Design Considerations for Space-Based Radar Phased Arrays†

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Abstract — **Space Based Radar (SBR) is being considered as a means to provide persistent global surveillance. In order to be effective, the SBR system must be capable of high area coverage rates, low minimum detectable velocities (MDV), accurate geolocation, high range resolution, and robustness against electronic interference. These objectives will impose challenging requirements on the antenna array, including wide-angle electronic scanning, wide instantaneous bandwidth, large power-aperture product, low sidelobe radiation patterns, lightweight deployable structures, multiple array phase centers, and adaptive pattern synthesis. This paper will discuss key enabling technologies for low earth orbit (LEO) SBR arrays including high efficiency transmit/receive modules and multilayer tile architectures, and the parametric influence of array design variables on the SBR system.**

Index Terms — **Space based radar, phased array, flat panel antenna, multilayer tile.**

I. INTRODUCTION

Space Based Radar (SBR) antennas will require rapid electronic scanning within a region of interest (ROI), with slower mechanical slewing to point the array at the center of the ROI. The size of the ROI is a major driver of SBR antenna performance, due to the impact on maximum electronic scanning angles. The desired capabilities of the system will influence the mass, volume, and power of the antenna. The minimum detectable velocity (MDV) of the system is proportional to the antenna diameter along track. The area search rates and geolocation accuracy will also be dictated by antenna size and radiated power. The range resolution is determined by the system bandwidth, and the ability to adaptively cancel electronic interference and clutter is influenced by the number of adaptive degrees of freedom and the sidelobe levels of the antenna.

Constellations of satellites at medium earth orbit (MEO) and low earth orbit (LEO) are presently under consideration [1], [2]. This paper addresses the LEO case. To achieve the desired geolocation accuracy, minimum detectable velocity, and area search rates, it is estimated that X-band antenna apertures in the range of 40–100 m^2 will be required. These apertures will require wide instantaneous transmit and receive bandwidths to obtain high resolution GMTI/SAR performance. To detect and track widely distributed ground targets, electronic scanning of up to ±45° in azimuth and up to ±20° in elevation will be required. To help mitigate electronic interference and clutter, low antenna sidelobes in both azimuth and elevation planes will be required, and 10–20 spatially adaptive degrees of freedom will be necessary. The average RF power radiated will typically be in the range of 500–2500 W.

This paper will discuss key active electronically scanned array (AESA) technologies and the parametric influence of array design variables on the SBR system.

II. ACTIVE ELECTRONICALLY SCANNED ARRAY TECHNOLOGIES

The block diagram of a generic AESA architecture is shown in Fig. 1. In this example, the AESA is divided into panels, with separate receivers and transmitters for each panel. An active transmit/receive (TR) module will feed every element, and short time delays can be applied with analog time delay units (TDU) at a subpanel level, with TDU spacing dependent upon bandwidth and maximum scan angle. The long time delays will be provided digitally at the panel level.

The radio frequency (RF) receiver/exciter units are nominally located on the array panels, as are the analog time delay units, distributed power supplies, and beam steering controller. Digital waveform generators produce the transmit signal at each panel, thus providing digital time delay on transmit. RF down-converters produce the intermediate frequency (IF) signals in each channel, which are then routed to the signal processor in the satellite bus for digitization and IF-to-baseband conversion.

AESA technology has been progressing through an evolution from the 'brick' technology towards 'tile' technology [3]. The brick technology typically uses TR modules with metal housings mounted perpendicular to the array face. Although the metal TR module housings offer additional shielding from ionizing radiation, they also add a large mass. In the brick approach, most of the RF combining, DC power distribution, and array control must be routed external to the array face. A large portion of the brick array mass is due to these analog combining networks, which consist of coaxial cables and discrete power combining modules.

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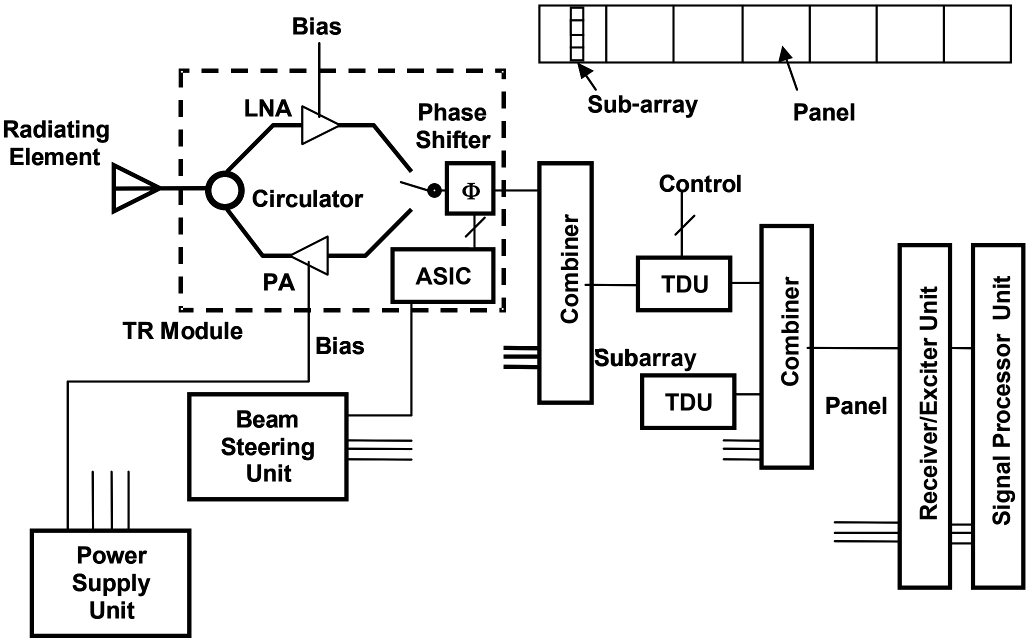

Fig. 1. Generic active electronically scanned array architecture

The tile architecture uses multilayer circuit boards to distribute the RF, DC, and control signals, and the electronic TR components can be attached directly to the multilayer boards to form TR cells, which are the functional equivalent of TR modules without the metal housing. Radiation shielding is provided in part by the multiple ground planes in the tile, and from aluminum honeycomb panels supporting the tiles. Additional spot shielding may also be required for vulnerable components. It will be shown in the next section that the mass of the tile architecture for SBR is nearly independent of the number of TR cells.

III. PARAMETRIC DESIGN STUDY

The electronic scanning requirements dictate the number of TR cells required in the array, which in turn influences the power, mass and cost of the system. It is assumed that the array will be pointed mechanically at a slow rate to the center of a ROI as the satellite passes by, and that rapid electronic scanning will be used to cover the ROI.

The array efficiency, defined as (P^{RF}_{OUT}/P^{DC}_{IN}), versus the number of TR cells is shown in Fig. 2 for a 40 m^2 aperture at 10 GHz, which is consistent with the size of the array from the Discoverer II SBR study. In this example, an insertion loss of 1 dB precedes the amplifier, and a dc-dc conversion efficiency of 80% is assumed. The plot shows results for different values of LNA drain power, ranging from 5–50 mW. The current state-of-the-art is 25–50 mW for the GaAs LNA drain power, with expectations of achieving 5–10 mW in 2005. The power added efficiency (PAE) of the transmit power amplifiers in this example is 50%. These curves clearly indicate the critical influence of LNA drain power on the array efficiency, particularly for arrays with 50,000 to 100,000 TR modules.

Fig. 3 shows the LEO antenna mass for three maximum scan angles for the brick and tile technologies at X-band. The brick design produces a very large antenna mass at the larger scan angles (±30° AZ × ±15° EL, ±45° AZ × ±15° EL). The tile array design leads to a nearly constant antenna mass versus array scan range. Since the mass of the tiles is dominated by the multilayer tile boards, the antenna mass does not increase significantly by adding more TR cells to achieve increased scan range. For the brick technology, the metal TR module housings, the external RF combiners, power distribution and control networks lead to an unacceptably high antenna mass for large scan angles. The results shown in Fig. 3 are for a 40 m^2 AESA at X-band. The assumptions used to calculate the array masses are shown in Table 1. The trends shown in the figure will not change significantly for different aperture areas or radiated power levels.

The results shown in Fig. 3 clearly indicate that the integrated tile technology will be essential for achieving the large scan angles required by the LEO SBR system.

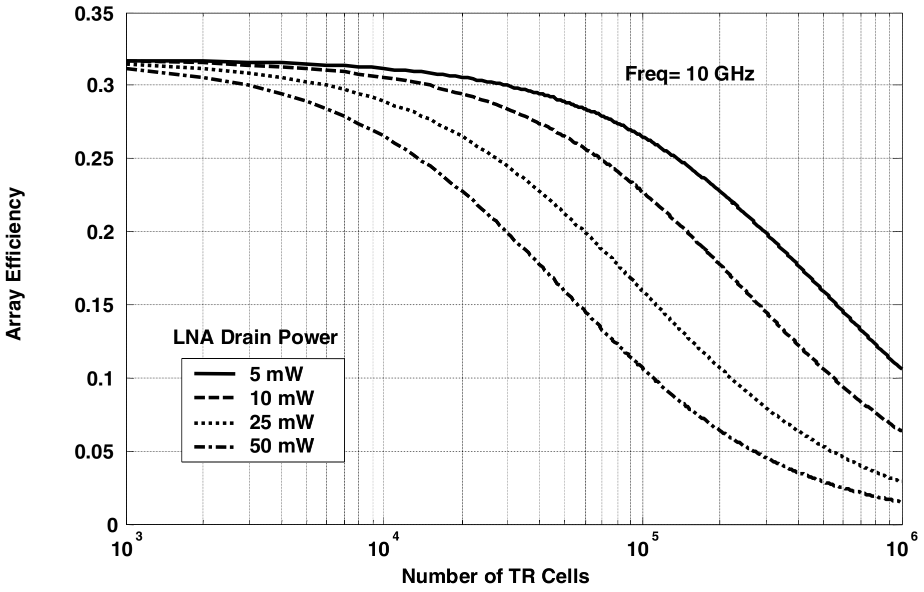

Fig. 2. Array efficiency versus number of TR cells.

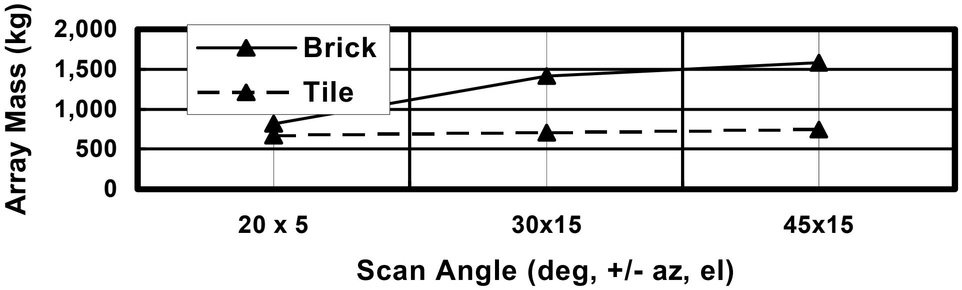

Fig. 3. Array mass versus maximum scan angle for brick and tile technologies.

Component	Mass/unit		Number of Units in Array versus Scan (Az × El)		
	Brick	Tile	±20° × ±5° (1 × 4 subarray)	±30° × ±15°	±45° × ±15°
T/R tile (.02 m^2)	NA	100 g/tile	2000	2000	2000
T/R cell	5 g/cell	1.5 g/cell	33,280	84,000	96,000
Radiating Element	1 g/element	1 g/element	133,200	84,000	96,000
TDU	20 g	20 g	100	400	600
Power Converter	100 g	100 g	150	225	250
Beam Steering Controller	500 g	500 g	20	20	20
Power and Control Distribution	2.5 g/cell	5 g /tile	33,280 (brick) 2000 (tile)	84,000 (brick) 2000 (tile)	96,000 (brick) 2000 (tile)
Subarray RF Combiner	5 g/cell	5 g /tile	33,280 (brick) 2000 (tile)	84,000 (brick) 2000 (tile)	96,000 (brick) 2000 (tile)
Support Structure	6 kg/m^2	6 kg/m^2	40	40	40

Table 1. Component mass and quantities for X-band SBR array mass estimates.

IV. SUMMARY

It has been shown that the use of multilayer tile technology reduces the mass of fully populated SBR arrays. Since the power distribution, control, and RF combining networks are embedded in the multilayer tiles, the mass of the tile arrays increases very gradually with active array element density, and this will enable SBR arrays with wide angle scanning. For large arrays with relatively low radiated power per TR cell, it has been shown in several examples that the LNA drain power is a critical parameter in the array efficiency.

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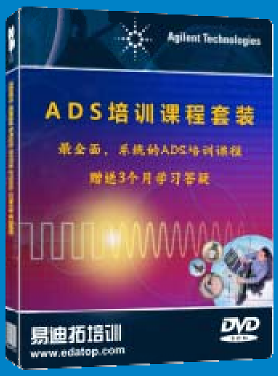

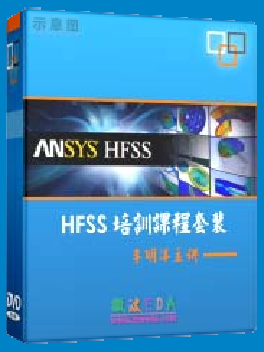

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