Aerogel Antennas Communications Study Using Error Vector Magnitude Measurements

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***Abstract*-- This paper discusses an aerogel antennas communication study using error vector magnitude (EVM) measurements. The study was performed using 4x2 element polyimide (PI) aerogel-based phased arrays designed for operation at 5 GHz as transmit (Tx) and receive (Rx) antennas separated by a line of sight (LOS) distance of 8.5 meters. The results of the EVM measurements demonstrate that polyimide aerogel antennas work appropriately to support digital communication links with typically used modulation schemes such as QPSK and π/4 DQPSK. As such, PI aerogel antennas with higher gain, larger bandwidth and lower mass than typically used microwave laminates could be suitable to enable aerospace-to-ground communication links with enough channel capacity to support voice, data and video links from cubesats, unmanned air vehicles (UAV), and commercial aircraft.**

I. Introduction

Recently, polyimide (PI) aerogel antennas have been investigated by our group since the PI aerogel's low dielectric constant, mass, and physical properties could enable antennas with higher gain, more bandwidth, and lower mass that commonly used microwave laminates (e.g., RT/Duroid) and waveguides with the same common configuration [1-3]. A picture of one of these 4x2 PI aerogel-phased slot-coupled antennas is shown in Figure 1.

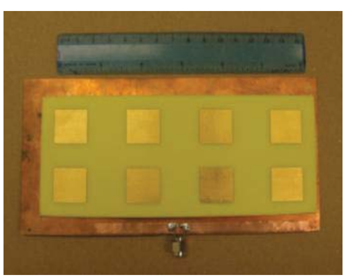

Fig. 1: 4x2 slot coupled PI aerogel antenna array with feed network

II. Antenna Design, Fabrication, and Performance

The array was designed to operate at 5 GHz using CST Microwave Studio (CSTMWS) [4]. The 2.0 x 2.1 cm gold (Au) radiators (~2 µm thick) were fabricated in NASA Glenn Research Center (GRC) clean room via shadow mask and electron beam (e-beam) evaporation techniques. For both the Aerogel and RT/Duroid 5880 4x2 element array antennas, the radiating elements are patterned onto a thick (~ 3 mm) substrate, which is then attached to a 0.254 mm thick Duroid 5880 substrate containing the feed network and ground plane with apertures.

Figure 2 shows the experimental and simulated H-plane and the E-plane gain data for the 4x2 array at 5.0 GHz. The simulated data were generated using CSTMWS. The experimental and simulated results are in close agreement. As shown in Figure 3, the 4x2 aerogel antenna gain is more than 1 dB higher than its RT/Duroid 5880 counterpart (17.6 dBi versus 16.3 dBi, respectively) and the mass savings of the aerogel array are substantial as shown in Table 1.

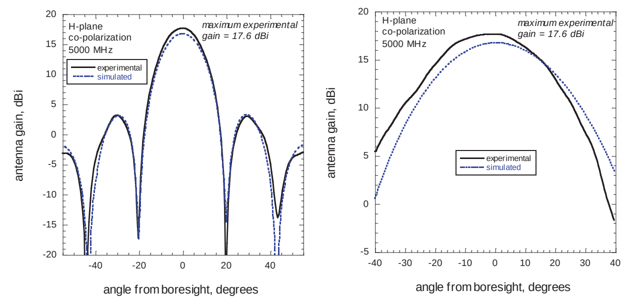

Fig. 2: Gain versus angle from boresight for a 4x2 slot coupled aerogel antenna array. Aperture size is 15.3 cm x 5.8 cm.

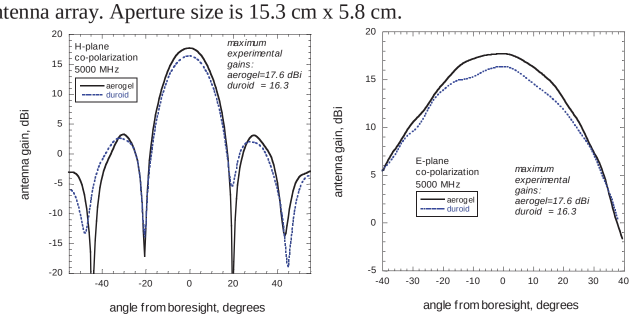

Fig. 3: Comparison of gain versus angle from bore sight for 4x2 slot coupled aerogel and RT/Duroid 5880 arrays.

Table 1: Mass comparison between 4x2 aerogel antenna and its 4x2 Duroid counterpart

Item	Aerogel	Duroid
Radiator tile only	5.8 g (3.68 mm thick)	88.1 g (3.18 mm)
Feed network and ground plane (i.e., 254 µm) Duroid with copper metallization	13.9 g	14.4 g
SMA connector weight	3.9 g (male)	1.3 g (female)
Total antenna weight	23.6 g	103.8 g

III. Error Vector Magnitude Measurements

Based on the results presented in section II, a LOS experiment was performed to investigate the suitability of these antennas to support digital communication links with typically used modulation schemes. Accordingly, an EVM measurement experiment was implemented using two identical 4x2 aerogel arrays, one as transmit (Tx) and the other as receive (Rx) antennas, 8.5 meter apart. This separation satisfies the $2D^2/\lambda$ far field criteria, where D is the maximum antenna aperture dimension and λ is the wavelength corresponding to the frequency of the array. In our case, D=16.1 cm, λ=6.0 cm, and $2D^2/\lambda$=0.864 meters. The gain of the Tx and Rx antennas was 15.6 dBi, as determined by free space link calculations.

The constellations diagrams associated with EVM or receive constellation error, as it is also known, provide a visual indicator of link quality. That is, EVM is a measure of how far the experimental values deviate from the reference values in the constellation diagram. Tests were performed at 4600, 5000 and 5400 MHz to demonstrate the broadband capabilities of the antennas. An Agilent 8267D vector signal generator (VSG) was used in the Tx end and an Agilent E4407B spectrum analyzer (SA) with option 229 modulation analysis personality was connected to the Rx antenna in the received end of the test set up. A symbol rate of 7 Megasamples per second (Msps) was used, which with a spectral efficiency of 2 bits/symbol resulted in a data rate of 14 Mbps. The resolution bandwidth of the SA is set to 10 MHz to enable this data rate. The high noise figure of the SA (~26 dB), combined with the wide resolution bandwidth, introduced a high noise floor which masked the capability of the Rx antenna to detect low signal power levels. Hence, amplifiers (Avantek AWT-6053) were used between the SA and Rx antenna to improve sensitivity and thus demonstrate that the antennas can reliably detect low power signals.

The following parameters are used in the experiment: transmit power= (-23 dBm, 20 dBm, 0 dBm, and 20dBm); Tx and Rx antenna gain=15.6 dBi; link distance: 8.5 m; frequency: 5.0 GHz; data rate: 14 Mbps; modulation schemes: quadrature phase shift keying (QPSK) and $\pi/4$ differential QPSK ($\pi/4$ DQPSK). Figure 4 shows the constellation plots for QPSK and $\pi/4$ DQPSK modulation schemes at different input powers, and with no amplifier between the Rx antenna and the SA.

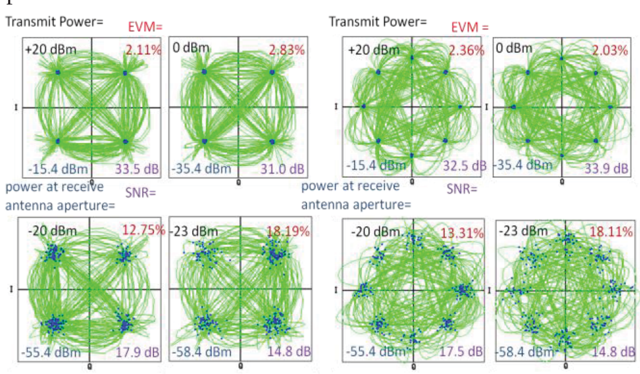

Fig. 4: Aerogel Phased Array Antennas EVM Test using QPSK (left) and ($\pi/4$ DQPSK) Modulation Schemes.

As expected, for both modulation schemes the EVM increases and the SNR decreases with decreasing Tx power. In other words, the increased spreading of the constellation points with decreasing power is an indication of the degradation of the link quality. On the other hand, and as shown in figure 5, when an Avantek AWT-6053 amplifier (small signal gain of 27 dB and a noise figure of 4 dB) is inserted between the SA and the Rx antenna, the aerogel antennas are able to support a link even when the power levels at the receive antenna aperture are as low as -83.4 dBm. Figure 6 shows the EVM and SNR versus transmit

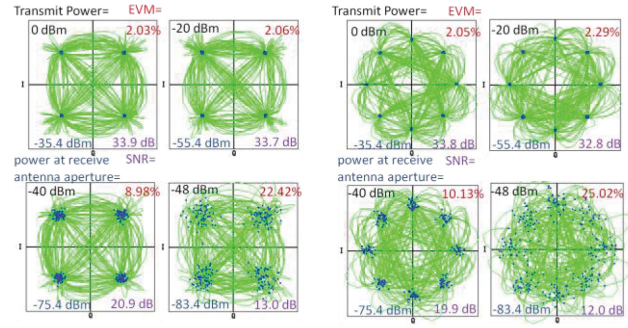

Fig. 5: Aerogel Phased Array Antennas EVM Test using QPSK (left) and ($\pi/4$ DQPSK) modulation schemes with amplifier included in experimental setup.

power data measured in this experiment. Note that even at 4.6 GHz, the antennas are able to maintain a communication link with only ~ 2 dB loss relative to the antenna performance at 5.0 GHz. Similar results were also observed at 5.4 GHz.

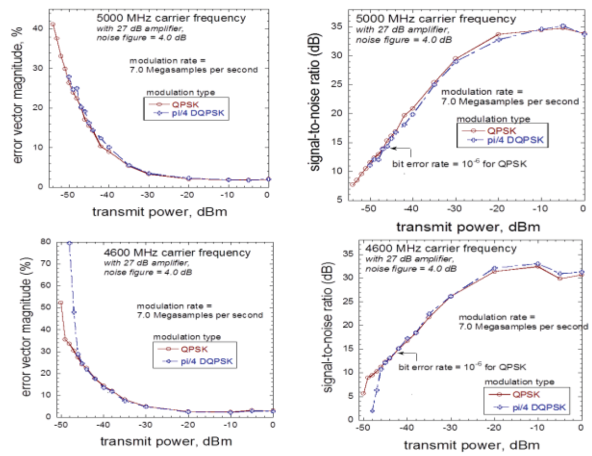

Fig. 6: EVM and SNR versus transmit power at 5.0 GHz (top) and 4.6 GHz (bottom) for the two modulation schemes discussed in this work.

IV. Conclusions

The suitability of Polyimide aerogel antennas for supporting digital communication links with traditionally used modulation schemes was demonstrated through error vector magnitude measurements has been discussed in this paper. The EVM data indicate that 4x2 aerogel polyimide arrays can support digital communications links under commonly used modulation schemes for aerospace communication applications.

References

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[4] CST Microwave Studio® (CST MWS), ww.cst.com/Products/CSTMWS