Faster Frequency-Agile Reconfiguration of a High-Power Cavity Tuner for Cognitive Radar Using Previous Search Results

Angelique Dockendorf[1], Ellie Langley[1], Charles Baylis[1], Anthony Martone[2], Kyle Gallagher[2], and Ed Viveiros[2]

[1]Baylor University, Waco, Texas 76798, United States
[2]Army Research Laboratory, Adelphi, Maryland 20783, United States

Abstract **— Dynamic spectrum allocation requires real-time adjustment of operating frequency and bandwidth in future cognitive radar transmitters. We demonstrate the hastening of a previous frequency-agile reconfiguration algorithm by using prior search endpoints to intelligently inform the starting location of the next search at a previously visited frequency. Measurement results are shown for successive reconfiguration between 10 operating frequencies within the S-band radar allocation. Experimental results demonstrate improved power-added efficiency and speed from the initial information, improving the algorithm's usefulness in real-time reconfigurable transmitters.**

Index Terms **— Algorithms, cognitive radar, impedance matching, power amplifiers, radars, reconfigurable circuits.**

I. Introduction

The radio frequency (RF) spectrum has become increasingly congested. In this environment, future cognitive radar systems must be capable of real-time reconfiguration utilizing fast search algorithms to insure maximum power-added efficiency (PAE) at each operating frequency while meeting spectral constraints. Tunable amplifiers have been built based on micro-electrical mechanical systems (MEMS) technology using a genetic search algorithm [1], but MEMS technology is limited in its power-handling capability and genetic search algorithms are inherently slow in searches where criterion characteristic attributes are partially known. Particle swarm optimizations have been attempted, but hundreds of experimental queries can be required [2]. In the present paper, we utilize a 90 W evanescent-mode cavity (EVA) impedance tuner designed by Semnani for radar applications [3]. The impedance presented by the tuner to the amplifier is based on the variation of the two cavity piezoelectric disc positions, given by position numbers n_1 and n_2. In a previous paper, we have demonstrated a modified gradient search for frequency agility [4].

This paper presents an addition to our previous algorithm [4] that reduces the time necessary for reconfiguration by using previous search results at each operating frequency using a look-up table (suggested by Sun [5]). Our objective is to use an EVA tuner [3] as the power amplifier load matching network in a cognitive radio that can perform target tracking while avoiding radio-frequency interference (RFI) (Fig. 1). In the eventual application, ten 10-MHz sub-bands between 3.25 GHz and 3.35 GHz will be used. The radar bands will be chosen in real time based on a Markov Decision Process predictive algorithm with reinforcement learning [6]. In such a scenario, the radar will need to quickly perform multiple relocations. The ability to predict frequency will further extend previous work from the literature on spectrum scanning [7-8]. To develop and demonstrate fast frequency agility, we consider relocations directed by a random selection of one of the ten sub-bands.

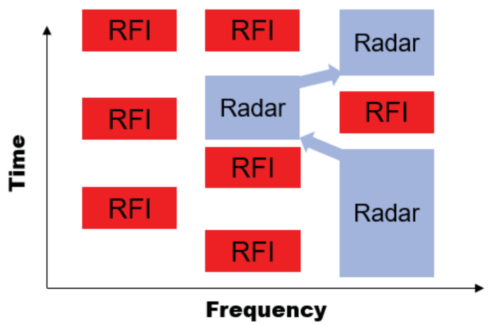


Fig. 1. Cognitive radar interference scenario: The radar ("Radar") responds to RFI by moving to bands determined to be absent of RFI.

III. Tuning Algorithm

The gradient-based search implemented in our previous paper [4] tunes n_1 and n_2 to maximize power-added efficiency (PAE) while maintaining spectral compliance ($S_m \leq 0$) according to the S_m metric:

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

where s is the spectrum and m is the mask (both in dBm) over all measured frequency points. Thus, $S_m \leq 0$ indicates a spectrum that is in compliance with the mask, while $S_m > 0$ indicates a spectrum that is out of mask compliance. The progression of a sample search at 3.315 GHz is shown in Fig. 2.

The initial search to populate the look-up table can either be performed with the system online or with a separate, off-line initial search. For the initial search used to populate the look-up table at each frequency, search parameters of $D_n = 10$, $D_s = 100$, and $D_r = 5$ were used. For each subsequent time a frequency is visited, the look-

978-1-5386-5944-1/19/$31.00 ©2019 IEEE

up table starting location is used for the gradient part of the search, removing the five initial measurements required by "Sarvin's Method" [4]. The search parameters for subsequent searches utilizing the lookup table are changed for finer tuning and faster convergence to $D_n = 10$, $D_s = 40$, and $D_r = 2$. The look-up table is updated if a higher constrained optimum PAE is achieved.

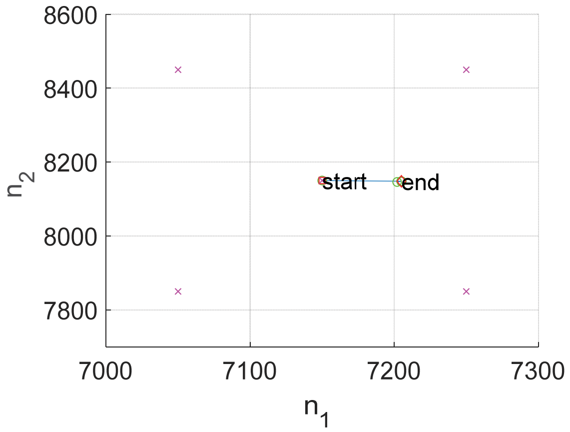


Fig. 2. Initial search trajectory at 3.315 GHz in the (n_1, n_2) plane

IV. Measurement Results

For all the results presented in this section, the input radar signal was limited to a bandwidth of 1 MHz. This allows the frequency to be changed as in the scenario of Fig. 1 without incurring effects of tuner impedance variation over the frequency range of the input signal spectrum. Future efforts will address a wider bandwidth approach.

A. Single Frequency

Measurements were first performed to examine the ability to reduce search time and maintain or improve performance in repeated measurements at a single frequency. For this test, the real-time search algorithm was repeated at a center frequency of 3.305 GHz to produce maximum use of the lookup table. Table I shows the search end values of n_1 and n_2, PAE, and S_m, along with the number of measurements and time required. PAE shows a slightly improving trend over the succession of searches, and the end cavity position numbers also shift for later searches. While time is shown, the number of measurements may be a better metric for use here, as a traditional load-pull bench is used and not the final cognitive radar platform, resulting in significant equipment communication overhead time. The experiment was repeated without allowing the lookup table to be used, and a comparison is presented in Fig. 3.

TABLE I
RESULTS OF REPEATED 3.305 GHZ SEARCHES

n_1	n_2	End PAE (%)	End S_m (dBc)	# Meas.	Time (s)
7212	8091	20.17	-1.18	33	351.53
7212	8091	20.21	-1.16	7	70.09
7212	8091	20.13	-1.14	7	70.44
7219	8077	20.23	-1.17	13	134.47
7213	8074	20.20	-0.81	9	92.33
7219	8077	20.16	-1.07	7	71.80
7212	8073	20.55	-0.83	13	150.09
7212	8073	20.61	-0.80	7	70.10
7212	8073	20.68	-0.80	7	71.63
7212	8073	20.65	-0.76	7	69.75

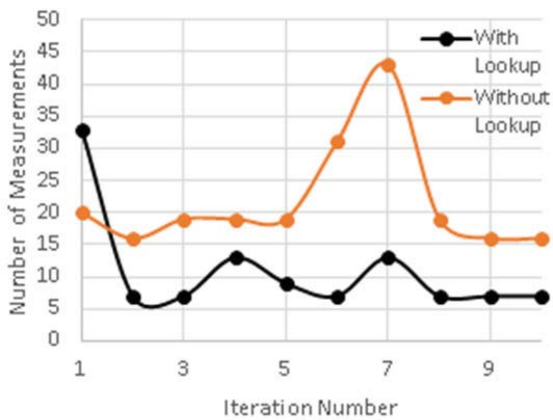


Fig. 3. Number of measurements vs. iteration number for 10 reconfigurations at 3.305 GHz with and without using a look-up table

B. Multifrequency

In this experiment, one of the ten center frequencies between 3.255 GHz and 3.345 GHz was randomly chosen for each iteration to emulate the frequency agility shown in Fig. 1. The search was repeated 100 times in total (this means that each frequency receives an average of approximately 10 iterations). Fig. 4 shows the number of measurements required for each iteration, with colored markers used to designate the operating frequency of each iteration. The average number of measurements required to reconfigure tends to decrease over time in general, as expected. By iteration 49, all frequencies have been used at least once. Figs. 5(a) and 5(b) show generally decreased measurements and consistent PAE performance for repeated searches at individual frequencies. The higher optimum PAE for higher frequencies (Fig. 5(b)) coincides with measured load-pull data.

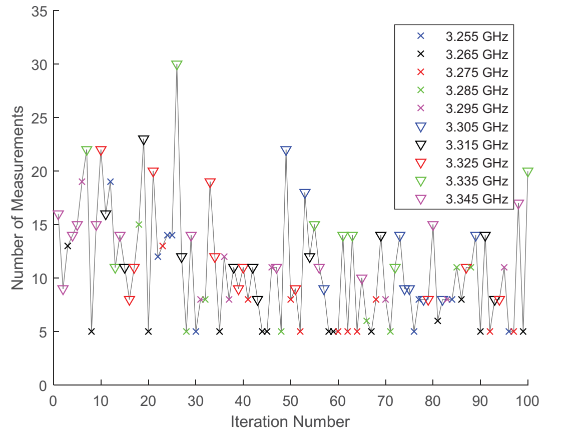
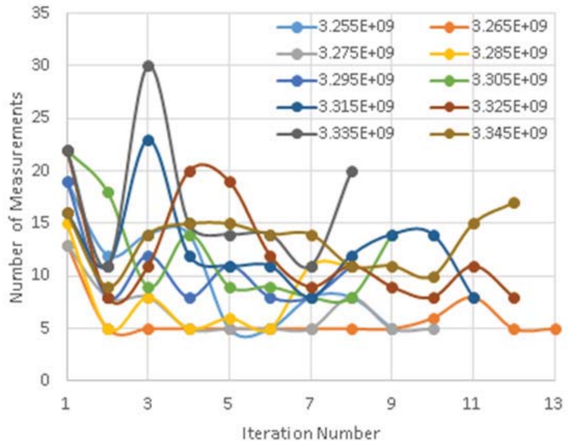
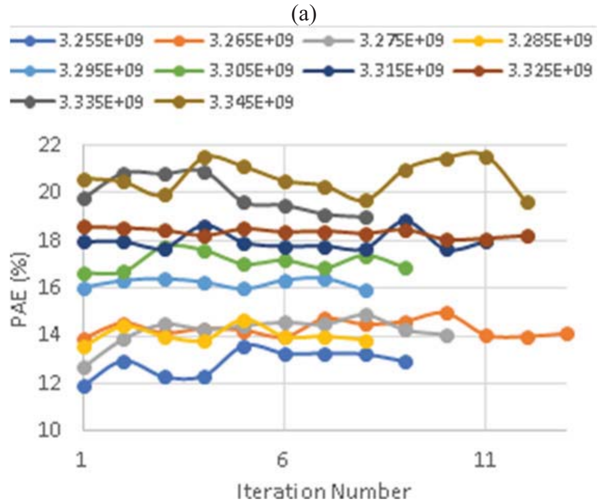


Fig. 4. Number of measurements vs. iteration number for 100 reconfigurations at randomly chosen frequencies between 3.255 GHz and 3.345 GHz



(a)



(b)

Fig. 5. (a) Number of measurements versus visits to given frequencies and (b) PAE versus visits to given frequencies

V. Conclusions

A fast search algorithm has been demonstrated in a frequency-agile coexistence scenario using a high-power impedance tuner. The use of a look-up table to provide a good search starting point based on past search results provides for tuning with fewer measurements while maintaining PAE search results. The improvement on impedance tuning time will have a significant impact on radar performance metrics such as output power and detection range, as well as power-added efficiency. This will allow radar performance to be maintained in a dynamic cognitive radar spectrum sharing environment.

Acknowledgements

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. The authors are grateful to John Clark of the Army Research Laboratory for assistance in development of this paper.

References

[1] D. Qiao *et al.*, "An Intelligently Controlled RF Power Amplifier with a Reconfigurable MEMS-Varactor Tuner," *IEEE Trans. Micro. Theory Tech.*, Vol. 53, No. 3, March 2005, pp. 1089-1095.

[2] Y. Ma and G. Wu, "Automatic Impedance Matching Using Simulated Annealing Particle Swarm Optimization Algorithms for RF Circuit," 2015 IEEE Adv. Info. Technology, Elec. and Automation Control Conf. (IAEAC), Chongqing, 2015, pp. 581-584.

[3] A. Semnani, M. Abu Khater, Y.-C. Wu, and D. Peroulis, “An Electronically-Tunable High-Power Impedance Tuner with Integrated Closed-Loop Control,” *IEEE Micro. Wireless Comp. Let.*, 27(8), August 2017, pp. 754-756.

[4] A. Dockendorf *et al.*, “Reconfigurable Amplifier Matching Circuit to Enable Radar Spectrum,” submitted to *IEEE Trans. Aero. Elec. Sys.*, July 2018.

[5] Y. Sun, J. Moritz and X. Zhu, "Adaptive Impedance Matching and Antenna Tuning for Green Software-Defined and Cognitive Radio," IEEE 54th Int'l Midwest Symp. on Circ. Sys .(MWSCAS), Seoul, South Korea, 2011, pp. 1-4.

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

[7] R. Deng, J. Chen, C. Yuen, P. Cheng, and Y. Sun, “Energy-Efficient Cooperative Spectrum Sensing by Optimal Scheduling in Sensor-Aided Cognitive Radio Networks,” *IEEE Trans.Vehicular Tech.*, Vol. 61, No. 2, pp. 716-725.

[8] Y. Liu, S. Xie, R. Yu, Y. Zhang, and C. Yuen, “An Efficient MAC Protocol with Selective Grouping and Cooperative Sensing in Cognitive Radio Networks,” *IEEE Trans. Vehicular Tech.*, Vol. 62, No. 8, pp. 3928-3941.