Space-Based Ka-Band Direct Radiating Phased Array Antenna Architecture for Limited Field of View

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Introduction – Motivation

Problem or Challenge

Space Borne Phased Array Antenna
- Scan Coverage
- Array Design Methodology
- Array Element & Feed Design
- Array Size vs. Number of Elements
- Optimum Element Size
- Array Grid Arrangement

Beam-Forming Network
- Overlapped Sub-Array Techniques

Power Amplifier Modules
- Gallium Nitride (GaN) Based Power Amplifiers (PAs)

Conclusions
To investigate the feasibility of designing a direct radiating phased array antenna as a replacement for the TDRS reflector antennas without compromising performance (EIRP = 63 dBW, G/T = 26.5 dB/K, bandwidth, etc.)

Specifically, to investigate if a phased array with microstrip patch antenna elements coupled with Gallium Nitride (GaN) based amplifiers can meet the above requirements.
The altitude $h = 35,786$ km above mean sea level & Earth’s radius $r_e = 6378$ km

At such a distance, the Earth subtends a small conical angle of $\theta = \pm 8.7^\circ$. Consequently, the phased array onboard the relay satellite has to scan a limited field of view (LFOV).
Individual Beam Scan Angle Within a Coverage

Phased Array on Satellite

Total Coverage Angle

Scan Angle, $\theta$, Away From Nadir

Nadir direction

Edge Of Coverage (EoC)

Section Through Surface of Earth

Required Coverage

Diameter of Spot Size on Ground is the 3 dB Beam Width
Array Design Methodology

★ Step 1:  Antenna Element
★ Step 2:  Array Size
★ Step 3:  Element Size

▸ The computations are carried out using the equations presented in the following reference:

★ Step 4:  Beam-Forming Network
Antenna Element

★ Aperture Coupled Circularly Polarized (CP) Microstrip Patch Antenna

➢ Key Advantages

✦ Patch antenna and the feed network reside on two separate dielectric substrates of different relative permittivity and thickness

✦ Gain/bandwidth of the patch antenna and the efficiency of the feed network can be independently optimized

✦ The two substrates can either be in intimate contact or can be separated by a small air gap to enhance coupling efficiency
Antenna Element & Feed Design

Antenna Superstrate
($\varepsilon_0\varepsilon_{r1} = 10.2$, 0.254 mm)

Symmetric Cross Aperture

50 $\Omega$
Microstrip Feed Line

Feed Substrate
($\varepsilon_0\varepsilon_{r2} = 2.2$, 0.254 mm)

Square Patch with Corners Truncated

$W_s, W_m, L_{oc}$

50 $\Omega$ Microstrip Feed Line
Beam-Forming Network

★ Overlapped Sub-Array Technique

➢ Key Advantages
  ✧ Significant reduction in the number of control elements, such as variable gain amplifiers and phase-shifters, required to achieve the desired scan performance
  ✧ Significant reduction in the array complexity, power consumption, overall size/mass, and cost.
  ✧ Enhanced overall antenna reliability
Power Amplifier Modules

★ Gallium Nitride (GaN) Based Power Amplifiers (PAs)

- Key Advantages
  ✦ GaN PAs have three to four times higher output power density than gallium arsenide (GaAs) based PAs
  ✦ GaN transistors can operate at higher junction temperatures than GaAs transistors

- Output Power
  ✦ Ka-Band GaN-on-SiC MMIC PAs with output power on the order of 5W are commercially available.
Conclusions

★ Design methodology for a direct radiating phased array Antenna for limited field of view (LFOV) has been presented

★ The number of array elements required for a given scan gain and scan angle has been presented

★ The edge of coverage directivity as a function of the element size has been presented

★ The optimum array elements size for the desired LFOV of ±8.7° has been presented

★ By integrating a GaN power amplifier with each sub-array input terminal the desired EIRP can be achieved

➢ For example: It has been shown that an array of 1225 elements has a directivity > 40 dB and if each element radiates 1W, the target EIRP of 63 dBW can be achieved