Josh Martin, Matthew Moldovan, Charles Baylis, Robert J.Marks II, Lawrence Cohen, Jean de Graaf,
"Radar chirp waveform selection and circuit optimization using ACPR load-pull measurement,"
2012 IEEE 13th Annual Wireless and Microwave Technology Conference (WAMICON), pp.1-4, 15-17 April 2012
doi: 10.1109/WAMICON.2012.6208465

Radar Chirp Waveform Selection and Circuit Optimization Using ACPR Load-Pull Measurements

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***Abstract*—Due to tightening spectral criteria, joint optimization of radar transmitter waveform and circuit is considered to minimize the nonlinearity and waveform induced spectral spreading of radar transmitters. This work demonstrates the ACPR load-pull measurement of a power amplifier under excitation from two chirp waveforms. The results are compared to allow selection of the optimum chirp and transmitter load impedance. This work represents a beginning effort toward the real-time, computationally intelligent transmitter optimization in future reconfigurable radar systems.**

I. Introduction

In a struggling international economy, wireless broadband applications show promise in providing significant financial return. As such, new developments such as the U.S. President's Broadband Plan [1] are requiring that additional spectrum be allocated for wireless broadband use. Such developments are requiring radar transmitters to operate in more narrow slices of spectrum. For future radar systems, transmitters will need to be efficient, spectrally confined, and reconfigurable. Radar systems are required for critical sensing applications directly related to civilian safety and military tactics. In the United States, spectral allocations are determined by the National Telecommunications and Information Administration (NTIA). The NTIA sets *spectral masks* in the United States within which radar signals are required to be confined [2], as shown in Fig. 1. Allocations are pushing the technical limits of operation for presently used radar systems, which include legacy radars.

A recent paper by the authors [3] demonstrates a test bed that can be used for the measurement and optimization of radar transmitter waveforms. This test bed is a precursor to developing computationally intelligent optimization methods to be used in *cognitive radar*, the radar counterpart to cognitive radio [4,5,6]. The test bed consists of a signal generator, two load-pull tuners, a power meter, and a spectrum analyzer, and is capable of assessing linearity and efficiency through adjacent-channel power ratio (ACPR) and power-added efficiency (PAE) measurements.

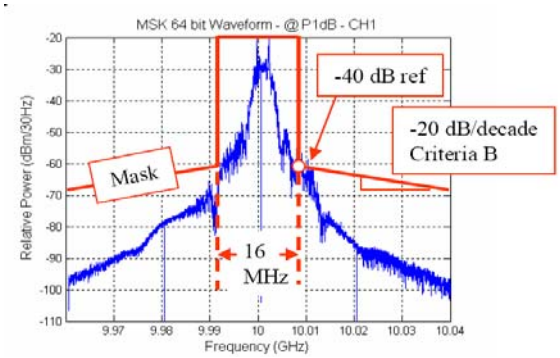


Fig. 1. Spectral Mask Example, Reprinted from [1]

The PAE is a metric that measures the efficiency of the system:

$$PAE = \frac{P_{out,RF} - P_{in,RF}}{P_{DC}} \quad (1)$$

The PAE is a ratio of the added power to the DC power; it tells how much of the DC power is converted in an amplifier to additional RF power leaving the device under test.

The ACPR is the ratio of the power in a defined adjacent channel to the power in the channel under consideration. It is desired that the ACPR be as low as possible. A high ACPR indicates that significant spectral spreading has occurred due to nonlinearities in the device, undesirable waveform characteristics, or a combination of both. A major source of spectral spreading is third-order intermodulation distortion in the amplifier transistor. Third-order products degrade the system linearity. A chirp is a broadband signal. A broadband signal can be thought of as a large number of closely spaced tones; each pair of tones intermodulates, with an overall

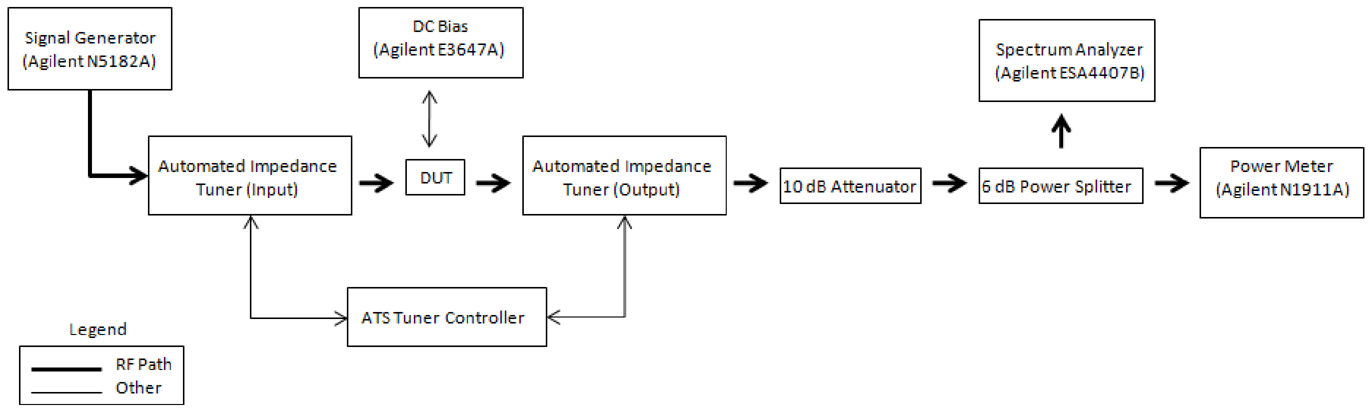


Fig 2. PAE/ACPR Reconfigurable Measurement Setup Block Diagram

result of both in-band and out-of band distortion. The ACPR specifically measures out-of-band distortion. ACPR load-pull has been significantly used to assess the linearity of communication transmitters; however, this paper illustrates the use of ACPR load-pull to optimize a system under chirp excitation for radar applications, and demonstrates that the approach shows significant promise for computationally intelligent algorithm creation for joint optimization of power amplifier transmitter circuitry and the chirp waveform.

A load-pull measurement consists of varying the load and source impedance while measuring some desirable output characteristic for each passive source impedance. The results are then plotted as contours; example characteristics for which contours might be plotted in a load-pull include output power, PAE, and ACPR.

This measurement is crucial for optimizing the waveform and circuit for both linearity and efficiency. Both have been examined in the literature for their impact on radar [7], [8]. Linearity and efficiency are a well-known design tradeoff, as shown by simulation in Agilent Advanced Design System (ADS) for a GaAs FET, as shown in Fig. 3. At the input power where PAE is maximized, the gain is nearly 2 dB into compression, creating a significantly nonlinear operation.

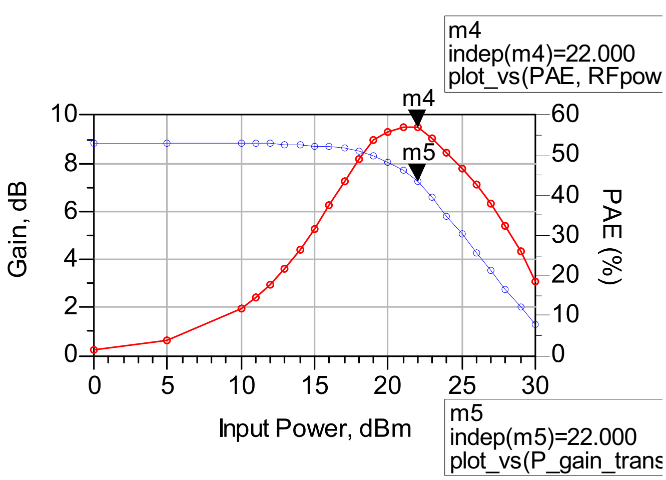


Fig. 3. Gain (Left Axis) and PAE Simulation Results for a GaAs FET

II. Test Setup

The test setup constructed at Baylor University is shown in Fig. 2. A conceptual hierarchical diagram of the test setup is shown in Fig. 4. MATLAB is used in concert with an Agilent vector signal generator to generate the chirp waveform. The Maury ATS load-pull software and tuners are used to perform load-pull measurements. ACPR measurements are taken with a spectrum analyzer, and a wideband power meter is used for output power measurements. While output power, rather than PAE, was used in these measurements, the results seem easily extendable to PAE load-pull. Data for ACPR and output power load-pull can then be inspected to accomplish a design trade-off decision, or in later stages of the work, used in an automatic optimization. A Skyworks packaged amplifier, mounted on an RF test board, was used as the test device for this experiment.

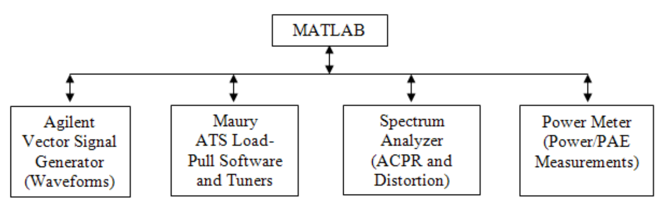


Fig. 4. Hierarchical Diagram of the Baylor Joint Waveform and Circuit Optimization Test Platform

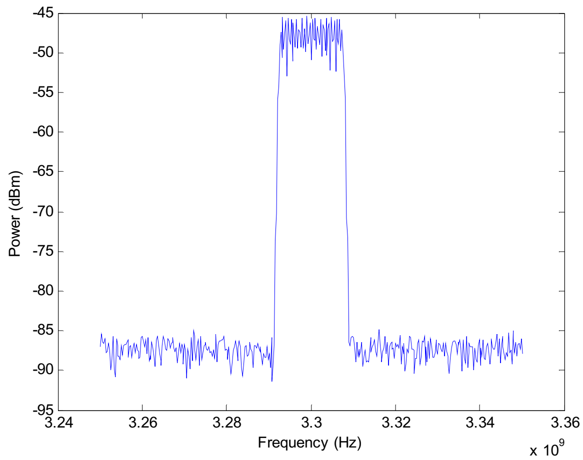
III. Experimental Results

A manual optimization can be performed as follows: load-pull measurements can be performed on multiple chirps for linearity (ACPR) and output power. The optimum chirp is selected to be the chirp with the best tradeoff between high output power and low ACPR. For the best chirp, a load impedance is selected between the impedances measured to have maximum power and minimum ACPR, again based upon the tradeoff between the two criteria (possibly set in place by the spectral mask in the frequency band of operation).

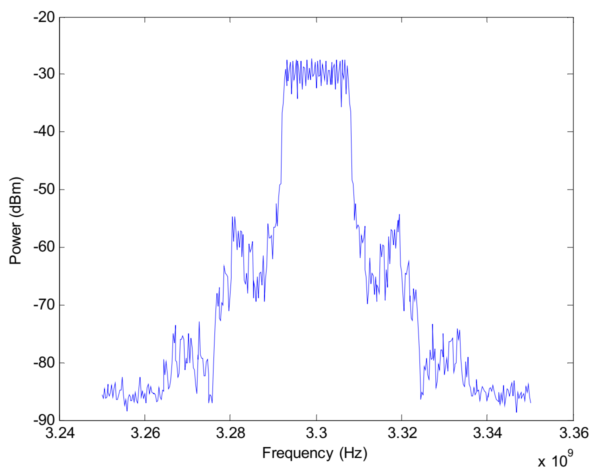
In the experiment detailed in this paper, two chirps were compared for a Skyworks packaged amplifier measured in the designated S-band radar frequency range (3.3 GHz). The first chirp, hereafter called "Chirp 1," possessed a defined amplitude-versus-time characteristic given by

$$\varphi(t) = cos\left(\omega_0 t + t^2\right) \qquad (2)$$

This chirp possesses nonlinear frequency modulation. Fig. 5 shows the input and output measured spectra of the chirp. The spectral spreading is clearly evident in Fig. 5(b).



(a)



(b)

Fig. 5. Measured (a) Input and (b) Output Waveforms for Chirp 1

ACPR and output-power load-pull results were measured for Chirp 1. The Maury software places the spectrum analyzer in adjacent-channel-power measurement mode during the load-pull. A screen shot of the spectrum analyzer captured of chirp 1 is shown in Fig. 6. Markers can be seen on the spectrum-analyzer screen displaying the boundaries of the adjacent and main channels. The ACPR is calculated by summing the power from measured points in the adjacent channel and main channel and then taking the ratio.

The load-pull results for Chirp 1 as displayed by the Maury software are displayed in Fig. 7. The maximum amplifier output power for Chirp 1 was found to be 18.86 dBm, with a minimum ACPR of -31.44 dBc.

Fig. 8 shows the input and output spectra of the Chirp 2 waveforms. Chirp 2 has an amplitude-versus-time characteristic given by

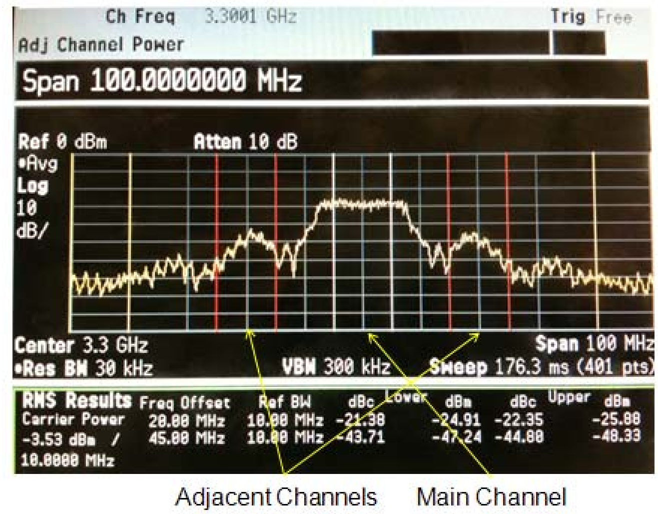


Fig. 6. Spectrum Analyzer Measurement in ACPR Mode

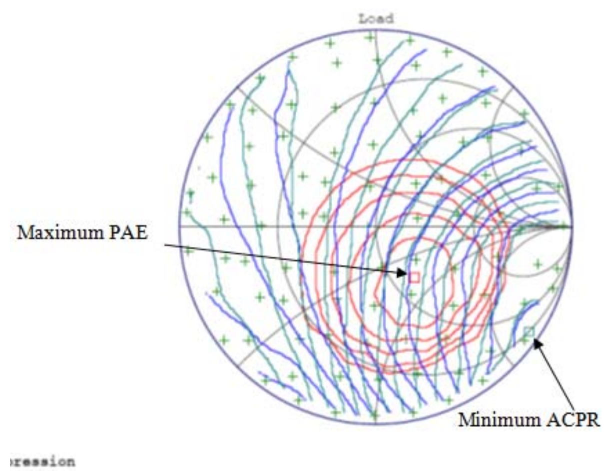
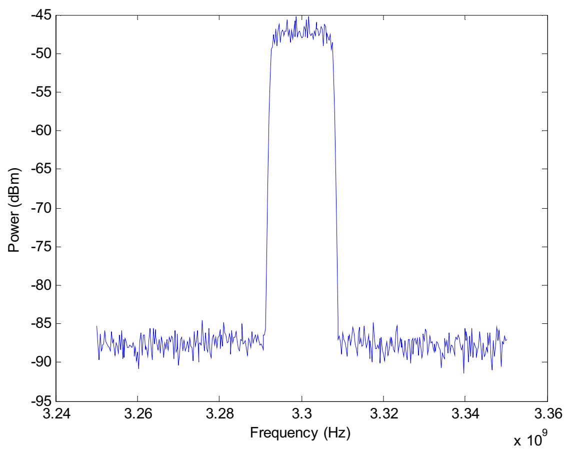


Fig. 7. Output Power and ACPR Load-Pull Results for Chirp 1.

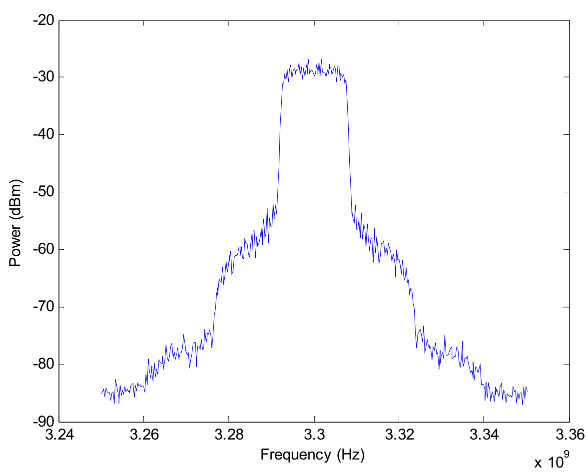
$$\varphi(t) = cos\left(\omega_0 t + t^{-2}\right) \qquad (3)$$

Fig. 9 shows the Chirp 2 load-pull results for output power and ACPR. The maximum output power for Chirp 2 was found to be 18.83 dBm, while the minimum ACPR for Chirp 2 was measured as -33.50 dBc. Comparing the results between Chirp 1 and Chirp 2, it appears the output power for both chirps is approximately the same (only 0.03 dB difference); however, a slight difference is seen in the minimum ACPR values, with Chirp 2 possessing a slightly lower (and hence more optimal) result. Thus, chirp 2 is selected as the optimum chirp for best linearity and gain characteristics. Fig. 9 shows a line along which the linearity and power would then likely be optimized, depending upon the relative importance of linearity and efficiency in the particular spectral region of operation considered. It may be possible that another trail of optimal joint behavior may be best (rather than a line), since this optimization is based upon nonlinear measurements.

This example is a simple example of joint waveform and circuit optimization for two criterion (linearity and efficiency). The use of ACPR measurements to design transmitter amplifier circuitry and waveforms for radar chirps forms a foundation for the next step: developing computationally intelligent methods of real-time optimization.



(a)



(b)

Fig. 8. Measured (a) Input and (b) Output Waveforms for Chirp 2

IV. Conclusions

The useful application of a new test bed to optimize both the waveform and impedance by examining load-pull over different radar chirp waveforms has been demonstrated. A simple joint optimization of amplifier chirp waveform and comparative design will be extensible to multiple-chirp waveform and load-impedance optimizations, and set the foundation for intelligent searches for the optimum point. ACPR load-pull measurement is a useful tool to demonstrate the dependence of radar transmitter spectral leakage on load impedance for radar chirp excitation. Future research will examine multiple chirp waveforms and structured optimizations.

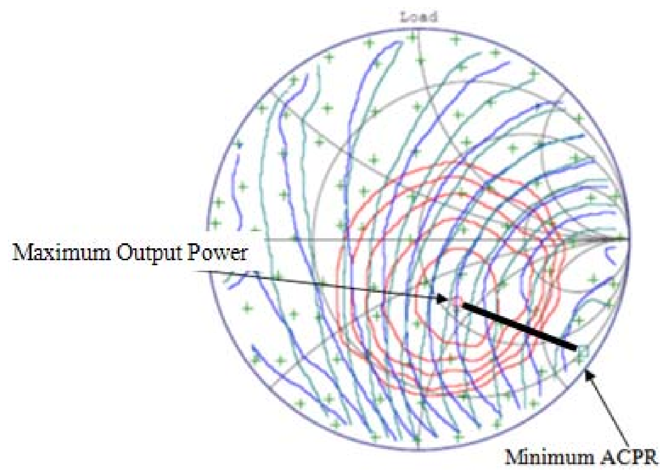


Fig. 9. Output-Power and ACPR Load-Pull Results for Chirp 2, with Power/Linearity Tradeoff Line

Acknowledgments

This work is funded by a grant to Baylor University from the U.S. Naval Research Laboratory. The authors would like to thank Dr. Eric Mokole of the Naval Research Laboratory , Dr. Michael Wicks of the University of Dayton Research Institute, and Gary Scalzi of the Air Force Research Laboratory for their insightful ideas that have fueled this work. Research assistants Loria Wang, David Moon, and Robert Scott have provided valuable assistance with setups in the laboratory and ideas for constructing the test setup related to this work. In addition, the work has been aided by funding from an Undergraduate Research and Scholarly Activity grant from the Baylor University Vice Provost for Research.

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