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Millimeter-Wave Integrated-Horn Antennas and Quasi-Optical Balanced Receivers

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ABSTRACT

We have designed a high-efficiency integrated antenna suitable for millimeter-wave applications. The quasi-integrated antenna consist of a flared machined section attached to a standard integrated horn antenna. Antenna designs with a gain of 20 dB and 23 dB has been built and tested at 91 GHz and 370 GHz. We also report on the design of a double balanced integrated-horn receiver using a horizontal dipole for local oscillator coupling and a vertical dipole for RF coupling. Application areas include millimeter-wave radar, phased-array and communication receivers.

INTRODUCTION

Millimeter-wave systems are becoming increasingly important in many military and commercial applications. We have concentrated our effort on designing high-efficiency integrated antennas and receivers suitable for the millimeter-wave region (f > 60GHz). Traditionally, integrated-circuit antennas suffer from poor patterns and substrate mode losses and this limits their coupling efficiency to reflector systems to around 30-40%, and results in receivers with a high noise temperature (or noise figure). We have solved the antenna problem by integrating a horn antenna. In this design, the horn cavity is etched in silicon (or GaAs) and the horn is excited using a dipole (or monopole) probe integrated on a very thin (1μm) dielectric membrane [1,2]. The horn antenna results in excellent patterns with gains around 12-13 dB at 94 GHz, 240 GHz and 802 GHz. We have also built a 91 GHz integrated horn antenna receiver consisting of a Schottky-diode attached to a dipole probe inside the horn cavity [3]. The measured receiver SSB conversion loss is 8 dB and currently we are working on optimizing this horn receiver. In this paper, we present the latest results on the synthesis of high-gain integrated horn antennas and on a quasi- optical balanced-mixer receiver. Application areas include receivers for communication systems and millimeter-wave radars.

HIGH-GAIN INTEGRATED HORN ANTENNAS

The high-gain quasi-integrated horn antenna consists of a flared machined section attached to a standard integrated horn antenna [4]. Any processing electronics can be integrated using the silicon portion of the horn. Alternatively, a thin GaAs wafer could be sandwiched between the silicon wafers for integration of high speed devices. The integrated portion is designed using full-wave analysis to determine the modes at the throat of the machined section. The abrupt change of the flare-angle at the junction of the integrated and the machined section of the horn acts as a mode converter which excites mainly the TE_{10}, TE_{12}/TM_{12} and TE_{30} modes. The modes are subsequently properly phased on the radiating aperture by selecting the length and the flare-angle of the machined section using the well known differential phase-shift formula [5]. A 20 dB and 23 dB horns were designed at 91 GHz and 370 GHz, respectively. The measured characteristics at 91 GHz (20 dB horn) and 370 GHz (23 dB horn) agree well with theory and shows a 97.3% coupling efficiency to a gaussian-beam (Fig. 1). The impedance of the probe dipole has been measured at 6 GHz and is centered around 50Ω for a dipole length of 0.36λ for both antennas. We have also established a systematic design procedure that will enable the millimeter-wave engineer to design a quasi-integrated horn antenna with different gains (from 17 to 26 dB) and this will be presented at the conference.

INTEGRATED SINGLE-BALANCED MIXER RECEIVER

A 92 GHz double balanced mixer-receiver is currently being developed at the University of Michigan. As is well known, the balanced receiver eliminates the need of quasi-optical diplexers and provides local oscillator AM-noise isolation at the IF port. The balanced receiver uses polarization duplexing to isolate the RF and LO signals. The same quasi- integrated horn geometry is used, but in this design, the RF is sampled by a probe dipole at the center of the membrane and the LO is sampled by a perpendicular dipole [6]. The IF is taken through a low-pass filter connected to the LO dipole. The 4 Schottky-diodes are placed at the center of the membrane as shown in Figure 3. Due to symmetry, RF currents do not flow in the orthogonal dipole, thus preserving a very low RF cross-polarization level. The biasing of each is achieved using an inductive netwrok at the edge of the LO dipole. The balanced mixer was modeled using a non-linear analysis program using commercially available diodes (Alpha) with DC characteristics of $C_j = 25\text{fF}$, $R_s = 6\Omega$, $C_p = 15\text{fF}$, $L_p = 0.1\text{nH}$, $n = 1.12, I_s = 2.6\text{x}10^{-15}\text{A}$ and $\phi_b = 0.76\text{V}$. The calculated RF input impedance is $34 - j8\Omega$, and the LO input impedance is $21 - j56\Omega$. The IF impedance at 1 GHz is 34Ω. The lengths of the RF and LO dipoles and their position inside the cavity are chosen to yield a good match for the RF and LO impedances. A dipole length of 0.3λ at a position of 0.38λ from the apex of the cavity results in a resonant input impedance of 40Ω (Fig. 2). The RF mismatch is 0.1 dB at resonance and is always less than 0.5 dB for a bandwidth of $\pm 7\%$. The predicted SSB conversion loss is 5.8 dB at the design frequency, which is competitive with the best waveguide balanced mixers. A 60 GHz double-balanced mixer consisting of four diodes is also under construction and will be presented at the conference.

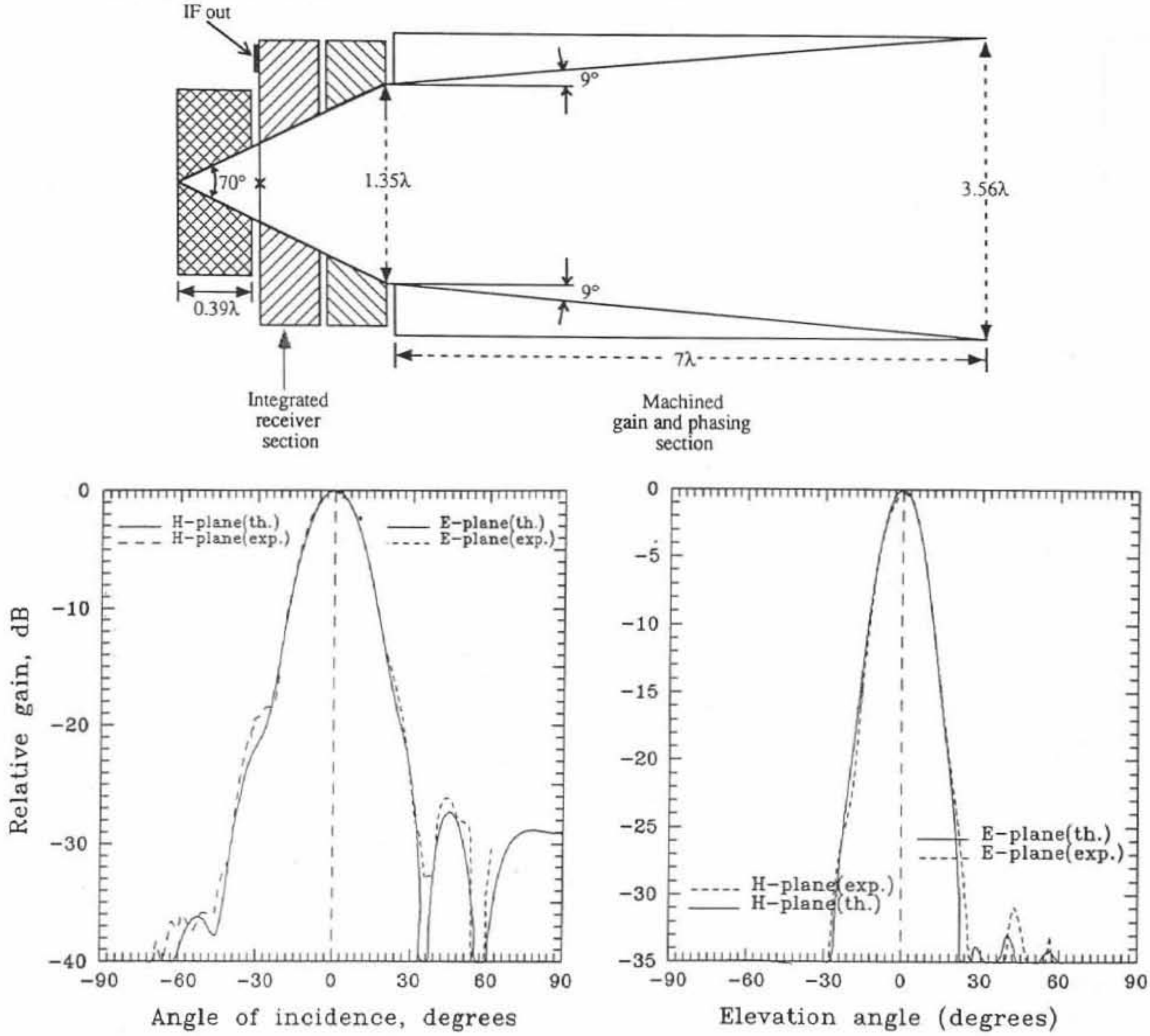

Figure 1: A cross-sectional view of the 20 dB quasi-integrated horn antenna (top), and the measured patterns at 90 GHz (20 dB gain) and 370 GHz (23 dB gain).

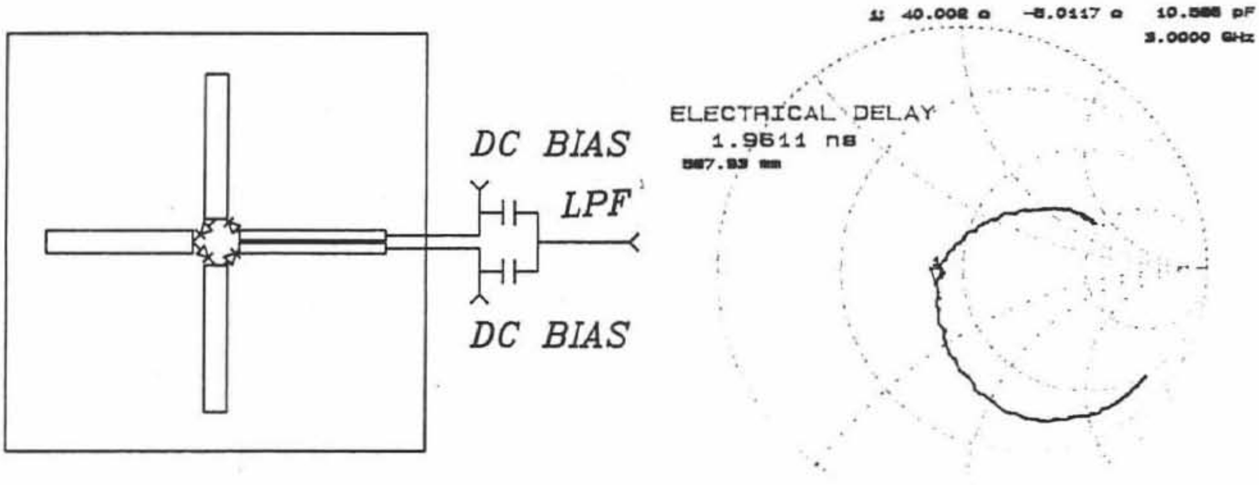

Figure 2: The balanced mixer with a dual-dipole antenna on the membrane for RF and LO diplexing, and the measured input impedance of a 0.3λ dipole on a microwave scale model.

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