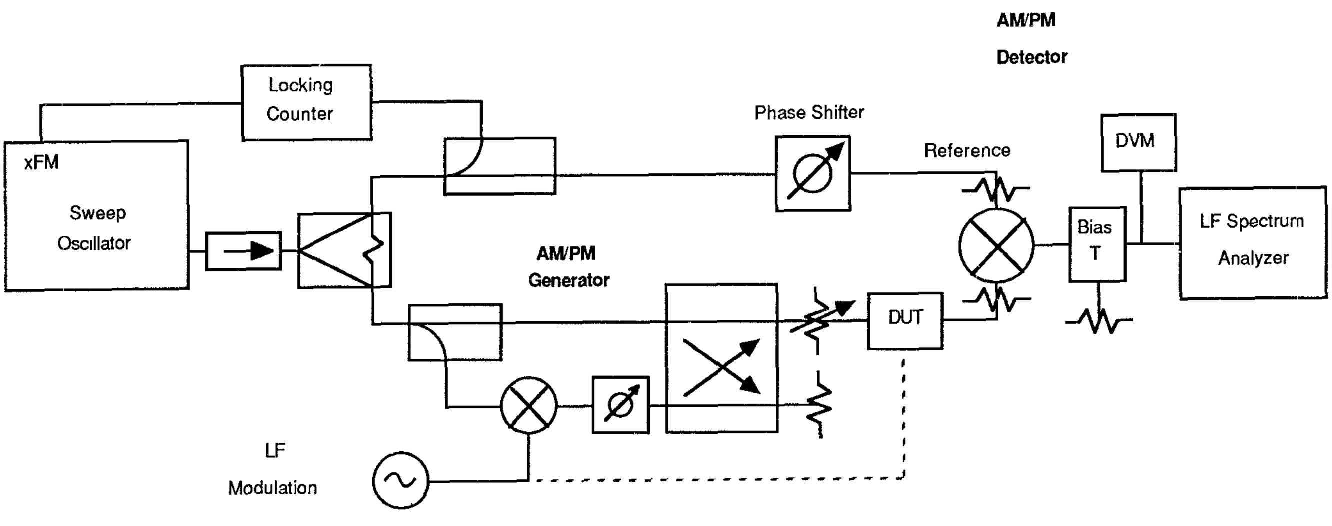

Figure 1. AM/PM generator and detector with device-under-test (DUT).

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MEASUREMENT SYSTEM

Figure 1 shows the measurement system. The system consists of an AM/PM generator, an AM/PM detector, and a device to be tested (DUT). A bridge circuit was used with the DUT in order to measure some oscillator parameters (Figure 2). The bridge circuit was conventional and has been used in static AM-PM conversion experiments [5]. A brief description of the measurement system is given in this section. A complete description of the system, its calibration, and its use is given in [2].

The noise of an oscillator may be predicted from a matrix of modulation conversion coefficients and a vector of amplitude and phase noise terms which include the upconversion of low frequency noise, as shown in the equation below [2]. The terms of this matrix then describe the modulation transfer through the circuit at the modulation frequency and signal level used. The matrix terms (T_{AA}, T_{PA}, T_{AP}, and T_{PP}) represent AM-AM, PM-AM, AM-PM, and PM-PM conversion through the network, respectively. The terms m and β correspond to the final oscillator amplitude and phase modulation noise, respectively. The n_i/A_o and n_q/A_o terms represent in-phase and quadrature noise to carrier ratios at the oscillation frequency. Finally, the partial derivatives of U and V with respect to ε represent derivatives of the real and imaginary part of the oscillator return difference (1–the loop gain) with respect to a device parameter, ε (such as gate bias). The n_i, n_q, and ε terms are statistically independent.

$$\begin{bmatrix} \frac{n_i}{A_o} - \delta\varepsilon \frac{\partial U}{\partial \varepsilon} \\ \frac{n_q}{A_o} - \delta\varepsilon \frac{\partial V}{\partial \varepsilon} \end{bmatrix} = \begin{bmatrix} T_{AA} & T_{PA} \\ T_{AP} & T_{PP} \end{bmatrix} \begin{bmatrix} m \\ \beta \end{bmatrix}$$

The measurements or calculations required to complete this matrix and vector allow a detailed understanding of the noise contributions in an oscillator, but require either a sensitive measurement system or a sophisticated nonlinear analysis program. The equipment described in this paper allows the modulation transfer characteristics of an arbitrary system to be measured. A typical measurement sequence follows:

- a high level signal with a small amount of amplitude modulation was generated, passed through the device-under-test (DUT), and the resulting amplitude and phase modulation at the output measured;
- a high level signal with a small amount of phase modulation was generated, passed through the DUT and the resulting modulation levels measured;

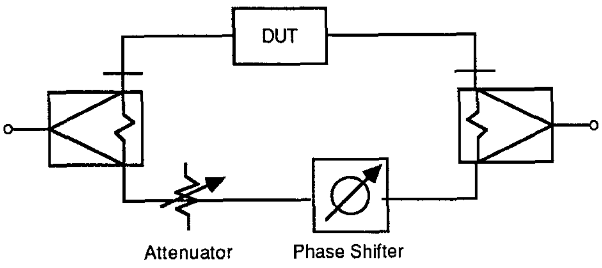

Figure 2. Bridge circuit for delay and amplitude non - linearity measurements.

- an unmodulated high level signal was generated and passed through the DUT while a low frequency signal was applied to the gate or base bias line while the resulting output modulations were measured.

The AM/PM generator consisted of a stable source and a modulator. The stable source was obtained by phase locking a sweeper, since a synthesizer was unavailable. The modulator used a low frequency signal generator and a double balanced mixer to create in–phase or quadrature sidebands [6]. The relative phase of these sidebands was adjusted with a phase shifter. The calibration of the generator was done in conjunction with the detector.

The AM/PM detector used a portion of the unmodulated signal from the AM/PM generator as a reference. This reference signal allowed substantial amplitude independence for the detector. The detector consisted of a phase shifter for the reference signal, a double balanced mixer, and a low frequency spectrum analyzer. The phase of the reference signal was varied with a phase shifter to allow amplitude or phase modulation detection. Since a double balanced mixer down converts signals which are in-phase with the local oscillator (LO), adjusting the phase of the reference signal allowed either amplitude or phase modulation of the signal to be converted to base band. The DC voltage out of the mixer indicated whether the signal and reference were in-phase or in - quadrature.

It is essential to remember that mixers have a dc offset voltage because the quadrature detection point is almost never at zero volts output for a mixer operating in the gigahertz range. When the system was properly adjusted, -57dbc modulation could be detected. This limit was due to the modulation leaking through the directional coupler and power divider in the modulator to the reference signal path. This AM/PM detector has a similar configuration to that in [7]; however, the previous circuit was not used as a modulation detector.

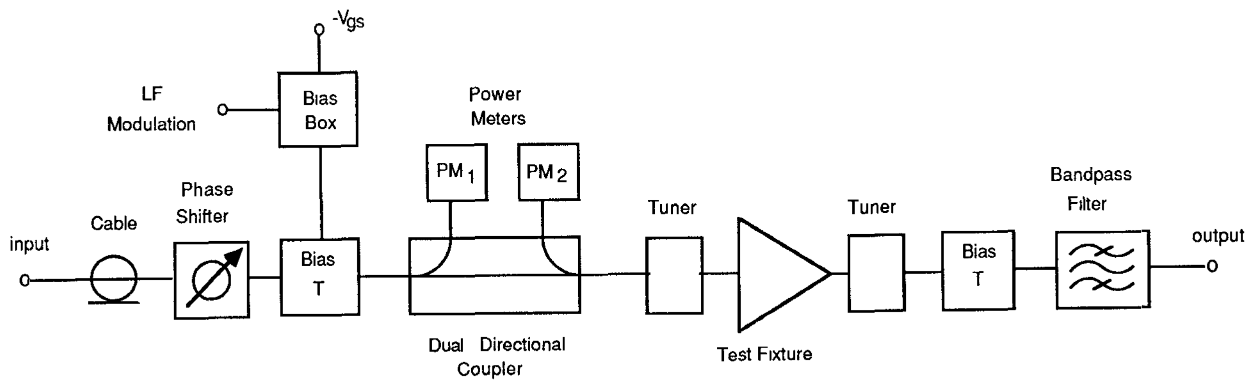

Figure 3. Open loop feedback oscillator circuit.

The bridge circuit shown in Figure 2 was used to measure the delay and amplitude nonlinearity of the circuit at large signals. The diagonal terms of the conversion matrix contained numerically small parts which depended on amplitude and/or frequency. These parts were most easily determined by using the bridge to null the constant part of the term. The bridge would be nulled at the amplitude and frequency of operation, and the parts arrived at through measuring the lack of cancellation at the output of the bridge for a small amplitude or frequency shift.

The oscillator circuit is shown in Figure 3. This circuit was measured at its large signal operating point (unity gain and a net phase shift of 0°) in an open loop configuration. An open loop configuration allows easier identification of circuit component contribution to crossmodulation and upconversion. An oscillating circuit's feedback loop creates a compensation which makes the isolation of individual contributions difficult. Negative resistance oscillators can still use this measuring system, but a high directivity power divider is required to separate the incoming and outgoing signals. Also, the negative immittance circuit would be tuned to oscillation (its large signal operating point), and the signal from the generator would cause injection locking. This would allow upconversion and crossmodulation to be measured.

CALIBRATION

The calibration of the AM/PM generator/detector involved a sequence of events. Initially the generator was hooked directly to the detector, and for the second half of the measuement the DUT was inserted between the generator and detector. Since the DC voltage out of the mixer would be a maximum when the signal and reference were in-phase, this gave a convenient starting point. The reference signal phase would be adjusted to achieve a maximum DC output from the mixer. The modulation phase could then be set for a maximum output (AM) or a minimum output (PM) on the spectrum analyzer. These readings were required for every different source frequency. The signal and reference were tuned for quadrature by changing the reference phase until the DC mixer output equaled the offset voltage (the average of the maximum and minimum DC output at that frequency and signal level). When the DUT was inserted, the relative phase of the signal and reference would change, but the AM and PM settings of the generator would remain the same. This allowed direct measurement of the modulation transfer characteristics once the mixer DC voltages had been used to recalibrate the reference and signal phase.

MEASUREMENTS

Table 1 shows measured results on a GaAs FET circuit. The results are given in db. These results show:

- amplitude modulation upconversion, first increasing with drive level and then decreasing;
- phase modulation upconversion increasing with drive level;
- AM–PM conversion, first increasing and then decreasing with drive level;
- amplitude modulation being reduced with drive level (i.e. the circuit was limiting);
- no effect on phase modulation conversion;
- and PM–AM conversion increasing with drive level.

Table 1. Modulation Characteristics of a GaAs FET.

Modulation	Pin (dbm)		
	-9.5	-2.2	3.4
up AM	-28.1	-26.3	-29.6
up PM	-16.2	-13.6	-3.2
AM-PM	-39.5	-32.0	-51.4
AM-AM	-0.3	-3.5	-12.2
PM-PM	0.0	0.0	0.0
PM-AM	-45.5	-46.0	-37.4
freq.(GHz)	3.9205		

The oscillator noise spectrum was predicted using the upconversion measurements and the low frequency noise data from the device. Although this general approach would allow noise floor predictions, the phase noise slope followed the roughly 1/f character of the device noise since the measurements were done relatively close to the carrier frequency. The best results were made at 10kHz offset and gave a predicted £ (script L) of –76.6db when the oscillator was tuned to the center frequency of the filter and –68.9db when the oscillator was tuned to the –3db frequency of the filter. The measured £ were –76.5db and –69.2db. A low Q filter (≈ 540) was used in the oscillator circuit so that accurate measurements could be easily made. Of course, the oscillator phase noise scales with the Q of the filter.

CONCLUSIONS

An accurate method for measuring modulation transfer and upconversion has been presented. This method allows prediction of oscillator noise near and far from the carrier. This technique used readily available equipment and easily achieved a sensitivity of –50dbc. This is substantially greater than the –30 to –35dbc limitations of most detectors and discriminators. Although the equipment was mainly used for oscillator noise characterization, the method is applicable to any circuit where modulation transfer or large signal characterization are a concern.

ACKNOWLEDGEMENTS

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