Harmonic Configurable Time Modulated Array -Based Wireless Power Transfer System with Concurrent Beam Steering and Side Lobe Level Control

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***Abstract*—Time Modulated Antenna Arrays (TMA) can play a critical and versatile role in multi-user heterogeneous Wireless Power Transfer (WPT) system, with each user uniquely identified by a harmonic. This project focuses on developing a timed array architecture that provides precise control over the number of radiated harmonics, independent steering of individual beams, and adjustment of radiated beam power levels. The proposed timed array is experimentally validated using a 1x4 microstrip antenna array operating at 2.4 GHz, with a control signal generated by a PYNQ-Z2 FPGA. The report also discusses the impact of the control signal waveform and compares it with traditionally used control signals.**

***Index Terms*—Beam steering, multi-harmonic, time modulated array (TMA) .**

I. Introduction

WIRELESS Power Transfer (WPT) has found diverse applications across various domains where distributed sensors are employed. It has crucial applications in medical implants, where it eliminates the need for invasive procedures to replace batteries in devices like pacemakers. Other interesting and recent applications include the possibility to empower drones for extended operational range by wirelessly recharging, enhancing their capabilities in surveillance, monitoring, and delivery, powering distributed sensors etc.

Timed arrays are among the best choices in a dynamic wireless environment. Conventional timed arrays generate steering and harmonic beams via low-cost switches [1], [2]. However, it is not possible to regulate each of the harmonics generated by a square wave separately. The majority of the available literature uses optimisation techniques to lower SBR [3], [4]. Additionally, this modulation approach is unable to independently steer or regulate the harmonic power levels. By tailoring the modulating signal, the proposed architecture may individually direct each harmonic, regulate the number of harmonics that are radiated, and adjust the power levels of the harmonics. Thus, the system can generate a unique harmonic frequency dedicated to each user. The next sections of the report give an overview of the proposed system and its functioning along with the simulated and experimented results.

II. Sytem Design and Theory

The radiated field of a conventional TMA with N isotropic elements distributed along the y-axis using SPDT switches is given by [5](1),

$$F(\phi,\theta,t) = e^{i2\pi f_c t}\sum_{n=0}^{N-1} I_n g_n^{T_o}(t)\, e^{ikz_n \sin\phi \ \sin\theta} \tag{1}$$

where $g_n^{T_o}(t)$ is the periodic pulse function (time period T_o) which controls the n^{th} antenna element. The proposed architecture replaces the conventional modulating signal $g_n^{T_o}(t)$ with a novel modulating signal $p_k(t)$. The waveform $p_k(t)$ contains the radiated harmonics and the undesired harmonics. The user can control the direction, level and number of radiated beams by appropriately tailoring $p_k(t)$. The functioning

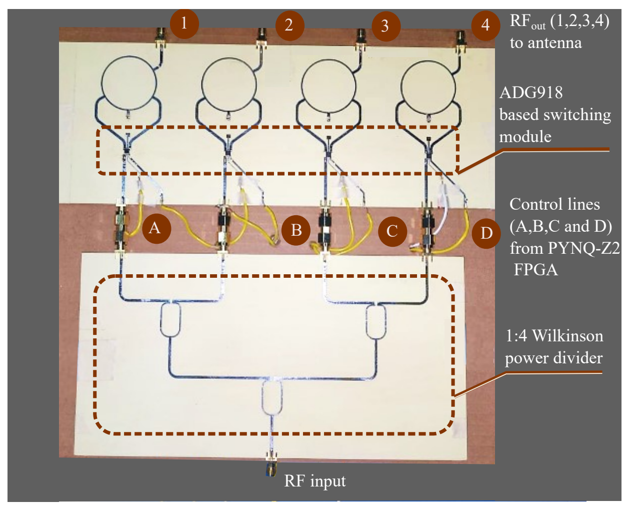

Fig. 1. The fabricated 1×4 switching module based on ADG918 RF switching IC connected to the 1×4 Wilkinson power divider.

of the system is validated using MATLAB Simulink and HFSS. The switching module is designed using ADG918 absorptive RF switches and fabricated on ROGERS 4350B substrate (ϵ_r=3.66, tan δ =0.001) of 30 mils thickness as in Fig.1. A 1×4 linear patch antenna with a center frequency of 2.4 GHz and a bandwidth of 30 MHz is employed as the radiator to measure the radiation patterns. The microstrip edge-fed patches designed on FR4 (ϵ_r=4.4, tan δ =0.03 at 1 GHz) laminate of thickness 30 mils are separated with an interelement distance of 62.5 mm (0.5λ). Each patch antenna has a dimension of 40.92×32.5 mm^2. Fig.2 shows the complete TMA system test set up in the fully calibrated anechoic

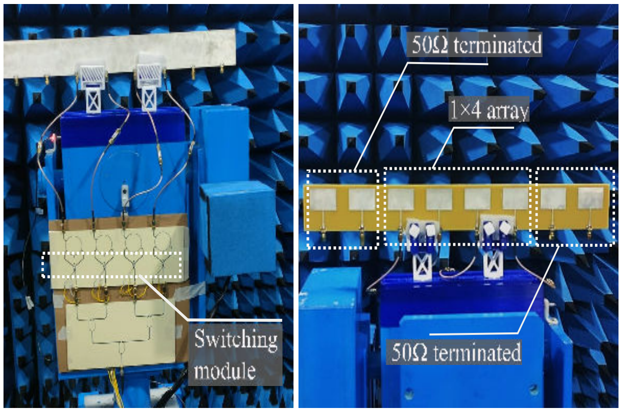

Fig. 2. The TMA system, which is installed in an anechoic chamber with a 1×4 patch antenna as the radiator, is connected to the designed switching module.

chamber. An antenna array of size 1×8 with the two elements from the edges being terminated with matched loads to avoid edge effects is depicted. As shown, the switching module set-up and FPGA board for control signal generation are placed behind the antenna mount to avoid spurious radiations during the measurement.

III. Results and Discussion

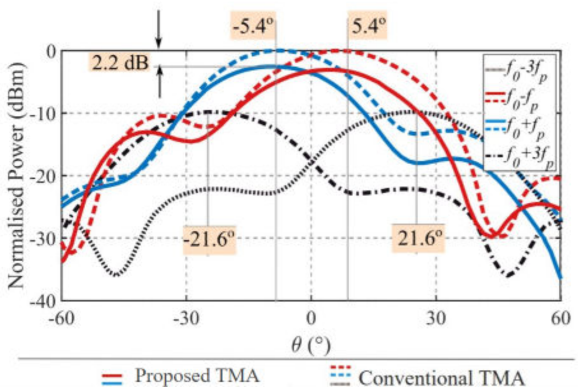

Fig. 3. Comparison between the measured normalised radiation pattern of conventional TMA with 50% duty cycle and proposed TMA (m=1), normalised to the first harmonic of the former architecture.

A performance comparison is made between the proposed timed array and the traditional TMA. In the typical TMA, the maximum amplitude for the first harmonic is guaranteed by using a square waveform (50% duty cycle). The even harmonic coefficient magnitudes fall to zero for a duty cycle of 50%, leaving odd harmonics as the only constituent frequencies. The proposed timed array is operated in single harmonic mode(m = 1) as shown in Fig. 3. ($f_0 \pm f_p$) mode, with the measured main beam oriented to 5.4° against the simulated beam direction of 6° via a 20° phase shift. In the single harmonic example of the current timed array, higher harmonics ($f_0 \pm 3f_p$, $f_0 \pm 5f_p$, and so on) have been eliminated, but in a normal timed array, higher harmonics are present with falling strength and are automatically steered according to the phase of the first harmonic. Similarly, the proposed architecture can operate at

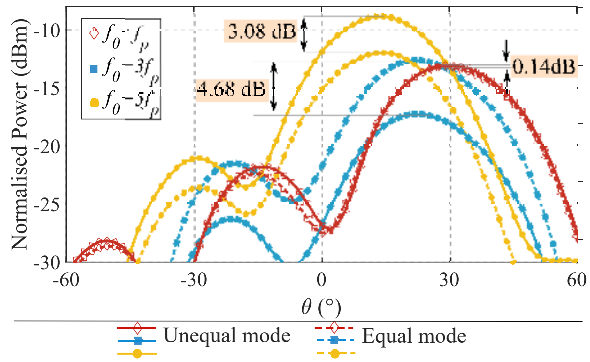

Fig. 4. Comparison between the measured normalised radiation pattern of proposed TMA operating at three harmonic equal power and unequal power modes.

user-defined power levels for each harmonic while retaining the flexibility to direct the beam independently as shown in Fig.4. The simulated and experimental values of the beam steering angles are in close agreement. Obtained minor angular deviation may be due to the angular step size of the antenna rotation within the azimuthal plane of the experimental setup, alignment mismatch of the positioners and fabrication errors.

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IV. Award Impact and Future Plans

IEEE MTT-S Undergraduate/Pregraduate Scholarship is one of the most prestigious scholarships in the field of microwave engineering for students worldwide and, I am grateful to the society for recognizing our efforts. The award has encouraged me to continue my research in RF and Microwave engineering. Currently, I am working as a scientist in the Microwave Remote Sensing Area at the Indian Space Research Organisation (ISRO) and plan to pursue high-impact, application-oriented research in my future endeavors.

References

[1] HE Shanks and RW Bickmore. Four-dimensional electromagnetic radiators. Canadian journal of physics, 37(3):263–275, 1959

[2] Y Tong and A Tennant. Simultaneous control of sidelobe level and harmonic beam steering in time-modulated linear arrays. Electronics Letters, 46(3):1, 2010

[3] Lorenzo Poli, Paolo Rocca, Luca Manica, and Andrea Massa. Handling sideband radiations in time-modulated arrays through particle swarm optimization. IEEE Transactions on Antennas and Propagation, 58(4):1408–1411, 2010. doi: 10.1109/ TAP.2010.2041165.

[4] Feng Yang, Shiwen Yang, Weijun Long, Kejin Chen, Fang Wang, Bin Li, and Lei Sun. Synthesis of low-sidelobe 4-d heterogeneous antenna arrays including mutual coupling using iterative convex optimization. IEEE transactions on antennas and propagation, 68(1):329–340, 2019.

[5] A. Tennant and B. Chambers, "A Two-Element Time-Modulated Array With Direction-Finding Properties," in IEEE Antennas and Wireless Propagation Letters, vol. 6, pp. 64-65, 2007.