Performance Comparison of Ka-Band Cross-Aperture Coupled Circularly Polarized Microstrip Patch Antenna with Single Feed

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Tuesday, June 28, 2016, 14:20 - 14:40
Grand Caribbean Salon I-II
Outline

★ Introduction – Motivation
★ Problem or Challenge
★ A Possible Solution
  ➢ Aperture Coupled Microstrip Patch Antenna
★ Prior Art Antenna Configurations
  ➢ Limitations
★ New Configuration
★ Design Methodology
★ Measured Characteristics
  ➢ Return Loss
  ➢ Axial ratio
★ Conclusions
Introduction - Motivation

NASA's Third Generation GEO Tracking & Data Relay Satellite (TDRS)

- TDRS-K, Launched Jan 30, 2013
- TDRS-L, Launched Jan 23, 2014
  - Power: 2.2 kW
  - Weight: 3455 kg at liftoff with fuel
  - Dimensions: 21 m (L) by 13.1 m (W)
  - Designed Mission Life: 11 years

Space-to-Ground Link Antenna
- White Sands Complex (WSC)
- Guam Remote Ground Terminal
- Perpendicular LP

Tri-Band Single Access Antenna
- Two (15-foot diameter & steerable)
- S-Band (2.0 to 2.3 GHz)
- Ku-Band (13.7-15.0 GHz) (300 Mbps)
- Ka-Band (22.5-27.5 GHz) (800 Mbps)

Multiple Access Antenna
- Array (32 Tx & 15 Rx elements, LCP)
- S-Band (2.0 to 2.3 GHz)
To investigate the feasibility of designing a direct radiating phased array antenna with performance characteristics (EIRP = 63 dBW, G/T = 26.5 dB/K, bandwidth, etc.) similar to the reflector antennas on the current generation TDRS satellite.

Specifically to investigate, if microstrip patch antenna element based phased array antenna can meet the above requirements.
A Possible Solution

Aperture Coupled Microstrip Patch Antenna

**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
- If required the two substrates can be separated by a small air gap to enhance coupling efficiency
- Furthermore a parasitic patch can be stacked over the driven patch to enhance the gain/bandwidth
- The radiation can be circularly polarized (CP)
At Ka-band frequencies, the cross-aperture resonant length $2L$ becomes very small, for example at 27.0 GHz, $2L = 0.0251$ inches, which is approximately equal to $2 \times W_m$. Consequently, it is a challenge to scale the design to higher frequencies.
New Configuration

Field Configurations for Square Patch

$\text{TM}_{x010}^y$ mode produces an electric far-field $E_y$ linearly polarized (LP) in the $y$ direction.

$\text{TM}_{x001}^z$ mode produces an electric field far-field $E_z$ LP in the $z$ direction.

To achieve circular polarization (CP) the magnitude of the axial ratio must be unity while the phase must be ±90°.

A practical way to achieve CP is to trim the ends of two opposite corners of a square patch.
New Configuration (Continued)
Design Methodology

★ Step 1: Corners of a square patch are truncated for circular polarization. The dimensions are designed based on the equations from: T.A. Milligan, *Modern Antenna Design*, 2nd Ed.

★ Step 2: The design is validated by fabricating a set of patch antennas and measuring the return loss and resonant frequency.

★ Step 3: A symmetric cross-aperture is selected for exciting the patch. The aperture slot width is set equal to 0.01 inches from ease of fabrication.

★ Step 4: The symmetric cross-aperture length (2L) is empirically determined to be equal to $0.22 \lambda_{g(slot)}$, where $\lambda_{g(slot)}$ is the guide wavelength in an equivalent slotline of width equal to 0.01 inches.

★ Step 5: The $Z_0$ of the microstrip feed line of width $W_m$ is set = 50Ω.

★ Step 6: The length of the microstrip line $L_{oc}$ beyond the junction of the cross-aperture is empirically determined to be $0.11 \lambda_{g(microstrip)}$, where $\lambda_{g(microstrip)}$ is the guide wavelength.
Conclusions

- The design methodology for a CP square patch with corners truncated and coupled to a 50Ω microstrip feed line through a symmetric cross-aperture in the ground plane is presented.

- The analytical model for the square patch design is validated through experiments over a wide range of frequencies.

- An empirical model for the design of the symmetric cross-aperture is presented and validated through experiments over a wide range of frequencies.

- Typical measured return loss and axial ratio are presented.

- Future efforts include:
  - Measurement of antenna gain, radiation patterns, and front-to-back ratio.
  - Performance improvement by including a stacked parasitic patch.
  - Design to a planar array at Ka-band.