Reconfigurable and Adaptive Radar Amplifiers for Spectrum Sharing in Cognitive Radar

Charles Baylis
Electrical & Comp. Engineering
Baylor University
Waco, USA
Charles_Baylis@baylor.edu

Austin Egbert
Electrical & Comp. Engineering
Baylor University
Waco, USA
Austin_Egbert@baylor.edu

Jose Alcala-Medel
Electrical & Comp. Engineering
Baylor University
Waco, USA
Jose_Alcala-Medel1@baylor.edu

Angelique Dockendorf
Electrical & Comp. Engineering
Baylor University
Waco, USA
Angelique_Dockendorf@baylor.edu

Caleb Calabrese
Electrical & Comp. Engineering
Baylor University
Waco, USA
Caleb_Calabrese@baylor.edu

Ellie Langley
Electrical & Comp. Engineering
Baylor University
Waco, USA
Ellie_Langley@baylor.edu

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

Kyle Gallagher
Army Research Laboratory
Adelphi, USA
kyle.a.gallagher3.civ@mail.mil

Ed Viveiros
Army Research Laboratory
Adelphi, USA
edward.a.viveiros2.civ@mail.mil

Dimitrios Peroulis
Electrical & Comp. Engineering
Purdue University
West Lafayette, USA
dperouli@purdue.edu

Abbas Semnani
Electrical & Comp. Engineering
Purdue University
West Lafayette, USA
anthony.f.martone.civ@mail.mil

Robert J. Marks II
Electrical & Comp. Engineering
Baylor University
Waco, USA
Robert_Marks@baylor.edu

***Abstract*— The increased use of the wireless spectrum for broadband applications has necessitated a new approach to radar transmission. Future radar systems will be required to adjust operating frequency in real time to avoid interference from other wireless devices operating in the same band. This paper describes the use of a 90 W tunable power-amplifier matching circuit to reconfigure a power amplifier for high power-added efficiency and spectral compliance at multiple frequencies within the S-band. To reconfigure the amplifier in real-time spectrum sharing scenarios, a modified gradient search algorithm is employed to tune the amplifier based on measured data. A look-up table allows previous optimum tuner settings to be stored after the first reconfiguration at each operating frequency, allowing faster optimizations upon re-visits to each frequency. Next research steps are discussed; including the streamlining of system timing, operating the search algorithm under control of spectral prediction and decision-making processes and analyzing the effect of impedance tuning on range and Doppler detection.**

***Keywords*—cognitive radar, power amplifiers, radio spectrum management**

I. Introduction

The astounding increase of wireless broadband applications continues to encroach upon traditional radar frequency bands. While 3.55 GHz to 3.7 GHz has already been repurposed for radar sharing with the Citizens Broadband Radio Service (CBRS), the National Telecommunications and Information Administration (NTIA) in the United States announced in 2018 that the 3.45 to 3.55 GHz band will also be repurposed for sharing between radar and wireless communication, potentially for the fifth-generation (5G) wireless systems [1]. The ongoing trajectory that includes the loss of 250 MHz of contiguous radar spectrum over the last decade requires that radar systems change their operating methods. Future radar transmitters must be adaptive and reconfigurable; capable of actively sharing spectrum with wireless communication devices.

A typical spectrum sharing scenario facing a radar transmitter could be depicted as shown in Fig. 1 [2]. Future radar systems must predict, detect, and avoid potential RF interferers (RFI). Significant development is needed to facilitate this approach, including the ability to perform spectrum sensing, predict spectral usage, and re-tune transmitter circuitry quickly. In the planned approach, the radar system will attempt to avoid the interferer, maximize signal-to-interference-plus-noise ratio (SINR) while also maximizing the number of subbands in which it can transmit to enhance range resolution' as described by Selvi [3].

Reconfigurable radar transmitter amplifiers provide a means by which the amplifier can be reconfigured to operate at different frequencies with low-loss matching networks. While broadband matching networks can be designed, the low quality factor of the resonators in these networks results in significant loss, which reduces detection range and power efficiency. An

This work has been funded by the Army Research Laboratory (Grant No. W911NF-16-2-0054). The views and opinions expressed do not necessarily represent the opinions of the U.S. Government.

evanescent-mode resonant cavity (EVA) matching network has been demonstrated in two generations. The first-generation tuner has been demonstrated by Semnani [4] and can be tuned across much of the radar S-band allocation. Figure 2 shows this tuner, designed and constructed at Purdue University. The resonant cavity positions are adjusted in real-time to re-optimize the tuner for power-added efficiency (PAE) and spectral performance when the circuit is changed to a new operating frequency [5].

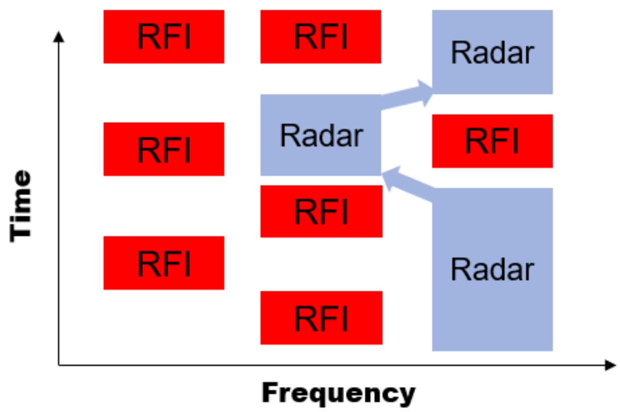

Fig. 1. Cognitive radar spectrum sharing scenario with an RF Interferer (RFI). Radar systems must detect and avoid collisions with other wireless interferers in crowded frequency bands, reprinted from [2].

Fig. 2. 90 W EVA tuner constructed at Purdue University [4]

The scope of this paper summarizes initial experiments on the use of the cavity tuner for fast tuning. The lessons learned from these experiments will be integrated into an approach that allows fast tuning in the cognitive radar spectrum sharing environment described in Fig. 1.

II. Fast Tuning Algorithm

Upon a reconfiguration of center frequency or bandwidth, the tuner must adjust its circuitry quickly to re-optimize PAE while meeting spectral requirements. The first research issue to be addressed is the ability to quickly optimize the tuner based on measurement results. A modified gradient search algorithm is used to perform a constrained optimization of PAE, constrained by compliance with the spectral mask [5, 6]. Spectral mask compliance is described by the metric

$$S_m = \max(s - m), \quad (1)$$

which gives the maximum difference between the spectrum and the mask over all frequencies measured [2, 6]. If a value of $S_m \leq 0$ is obtained, then the spectrum is in compliance with the mask, while $S_m > 0$ indicates that the spectrum is out of mask compliance.

For future visits to a specific proposed operating frequency, a look-up table can be used to speed the search. This has been examined recently [2], where data is shown the for returning to a frequency. The experiment involved re-optimization at random seeded frequencies. The band used for experimentation was the S-band range of 3250 MHz to 3350 MHz. In the experiment, one of ten possible operating frequencies in the band was chosen. The first time the load reflection coefficient, Γ_L, provided by the matching circuit is optimized at a given frequency, a look-up table was used to store the best performing Γ_L. During any return to this frequency, the look-up table value was used as the starting point for the modified gradient-based search. The use of the look-up table provided a decrease in optimization measurements in many cases [2].

III. Algorithm Demonstration

Figure 3 shows the measurement setup to assess this algorithm for the first-generation tuner of Semnani [4]. A Microwave Technologies MWT-173 field-effect transistor (FET) was used as the device under test with the EVA tuner. We have shown that this tuner can be reconfigured to three different frequencies in the S-band in the following order: 3.3 GHz, 3.1 GHz, and 3.5 GHz; and that measurement results are highly consistent with full load-pull measurements at each frequency [5].

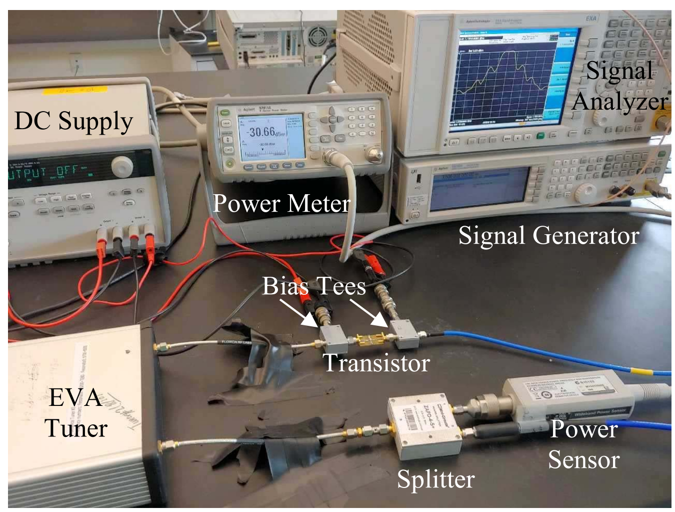

Fig. 3. Measurement setup

Figure 4 shows an example of the optimization search performed at each frequency in terms of the resonant cavity position numbers n_1 and n_2. The search progresses through the (n_1, n_2) plane in effort to fined the constrained optimum which is defined asthe (n_1, n_2) combination providing the maximum efficiency while remaining in the region of spectral mask compliance. In the Fig. 4 comparison with the PAE contours taken from a full load-pull measurement of the (n_1, n_2) plane, the endpoint of the fast search is reasonably close to the constrained optimum. Typically the constrained optimum is not the global optimum if maximization of PAE causes the spectrum to violate the mask.

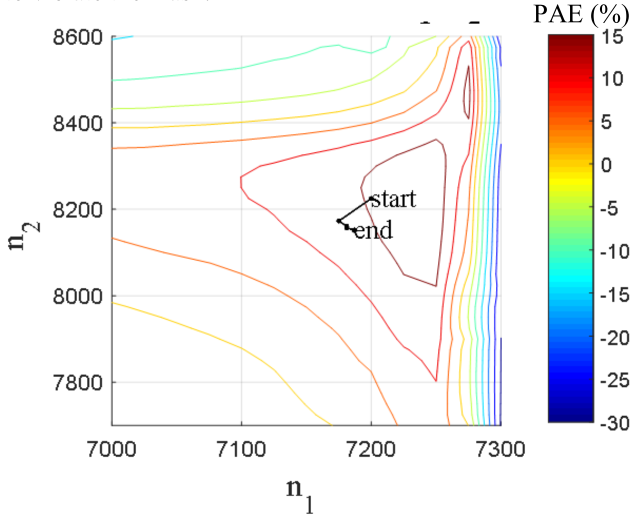

Fig. 4. Fast load optimization search results in the (n_1, n_2) plane at 3.3 GHz along with traditional load-pull PAE contours. The colored scale on the right shows the PAE in percent.

IV. Areas of Ongoing Research

The implementation of a fast tuning algorithm on the 90 W impedance tuner has demonstrated the ability of a high-power matching network to re-tune over a large part of the S-band. The algorithms have demonstrated that the optimum can be obtained with a small number of measurements. This solves a significant problem on the path toward a reconfigurable, frequency-agile radar. However, other challenges still exist. Some of the present areas of research include the following: (1) streamlining of system timing, (2) operating the circuit search algorithm under control of a spectral prediction and decision-making algorithm, and (3) analyzing the effect of impedance tuning on radar range and Doppler detection.

Streamlining of system timing can be accomplished in a software-defined radio (SDR) controlled setup by analyzing communications and measurement times by each of the equipment pieces. Centralizing the control of the system to the SDR platform eliminates complications from the General Purpose-Interface Bus connections used in the measurement system. Also inclusion of the next-generation tuner in the measurements is expected to decrease the tuning time.

Using a spectral prediction and decision-making algorithm, such as that developed by Selvi [3], to control the tuning of the circuit may allow for advance planning of the impedance tuning. If prior knowledge of previous impedance tuning at different frequency and bandwidth settings is available, then an advance schedule of the impedance tuning frequencies can be created, and impedance tuning can be planned to provide best overall performance in a given part of the schedule. This will be useful because the time to search and optimize an impedance using the mechanical EVA tuners is expected to be significantly longer than the coherent processing interval of the radar. As such, it may be necessary to accept performance that is less than optimal in some situations to ensure the efficiency and output power are acceptable and reasonable at as many of the frequency and bandwidth settings as possible.

V. Conclusions

Fast impedance tuning is critical for real-time frequency agility, allowing radar transmitters to adaptively avoid RFI from other wireless spectrum users. This work has overviewed fast impedance tuning within the S-band, including the use of a 90 W EVA tuner for fast optimization of PAE of the transmitter amplifier under spectral constraints. These algorithms will be useful in next-generation radar transmitters. A next step, using an SDR platform to control the tuner, is expected to result in faster performance of measurements and communication of measurement results, reducing the “overhead” of the system required for the use of multiple pieces of measurement equipment. Further improvements are expected from using second-generation tuner technology, which takes advantage of faster actuators and miniaturized control. Future development is also needed to integrate the impedance tuning into a decision-making process based on spectral prediction algorithms. In such scenarios, the timing of the tuning will become a limiting factor of the system reconfiguration, and it will be important to determine (1) the effect of the tuner on accurate detection of range and Doppler and (2) potential spectrum occupancy decision influence based on impedance tuning timing and limitations.

Acknowledgment

The authors wish to thank John Clark of the Army Research Laboratory for his helpful suggestions and comments in the development of this paper.

References

[1] “NTIA Identifies 3.45 – 3.55 GHz Band for Commercial Wireless,” February 27, 2018, Radio Resource International, https://www.rrmediagroup.com/News/NewsDetails/NewsID/16576.

[2] A. Dockendorf, E. Langley, C. Baylis, A. Martone, K. Gallagher, and E. Viveiros, “Faster Frequency-Agile Reconfiguration of a High-Power Cavity Tuner for Cognitive Rdar Using Previous Search Results,” 2019 IEEE Radio and Wireless Symposium, Orlando, Florida, January 2019.

[3] E. Selvi, R.M. Buehrer, A. Martone, K. Sherbondy, “On The Use of Markov Decision Processes in Cognitive Radar: An Application to Target Tracking,” 2018 IEEE Radar Conference, Oklahoma City, Oklahoma, April 2018.

[4] A. Semnani, M. Abu Khater, Y.-C. Wu, and D. Peroulis, “An Electronically-Tunable High-Power Impedance Tuner with Integrated Closed-Loop Control,” *IEEE Microwave and Wireless Components Letters*, Vol. 27, No. 8, August 2017, pp. 754-756.

[5] A. Dockendorf, E. Langley, A. Egbert, C. Calabrese, J. Alcala-Medel, S. Rezayat, Z. Hays, C. Baylis, A. Martone, E. Viveiros, K. Gallagher, A. Semnani, and D. Peroulis, “Reconfigurable, Frequency-Agile Amplifier Matching Circuit to Enable Radar Spectrum Sharing,” submitted to *IEEE Transactons on Aerospace and Electronic Systems*, July 2018, under review/unpublished.

[6] M. Fellows, C. Baylis, L. Cohen, and R.J. Marks II, “Real-Time Load Impedance Optimization for Radar Spectral Mask Compliance and Power Efficiency,” *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 51, No. 1, January 2015, pp. 591-599.