URSI GASS 2021, Rome, Italy, 28 August - 4 September 2021

Wideband, Electronically Reconfigurable Phased-Array Element with 1-Bit Phase Quantization and High-Power Handling Capability

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Phased-array antennas have been used in various applications ranging from satellite and airborne communications to radar and imaging systems. Phased-array antennas designed for some military applications are expected to be capable of operating over very wide bandwidths and radiate very-high power levels. One such application is electronic warfare (EW) in which phased arrays are often expected to radiate a wide range of different wideband waveforms at different frequency bands. The capability to radiate high power levels in such systems is essential, particularly if they are used for electronic attack applications. The simultaneous requirements of wide bandwidth and high radiated power levels are extremely challenging to meet with many existing phased-array design approaches. This is particularly the case in active phased-array architectures, in which individual transmit/receive modules are integrated with each radiating element of the array. In such cases, the wide bandwidth requirements of the EW system result in power amplifiers (PA) operating in low-efficiency regimes, thereby limiting the average radiated power. Furthermore, the lower PA efficiency results in generation of significant heat that must be efficiently dissipated from the aperture. These challenges are motivating factors for development of less complex, high-power-capable, wideband, passive phased array antennas.

Recent studies of 1-bit phase shifters have exploited the concept of polarization rotation (PR) as a promising solution to design wideband, low-complexity reflectarrays [1] and transmitarrays [2]. In this paper, we present the design of a high-power capable, wideband phased-array element that exploits PR to achieve 1-bit electronic phase shifting capability. The proposed element can be used either in a transmitarray architecture or in a direct-fed, phased-array architecture. The unit cell of the array consists of a polarization-rotating element operating in a double-ridge waveguide environment. The PR phase shifter can be electronically reconfigured to rotate the polarization of the transmitted wave by 90º in either the clockwise or counterclockwise direction. This creates a phase shift of 0º/180º between the waves transmitted from differently configured PR phase shifters. To accommodate the high-power capability and thermal management requirements, aluminum nitride (AlN) ceramic substrate with a high thermal conductivity of 170W/mK is used to construct the PR phase shifter. Electronic reconfigurability of the device is achieved by using high-power capable PIN diodes as the main switching component.

A prototype of the proposed direct-fed unit cell was designed and fabricated. The device was designed to operate over bandwidth of one octave covering the 6-12 GHz frequency range. The desired power handling capability of each unit cell is 22.2 W/cm^2 (average) and 222 W/cm^2 (peak with 10% duty cycle). This prototype uses custom-made components including double-ridge waveguides, waveguide transitions, and waveguide shims. Commercially-available coax to standard double-ridge waveguide adapters are used to interface the device with the external test setup. The complete system was simulated and optimized in CST Studio Suite. Full-wave simulation results indicated that nearly-complete polarization conversion can be performed, resulting in wideband 0º/180º phase shifts within the 6-12 GHz band. The simulated transmission coefficient, T_{xy}, was larger than -1 dB over this band. Initial experimental characterization of the device at low power levels have been completed. Complete characterization of the fabricated prototype, including high-power experiments, are currently ongoing and are scheduled to be completed within the next few months. Details of the design along with the simulation and measurement results of this phased-array element will be presented and discussed at the conference.

References

[1] H. Luyen, Z. Zhang, J. H. Booske and N. Behdad, “Wideband, beam-steerable reflectarrays based on minimum-switch topology, polarization-rotating unit cells,” IEEE Access, vol. 7, pp. 36568-36578, 2019.

[2] K. Mavrakakis, H. Luyen, J. H. Booske and N. Behdad, “Wideband transmitarrays based on polarization-rotating miniaturized-element frequency selective surfaces,” IEEE Trans. Antennas Propag., vol. 68, no. 3, pp. 2128-2137, March 2020.