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

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Tuesday, June 28, 2016, 08:00 – 08:20
Culebra
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Problem Or Challenge

★ 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
Spaceborne Phased Array Antenna

The altitude \( h = 35,786 \text{ km} \) above mean sea level & Earth’s radius \( r_e = 6378 \text{ km} \)

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

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

Required Coverage

Edge Of Coverage (EoC)

Section Through Surface of Earth

3-dB Beamwidth

Edge Of Coverage (EoC)
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

Square Patch with Corners Truncated

Feed Substrate
($\varepsilon_0 \varepsilon_{r1} = 10.2, 0.254 \text{ mm}$)

Symmetric Cross Aperture

50 $\Omega$ Microstrip Feed Line

Antenna Superstrate
($\varepsilon_0 \varepsilon_{r2} = 2.2, 0.254 \text{ mm}$)

- $W_s$ Width of square patch
- $W_m$ Width of microstrip feed line
- $L_{oc}$ Length of open circuit
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