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ADVANCES IN MILLIMETER-WAVE ANTENNAS AND SENSOR FRONT-END TECHNOLOGIES

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Abstract This paper presents an overview of millimeter-wave integrated antennas and receivers at the University of Michigan. The research effort addresses both uniplanar and micromachined antennas in silicon/GaAs for high-efficiency applications. Recent results, such as 94 GHz dual- polarized cpw-fed slot-ring antennas, 12-13 GHz microstrip antennas on localized micromachined dielectrics and 10 GHz and 30 GHz tapered slot-antennas on micromachined photonic-bandgap substrates will be presented.

I. INTRODUCTION

The goal of the research effort at the University of Michigan is to develop low-cost millimeter-wave front-end sensors. The idea rests on the near total integration of the front-end, using high- efficiency planar antennas, active and passive MMICs high-Q filters. It is expected that planar mm-wave sensors, while being more expensive to develop, are much less expensive when large numbers are required for applications such as automotive collision-avoidance systems, mm-wave personal communication devices and imaging arrays for landing systems and contraband detection.

II. SINGLE AND DUAL-POLARIZED 94 GHz SLOT-RING ANTENNAS

A recent development is the cpw-fed slot-ring antennas at 94 GHz on a silicon dielectric lens [1]. The dielectric lens synthesizes a semi-infinite dielectric medium and eliminates the excitation of substrate modes. The slot-ring antenna radiates 92% of its power in the dielectric-lens and 8% into the air and no backing cavity is used. The slot-ring antenna is linearly polarized and can be arrayed in a 2×2 configuration to result in monopulse patterns (Fig. 1). The antenna impedance at resonance (the circumference is around $1.05\lambda g$) is 105Ω (± 10% bandwidth) and can be matched to 50Ω using a cpw quarter-wave transformer. The slot-ring antenna can support two orthogonal modes and therefore could be used as a dual-polarized antenna. The measured polarization isolation from 94 to 98 GHz was better than 22 dB.

The slot-ring antenna has been used in the development of a state-of-the-art 94 GHz monopulse tracking receiver. Details of the receiver will be presented at the conference.

III. MICROSTRIP ANTENNAS ON LOCALIZED MICROMACHINED SUBSTRATES

Micromachining techniques using closely spaced holes have been used underneath a microstrip antenna on a high dielectric constant substrate to synthesize a localized low dielectric constant environment [2]. The idea is to etch a series of very closely spaced holes ($< \lambda_d/10$)

underneath and around the antenna, and to control the effective dielectric constant with the choice of the density of the holes (Fig. 2). The period of the holes must be small compared to a wavelength so as quasi-static capacitance measurements result in a good estimate of the effective dielectric constant.

A 12.5-13.5 GHz microstrip antennas has been fabricated on ϵ_r=10.8, h =0.635 mm ($\lambda_d/11$) Duroid substrate. The hole design was hexagonal with a hole diameter of 0.6 mm and a hole center to center spacing of 0.7 mm . The resulting ϵ_{eff} using quasi-static capacitance measurement was 2.3. In order to compare the performance of this antenna, we have fabricated other microstrip antennas on ϵ_r=2.2, h = 0.635 mm ($\lambda_d/25$) with dimensions of 0.74 × 0.91 cm and on ϵ_r=10.8, h=0.635 mm ($\lambda_d/11$). All antennas were designed to resonate around 12.8-13.0 GHz and were matched to approximately 50Ω using a short stub-transformer.

The efficiency of the three microstrip antennas was measured using a radiometric method and a hemispherical Hot/Cold load. The measurement is referenced to the RF connector, and includes the antenna ohmic loss and loss due to the substrate modes, feedline loss and mismatch loss to 50Ω. It is seen in Figure 2 that the radiation efficiency improved from 45% for ϵ_r=10.8 to 72% for ϵ_r=2.3 synthesized, and that the synthesized dielectric antenna yields similar values as the ϵ_r=2.2 antenna. We believe that this technique can be applied to millimeter-wave (30-100 GHz) planar antennas (dipoles, slots, microstrip, etc.) on GaAs substrates to result in relatively wideband (4-6%) MMIC active antenna modules for phased-arrays and collision avoidance systems.

IV. TAPERED SLOT ANTENNAS ONPHOTONIC BANDGAP SUBSTRATES

Dramatic improvements in the radiation properties of tapered slot antennas (TSA) integrated on high dielectric constant substrates have been achieved through micromachining techniques. A periodic hole structure was micromachined into the substrate converting it into a photonic bandgap material [3,4]. The photonic-bandpass results in wide frequency stop-bands and a large percentage of the power fed to the TSA is radiated out into the space above the dielectric, greatly increasing the directivity and gain of the antenna. The TSAs are $4\lambda_0$ long with a flare angle of 12°, resulting in an aperture width of $0.8\lambda_0$ (Fig. 3). One antenna is made on a thin, low dielectric constant Duroid substrate (ϵ_r=2.2) and is used as a reference antenna for performance comparison. Another antenna is fabricated on thick (50 mil), high dielectric constant Duroid (ϵ_r=10.5). The last antenna was made on the same thick Duroid substrate but was machined with hexagonal holes to suppress the substrate modes that are normally excited.

The radiation patterns and properties at 10 GHz for the TSAs are shown in Fig. 3 and Table 1. The reference antenna (ϵ_r=2.2, t=30 mils) agree well with previously published results. The antenna on the standard high dielectric constant material performed as poorly as expected with a directivity of 4.4. There is a 240% increase in the directivity of the antenna when the supporting dielectric has been properly machined to suppress substrate modes. A similar improvement was observed when the process was performed at 30 GHz on a 350 μm silicon wafer. We believe the technology can be scaled to 60 GHz and 94 GHz for phased arrays, imaging arrays and power combining systems.

	Reference-$\epsilon_r=2.2$	Thick-no holes-$\epsilon_r=10.5$	Hexagonal holes- $\epsilon_r=10.5$
Directivity	13.7	4.4	14.9
Beamwidth (-10 dB)	E=30° H=45° D=45°	E=45° H=90° D=70°	E=40° H=45° D=45°
X-Pol (45° Plane)	-7 dB	-7 dB	-13 dB

Table 1: Measurement results of the 10 GHz tapered slot antennas.

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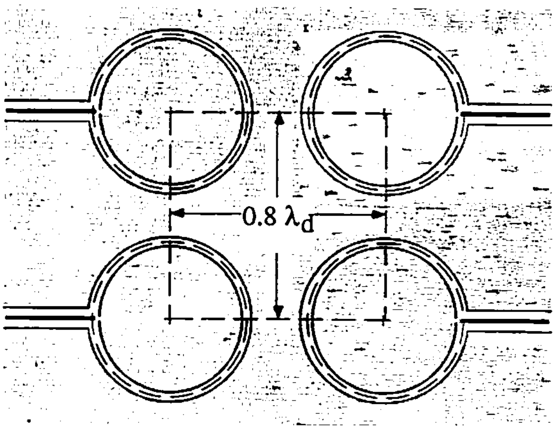
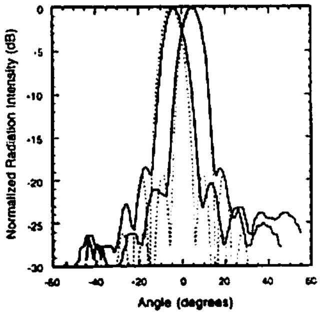
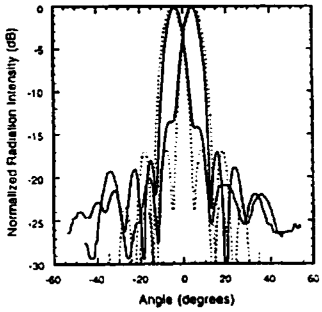




(a) Elevation Scan



(b) Azimuth Scan

Figure 1: A 2×2 array of slot-ring antennas (left) and the measured patterns at 94 GHz (right).

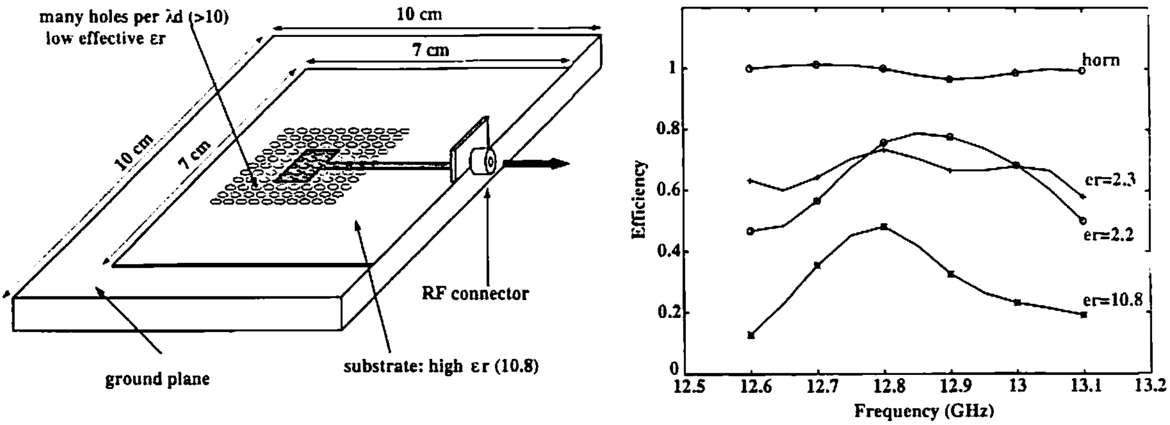


Figure 2: The localized micromachined substrate (left) and the measured radiation efficiency of different microstrip antennas (right).

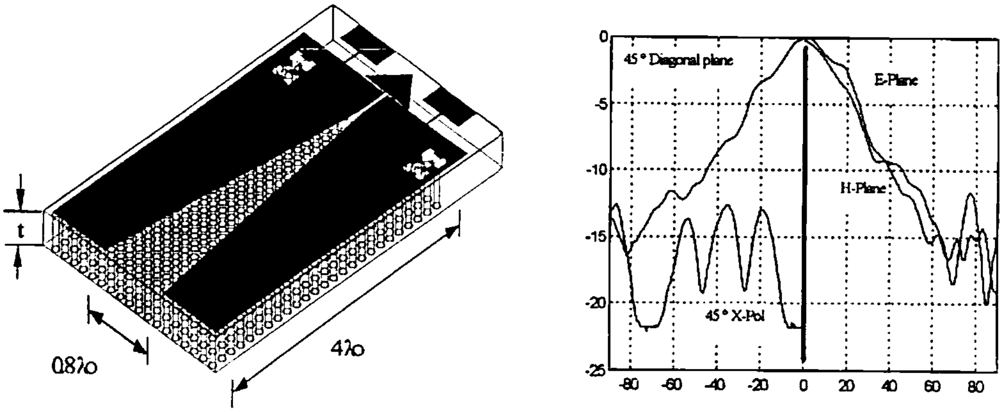


Figure 3: A tapered-slot antenna on a photonic-bandgap dielectric (left) and the measured 10 GHz pattern on a hexagonal hole spacing (right).