

0.5-45GHz Simultaneous Transmit and Receive (STAR) Antenna System for Electronic Attack

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Abstract: A shared antenna aperture for simultaneous transmit and receive (STAR) operating from 0.5 to 45GHz with isolation $>50\text{dB}$ over the entire band is discussed. The co-located antenna aperture system is designed across 4 overlapping bands: 0.5-2.5GHz, 2-7GHz, 6-19GHz, and 18-45GHz. The lowest band utilizes a novel monostatic STAR approach based on a four-arm spiral antenna. The required isolation for other bands is achieved by physically displacing the transmitting and receiving antennas (i.e. bistatic approach) as well as implementing efficient isolation improvement techniques. Small linearly tapered slot array, TEM and quad-ridge horns are employed to achieve excellent wideband performance, single/dual polarization operation, and high-power handling capability required for electronic attack. In this work, only the individual standalone subsystems are discussed.

Keywords: Electronic attack; isolation; STAR.

Introduction

Simultaneous transmit and receive (STAR) is a critical capability that will improve effectiveness of the electronic attack and supporting RF systems. The chief challenge to implement such operation is the required high isolation levels (far greater than 100dB) between the co-located transmitter and receiver [1]. To achieve this level of isolation, multiple layers of antenna, analog, and digital self-interference cancellation techniques should be utilized. If a significant portion of the cancellation process is performed at the antenna level the overall system complexity will be significantly reduced. Typical STAR systems are relying on the use of multiple apertures (i.e. bistatic approach) where the TX and RX antennas are depolarized, or separated multiple wavelength distance, or arranged/excited in a specific way to cancel the near-field interaction. Single-aperture STAR systems implementing RF and photonic circulators have also been considered. The main issues with these approaches are one or more among: power handling, cost, size, unequal radiation characteristics, bandwidth, and complexity. This paper demonstrates the design of high-power, wideband, and compact STAR antenna system operating from 0.5-45GHz (divided into four bands) with isolation $> 50\text{dB}$ and consistent and similar single/dual-pol [2] TX/RX radiation characteristics. The principles of monostatic and bi-static STAR are adopted within the considered bands and additional approaches including material loading, addition of controlled

losses, corrugation, and antenna shaping and orientation are used to further improve the isolation.

System Description

The STAR aperture system sketched in Fig. 1 utilizes 4 distinct band breaks: 0.5-2.5GHz, 2-7GHz, 6-19GHz, and 18-45GHz. The apertures of each band are integrated on 30cmx30cm ground plane, size or which is driven by the lowest sub-band. To avoid using a bistatic subsystem which will further increase the aperture size, a novel monostatic configuration based on a single four-arm spiral aperture is considered. The four-arm spiral antenna is configured such that two arms are used for transmitting and the other two arms for receiving, as shown in Fig. 2. The symmetry of antenna elements (arms) along with the applied excitations enables a high isolation (theoretically infinite) between transmitter and receiver over the antenna's operating bandwidth [3]. To improve TX/RX gain, efficiency, axial ratio, and allow the use of metallic backing instead of absorber, a spiral-helix STAR configuration [3] is considered. Two microstrip feeds printed on the opposite of the spiral arms with impedance transformer as shown in Fig. 2 are employed to provide 180° phase offset between the opposite arms as well as match 50Ω coaxial feed to 140Ω at the input of the spiral. Employing this feed eliminates the need for the 180° hybrid and simplifies the proposed monostatic STAR configuration. The proposed spiral-helix has diameter of 15.24cm and height of 5.08cm. The antenna geometry is shown in the inset of Fig. 3.

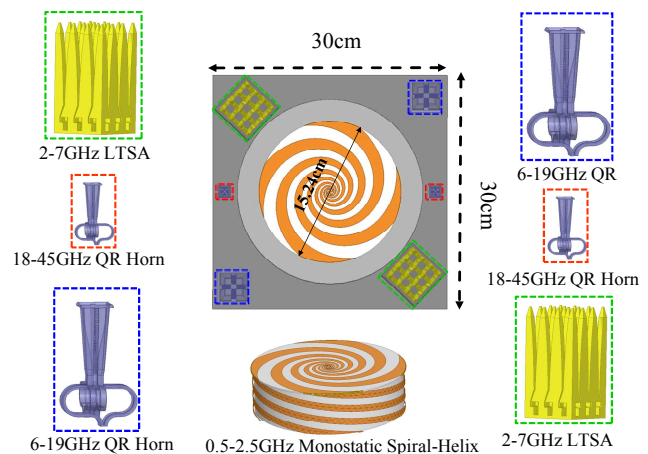


Figure 1. Illustration of the 90:1 bandwidth STAR antenna sub-system.

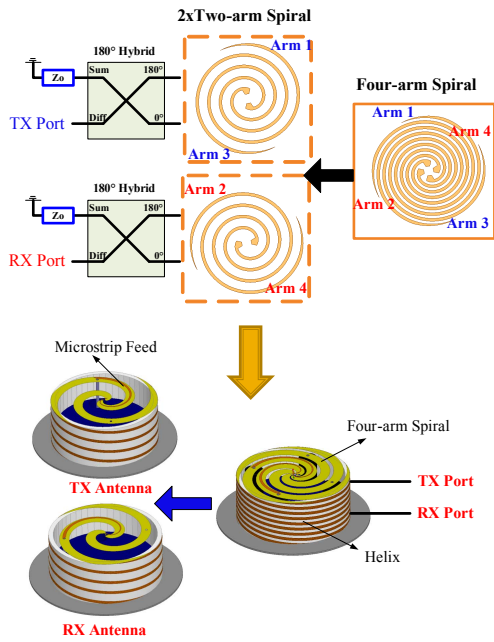


Figure 2. Monostatic four-arm spiral STAR sub-systems.

For all other bands, bistatic STAR front-end of two identical TX/RX antennas displaced as shown in Fig. 1 are used. Specifically, for 2-7GHz band, two different apertures are considered: two-element array of compact TEM horns, and 3x4 linear tapered-slot array (LTSA) which can be designed to support single or dual polarization. Antennas are recessed in a cavity to improve the isolation and reduce the interaction with other antennas. TX and RX TEM horn array cavities are loaded with ferrite beads and ECCOSORB[®] MCS absorber (magnetically-loaded silicone rubber material), respectively to reduce currents on the cavity walls and eliminate negative impact of cavity resonances. The nominal radiation efficiency of the ferrite- and absorber-loaded TEM horn arrays is 75% and 70%, respectively. The novel approach of connecting the edge elements of the LTSA to the cavity wall in E-plane eliminates any cavity resonance due to the cancellation of the currents on the cavity walls. The proposed cavity-backed LTSA exhibits multi-octave operation with consistent impedance match, radiation patterns, and high aperture efficiency. The TEM horn array and LTSA total size including the cavity is 7.2cm × 7.2cm × 6.3cm and 10cm × 7.4cm × 11cm, respectively. Both considered apertures have TX gain > 5dBi (max. of 13dBi for LTSA) and return loss (RL) > 10dB over the operating bandwidth.

To achieve high effective radiated power (ERP) over 6 – 19GHz range and maintain high isolation between the TX and RX apertures, a bi-static configuration of aperture-matched dual-polarized quad-ridge horn antenna (size: 3.8cm × 3.8cm × 9.5cm) backed by the orthomode transducer (OMT) is developed. A scaled version of 6-19GHz quad-ridge horn is used for 18-45GHz band.

Scaling factor of 0.4 is used. TX gain > 7dBi (max. of 15dBi) and RL > 10dB are obtained over both bands.

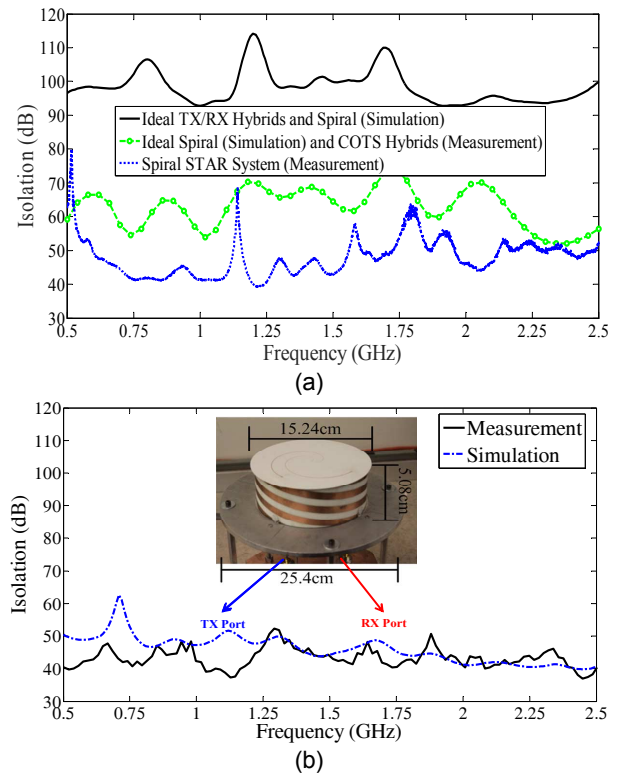


Figure 3. Measured and simulated isolation of the (a) conventional Archimedean four-arm spiral and (b) microstrip-fed spiral-helix monostatic STAR sub-systems.

Isolation Performance

At this point, the isolation performance of each STAR front-end is evaluated individually using full-wave analysis based on HFSS and experimentally. The monostatic STAR four-arm spiral/spiral-helix configurations are shown in Fig. 2. 180° hybrids and microstrip feeds are used as mode 1 beamformer for the conventional two-arm and spiral-helix configurations, respectively as shown in Fig. 2. The utilized conventional aperture is a two-turn four-arm Archimedean spiral having outer and inner radii of 7.62cm and 0.25cm, respectively. The antenna is fabricated on a 1.52mm-thick Rogers RO3003 substrate. A 50Ω coaxial bundle composed of four 0.141” semi-rigid cables is used to feed the antenna. The measured and simulated TX-RX isolation of the proposed STAR spiral system is shown in Fig. 3(a). As seen, the computed isolation of an ideal spiral system (with use of ideal hybrids) is > 90dB over wide bandwidth. The theoretical analysis shows that in absence of any imbalances and asymmetries the computed isolation of the monostatic system is limited by the level of the simulation noise. As the ideal hybrids are replaced by actual COTS hybrid measurements in AWR circuit simulator, the simulated isolation of the ideal system degrades about 30dB due to the hybrid imbalances. This indicates a significant impact of the phase/amplitude imbalances on the signal cancellation. Experimental data demonstrate that isolation

levels greater than 40dB over multiple octaves are achievable with realistic components. The measured and simulated isolation of the spiral-helix STAR configuration is shown in Fig. 3(b). Although the 180° hybrids are eliminated in the case of the microstrip-fed spiral-helix configuration, the isolation is still deteriorated. This degradation is due to the feed region and antenna construction asymmetry which significantly affects the signal cancellation at the antenna feed. The isolation of this configuration can be improved further by enhancing the symmetry of the feed region.

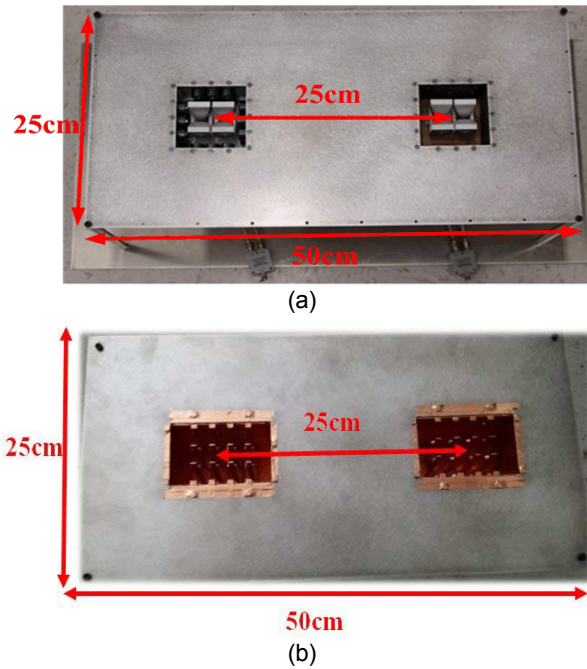


Figure 4. 2-7GHz band bistatic STAR sub-systems: (a) TEM horn array (b) LTSA system.

The fabricated 2-7GHz band TEM horn array and LTSA bistatic systems are shown in Figs. 4(a) and (b), respectively. For measurements, the recessed arrays are flush-mounted on a 25cm × 50cm ground plane. As mentioned, TX and RX TEM horn arrays are loaded with the ferrite and ECCOSORB® MCS absorber as shown in the inset of Fig. 5(a). The center-to-center spacing between the TX and RX arrays is chosen to be 25cm ($1.67\lambda_{2GHz}$) for both arrays. The TX/RX arrays are oriented in H-plane since the patterns have lower azimuthal gain and narrower beams in this plane. The measured and simulated isolation of the proposed systems are shown in Fig. 5. As seen, isolation >47dB (>60dB starting from 4GHz) is measured over the operating bandwidth for both cases. At the low end, the antennas are coupled through radiation. As the frequency increases, the beamwidth decreases, path loss increases and the coupling predominately will be through the surface currents and edges diffractions of the ground plane. Different techniques are evaluated to suppress the surface currents and edge diffraction including the use of ferrite, absorptive paint, and rolling the edges. These techniques lead to isolation

improvement mainly at the mid and high bands with no noticeable improvement at the low end. To improve the isolation, a simple approach based on inserting a metallic wall or step between the TX/RX antennas, as shown in the inset of Fig. 6, can be utilized. This step can be also used to host the monostatic STAR spiral aperture. As seen from Fig. 6, the isolation improvement of 10dB and more is achieved with 5cm-tall wall at the expense of a beam squint and reduced broadside gain. As expected, isolation improves with the wall height.

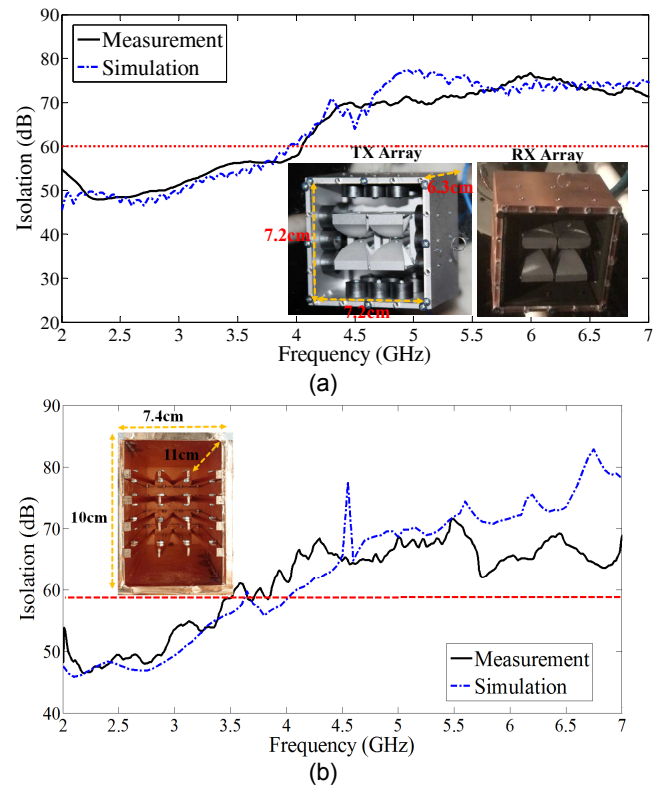


Figure 5. Measured and simulated isolation of the 2-7GHz band bistatic STAR sub-systems: (a) TEM horn array (b) LTS array system.

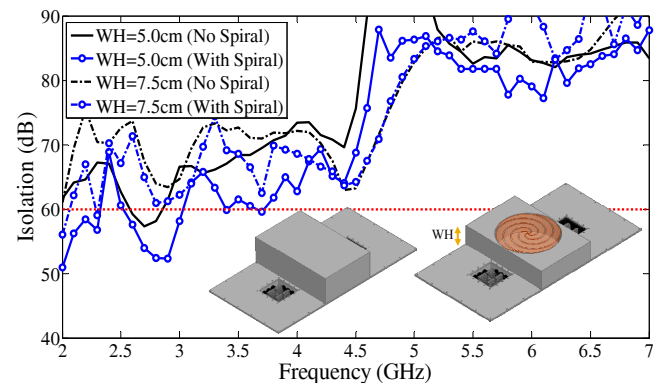


Figure 6. Computed isolation of the TEM horn array bistatic system with the metallic wall.

The fabricated 6-19GHz dual-polarized bistatic system is shown in Fig. 7(a). The TX/RX quad-ridge horns, shown in the inset of Fig. 8, are flush-mounted over 13cm × 36cm

ground plane and separated 24cm ($4.8\lambda_{6GHz}$). Since the antennas are dual-polarized, orienting the antenna in H-plane will improve the isolation of only one mode of polarization. In order to achieve high isolation for both polarizations, the horns are rotated 45° around their axis. Significant improvement in isolation (about 15dB) is observed at the mid and high bands using this approach. To further improve the isolation, four groove corrugations are implemented around the TX horn as shown in Fig. 7(b). These corrugations are $\lambda_{6.5GHz}/4$ depth shorted slots used to create high impedance over certain bandwidth thus forcing the surface currents to radiate rather than propagate along the surface of the ground plane [5]. The RX quad-ridge horn is also recessed in an absorber. High isolation >60dB is obtained over the designated bandwidth as shown in Fig. 8. The measurement of this configuration is currently under progress.

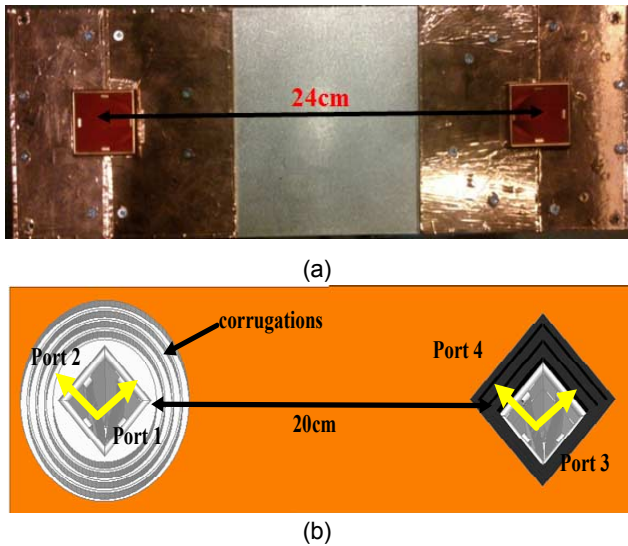


Figure 7. 6-19GHz band bistatic STAR sub-system: (a) fabricated configuration (b) computational model of the system with improved isolation.

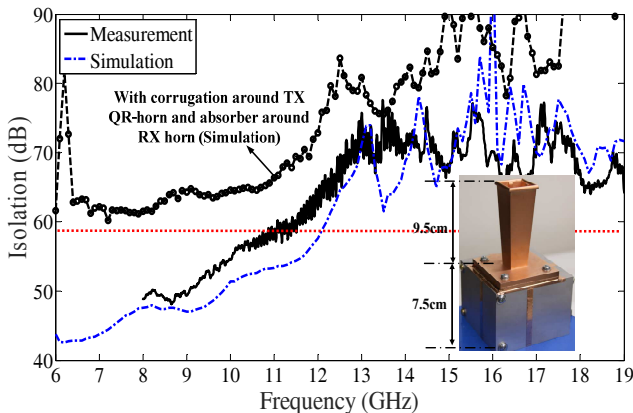


Figure 8. Measured and simulated isolation of the 6-19GHz band bistatic STAR sub-system.

The 18-45GHz dual-polarized bistatic system utilizes a scaled model of the 6-19GHz quad ridge horn. The

computed isolation of 18-45GHz bistatic system exploiting corrugation and recessing in absorber at TX and RX sides (i.e. similar to Fig. 7(b)) is shown in Fig. 9. The TX/RX center-to-center spacing is 24cm ($14.4\lambda_{18GHz}$). Isolation >70dB is obtained over the operating bandwidth for the two polarizations.

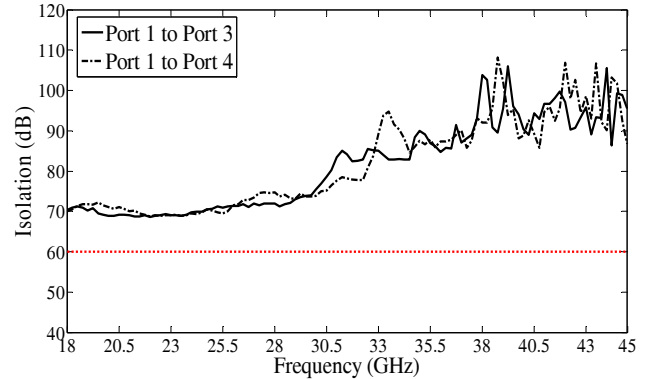


Figure 9. Computed isolation of the dual-polarized 18-45GHz band bistatic STAR sub-system.

Conclusions

This paper discusses the design of shared-aperture STAR antenna system operating across 4 overlapping bands: 0.5-2.5GHz, 2-7GHz, 6-19GHz, and 18-45GHz. Different antenna configurations are designed and fully characterized for each band. Initial isolation measurements are conducted inside anechoic chamber for the first three bands and high isolation levels are obtained. Good agreement between the measurements and the full-wave simulations is observed. Different techniques to improve the isolation of the 2-7GHz bistatic STAR system including the use of parasitic elements and analog cancellation techniques are currently researched along with the system integration.

Acknowledgment

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