Electrical Design of a Multi-beam Large Antenna for Satellite Payload

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1. Introduction

As the demand for the universal communication and broadcasting services to personal portable terminals has recently increased, the needs for necessity of a large satellite antenna with a high gain have been on the rise. Multi-beam system applied to a large antenna can dramatically increase transmission capacity and reuse of allocated frequency band [1]. An array-fed reflector antenna by the name of a hybrid antenna composed of a over 20m-class reflector and multi feed array elements are an attractive option for this demand because of their flexibility with regard to beam scanning and beam shaping [2]. Hybrid antennas can be implemented by single fed systems or array-fed systems. Single fed antenna systems maximally use the surface of reflector but the wide angle scanning which is more than ten times of beamwidth is impossible to achieve acceptable quality [1], [3]. The wide angle scan with high gain is possible only if a group of radiating elements in the phased array elements is excited simultaneously with appropriate amplitude and phase. Therefore, the electrical design method of the offset reflector antenna fed by array elements will be described and the electrical analysis of the multi-beam system will be performed in this paper.

2. Design of a Multi-beam Antenna

2.1 Multi-beam Hybrid Antenna

There are some kinds of design methods for hybrid antennas. Ray-path or GO (Geometrical Optics) method gives a good approach in the case the reflector diameter is greater than one wavelength. Ray-path analysis enables to understand physical sense and recognize restrictions and possibilities at the first stage of hybrid antenna development [4]. When the antenna is operating in receiving mode, the incident bundle of rays falls on the focal point. On the other hand, when a bundle of rays falls with some angle relative to the focal line the reflected rays are not focused into a point. In this case, there is the narrowest region, crossover, of the bundle cross-section in the two-rays path area. This interference region is limited by two rays passing from reflector edges and caustic surface. The larger is the angle of beam deflection, the greater is the size of crossover and the farther from the focus. A single feed which has a phase centre like a horn is able to realize the needed ray structure only in the case of non-deflection, when the rays are concentrated in a point. Nevertheless, principally it is possible to deflect the pattern as less than 2-3 times of beamwidth by moving the single feed toward crossover region. The further displacement of single feed leads to rapid increasing of phase errors in reflector aperture and it causes abrupt gain decrease and sidelobe growth. This can be avoided by the extensive feed which has not a point phase centre. The extensive feed is implemented in form of a phased array, where a quasi-continuous distribution of field is realized. According to GO-lows, the needed amplitude and phase distribution on the array feed can be calculated for each pattern beam position [5]. A typical field distribution of the feed located in crossover has oscillating amplitude and rapidly changing phase function. If the deflection angle increases, the excitation zone moves along the phase array aperture and the array size enlarges. Using GO-approach it is simple to fine the optimal displacement of feed array and the optimal antenna structure such as reflector diameter, focal length and feed size. The feed location should be chosen based on the following requirements; a) maximum gain of each beam, b) the optimal number of feed elements for each beam, c) the limit of power per one element, d) the minimal size of feed array, e) the same number of feed elements for each beam. Because of close arrangement of beams, the neighbour clusters have the inevitable intersect each other. It means that the element has to take place in forming two or three neighbour beams simultaneously and grow the radiated power.

It is reasonable to consider the hybrid antenna with offset parabolic reflector for no blockage, low sidelobe level and good beam to beam isolation. Now, let's assume the inclined dimension is 30 m because of the restriction of reflector dimension. The hybrid antenna is designed as shown in Fig. 1. The number and location of feed clusters can be controlled at the final design phase [6].

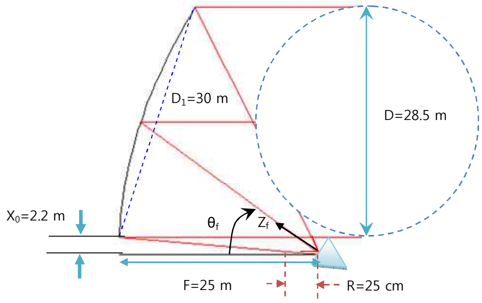

Figure 1: Design Parameter of a Offset Parabolic Reflector

2.2 Design of the Feed Configuration for Multi-beam

In order to form individual beam the non-uniform amplitude and phase distribution of feed array should be provided. The implemented field has some error due to discrete location of elements in feed array. The shorter the array spacing, the lower the error. But, the element spacing is limited by necessity of constructive placement. In practice, the array spacing is proper between 0.5 to 0.7 wavelength. The element pattern must also be sufficiently wide to excite the entire reflector's surface effectively, that is, the edge taper of 1.5 or 2.0 dB is desirable [7]. The other main parameters to define the array size are EIRP (Effective Isotropically Radiated Power) and the power limit per element. With the array size decreases, the power per element increases. Therefore, the value of EIRP determines the minimal array dimension. EIRP, one of the performance requirement, should be greater than 68.5 dBW per beam and the radiated power per element should be lower than 35 W. The service region should cover the Korean Peninsula and the number of beams should be 19.

To form feed clusters for the field analysis and the beam implementation is achieved by two stages. At first stage, the array size and position can be determined from the construction of ray-path field by GO-method. The intersection region of these ray-path fields consists of groups of excited elements of clusters, which form the required beams. A choice of the array position is ambiguous because a clusters may be placed in any cross-section of ray-path field. Fig. 2 shows feed clusters which are located in the regions of ray-intersection of array plane. The grey points in Fig. 2 indicate the location of elements and red color corresponds to array position R=0.7 and blue is R=0.3 m. Here R is the distance between focus and point of intersection of array plane as shown in Fig. 1. When the absolute angle for positive increases the clusters move down and stretch out in horizontal direction and when negative angle increases they move up and stretch out in vertical. For example, the ray with elevation angle of -0.6° and R=0.7 m involve 21 elements. In addition to, neighbour elements may be taken into account then the element would be 43. The smaller is a cluster the higher is a power per element, while the smaller are overlapping areas. It means each radiator takes part in forming lesser number of beams. As the location and the inclination of the feed array change, the antenna geometric parameters and the feed cluster configuration are optimally determined by GO-method. The optimal structure parameters are D=28.5 m, F=25 m, Xo=2.2 m and R=25 cm as shown in Fig. 1. The results of GO analysis according to deflection angles are presented in Fig. 3(a). Among these, the beam patterns with the biggest deflection angle are shown in Fig. 3(b) and Fig. 3(c).

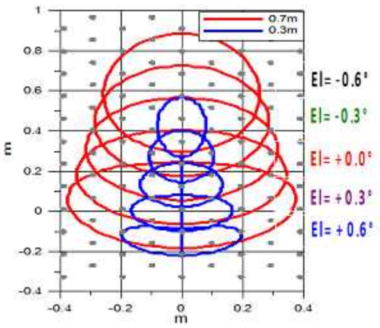

Figure 2: GO-bundles on array plane according to array location

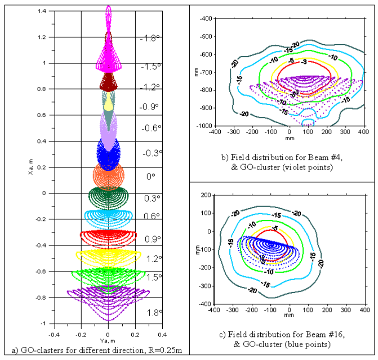

Figure 3: GO-bundles of Designed Antenna

2.3 Excitation Coefficient of the Feed Clusters

At second stage, the required beams are formed by exciting the elements which was chosen at first stage. To find excitation coefficient, it is necessary to calculate the field in array aperture plane for transmitting mode. The analysis is done by PO-approach. The individual pattern of the antenna excited by one element is calculated and the antenna pattern for a corresponding cluster is the summation of the individual patterns. The amplitude level of antenna patterns is the criterion for grouping elements and is called boundary level in this paper. After the amplitude and phase distribution in array aperture plane are determined, the individual patterns for each element having an amplitude no less than boundary level are chosen and these individual patterns are summarized with own amplitudes and phases. When the boundary level is lower than -15 dB, the aperture efficiency is nearly constant of 70 %. If the deflection angle is 1.8° and the boundary level is -25 dB, the feed array is composed of 80 elements. The other important thing for grouping elements is that the number of elements is preferable to the same for each cluster. Fig. 4 thru Fig. 6 show the beam patterns according to the number of elements per cluster. The best performance is obtained by 32 elements as shown in Fig. 4 and the peak directivity is 54.2 dB. The beam pattern by 8 elements is deformed and the performances are became worse, like the peak directivity of 53.3 dB, as shown in Fig. 5. Therefore, the selected elements are 16 in order to minimize the number of element and obtain the proper performance. The peak directivity is 53.9 dB for 16 elements as shown in Fig. 6.

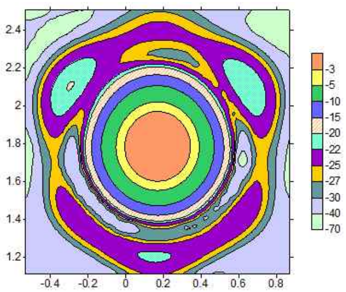

Figure 4: 32 elements

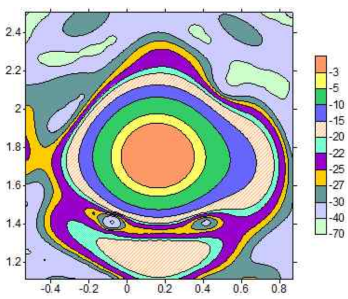

Figure 5: 8 elements

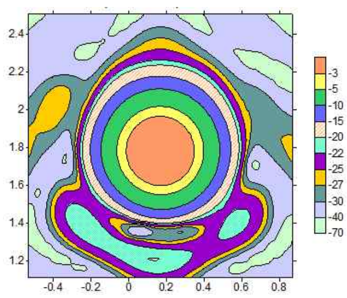

Figure 6: 16 elements

In order to form 19 multi-beams the hybrid antenna with 80 elements and each cluster consisted of 16 elements were designed. The array configuration composed of 80 elements is shown in Fig. 7. The location as well as the grouping of elements are indentified. The peak directivity of each beam is between 53.9 and 54.1 dB according to beam location. The contour of 3 dB lower than the peak directivity is shown in Fig. 8. We can find that the 3 dB contour for 19 beams covers the Korean Peninsula. The power distribution of the array is concentrated at centre as shown in Fig. 9 because the centre element takes part in 8 clusters simultaneously. The maximum radiated power is 33.6 W around the centre.

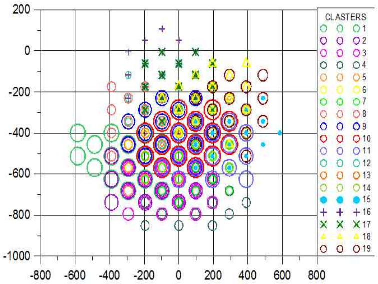

Figure 7: 80 Feed elements

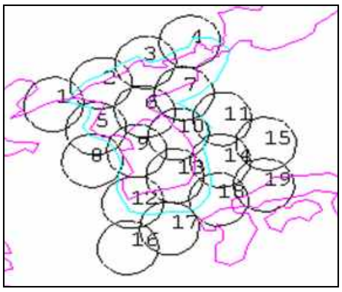

Figure 8: 3 dB Contour for 19 Multi-beams

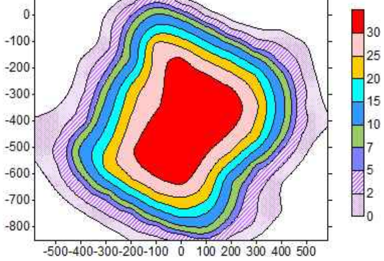

Figure 9: Power Distribution over Feed Array

3. Conclusions

In order to meet the demands for smaller personal portable terminals and the efficient employment of frequency, the antennas for satellite payload become larger and multi-beam system tends to be applied. In this paper, The hybrid antenna composed of 30 m reflector and 80 feed elements was designed. Each beam has the different deflection angles with respect to the position and it is the criterion of choosing excited elements. The antenna structure and the feed configuration such as the number of elements and the array dimension were optimized. The amplitude and phase of each element were also optimally designed by GO and PO methods. The proposed design method for hybrid antennas provides the implementation of multi-beam and the analysis of beam patterns. In future, the system requirement including electrical and mechanical aspect will be released based on these results. The multi-beam large antenna for satellite payload also will be able to implement.

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