An Amplitude Distribution Network in the T/R Module for Beamforming Applications

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Abstract — **To catch up with the rapid technology changing trend in the smart antenna industry, the modular design approach is inevitable amongst the researchers and manufacturers to maintain their competitiveness in term of cost and technology adoption. In the smart antenna system, the modular approach has gained its popularity, particularly the building block such as transmit and receive (T/R) module which is complex and subjected to upgrade due to its components upgrade and technology improvement over the time. Amplitude Distribution in the beamforming antenna array system is crucial to achieve the optimum antenna radiation performance such as gain, half-power beamwidth (HPBW), side lobe level (SLL) etc. The highly flexible and scalable T/R module with Amplitude distribution network has been proposed, the Amplitude Distribution for the linear array can be easily simulated using Computer Simulation Technology (CST) tools eliminating the needs of going through the complex and time-consuming mathematical analysis approach. The Amplitude Distribution has been simulated using CST tools and the performance was validated using the T/R module with the 4 x 4 array.**

Index Terms—T/R Module , Amplitude Distribution, Antenna Array.

I. INTRODUCTION

The RF beamforming frontend has been evolved over the years, and the sub-system has been modularized and miniaturized using the commercially off-the-shelf components into the transmit and receive (T/R) module that increases the deployment friendliness and the cost benefits by mass producing the T/R module. In [1], the authors pointed out the importance of T/R module that can be integrated as the slat and tile architecture for the Multifunction Phased Array Radar (MPAR). Significant cost reduction of the T/R module was contributed by increases in production volume and the advancement in automated assembly and test equipment. In [2], the authors highlighted that in the military phased array radar systems, detailed cost figures of the main segments are indicating that the T/R module of the phased array antenna accounts for nearly 45% of the system cost and justify the cost of the T/R module is crucial to determine the total system cost. In [3], the Arrays at Commercial Timescales (ACT) program constitutes a forward-looking approach to the design, construction, and upkeep of phased arrays accomplished through modular array component architectures T/R module that leverage on commercial semiconductor technologies that evolve at much faster rates than traditional RF components.

In the beamforming antenna system, the amplitude and phase of each port must be varied to achieve optimum gain, half-power beamwidth (HPBW) and side lobe level (SLL) performance. Some well-known Amplitude Distribution techniques are listed here, (i) Uniform distribution, where the amplitude at all the antenna ports are set equal, best gain and HPBW can be achieved while SLL suffered, (ii) Optimum distribution technique with the amplitude being highest at the middle ports and gradually decrease towards the side of the other ports, this technique produces moderate gain, HPBW and SLL performance, while (iii) Binomial distribution provides the best SLL performance but suffer from lower gain and wider HPBW.

In [4], the author demonstrated the radiation characteristics between Uniform, Tschebyscheff and Binomial Amplitude Distributions of the linear patch antenna array and revealed that the Tschebyscheff distribution delivers the best SLL. In [5], the Amplitude Distribution analysis on a linear array was presented, and the authors revealed that the grating lobes appear if the Amplitude Distribution within a module and a system of modules are independent of each other. In [6], amplitude taper function was applied to improve the SLL of the phased array antenna system, and approximately 10 dB improvement on the SLL level was demonstrated.

In this paper, a highly scalable transmit and receive (T/R) module with Amplitude Distribution function is proposed, the T/R module has been built using commercial semiconductor that is flexible to be integrated into the conventional phased array to form a smart beamforming antenna system. This paper covers the simulation and verification of the Amplitude Distribution of the T/R module to achieve the best HPBW, SLL and gain, which is one of the important functions in the beamforming antenna system.

II. T/R MODULE

The T/R module [7] shown in Fig. 1 consists of all the necessary functional blocks to handle the beamforming activities such as Amplitude Distributions, phase shift, receive signal amplification and antennas switches. In this paper, we focus on the Amplitude Distribution, the Amplitude Distribution block of each T/R module is shown in the red box in Fig. 1. It consists of a power amplifier (PA) TQP5525 from Qorvo with 32 dB gain and P1dB of 32dBm and an RF attenuator (ATT) IDTF2258NLGK from IDT with 33.6 dB attenuation range and 2.7 dB low insertion loss. The amplitude of the transmit power can be controlled via an analogue input, **P*ctrl*** by the external peripheral such as microcontroller and field programmable grid array (FPGA), the actual output power can be accurately set by monitoring the analogue output, **P*det***. Each T/R module can support up to 4 antenna ports. Multiple T/R modules and antenna arrays can be easily cascaded to form a large antenna system, hence, infrastructure upgrade becomes simple and less costly, thanks to the modular approach that allows technology refresh by replacing just the module instead of the whole antenna system.

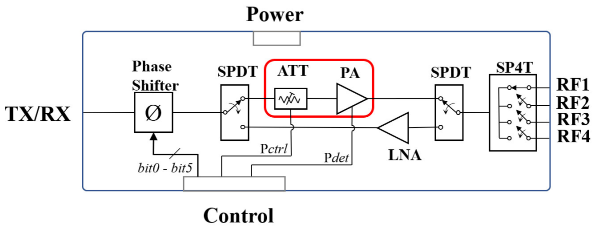
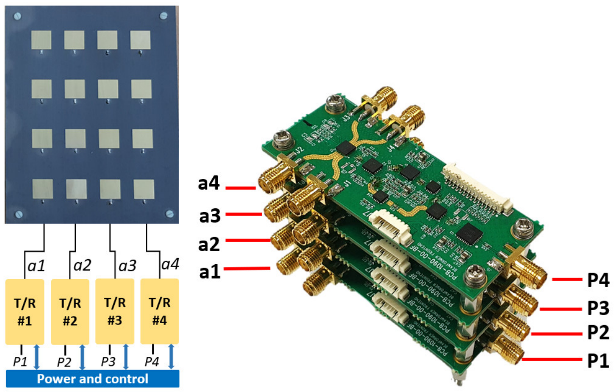


Fig. 1. Block Diagram of the T/R Module

The gain distribution model is presented in Fig. 2(a). The antenna array [8] consists of 4 vertical elements combined into a single port using the corporate fed method, in this case, 4 units of T/R modules as shown in Fig. 2(b) are used to evaluate the Amplitude Distribution of the antenna system. The notation for the Amplitude Distribution is presented as a1–a2–a3–a4 where a1 is the amplitude ratio for port 1, a2 is the amplitude ratio for port 2 and so on, the amplitude ratio ranged between 0 and 1 where 1 is the full power and 0.5 is half power.



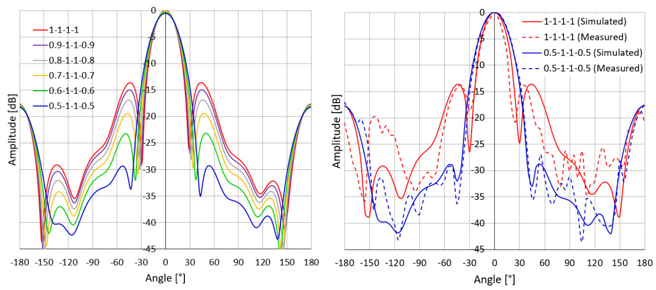
(a) Test Setup (b) photo of the T/R modules

Fig. 2. Gain Distribution on the 4 × 4 array

III. Amplitude Distribution Results and Discussion

The Amplitude Distributions of the T/R module integrated with the 4 x 4 array is simulated using Computer Simulation Technology (CST) tool, the simulation results at 5.5 GHz operating frequency are presented in Fig. 3(a). As we can observe from the results, the antenna radiation pattern is compromised between the gain, HPBW and SLL, and the optimal results are observed when the Amplitude Distribution factor is 0.5-1-1-0.5 (optimum distribution) where the gain is 17.4 dBi, HPBW is 29.2° and SLL is -28.7 dB compared to the uniform Amplitude Distribution of 1-1-1-1 that produces the gain of 17.9 dBi, HPBW of 24.5° and SLL of -13.6 dB, thus, the optimum Amplitude Distribution delivers good SLL improvement of 15.1 dB for interference performance and reasonable gain and HPBW as compared to uniform distributions. Further simulation has been carried out to evaluate the SLL improvement with Amplitude Distribution 0.5-1-1-0.5 for the entire steering angle supported by the array, SLL of 11.1 dB and 5.27 dB improvement were observed for ± 20° and ± 40° steering angle. However, the Amplitude Distribution was not able to suppress the grating lobe level at the end-fire around ± 40°.

The SLL performance results at 5.5 GHz, 0° beam with Amplitude Distributions of 1-1-1-1 and 0.5-1-1-0.5 are experimentally validated using the T/R modules and the 4 x 4 linear arrays and presented in Fig. 3(b). The optimum side lobe and gain are achieved when the Amplitude Distribution is at 0.5-1-1-0.5 where the results are agreed well with the simulation results presented earlier.



(a) Simulated Results (b) Measured Results

Fig. 3. SLL Performance with Different Amplitude Distribution Factor

IV. Conclusion and Future Works

The highly flexible and scalable Amplitude Distribution network in the T/R module has been proposed, the Amplitude Distribution in the T/R module and the 4 × 4 antenna array has been simulated and the result has been validated with the experimental result. The optimum Amplitude Distribution of 0.5-1-1-0.5 delivers good SLL of -28.7 dB, and reasonable gain of 17.4 dBi and 29.4° for HPBW. Multiple T/R modules and antenna array can be easily cascaded to form a large antenna system, in addition, the modular approach will certainly bring down the technology refresh cost and broaden the smart antenna adoption.

As the future work, the T/R modules will be integrated with the controller module such as FPGA to realize the full functionality of the T/R module including the phase shift, complex beamforming weight etc. for beamforming antenna application.

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