COMPARISON OF AM NOISE IN COMMERCIAL AMPLIFIERS AND OSCILLATORS AT X-BAND[1]

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Abstract - **In this paper we discuss the importance of amplitude-modulated (AM) noise. AM noise is often neglected and considered as a minor problem. However, AM noise can become very important in high performance systems that require ultra-low phase-modulated (PM) noise and where the designer is struggling with AM-PM conversion. Few discussions are available on the AM noise of different microwave components. In this paper we report the AM noise of different commercial amplifiers and oscillators at 10 GHz. To adequately characterize the AM noise of high performance amplifiers, we design and investigate an air-dielectric cavity resonator oscillator with outstanding AM noise performance. We also present the AM noise of different AM detectors at 10 GHz.**

I. INTRODUCTION

Recent developments in microwave oscillators have rightfully focused on realizing excellent phase-modulated (PM) noise performance. This performance is required for many applications including low-jitter communication systems, surveillance and radar systems, indeed all systems requiring spur-free, low-phase noise signals [1-3]. Several low-noise oscillators, either commercially available or special-purpose state-of-the-art oscillators, are discussed in the literature [4]. One of the key components of these oscillators is an amplifier, used both in the loop for oscillation and outside the loop for signal isolation and distribution. PM and AM noise of an amplifier play an important role in establishing the noise performance of an oscillator. Besides this an amplifier is also important as a distribution amplifier. For example, in order to distribute the signal from low-noise oscillators to one or more locations, at least one amplifier is usually required. Therefore, low-noise microwave amplifiers are very critical in establishing the noise of the amplified signals from these low-noise oscillators.

Several studies can be found in the literature on the PM noise performance of different types of amplifiers and its effects on the PM noise of an oscillator. However, very few discussions are available on the AM noise of different amplifiers and oscillators [5-7]. AM noise is often neglected and considered as a minor problem. However, even low-level non-linearity in a system can convert AM noise to PM noise, and this conversion may degrade overall performance.

In this paper we extensively study the AM noise performance of different commercial amplifiers and oscillators at 10 GHz under different operating conditions. Section II describes our two-channel cross-correlation AM noise measurement system for testing amplifiers. In Section III, the PM and AM noise performance of an air-dielectric cavity resonator oscillator that has been used as a reference source at 10 GHz are presented. AM noise performance of different commercial amplifiers and detectors are presented in Section IV. Finally, a summary is provided in Section V.

II. CROSS-CORRELATION AM NOISE MEASUREMENT SYSTEM FOR AMPLIFIER

Figure 1 shows the block diagram of a two-channel cross-correlation AM noise measurement system [8]. A reference oscillator drives the device under test (DUT), which in this case is an amplifier. The output of the DUT is split by the use of a power splitter and each channel is fed to an AM detector. The output of the detector is then amplified and fed to a two-channel fast Fourier transform (FFT) spectrum analyzer. The advantage of this technique is that only the coherent noise, i.e., noise of the DUT and reference oscillator, which is present in both channels, averages to a finite value whereas the time average of the incoherent noise processes approaches zero as $\sqrt{N}$, where N is the number of

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averages used in FFT. A Gaussian noise source of known level is superimposed on the source to calibrate the system.

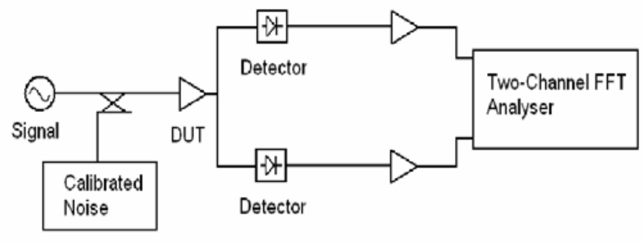

Figure 1. Block diagram of a two-channel cross-correlation system for measuring AM noise in an amplifier.

However, there is one drawback of this measurement technique. If the AM noise of reference oscillator is comparable to or higher than the AM noise of the DUT, accurate measurements of the amplifier AM noise cannot be made. There are few alternatives, such as using a limiter after the reference source, to reduce its AM noise [9]. In our tests, a back-to-back diode limiter after the source did not noticeably reduce the AM noise. Another alternative is to use a carrier suppressed measurement technique [10]. The challenge of this technique is maintaining a very good amplitude and phase match in the bridge channels that are required to suppress the carrier power. Therefore, we focused on building an air-dielectric cavity resonator oscillator (ACRO) with the lowest-possible AM noise, ideally, lower than the AM noise of state-of-the-art amplifiers.

III. AIR-DIELECTRIC CAVITY RESONATOR OSCILLATOR (ACRO) AT 10 GHZ

The block diagram of an ACRO is shown in Figure 2a. It consists of an air-dielectric cavity as the resonator, an array amplifier for loop gain, and a phase shifter. The loaded Q for the cavity is 20,000 and it has an insertion loss of 6 dB; the loop amplifier is a state-of-the-art array amplifier that is designed for low PM noise; it has a gain of 18 dB and a resulting noise figure (NF) of 8 dB. The directional-coupled output power of the ACRO is 19 dBm. The experimental set-up of the oscillator is shown in Figure 2b.

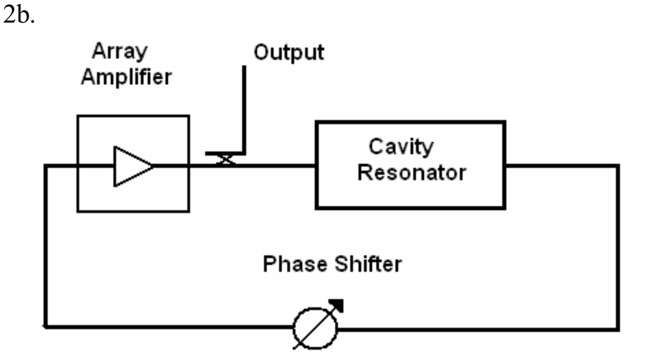

Figure 2a. Block diagram of air-dielectric cavity resonator oscillator.

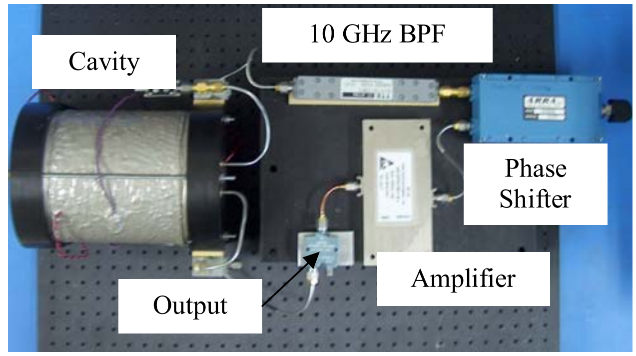

Figure 2b. Experimental set-up.

First we measured the PM and AM noise of the array loop amplifier at 10 GHz, and the results are shown in Figures 3a and 3b (spurs are due primarily to local EMI pickup and not intrinsic to the DUT). We also measured the PM noise and AM noise of the ACRO, which are shown in Figures 4a and 4b. The results are compared with that of a sapphire loaded cavity oscillator (SLCO) [11]. The PM noise of the ACRO is higher than that of SLCO. However, its AM noise is 20-30 dB lower than the SLCO. The AM noise performance of the ACRO is lower than the AM noise of any existing oscillators at 10 GHz of which the authors are presently aware.

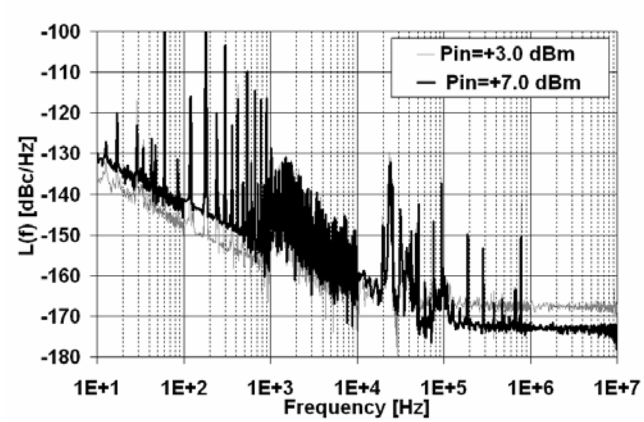

Figure 3a. PM noise of the array amplifier at 10 GHz.

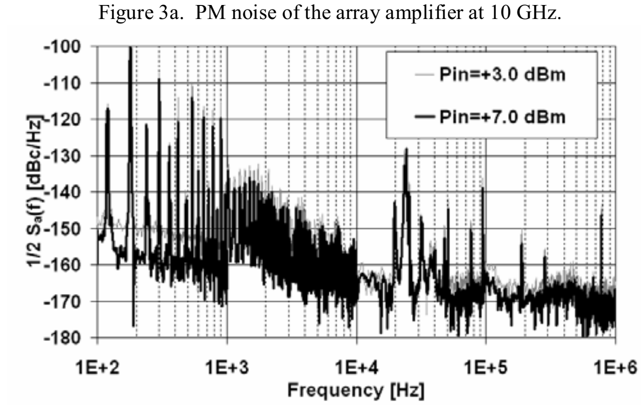

Figure 3b. AM noise of the array amplifier at 10 GHz.

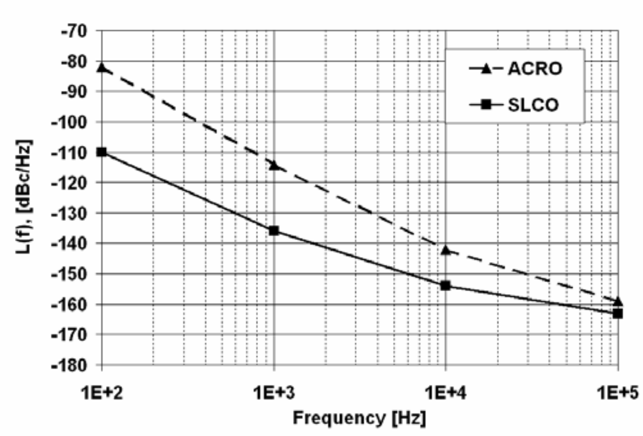

Figure 4a. PM noise of ACRO and SLCO.

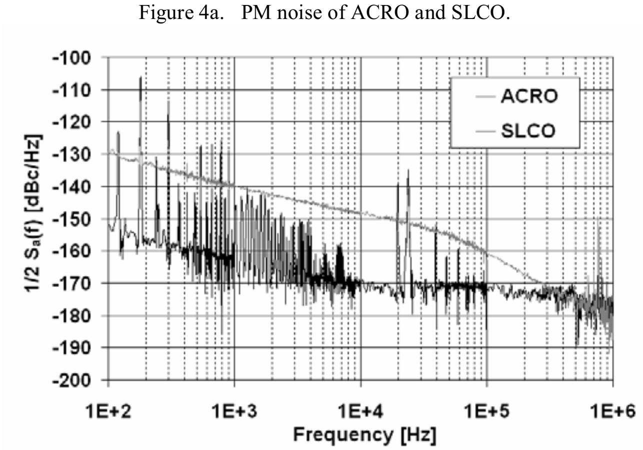

Figure 4b. AM noise of ACRO and SLCO.

IV. Experimental Results

We used the ACRO as a reference oscillator and used the set-up shown in Figure 1 to measure the AM noise of different amplifiers. Most of the amplifiers are GaAs amplifiers. Figure 5 shows the AM noise of different amplifiers when they are operating at 1 dB compression. Measurements of amplifiers with the highest NF have the lowest AM noise performance in the group tested. Figures 6a and 6b show the AM noise of two different amplifiers at various input powers. The GaAs HEMFET of Figure 6a indicates 1/f AM noise that is independent of input power, whereas the GaAs FET of Figure 6b has 1/f AM noise that reduces with increasing input power, which is most often the case.

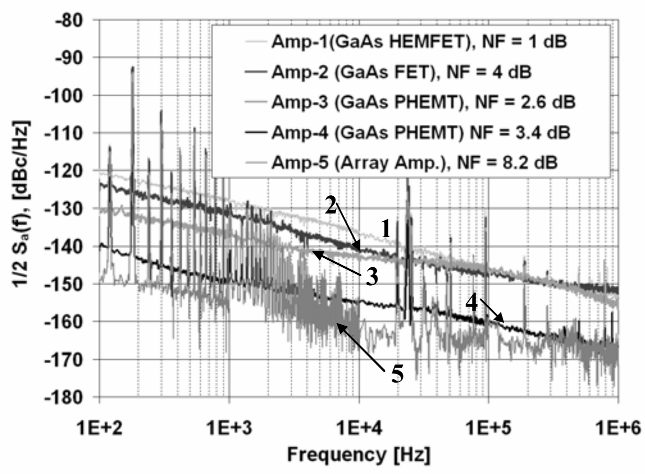

Figure 5. AM noise of commercial amplifiers at 10 GHz.

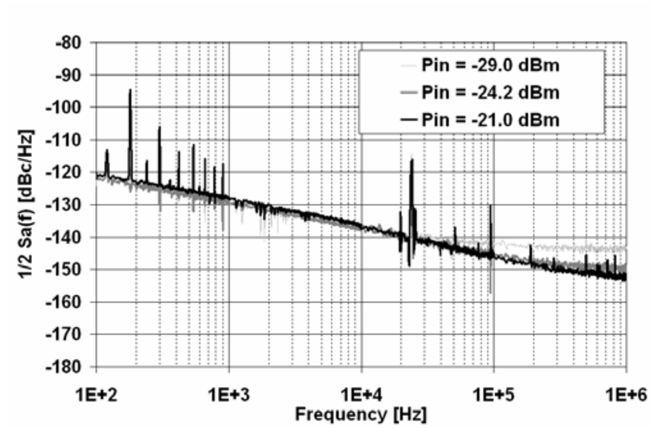

Figure 6a. AM noise of GaAs HEMFET amplifier at 10 GHz for different input power. Gain = 32.5 dB, NF = 1 dB, Pout(1 dB) = 10 dBm.

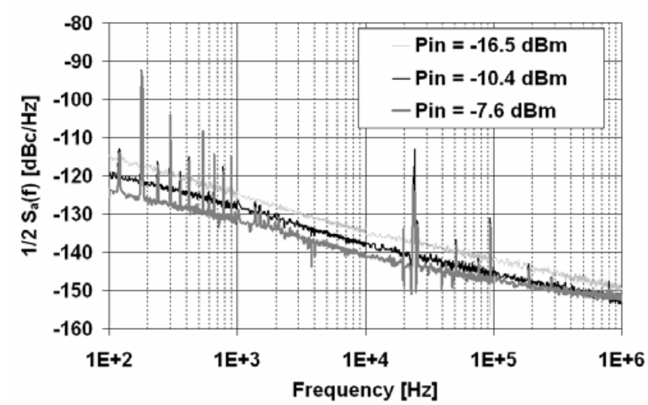

Figure 6b. AM noise of GaAs FET amplifier at 10 GHz for different input power. NF = 4 dB, Gain = 25 dB, Pout(1 dB) = 15 dBm.

We also measured the noise of different AM detectors using the set-up shown in Figure 7a. This configuration actually measures the AM noise of source and detector as well as that of our intermediate frequency (IF) amplifier. However, we separately measured the AM noise of the source and the noise of the IF amplifier, and both were found to be much lower than the detector noise.

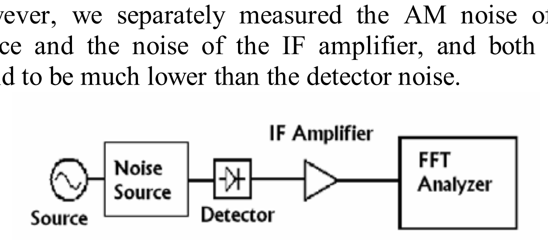

Figure 7a. Single-channel AM noise measurement system for diode.

The AM noise of three different diode detectors are shown in Figure 7b. One notes the wide variability in AM noise among the detectors, indicating the need to hand select for lowest noise.

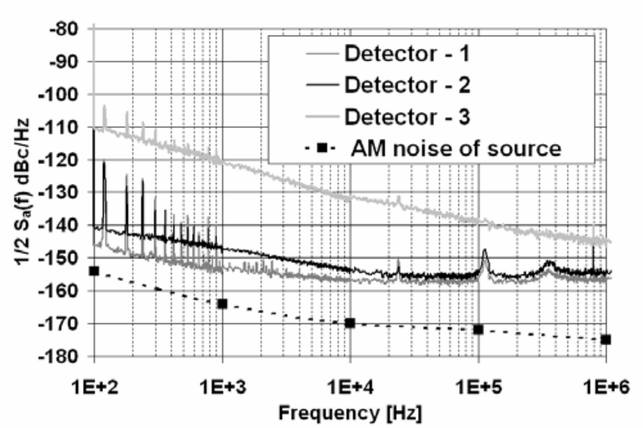

Figure 7b. The AM noise of different diode detectors at 10 GHz.

Finally, we tried to improve the AM noise performance of the SLCO using a limiter at its output; however, we observed no significant reduction in its AM noise. However, when we used our array amplifier instead of a limiter, we observed almost 8 dB reduction in the AM noise of the SLCO, as shown in Figure 8.

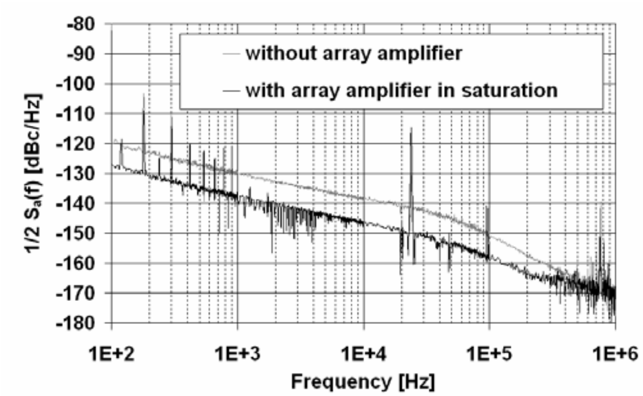

Figure 8. Improvement of source AM noise with the array amplifier operating in saturation at the oscillators output.

V. SUMMARY

AM noise can become important in high performance systems where the designer is struggling for every decibel of performance. Non-linear devices in a system can convert AM noise to PM noise and may degrade the overall phase noise performance. The AM noise of an array of amplifiers in parallel is best among the other commercial amplifiers tested, even though it has higher NF. The AM noise performance of an air-dielectric cavity resonator oscillator in a simple feedback-loop architecture using the array amplifier is better than any other existing oscillator at 10 GHz. We also concluded that an array amplifier actually helps in improving the AM noise of any source by almost 10 dB if this amplifier is used in saturation.

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