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A Test Platform for Real-Time Waveform and Impedance Optimization in Microwave Radar Systems

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***Abstract*—A test platform has been constructed at Baylor University to develop methods of simultaneous waveform and circuit optimization for cognitive radar. The ultimate goal of this work is to allow on-chip, simultaneous optimization of the waveform and the load impedance of the transmitter power amplifier from an FPGA cognitive-radio platform. The test bed includes a vector signal generator, load-pull tuners, a DC power supply, a power meter, and a spectrum analyzer, all controllable by MATLAB. The power meter and DC power supply are used to measure the power efficiency of the device under test, while the spectrum analyzer can be used to assess the spectral spreading, and hence linearity, of the device, through measurement of adjacent-channel power ratio or other means. Computationally intelligent routines for both load-impedance and waveform optimization will be created and evaluated using the test bed.**

I. Introduction

The recent evolution of useful wireless broadband applications has caused new attention to be drawn to spectrum allocation. As these applications continue to fuel demand for new types of on-demand communication and stimulate the international economy, they continue to require a larger share of the spectrum. As such, radar systems, required for critical sensing applications directly related to civilian safety and military tactics, are being required to operate in much smaller bandwidths by regulatory agencies worldwide. In the United States, the spectral allocations are determined by the Federal Communications Commission (FCC), and constitutive spectral constraints are then derived and imposed 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 [1]. Allocations are becoming increasingly stringent and are pushing the technical limits of operation for presently used radar systems, which include legacy radars.

Many of the spectrum problems stem from noble top-level motivations to help stimulate a struggling economy in difficult economic times. To stimulate innovation in wireless broadband, the National Broadband Plan of the United States mandates the release of 500 MHz of newly available spectrum to be released for wireless broadband applications in the next ten years [2]. Much of this released spectrum will be taken away from radar systems. Possibilities for enabling radar applications to yield this spectrum include (1) more stringent band-limiting regulations on present radar applications and (2) the implementation of *dynamic spectrum access* (DSA) [3]. DSA allows certain applications to search for and use temporarily available spectrum, rather than being confined to a particular pre-assigned band. DSA can be implemented through the use of cognitive radio operating from a *software defined radio* (SDR) platform. In a new DSA environment where spectrum access is based partially on use and not merely on a regulatory assignment, radar systems may operate much more effectively within the paradigm if they too are reconfigurable and can operate at different frequencies. The implementation of reconfigurable radar systems and, perhaps eventually, DSA for radar will require next-generation radar transmitter RF circuitry (power amplifiers) to be spectrally conformant and to be flexible and reconfigurable.

A cognitive radio must be able to adjust the frequency, output power, and modulation protocol of the transmitter and/or receiver to adapt to its environment [3]. In a technical report issued by the European Telecommunications Standards Institute, a European Standards Organization recognized by the European Union, it has been noted that the power consumption of radio network affects the CO_2 footprint of reconfigurable base stations [4]. The report mandates that designers should focus on green aspects of reconfigurable base stations by minimizing power consumption and associated increased power efficiency. While many have ignored the RF circuit design in discussing challenges to cognitive radio, cognitive radar, and DSA, the report states, "...even though theoretically possible, the practical aspects of implementing RF filters for SDR application make this to be the most challenging area within the SDR design." [4] (emphasis added). The idea that the RF circuitry in a cognitive radio system must maintain sufficient flexibility to vary in bandwidth and center frequency is also presented in the literature [5]. A test configuration is necessary to evaluate intelligent, real-time optimization routines for optimizing linearity and efficiency in radar systems.

Cognitive radar is the radar counterpart to cognitive radio. In a groundlaying January 2006 article describing the idea of cognitive radar, Haykin overviews the adaptivity of the radar transmitter and waveform for such objectives as detection and clutter avoidance [6]. The cognitive radar is one that can adapt its waveform, its beam, and its circuit to meet changing operation and detection criteria. A recent book by Guerci details specifics about the cognitive radar approach [7].

Haykin outlines an approach for waveform design and optimization based on detection criteria for waveforms [8]. Using this approach, the waveform is adapted based on information about the radar environment. The approach is based on a Pareto optimization depending on the objectives; specifically, Haykin discusses the basing the optimization on the types of possible targets to be detected.

In this paper, we detail the framework of a bench-top prototype system that will be used to explore computationally intelligent optimization approaches for the waveform and the transmitter hardware. The novelty of the work that will follow from this setup will be an algorithm that optimizes both the waveform and transmitter simultaneously, rather than considering these optimizations as separate problems. This approach combines the disciplines of microwave adaptive circuitry and waveform diversity. The test bed that is detailed will explore and validate routines for eventual implementation in an FPGA-controlled, on-chip, adaptive cognitive radar transmitter.

II. TEST PLATFORM OBJECTIVES

The objective of the test bed is to perform load-impedance (load reflection coefficient) optimization and input waveform for a radar transmitter power amplifier. As such, the test platform must be able to evaluate computationally intelligent candidate routines for implementation in a software-defined radio environment. The objectives for the optimization are (a) linearity, (b) power-added efficiency, and (c) target detection. The linearity can be measured by direct examination of the spectrum and comparison to a spectral mask, or through the use of a spectral-spreading measurement metric such as adjacent-channel power ratio (ACPR).

The development approach for the computationally intelligent procedures will begin with bench-top testing using load-pull tuners, power meter, and spectrum analyzer under the control of MATLAB. In addition, simulation tools such as Agilent Advanced Design System (ADS) presently available at Baylor can be used in concert with MATLAB for development of optimization routines. After suitable approaches for the optimization have been bench-tested, it will be attempted to incrementally integrate the functionality on-chip. The ultimate goal of this work is to use on-chip measurement instrumentation, signal generation, and tunable MEMS devices or varactor diodes to place the entire reconfigurability on the chip, under the control of an FPGA board in a software-defined radio setup.

A hierarchical flow diagram of the test platform is shown in Figure 1. On the bench, MATLAB serves as the "master" for the optimization, optimizing waveforms through control of the vector signal generator, optimizing load impedance through the control of the Maury Microwave automated Tuner System (ATS) load-pull software and tuners, and performing measurements. Evaluation of metrics will be performed through measurements of power-added efficiency (PAE) using the power meter and ACPR using the spectrum analyzer. Because PAE is related to the efficiency of the device and ACPR is related to the linearity of the device [9], these measurements will enable the Pareto optimization of both using a carefully constructed cost function. MATLAB is used to control an Agilent vector signal generator, Maury Automated Tuner System (ATS) load-pull system with tuners, an Agilent spectrum analyzer, and an Agilent wideband power meter. The power meter is capable of measuring power and can combine with the digital DC power supply to measure the power-added efficiency.

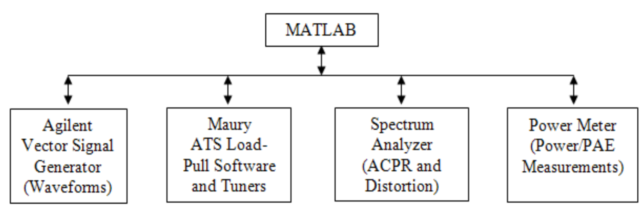


Figure 1. Hierarchical Diagram of Waveform and Load Optimization Bench-Top Test Bed

The block diagram of the measurement system is shown in Figure 2. The power meter measures broadband RF power based on a careful calibration of its sensor. The input power (on the DUT side of the source tuner) is then related to the vector signal generator power setting using a calibration with a thru in place of the DUT. Following the system calibration, the amplifier-device DUT is inserted and the output power is read by the sensor. This power is de-embedded back to a reference plane at the output of the device by using the measured linear S-parameters of all components between the DUT and the power sensor. The power-added efficiency, given by

$$PAE = \frac{P_{out,RF} - P_{in,RF}}{P_{DC}}, \tag{1}$$

is measured by knowledge of the input and output RF power from the power meter and the DC power supplied to the DUT by the DC source.

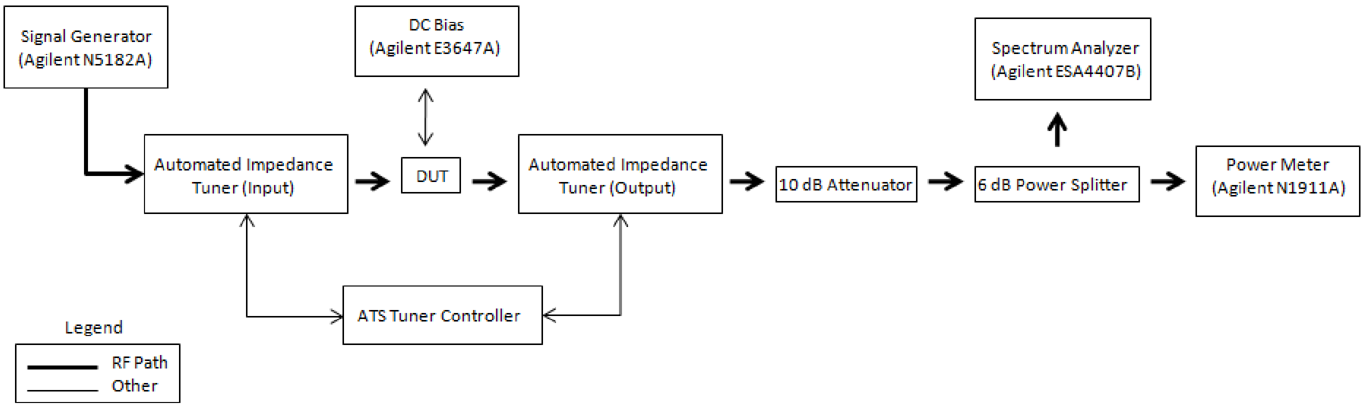


Figure 2. PAE/ACPR Reconfigurable Measurement Setup Block Diagram

III. INITIAL MEASUREMENT RESULTS

The authors have obtained initial measurement data with the test bed for a packaged amplifier under excitation by a 16-QAM signal. Figure 3 shows the spectrum analyzer screen setup for measurement of ACPR with the 16-QAM signal. The vertical lines indicate the adjacent and alternate channels, along with the integration bandwidth. Figure 4 shows the spectrum analyzer measurement of the amplifier input signal (Figure 4(a)) and output signal (Figure 4(b)). It is evident that a significant amount of spectral spreading is caused by the amplifier. This spreading is due to nonlinearities in the amplifier [9]. The load reflection coefficient can be optimized to minimize this spreading by minimizing the ACPR.

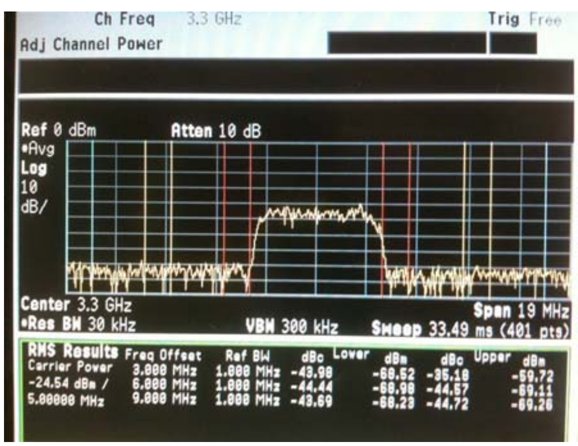
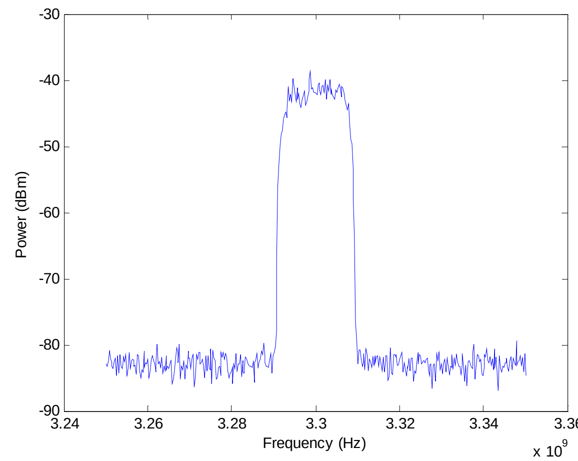


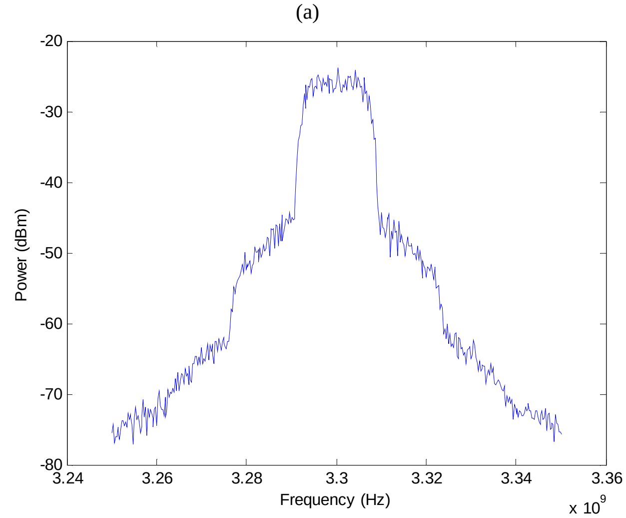
Figure 3. Example Spectrum Analyzer Screen Picture of ACPR Measurement

Figure 5 shows the contours for gain (it would be desired to obtain the maximum) and the ACPR (it would be desired to obtain the minimum) as measured by the ATS software. This measurement shows that evaluation of PAE and ACPR can be simultaneously performed using this setup and thus sets the stage for the performance evaluation and optimization of the circuit and the waveform.

The experimental approach used with this test system will involve (1) the creation of a PAE/ACPR cost function for a compromise between linearity and efficiency, (2) the implementation of waveform optimization using chirp and harmonic waveforms, (3) joint waveform and load-impedance tuning, and (4) implementation of reconfigurable waveform and load-impedance tuning on the chip, and (5) control of the optimization using an FPGA-based cognitive radar platform.



(a)



(b)

Figure 4. (a) Spectrum Analyzer Measurement of Amplifier Input Signal and (b) Spectrum Analyzer Measurement of Amplifier Output Signal with Spectral Spreading

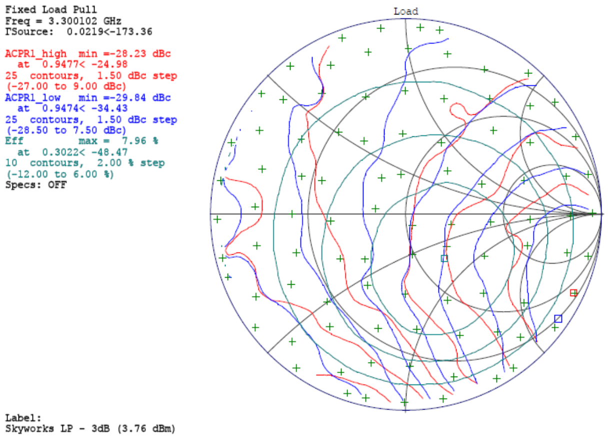


Figure 5. Load-Pull for Both ACPR and Gain Using a 16-QAM Signal

The results of this work will create a foundation for the RF implementation of next-generation cognitive radar systems.

IV. Conclusions

A test bed has been constructed at Baylor University to design and implement strategies for real-time, simultaneous optimization of waveform and circuit in radar transmitters. The test bed will provide a reliable platform for the implementation of computationally intelligent optimization strategies. Measurement of power-added efficiency and adjacent-channel power ratio will allow optimization for both efficiency and linearity criteria. After the successful development of the optimization routines, the approach should be implementable from an FPGA-based cognitive-radio/cognitive-radar platform.

Acknowledgments

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