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Hexagonal Radiator for Cellular Satellite Communication System

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Abstract

This paper tries to address the importance of beamforming for cellular satellite communication systems. In contrast to terrestrial cellular communication systems that the shape of the radio cells is more function of propagation loss and terrain features, the space version seems to be more function of beam projection on the earth curvature. In this way, beamforming may help to promote the system specifications regarding the shape of service area and co-channel interference. Here, the feasibility of hexagonal radiator for space cellular communications has been investigated for the first time.

1 Introduction

Satellites have several applications in communication so there are a variety of systems and custom designs. In this regard, coverage of the area and the required channel capacity might be considered as critical points leading to different satellite classifications. Coverage may include full continental contour coverage and/or spot beam. If the satellite footprint is subdivided into several radio cells, then antenna capable of radiating multiple beam might be favorable. During the past decades, there has been a continuous endeavor in the development of satellite systems using frequency-polarization reuse schemes in which the same bandwidth and/or polarization are allocated to some spot beams which are spatially isolated. Typically, several reflector antennas are used for every satellite. Such a system of massive reflectors is bulky, heavy and costly for accommodating onboard the satellite. Therefore, there is a quest to seek alternatives with lower mass, cost and higher performance [1].

One capable alternative is Reflectarray (RA), which is an array of reflective elements illuminated by one or more prime feed radiators. The reflective elements are arranged in a way that the secondary radiation produces favorable beam(s). RA inherited several advantages from the phased array and traditional reflectors. In comparison to the traditional reflectors, RA is low-profile, low-mass and low-cost reflector antenna. Furthermore, it provides a better phase control over the aperture surface leading to further flexibility of design, specifically for beam shaping and electronic beam steering. Besides, the aperture phase can be efficiently optimized with different optimization algorithms for the betterment of the antenna performance and can easily be realized by the standard PCB technology. In this sense, by using particular pixel design with independent phase for two orthogonal polarizations, RA can even show a better polarization performance than the traditional reflector. On the other hand, in comparison to the conventional phased array antenna, it avoids the usage of expensive and dissipative feeding and beamforming networks. Nevertheless, RAs typically show lower bandwidth and more SLL in comparison to the traditional reflectors, although during the past decade, many research projects tried to address the aforesaid shortcomings, extensively [2-3].

As mentioned above, the aperture phase of RA can conveniently be optimized. Here, the feasibility of the shaped Hexagonal spot beam is investigated by exploiting the beamforming algorithm. This type of beam is more compatible with the theoretical analysis and planning of such systems and might be interesting for cellular satellite communication systems.

2 Cellular satellite communication system

The main advantage of using spot beam is to increase the satellite throughput as a frequency band and/or polarization can be reused in a regular pattern of radio cells in the area of coverage, leading to more system capacity. However, there are some challenges. For example, co-channel interference (CCI) arises; the payload and antenna system get complicated, Typically, ideal radio cells are defined in a hexagon shape to fill up the satellite footprint without overlapping radio cells, as every cell fits tight with the adjacent cells which make the analysis easier. In a little bit more practical approach, the shape of the radio cells is inspired by the projection of a typical directive radiator (pencil beam) on the earth, which is almost circular. Usually, 3- or 4-dB perfect circular spots with the same radii are considered as the radio cells which are visualized from the antenna view angle. This means that the antenna is considered having equal beamwidth for all cells. For actual practical radiator, neither all spots have an exactly circular shape, nor the antenna gain and beamwidth remain constant as the beam sweeps toward the edge of the coverage (EOC). Furthermore, the projection of the circular radio cells on the earth's surface is only circular for the cell that is normally illuminated by the satellite antenna. The set of adjacent radio cells containing the total channels (C_t), the whole frequency and/or polarization assigned, are called a cluster which is repeated in the whole area of coverage. The size of the cell cluster, which is the number of beams inside a cluster, is called the reuse factor (k). Typically, it depends on the maximum amount of tolerable interference. Using a higher reuse factor increases the distance between the co-channel spots, so improves the CCI. However, it simultaneously decreases the bandwidth per beam leading to fewer users per beam. In other words, it decreases the number of channels per

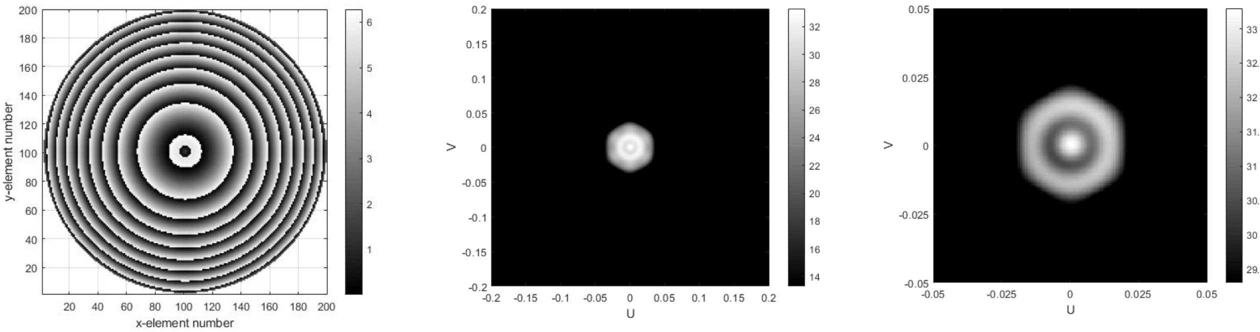

Figure. 1 (a) Optimized aperture phase, (b) 20-dB beam pattern, (c) 4-dB hexagonal spot.

cells or capacity per spot ($C_c = C_t/k$). If clusters are replicated N times in a geographic area, then the whole system capacity reads:

$$SC = N \times C_t = N \times k \times C_c \tag{1}$$

It is well known that the major drawback of the circular radio cell is the overlapping in order to avoid the gap among the radio cells. As mentioned before, hexagonal is a tessellating shape; hence, it does not need overlapping. Also, hexagonal is a simple shape that eases for analysis and is more appropriate for network planning and design. In fact, as mentioned before, the concept of circular radio cells has been used due to technical considerations. Another major factor is the CCI which is one of the most important parameters in every cellular network as there is a tendency to increase the whole system capacity by using higher coverage resolution (higher N values or equivalently smaller size of the spots) which decreases the physical distance between the co-channel spots. Therefore, it might be interesting to consider the impact of radio cell shape on the downlink interference [4].

3 Proposed Antenna with Hexagonal Beam

As mentioned in the previous section, there might be an interest in illuminating the service area in a hexagonal fashion. In addition to what is mentioned in the previous section, it may increase the efficiency of the payload resources utilization as each radio cell overlaps less percent of its total energy assigned with other cells. Here, the idea is to design an antenna capable of producing hexagonal radio cells for the satellite applications. This might be feasible by exploiting beamforming methods realizing antenna with a hexagonal-shaped beam. As mentioned before, RA might be a good candidate for this application. However, any other type of directive antenna might be employed for this purpose including traditional reflectors. Besides, RA can provide two almost independent polarizations [1] & [3] which might be more interesting for reuse schemes. Aperture phase is designed for GEO (35,786 Km above the equator) which might be used for cellular satellite communication systems such as high throughput satellite (HTS) systems using multiple-color frequency-polarization reuse schemes at K/Ka bands

3.1 Pattern synthesis

We considered the 20-dB as the maximum tolerable CCI. The aggregate interference and the cross-polar content are not considered here. Therefore, not only the 4-dB spot should be hexagonal, but also the skirt of the main beam which drops 20-dB down from the maximum gain should remain almost in hexagonal fashion. The radiation pattern is analytically calculated based on the method of aperture field. Any kind of beamforming method might be exploited for this purpose. To design the shaped beam, the alternating projection method (APM) has been recruited. Theoretically, APM is a simple algorithm that can find the intersection of two sets, if the intersection would be empty, it can converge to a set of points with minimum distance between the two sets [4]. Although the method is slow, it can be useful when fast analytical models are available. Typically, it is more suitable for the pattern synthesis of large apertures, especially in comparison to the population-based algorithms (like GA, PSO, etc.). For the case of the RA with several hundred to thousands of pixels that have a high computational cost for an algorithm recruiting several agents to find an optimum solution, even sometimes impossible to converge, such a point search algorithm is an asset. However, APM is a local optimizer and the correct method of convergence is of quite significance. Here, a simple pencil beam pattern is considered as the start point. Only the aperture phase is considered for the pattern synthesis of the RA. The unit cell realization and the whole antenna system including feed system, feed-struts, etc. are not treated here.

3.2 Prim-focused RA shaped beam

First, the prime-focused configuration is tested. The aperture phase and the calculated radiation pattern after 100 iterations are illustrated in Figure 1. The aperture diameter (D) is considered about 0.8 m and the aperture phase is designed for 20 GHz. The F/D for the antenna is considered 1.5 with almost 14 dB edge tapering. As can be seen, the calculated radiation pattern follows the hexagonal shape for both 4- and 20 dB spot beams.
This result shows the feasibility of illuminating the service area of physical radio cells by a hexagonal spot beam which as mentioned before, might be favorable for satellite cellular communication systems. However, the

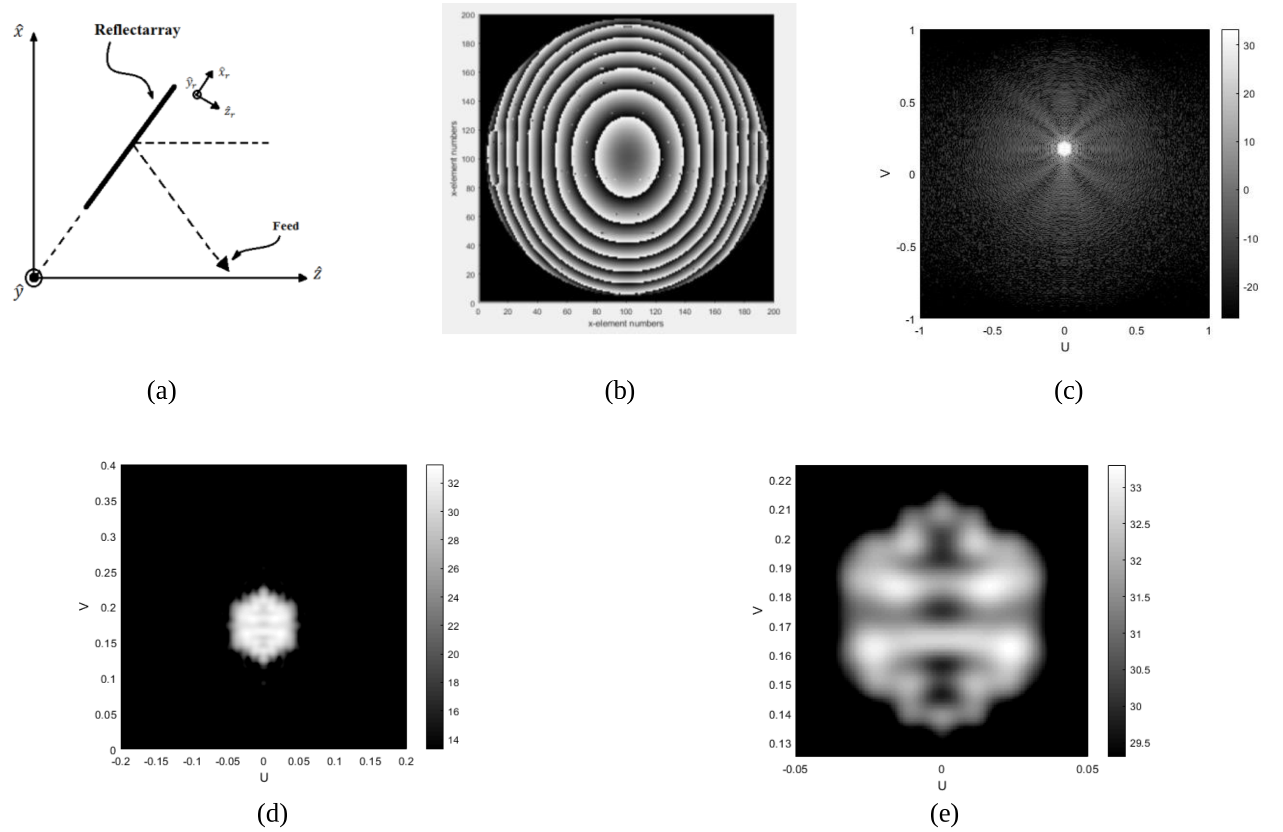

Figure. 2 (a) offset fed RA configuration, (b) Optimized aperture phase, (c) 60-dB beam pattern, (d) 20-dB beam pattern, (e) 4-dB hexagonal spot.

antenna must be oversized design for specific required of gain in comparison to conventional parabolic design which seems to be the prime cost of this shaped beam. A more accurate beamforming procedure may lead to less gain loss and minimization of the aforesaid cost.

3.3 Offset fed RA shaped beam

Cellular communication systems need several spot beams; therefore, the feed chain is typically massive and large. In this case, offset feeding is more interesting to avoid blockage. Here, the feasibility of offset fed RA antenna with shaped hexagonal beam is investigated. Again, APM algorithm is used for beamforming with the same number of iterations as preceding section. Here, the antenna is considered to be offset-fed (feed is rotated -15° along the x-axis in RA coordinate system). The antenna configuration is shown in Figure. 2a. The results for the aperture phase and the antenna radiation pattern are presented. Figure. 2b-2e. AS can be seen; the radiation pattern almost shows the shape of the hexagon. Further, promotion on algorithm and optimization procedure may needed to promote the quality of beam.

4 Conclusion

The feasibility of a hexagonal-shaped beam Reflectarray antenna for a cellular satellite communication system has been investigated. A more accurate beamforming procedure may promote the current results. The proposed method can provide a hexagonal-shaped beam but with the cost of gain loss in comparison to the parabolic pencil beam. Furthermore, the antenna should be capable of beam steering as the cellular communication systems need several multiple-beams with different polarization and frequency bands. Therefore, further investigations seem necessary to promote the presented work.

7 References

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