

CROSS CORRELATION TECHNIQUES APPLIED TO THE MEASUREMENT OF PM AND AM NOISE IN PULSED AMPLIFIERS†

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ABSTRACT

This paper describes a very fast, automated two-channel cross-correlation based system for measuring phase noise and amplitude noise in pulsed amplifiers. The system uses in-situ calibration to achieve an uncertainty of less than 1 dB for a 10% duty cycle. A typical single-sideband (SSB) noise floor at X-band is -158 dB below the carrier in a 1 Hz bandwidth (-158 dBc/Hz) for a 10% duty cycle and a measurement time of 30 s. The SSB noise floor for a 2% duty cycle is approximately -148 dBc/Hz.

correlation system for measuring phase modulation (PM) and amplitude modulation (AM) noise in pulsed amplifiers. The measurement of PM and AM noise in pulsed signals is much more difficult than continuous wave (CW) systems because of the spread of power over many harmonics of the pulse repetition frequency (PRF) about the carrier. This effect worsens as the duty cycle decreases. Figure 1 shows the microwave spectrum for an approximate 10% duty cycle relative to a CW signal. The power in the carrier is reduced as the duty cycle squared, while the number of signals that are converted to base-band goes as the approximately 1/duty cycle.

INTRODUCTION

In this paper we describe a very fast, automated two-channel cross-

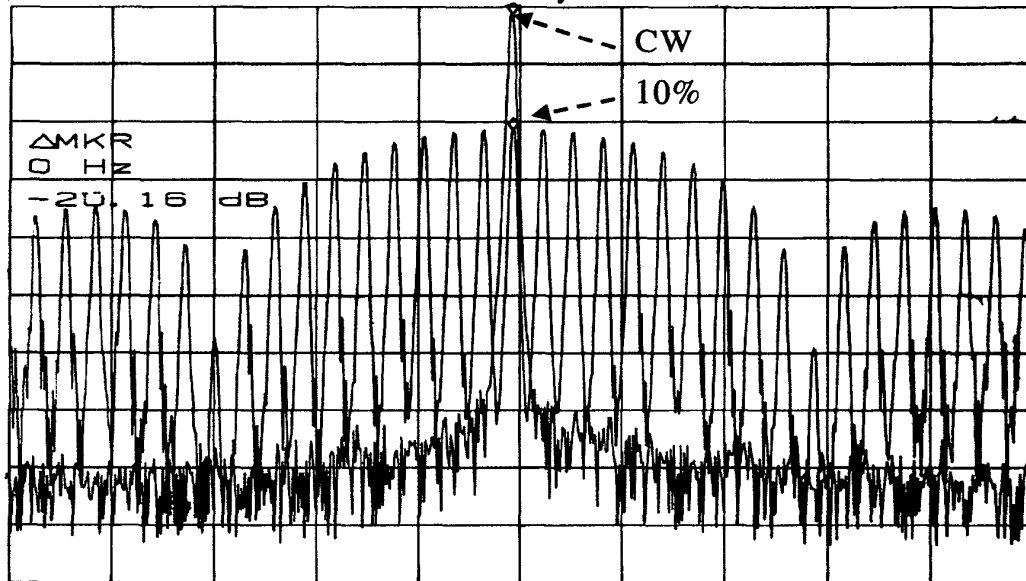


Figure 1. Power spectrum of a CW signal compared to that of a signal with square wave amplitude modulation with 10% duty cycle.

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The net effect is a loss of resolution that scales as the approximate duty cycle squared. An additional problem is that the beats between the various PRF components of the signals can lead to large signals at the PRF and its harmonics at the output of the phase detector. Unless attenuated they can saturate the low level amplifier needed

to achieve a low noise floor. These signals can be minimized by a very careful adjustment of the phase detector to minimize the sensitivity to AM components in the signal. Unfortunately the phase of many high power amplifiers varies with run time as they heat up, which then destroys the phase match

The new NIST system addresses all of these problems. By using a two-channel, cross-correlation approach we typically improve the noise floor by 15 dB over single channel approaches. We use in-situ calibrations to determine the mixer and amplifier gains over the full range of offset frequencies of interest to an uncertainty of approximately ± 1 dB for a 10 % duty cycle. We use a very fast FFT Spectrum Analyzer to minimize the operational time of the pulsed amplifier. For PM measurements we use a phase-lock-loop to maintain phase quadrature at the phase detector.

NIST TWO-CHANNEL PULSED PM AND AM SYSTEM

Figure 2 shows a simplified block diagram of the NIST two-channel system for measuring PM and AM noise in high-power pulsed amplifiers. The microwave signal is pulsed on and off for the selected duty cycle (1 to 100%) using a PIN Diode switch. The pulsed signal is then amplified to a peak power of roughly 1 W. Approximately 10% of the signal is routed through a delay line and split into two reference signals, one for each "LO" port of the two phase detectors.

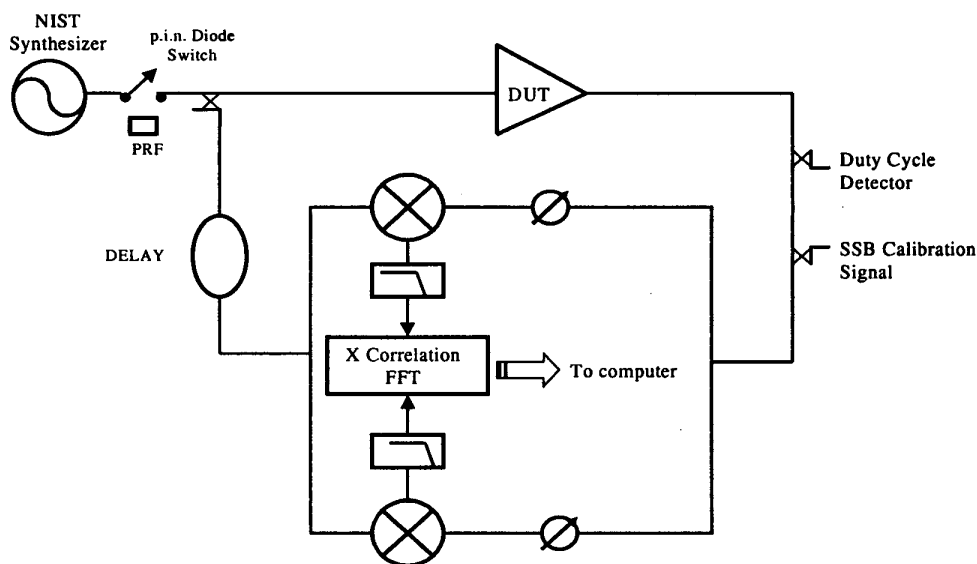


Figure 2. Simplified Block Diagram of NIST two-channel system for measuring PM and AM noise in high-power pulsed amplifiers

Approximately 90% of the power is routed to the device under test (DUT). One part of a dual-channel power meter senses the input power to the DUT. A portion of the signal from the DUT is processed by the "signal" side of the measurement system. A power sensor measures the average power from the DUT. A diode detector is used to determine the precise duty cycle. This information is then used to scale the power sensor data to obtain peak power at both the input and output of the DUT.

A directional coupler is used to inject calibration tones. Using a tunable synthesizer to generate the tones we are able to create both PM and AM tones with offsets from a few Hz to several MHz from the carrier. For example, a single-side-band (SSB) tone that is 50 dB below the carrier generates upper and lower PM and AM side bands that are 56 dB below the carrier. This arises because the SSB tone is only possible when the AM and PM are equal and 90° out of phase [1]. These calibration tones are used to calibrate the sensitivity of mixers when used as either PM or AM detectors. The uncertainty in the calibration is typically less than ± 0.5 dB for CW signals increasing to ± 2 dB at 1% duty cycle. The signal is then split, phase shifted and then used to drive the "rf" side of a double balanced mixer. For PM measurements the phase is adjusted to 90°, while for AM measurements it is adjusted to 0°.

The IF ports of the mixers are amplified and filtered using 9-pole low pass elliptical filters. By choosing a PRF (Pulse Repetition Frequency) that is at least 1.5 times the 3dB cutoff, the feed through signals are minimal. The DC error signal from the output of the IF amplifier is also used to drive a phase shifter on the signal side of the mixer to

compensate for phase changes in the DUT during the test.

The output of the IF amplifier drives a two-channel Fast Fourier Transformer (FFT) spectrum analyzer. The two channels are cross-correlated and averaged to reduce the contributions of measurement noise in the two independent channels. This reduction goes as $1/\sqrt{N}$ where N is the number of averages. On the 100 kHz span, the FFT acquires 512 averages per s. For 2 s of data the incoherent measurement noise is reduced by $5\log(1024)$ or 15 dB. For 10^4 averages the independent measurement noise is reduced by approximately 20 dB.

To suppress the noise in the frequency synthesizer it is very important to match the phase delay for both sides of each measurement channel. We typically try to match the delay to within 5 wavelengths. The phase match is easily determined by sweeping the microwave frequency. For the minimum phase difference of $\pi/2$ radians, the phase shift changes 0.1 radians for a frequency change of 6% of the carrier frequency.

MEASUREMENT CYCLE

Once the operator selects the type of measurement: AM or PM, the duty cycle (1%-100%), the Fourier range of interest, and the number of averages, the system controller initiates a data run. It first closes the phase lock servo about the DUT and then injects SSB calibration tones to cover the offset Fourier frequencies ranges of interest. The calibration cycle typically takes 20 s. The system then takes the cross-correlation noise data over the Fourier span of interest. The noise data is scaled by the calibration data and plotted. The entire data collection process takes 30 s

to several minutes depending on the numbers of averages selected.

Figure 3 shows a 30 s data run with a duty cycle of 10 % at X-band. Figure 4 shows a similar run with 2% duty cycle. In both cases the peak-to-

valley noise is approximately 5 dB, which indicates that the noise level is still determined by the single channel noise divided by $N/2$. Going to 10,000 averages typically reduces this noise floor by another 5 dB.

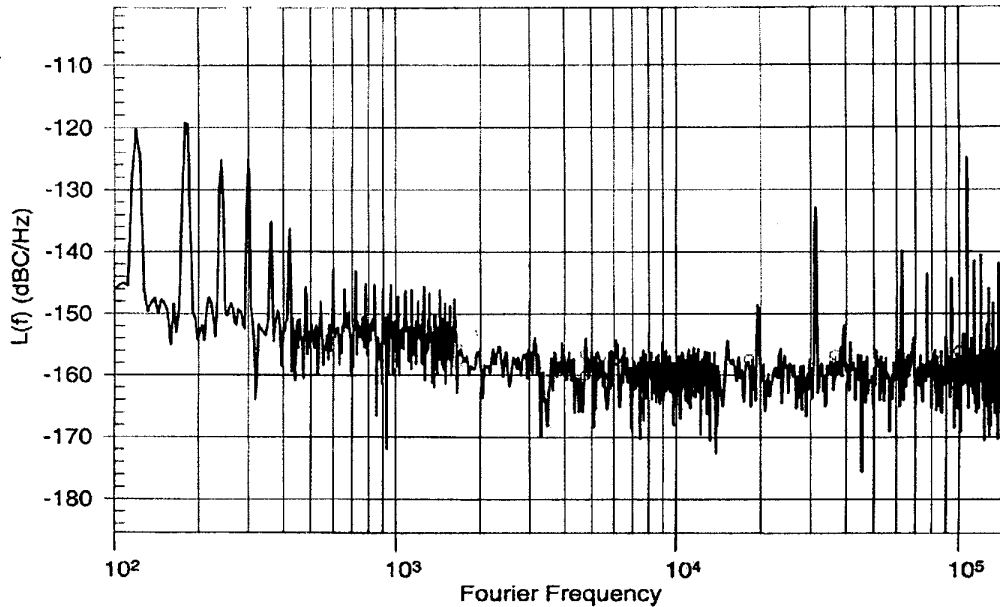


Figure 3. 30 s data from the NIST X-band system showing SSB PM noise floor for 10% duty cycle.

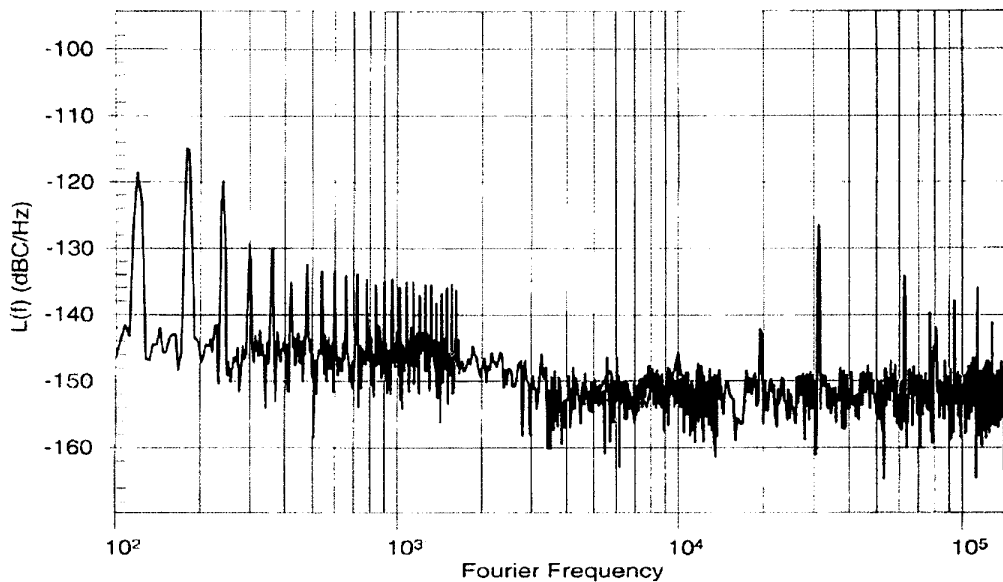


Figure 4. 30 s data from the NIST X-band system showing SSB PM noise floor for 2%.

CONCLUSION

We have described a very fast, automated two-channel, cross-correlative system for measuring PM or AM noise in pulsed amplifiers. Using in-situ calibration techniques we achieve a measurement uncertainty of ± 1 dB and a typical SSB PM noise floor at an offset of 10 kHz of -158 dBc/Hz for a DUT duty cycle of 10% in only 30 s. PM noise floors are even lower for longer measurement times. This approach is usable for carrier frequencies from RF to near 100 GHz.

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