Hexagonal Radiator for Cellular Satellite Communication System

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- **Outline:**

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II. Proposed Antenna with Hexagonal Beam

III. Pattern synthesis

IV. Prim-focused RA shaped beam

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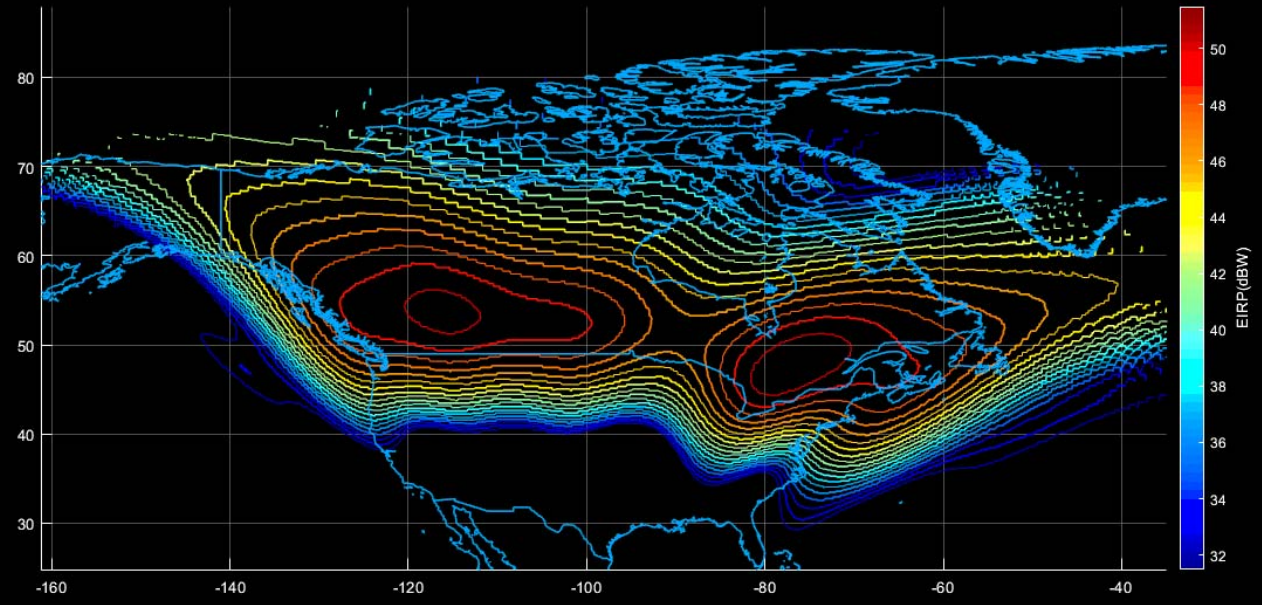
Introduction

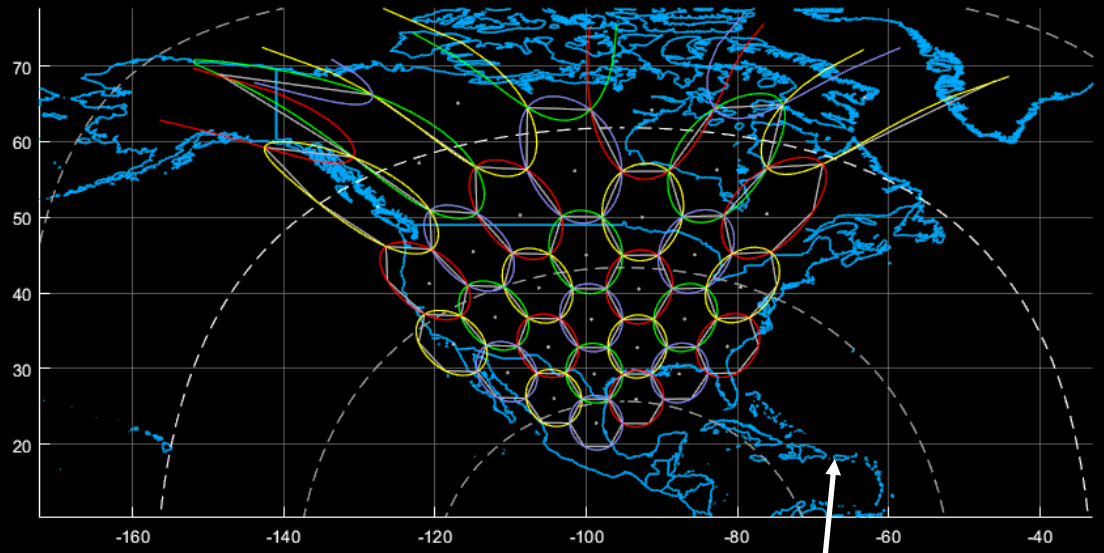
- The main goal of the broadband satellite systems is to provide most of the services that are offered by terrestrial networks in a very large coverage area, particularly in the area wherein it is uneconomic for terrestrial solutions to be present.
- Among those services, fast Internet access and multimedia services are the main basis for development of broadband satellite systems.
- To stay competitive with economical terrestrial solutions, it is necessary to reduce the cost per bit by increasing the capacity of the satellite systems.

Single-beam continental contour coverage

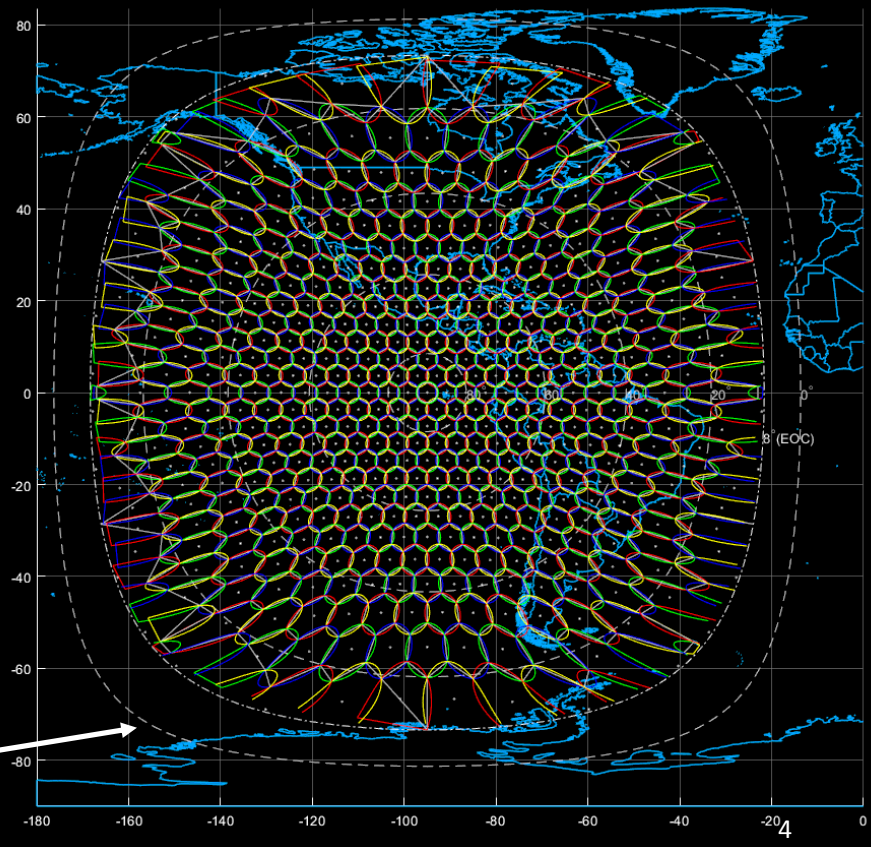


Introduction

- High throughput satellite (HTS) is a classification of communication satellite that has many times the throughput of a traditional FSS satellite. The HTS technology uses a large number of spot beams to cover the geographic coverage region from the satellite instead of a single contoured beam.
- Multi-beam architecture allows to reuse the capacity among the beams, resulting in total capacity expansion of the system.



Uniform multi-beam continental coverage



Introduction

- Throughput is the rate of successful (error-free) data delivery (bits/sec) which can be calculated by multiplying the spectral efficiency by the usable bandwidth:

$$Th = SE \times BW$$

- If clusters are replicated N times in a geographic area, then the whole system capacity reads

$$SC = N \times C_t = N \times k \times C_c$$

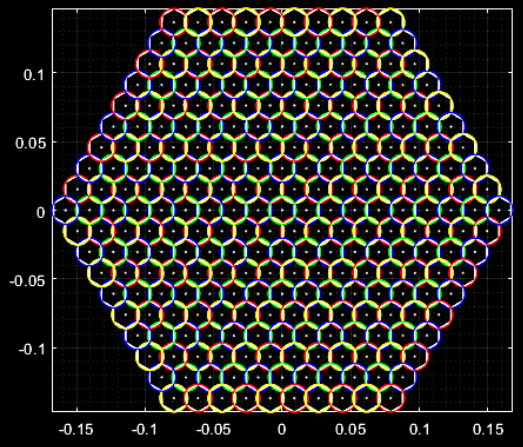
- Using higher reuse factor increases the distance between the co-channel spots so improves the CCI. However, it simultaneously, decreases the bandwidth per beam leading to less users per beam

- **Resolution of coverage:**

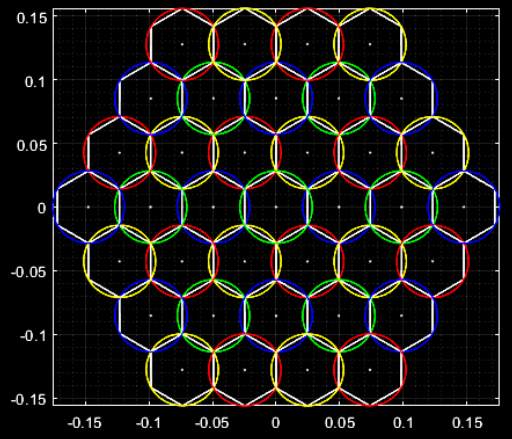
✓ Spot beams increases the *SE*. It also allows the use of smaller ground terminal antenna size.

o Higher resolution of coverage increases the replication of clusters but, typically, decreases *SE*.

o Greater distance between the radio cells increases *SE* but decreases the replication of clusters.



Cell pattern, 10-tire



Cell pattern, 4-tire

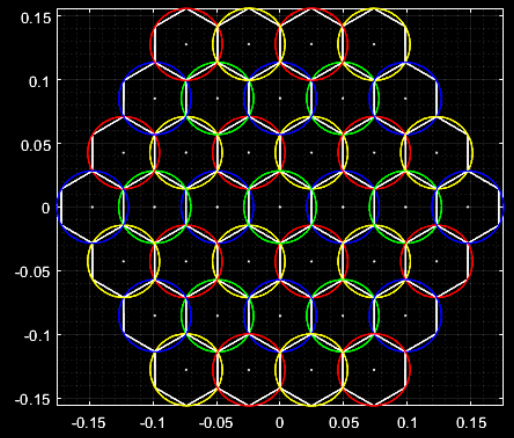
Introduction

- Key design objectives for the Multi-beam antenna (MBA) for satellite applications are:

1) maximize the minimum gain over the coverage
2) maximize the co-polar and cross-polar isolations
3) minimize the scan loss

- Co-polar isolation is defined as the ratio of co-polar gain at a given angular location of the beam of interest to the power addition of all the interfering signals from the other beams that reuse the same frequency and polarization.
- The parameter that defines the level of interference is the aggregate C/I (Carrier over Interference). It combines the interference effects coming from cross-polarization and side lobe radiation from all neighbor spots.

- Another important aspect in MBA design is the definition of the coverage, including the distribution of the beams over the service area and the reuse scheme. The arrangement of MBA spot centers is usually in a triangular lattice.
- Regular 3-cell, 4-cell, 7-cell and also hybrid schemes that employ different schemes over different regions of the coverage are currently used.
- Also coverage can be uniform or non-uniform (the radio cell size).



Uniform Cell pattern with 4cell reuse scheme

Reflectarray

- To make the SFPB approach more efficient, antenna solutions are needed which can both support large bandwidths, high gain and share apertures between multiple functions.

- Reflectarrays (RAs) are a promising high-gain antenna solution, particularly in areas where they can replace curved reflectors.

- The IEEE Standard for Definitions on Terms for Antennas designates a RA as:
- *"An antenna consisting of a feed and an array of reflecting elements arranged on a surface and adjusted so that the reflected waves from the individual elements combine to produce a prescribed secondary radiation pattern".*

- According to the standard, other accepted synonyms for this kind of antenna are as follows:

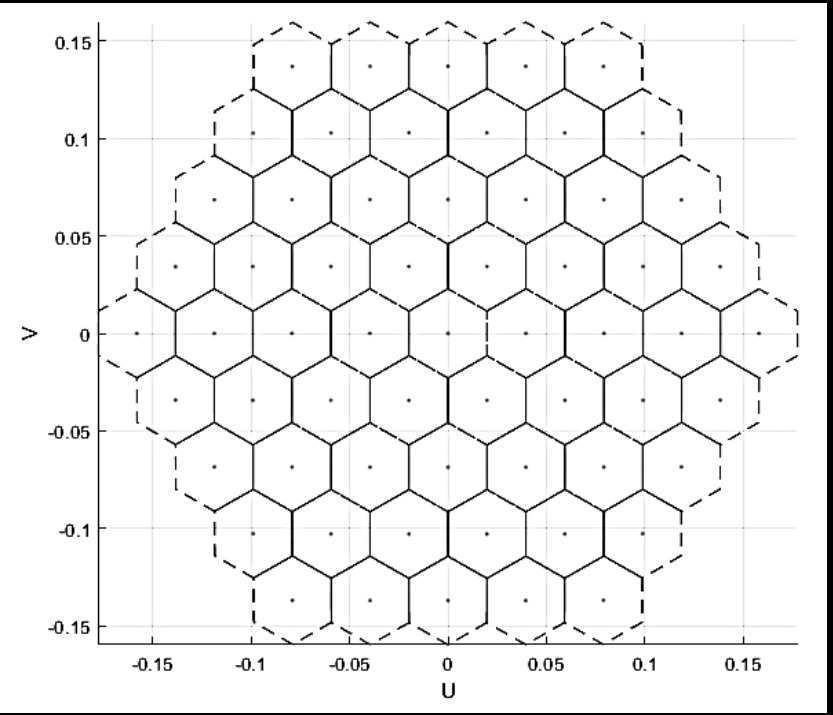
1) reflective array antenna
2) reactive reflector antenna

Proposed Antenna with Hexagonal Beam

- There might be interest to illuminate the service area in a hexagonal fashion. In addition to what 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 cell for the satellite applications. This might be feasible by exploiting beam forming methods realizing antenna with hexagonal shaped beam.
- 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.

- The radiation pattern is analytically calculated based on the method of aperture field.

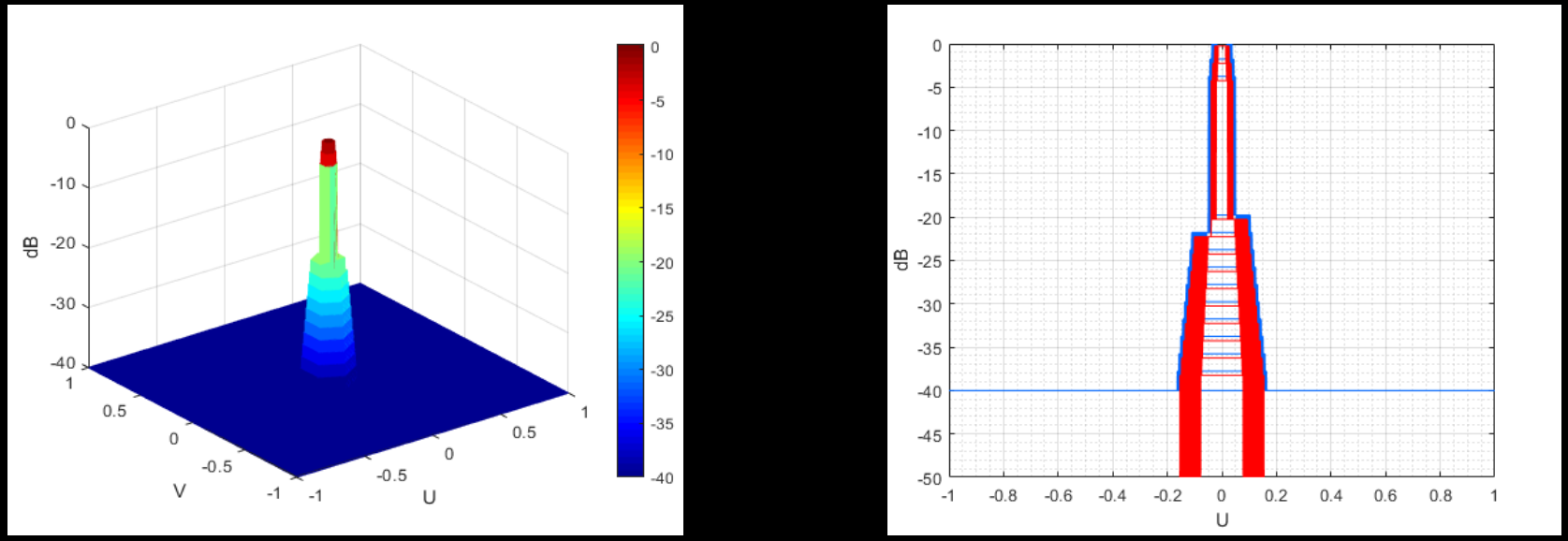


Pattern synthesis

- Any kind of beamforming method might be exploited for this purpose. Here, to design the shaped beam, 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. Although, the method is slow but can be useful when fast analytical models are available.
- The radiation pattern is analytically calculated based on the method of aperture field.
- However, APM is a local optimizer and the correct method of convergence is of quite significance.
- Here, simple pencil beam pattern is considered as the start point.

Prim-focused RA shaped beam

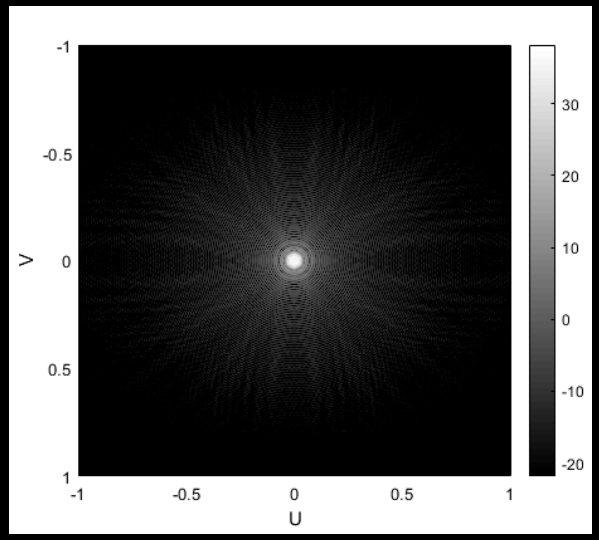
- First, the prime-focused configuration is tested. Several types of masks have been tested for the betterment of the beamforming and maximum achievable gain. The layout of the current mask used is presented in Figure.
- The aperture diameter (*D*) is considered about 1 m and the aperture phase is designed for 20 GHz. The *F/D* for the antenna is considered 1.5 with almost 14 dB edge tapering.



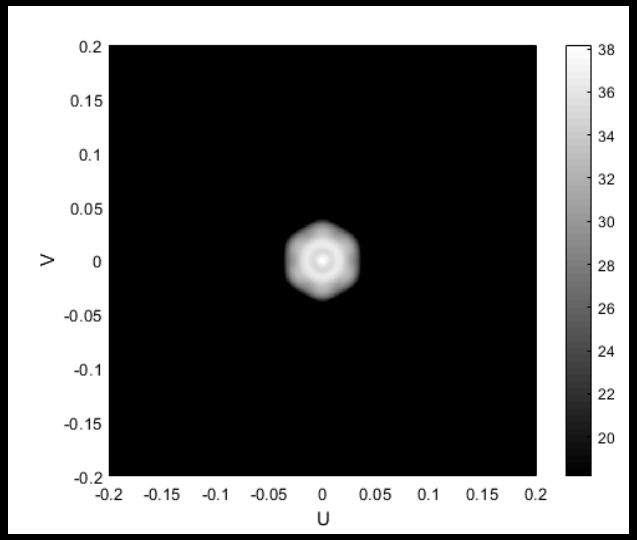
The layout of the used mask for beam forming, (left) 3D schematic view, (right) 2D schematic view showing the high mask (the blue one) and low mask (the red one).

- **Prim-focused RA shaped beam**

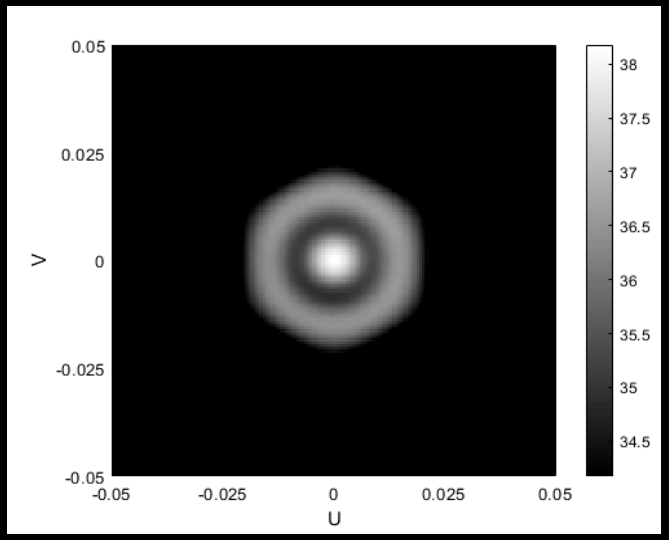
- This result shows the feasibility of illuminating the service area of physical radio cell by a hexagonal spot beam which as mentioned before, might be favorable for satellite cellular communication systems. However, antenna must be design oversized for specific required of gain in comparison to conventional parabolic design which seems to be the prime cost of this shaped beam. More accurate beam forming procedure may lead to less gain loss and minimizes the aforesaid cost.



(a)



(b)

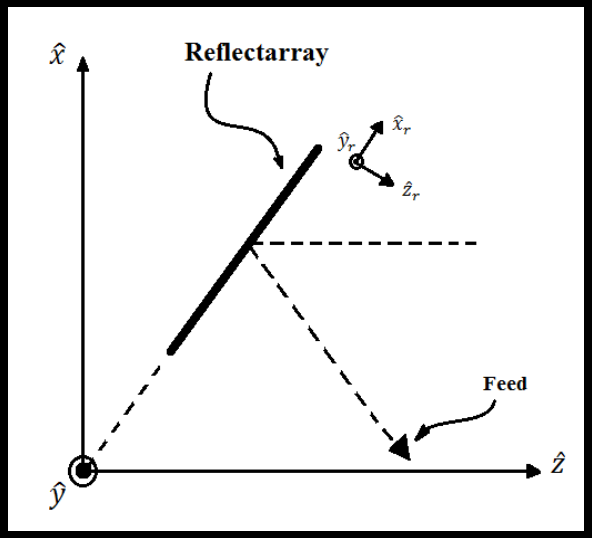


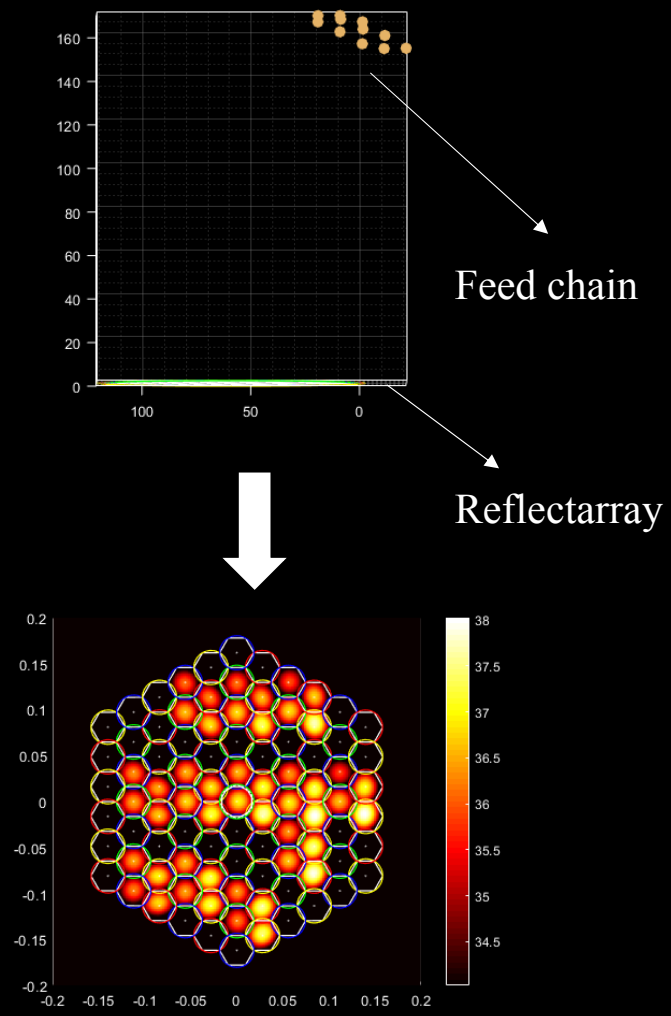
(c)

(a) The optimized aperture phase, (b) 60-dB beam pattern, (c) 20-dB beam pattern, (d) 4-dB hexagonal spot.

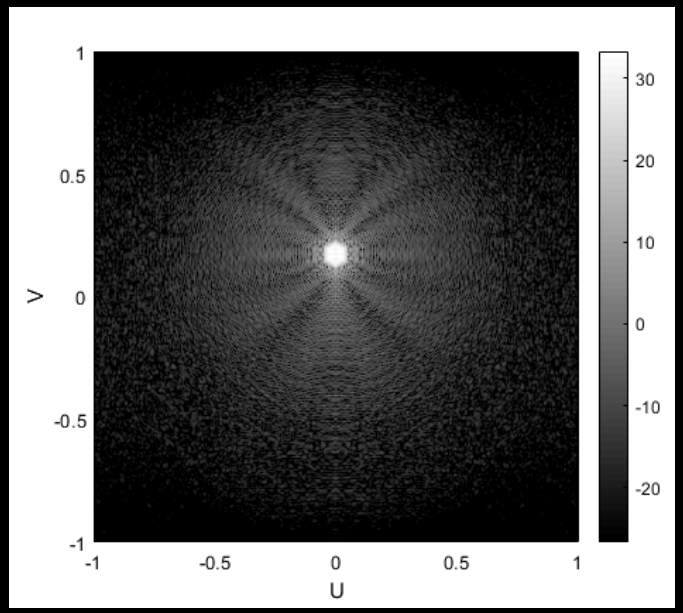
Offset fed RA shaped beam

- 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.
- 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 *y*-axis in RA coordinate system).

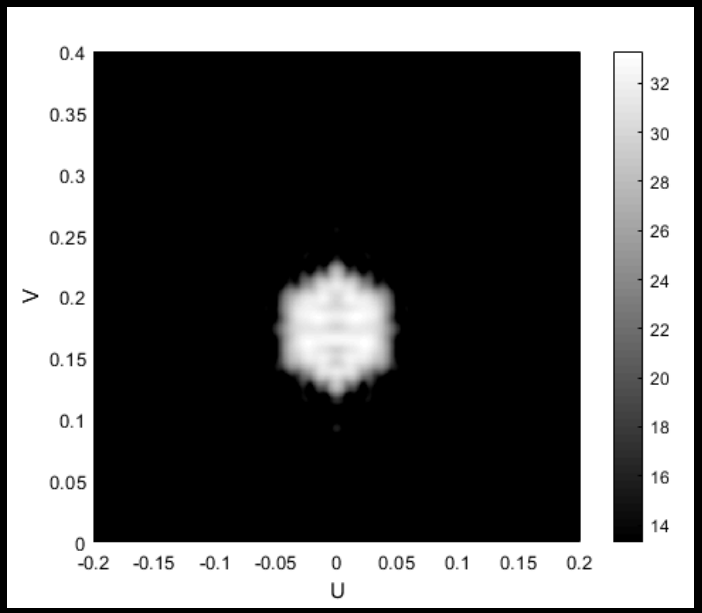




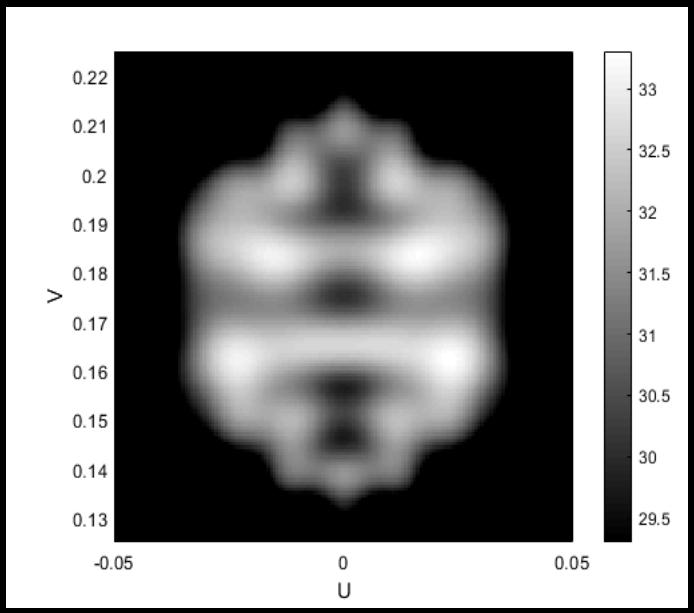
Offset fed RA shaped beam



(a)



(b)



(c)

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

Conclusion

- The feasibility of hexagonal shaped beam Reflectarray antenna for cellular satellite communication system is investigated in this paper. More accurate beam forming procedure may promote the current results. The proposed method, can provide hexagonal shaped beam but with the cost of gain loss in comparison to the parabolic pencil beam. Furthermore, 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.