Study on Beam Forming and Direction-of-Arrival Measurement for Solar Power Satellite

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An area of continuing uncertainty is the "energy resources". A huge and clean power source is needed for sustainable economic activities. One source of huge and clean power is the space solar power. Solar Power Satellite (SPS) can send enormous power to the Earth as the form of microwave (MW). Precise MW power beam steering is a most critical goal for SPS because without precise beam steering the higher efficiency of MW power can not be assured at the rectenna location. Retrodirective beam control system is a proposed method of precise beam directing.

Microwave Power Transmission (MPT) system designers must be concerned with Beam Collection Efficiency (BCE), Side Lobe Levels (SLL), size, weight, and cost among many other factors. It is needed to improve the MPT efficiency in order to reduce the SPS costs. BCE and Maximum Side Lobe Level (MSLL) are used for an evaluation of the MW beam. Reduction of SLL is of paramount importance especially for the MPT in order to achieve the highest possible BCE and to reduce interference to other communication systems. If all antennas are uniformly excited then the main beam will carry only a part of the total energy due to higher SLL. SLL are decreased and BCE is increased by adopting edge tapering for SPS. However, tapering the excitation causes thermal problem and it is a complicated task to maintain different power levels. Isosceles Trapezoidal Distribution (ITD) edge tapered antenna, which is a new concept, is studied for the first time for SPS as an optimization. ITD is better than full edge tapering and uniform amplitude distribution. It was found that the highest BCE and lowest SLL are possible to achieve in ITD edge tapering [1], [2]. Different amplitude distribution systems like uniform, Gaussian, Dolph-Chebyshev and the newly derived ITD method have been compared. The SLL reduction in ITD is even higher than those of other kinds of edge tapering.

The ITD has never been experimented any other places before. Only a small number of antennas from each side of the phased array antenna are tapered in this method. ITD edge tapering is almost uniform so it is technically better. The power density at the center of the array of the ITD system can be made lower than that of the Gaussian or similar kinds of distributions for the same power transmission. Therefore thermal behavior at the center of the ITD edge tapered phased array antenna is better than that of the Gaussian and other kinds of edge tapering. The higher BCE and better SLL performance than those with uniform distribution can be achieved in ITD with phase error and under unit failed condition.

A statistical method of achieving minimum SLL with random element spacing was also studied. Different properties of large antenna arrays with randomly, uniformly and combined spacing (uniform with little perturbation) of elements were studied. A new unified approach in searching for reducing SLL by exploiting the interaction of deterministic and stochastic element spacing was studied. The models indicated an advantage with respect to side lobes in the large area around the main beam and strongly reduced SLL in the entire visible range.

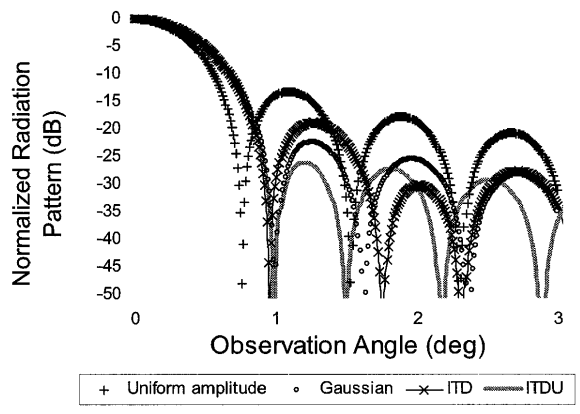

Figure 1 Normalized radiation patterns for phased array antenna of uniform amplitude, -10 dB Gaussian tapering, -10 dB ITD and -10 dB ITDU. 33 elements from each side were tapered in ITD. 30 elements from each side were tapered in ITDU and 40 elements from each side were of unequal spacing in ITDU.

Though it is possible to reduce SLL with statistically thinned array or combined stochastic algorithm but it does not guarantee higher BCE and needs edge tapering to achieve high efficiency. The performance of ITD was further improved from the perspective of both Maximum Side Lobe Level (MSLL) and BCE by using unequal spacing of the antenna elements [1]. The MSLL for ITD with Unequal element spacing (ITDU) was found to be the lowest (Figure 1) when it was compared with Gaussian, ITD and uniform amplitude distribution [1], [3]. The MSLL of ITDU is much lower than that of ITD. Moreover the BCE is found to be the highest in newly derived ITDU. The unequal spacing was derived from the ITD concept and by using the sinc function. The estimation of

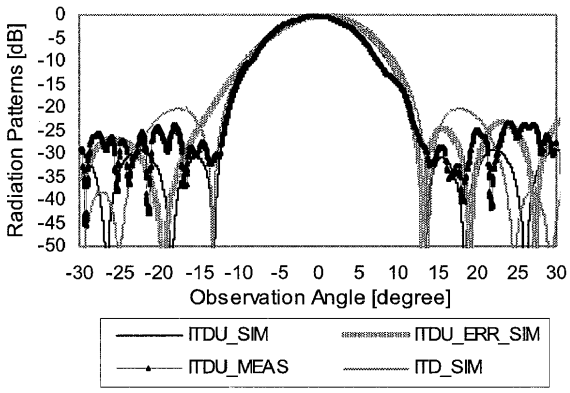

Figure 2 Simulated, measured and simulated (with error) radiation patterns of ITDU and simulated radiation pattern for ITD with 11 phased array antenna elements. (Experimental verification is done after submitting the dissertation).

unequal spacing is very easy. The unequal element spacing is chosen within such a range so that no grating lobe in the observation range of $\pm 90^{\circ}$ is formed due to unequal spacing with ITD. Both ITD and ITDU are new concepts. The merits of ITDU over ITD and Gaussian edge tapering were also studied [1]. Experimentation on ITDU was also done and it was found that the experimental results agree well with the simulation results (Figure 2). The experimentation on ITDU is also done for the first time and it was done no where before.

Detection of accurate phase and Direction of Arrival (DOA) of incoming pilot signal in SPS system is an important part of accurate beam forming. Imperfect knowledge of pilot signal receiving antenna spacing can cause DOA detection error. The displacement of antenna element spacing may occur after launching the satellite due to thermal expansion of the antenna or other reasons. The DOA error increases as the phase detection error increases. There are several sources of phase detection error such as element spacing error, ionospheric effect, antenna gain and phase errors. MUSIC and Time-Frequency MUSIC (TF-MUSIC) based DOA detection requires accurate knowledge of array element spacing and their performance can degrade substantially when there is a discrepancy between exact and presumed array element spacing. The effect of pilot signal receiving antenna spacing error on DOA was studied and a possible solution of element spacing calibration was investigated by using two reference signals in a time-sharing manner. TF-MUSIC method of DOA detection can increase the effective SNR and can detect the DOA of closely spaced signals. Therefore the TF-MUSIC for DOA detection in SPS was also studied. An experiment on simultaneously calibrating the antenna gain and phase errors and detection the DOA of two pilot signals were performed and the method is named as Calibrated_MUSIC (C_MUSIC) in the thesis. C_MUSIC was better than general MUSIC. TF_MUSIC was also tested by considering antenna gain and phase errors and the method is named as Calibrated TF_MUSIC (CTF_MUSIC). It was found that the CTF_MUSIC performed better (Figure 3) than C_MUSIC [1], [4]. The DOA errors were less and peaks were sharper in CTF_MUSIC than C_MUSIC.

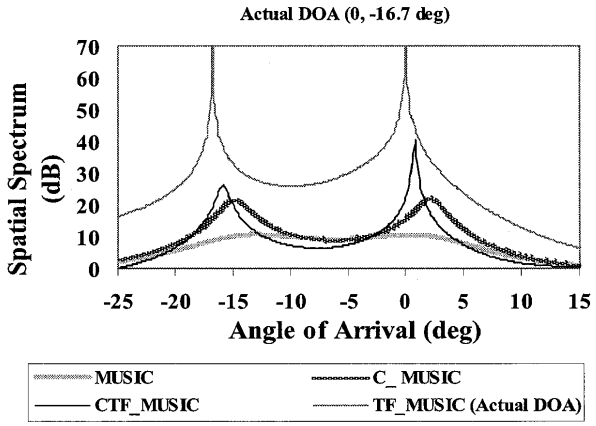

Figure 3 Spatial spectrum of MUSIC, C_MUSIC, and CTF_MUSIC of measured incoming signals and TF_MUSIC of actual (simulated) incoming signals (without any error). CTF_MUSIC performs better than MUSIC and C_MUSIC in real situations.

The effect of ionospheric total electron content (TEC) on the DOA of SPS pilot signal was studied and it was found that this effect can be neglected.

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