Real-Time Circuit Reconfiguration for a Cognitive Software-Defined Radar Transmission: A New Paradigm in Spectrum Sharing

Charles Baylis
Department of Electrical and Computer Engineering
Baylor University
Waco, USA
Charles_Baylis@baylor.edu

Austin Egbert
Department of Electrical and Computer Engineering
Baylor University
Waco, USA
Austin_Egbert@baylor.edu

Jose Alcala-Medel
Department of Electrical and Computer Engineering
Baylor University
Waco, USA
Jose_Alcala-Medel1@baylor.edu

Angelique Dockendorf
Department of Electrical and Computer Engineering
Baylor University
Waco, USA
Angelique_Dockendorf@baylor.edu

Anthony Martone
Army Research Laboratory
Adelphi, USA
anthony.f.martone.civ@mail.mil

Robert J. Marks II
Department of Electrical and Computer Engineering
Baylor University
Waco, USA
Robert_Marks@baylor.edu

***Abstract*—Future radar systems will must adapt to dynamic frequency constraints while maximizing target detection range. However, the impedance termination providing optimum power changes significantly with frequency and array scan angle. To maintain good detection range over operating frequency and scan angle changes, we introduce the use of high-power reconfigurable circuitry between the transmitter power amplifier and transmit antenna. This tunable matching network and its fast tuning algorithms will be implemented under the control of a software-defined radio (SDR) platform to allow real-time optimization.**

Keywords—microwave power amplifier, radar systems, spectral compliance, reconfigurable circuitry

I. Introduction

Future microwave radar transmitters will require fast reconfiguration of power amplifiers to maintain spectral coexistence with other systems. In contested and congested spectral environments, the ability of a radar transmitter circuit to reconfigure will allow radar detection range to be maximized over changes in operating frequency and array scan angle. Reconfiguring in frequency requires that the output power to be re-optimized at each operating frequency, maximizing the detection range, as shown in Fig. 1, while meeting spectral requirements. Fig. 2 shows the solution we present: placing a tunable matching network between the transistor and each antenna element in the radar array.

Given the recent and upcoming spectral allocation changes in the S-band [1], reconfigurable high-power circuitry is an enabling technology for adaptive radar. Upon changing operating frequency, the amplifier must be reconfigured to provide the optimum matching impedance at the new operating frequency. An additional issue requiring reconfiguration is the changing of the antenna input impedance with array scan angle [2], which can result in a 50 percent reduction of power transmitted from a single array antenna element. Fig. 3 shows our load-pull simulation results in Keysight Technologies Advanced Design System (ADS) for a fixed matching network, along with marker values representing extremities of the impedance locus traced out by the antenna based on array scan-angle variations, according to Allen [2]. In Fig. 2, at marker "m1 (fig caption says m2)" representing an impedance point in the trajectory of impedances presented by the antenna during array scan angle variations (according to Allen), the output power is reduced by approximately 3 dB from the maximum output power. This corresponds to a 16 percent reduction in radar range. A tunable matching network can solve this problem, as it can reconfigure upon scan-angle changes to maintain output power and range.

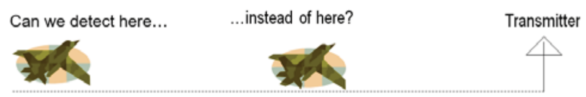

Fig. 1. Reconfigurable transmitter amplifier allowing increased detection range for radar

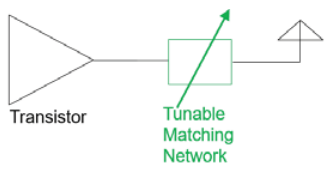

Fig. 2. A tunable matching network is placed between the transistor and antenna in each array element.

In addition to output power and power efficiency, the amplifier load impedance also affects the spectral output of the amplifier. In an environment where spectrum will be allocated dynamically, or spectral masks may change based on surrounding spectrum users, the ability to re-tune the circuit will allow the radar to meet changing spectrum requirements.

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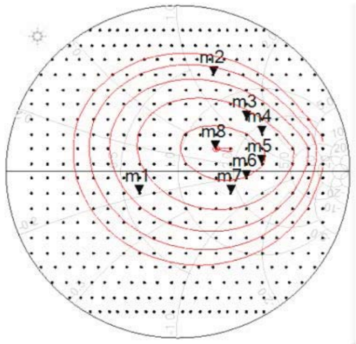

Fig. 3. Simulated output power variations based on scan-angle impedance variations presented by Allen [2]. The output power contours are in 1 dB steps. Notice that at point "m2 (text says m1)" representing an impedance for a particular value of array scan angle, the output power is approximately 3 dB below the maximum output power. This half-power loss corresponds to a 16 percent reduction in radar range.

Fig. 4 shows a desired approach for frequency usage in a cognitive radar environment. The radar transmitter is able to assess the spectrum usage of an interferer "RFI" and change its operating band so as not to be affected by the interferer [8].

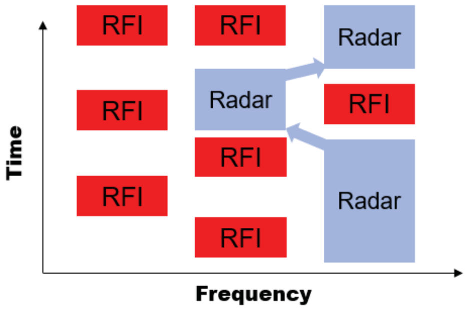

Fig. 4. Radar frequency agility to avoid interference "RFI", reprinted from [8]

The technology gap heretofore preventing the implementation of reconfigurable matching circuits in radar is the lack of high-power tunable components. Qiao presents a tunable amplifier for low-power applications using micro-electrical mechanical systems (MEMS) as the tuning element [3]. However, MEMS devices have low power-handling limitations. To address the high-power needs of radar transmitters, Semnani demonstrates an evanescent-mode cavity (EVA) tuner with piezo actuators capable of handling 90 W RF power [4]. In improving this technology, Semnani demonstrates a follow-on, smaller and faster tuner using MEMS actuators [5]. In a recent paper, Alcala-Medel demonstrates the capability to reconfigure this tuner using a small number of measurements [6].

This paper overviews some of our recent developments in the areas of fast, high-power tuning systems for cognitive and adaptive radar transmission that is spectrally sensitive. These developments allow the maximization of power-added efficiency (PAE), typically accompanied by an increase in output power, while meeting spectral requirements, upon a change in operating frequency.

II. Measurement Results

The impedance presented to an amplifier device by the EVA tuner [5] is adjusted by changing the positions of the discs atop its two resonant cavities. The positions of the two cavities are given by position numbers n_1 and n_2. As n_1 and n_2 are adjusted, the load reflection coefficient presented to the transistor by the tunable matching network (Γ_L) is adjusted.

A fast search algorithm has been demonstrated for tuner optimization using a modified gradient approach in the (n_1, n_2) plane, as demonstrated by Dockendorf [7] and demonstrated on the second-generation EVA tuner by Alcala-Medel [6]. The initial setup used for the demonstration of the second-generation tuner algorithm is shown in Fig. 4 [6], and includes a signal generator, signal analyzer, and power meter/sensor. Since the publication of these initial results, however, the signal generator, signal analyzer, and power meter functions have been integrated into an Ettus X310 SDR controller.

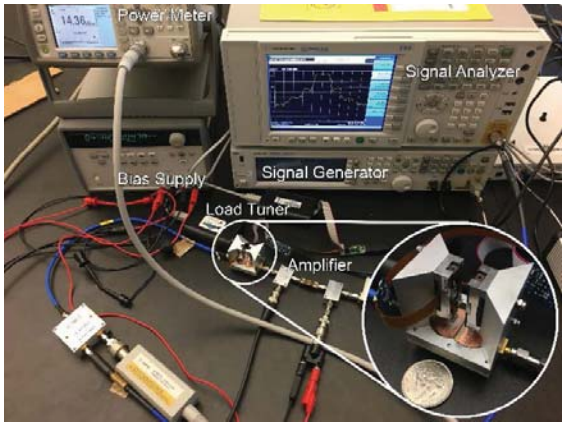

Fig. 4. Measurement setup for initial algorithm demonstration on the second-generation evanescent mode cavity tuner, reprinted from [6]

Measurement demonstration of the search algorithm for tuner optimization has shown that the load impedance can be typically optimized using between 10 and 50 measurements for the first optimization [6]. Dockendorf has shown that the use of a look-up table in future optimizations at a given frequency can reduce the number of measurements to 7 or fewer. Even in a look-up table case, however, 70 seconds are required to optimize using the bench-top measurement setup that is IEEE-488 (GPIB) connected to the computer. We demonstrate significant reduction of this time by integrating the optimizations and measurements into an SDR platform, as shown in a recently submitted journal manuscript [9].

Fig. 5 shows an example of the search described by Alcala-Medel using the Generation 2 tuner [6]. In this paper, successive searches were demonstrated at three consecutive frequencies: 3.3, 3.1, and 3.5 GHz. The purpose of this experiment was to demonstrate frequency agility. The search performed at 3.1 GHz is shown in Fig. 5 on the (n_1, n_2) plane. This portion of the search required 22 measurements and 17.90 seconds. It can be seen that while the selected start point begins in the spectrally forbidden region, it ends in a spectrally compliant region, providing the constrained maximum PAE.

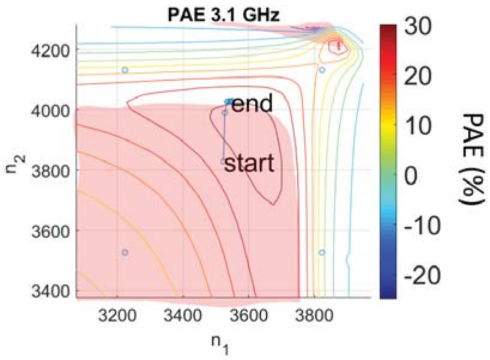

Fig. 5. 3.1 GHz search trajectory plotted atop the contours for PAE and the spectrally forbidden region (shaded). Reprinted from [6].

Fig. 6 shows the results of the three-frequency agility experiment, as shown by Alcala-Medel in a recent paper [6]. The calculated range is shown as the red trace, referred to the left vertical axis, and the measured spectral mask compliance metric (S_m) value is plotted in blue and referred to the right vertical axis. The metric S_m is first defined by Fellows [10] and repeated by Alcala-Medel [6] as follows:

$$S_m = \max(s_n - m_n), \tag{1}$$

where s_n is the spectrum in dBm and m_n is the spectral mask value in dBm. S_m represents the maximum difference between the spectrum and the mask over all measured points (over all values of n) For compliance, S_m must be less than or equal to zero.

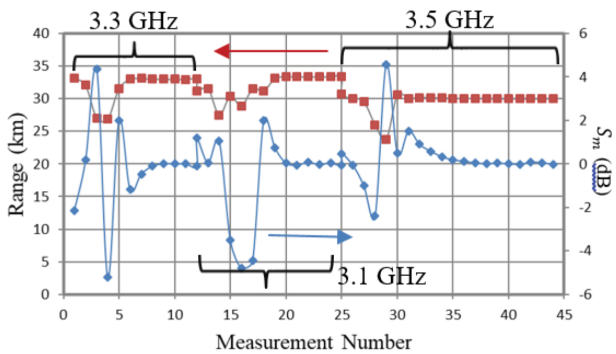

Fig. 6. Range and spectral mask compliance for the three-frequency agility experiment, reprinted from [6].

At the transitions between frequencies, two points are shown: one point that represents the measured range and S_m values at the final setting of the first frequency, and the second point that represents the measured range and S_m values at the same setting, but at the new frequency. At both transitions, a decrease in range is observed. In addition, the spectrum goes out of compliance with the mask at both transition points. However, during the optimization at each frequency, the spectrum is brought into compliance ($S_m \leq 0$) while maximizing the range under this constraint. As such, the optimization proves to be useful in both maximizing the range and ensuring spectral compliance after an operating-frequency change.

III. Conclusions

A summary of efforts to perform real-time optimization using EVA tuners has been provided. Using fast search techniques, an optimization adjusts the cavity position numbers of the two resonant cavities, adjusting the resonant frequencies of the cavities and the load reflection coefficient presented to the amplifier device. These optimizations can be performed upon a change in operating frequency or scan angle to ensure maximization of PAE while meeting spectral constraints. These intelligent reconfiguration capabilities will be useful in future radar systems, providing maximum radar performance while meeting spectral requirements in frequency-agile applications.

Acknowledgments

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