A Planar Parabola-Feed Frequency Multiplier

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***Abstract*—A novel quasi-optical all-planar frequency doubler that could provide an alternative approach to conventional waveguide circuits for millimeter- and submillimeter-wave signal generation is presented. The multiplier uses a quad-bridge diode configuration for inherent isolation between the input and output signals. Two pairs of double-slot antennas with orthogonal polarizations directly couple input and output signals to the diodes, without the need for hybrid couplers required in typical balanced circuits. The integrated quad-bridge-diode/slot-antenna circuit is mounted on a dielectric-filled parabola for coupling to quasi-optical propagation systems. Measurement results for an X to K-band doubler show frequency conversion loss of 6.8 dB at the output frequency of 20.3 GHz.**

***Index Terms*—Dielectric-filled parabola, diode frequency multiplier, slot antenna.**

I. Introduction

RECEIVER components in the ESA/NASA Far Infrared and Submillimeter Space Telescope and Submillimeter Intermediate Mission (FIRST/SMIM) require submillimeter-wave local oscillator sources with an output power of 50 to 100 μW in the Terahertz frequency range, in order to carry out submillimeter astrophysics from space. Whisker-contacted diode multipliers in the millimeter-wave bands have been space-qualified for several missions and were recently demonstrated in the laboratory at frequencies as high as 1 THz [1]. However, these waveguide-based multipliers involve an extremely labor intensive and low-yield assembly process, and the limitations inherent in the device geometry make implementing multidiode balanced circuits impossible. With the advent of high-quality submillimeter-wave planar diode technology, however, multidiode circuit fabrication has become realizable. Balanced multipliers and mixers utilizing planar diodes have demonstrated better performance than similar whisker-contacted structures up to 200 GHz [2], [3]. In this letter, a new approach is introduced where a planar frequency doubler circuit with a fully open antenna architecture combines device and circuit symmetries to yield an extremely simple and compact design with inherent port-to-port isolation. This all-planar quasi-optical multiplier can be fabricated monolithically, making the circuit easier to scale for use at higher frequencies than conventional waveguide circuits.

II. Design

The circuit employs a quad-bridge diode configuration for second-harmonic signal generation with built-in frequency isolation (a similar circuit geometry was independently proposed in [4]). This configuration maintains the same conversion efficiency with the same optimum input and output load impedances as single-diode multipliers, but quadruples the power-handling capability. More importantly, the quad-bridge diode circuit provides effective isolation between the two input and the two output antennas with its inherent even-harmonic rejection at the input and odd-harmonic rejection at the output, thus eliminating the need for complicated filter structures. The quad-diode configuration only requires simple matching circuits at the fundamental input and the second harmonic output frequencies.

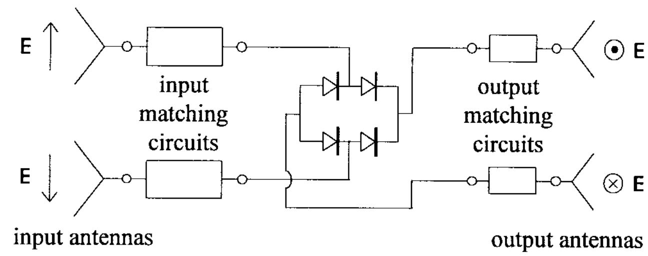

Fig. 1. Quad-diode frequency doubler configuration. The two pairs of antennas deliver to, and extract from the diodes, an equal amount of power with opposite polarity.

The circuit configuration shown in Fig. 1 is implemented on a parabola feed with two pairs of slot antennas. The two input slot antennas receive a vertically polarized signal with the same phase, but deliver to the diodes signals of opposite phase because of the reversed orientation of the two slot-feeds. The output signals generated by the diodes will be transmitted in phase, through the two horizontally polarized output antennas. Input and output signals are coupled to free-space by placing the doubler circuit on an electrically thick substrate lens (a dielectric-filled parabola in this instance). The twin-slot antennas provide excellent beam characteristics [5] with the beam profile set by the slot length and separation, and the waist diameter (f-number) adjusted by varying the parabola aperture size.

For the X/K-band feed circuit on a thick quartz substrate, the input and output slot antennas were chosen to be $0.4\lambda_0$ long and $0.24\lambda_0$ apart at 10 and 20 GHz, respectively (where λ_0 is the free-space wavelength). The slot-width of the input antennas and the gap-width between the ground planes for the coplanar transmission lines were fixed at 0.8 mm, while the output slot-width was 0.4 mm. In between the diodes and the slot antennas, coplanar transmission-line matching circuits were used to transform the slot antenna impedances to the desired optimum input and output load impedances for the diodes. Because distances between antennas and the diodes

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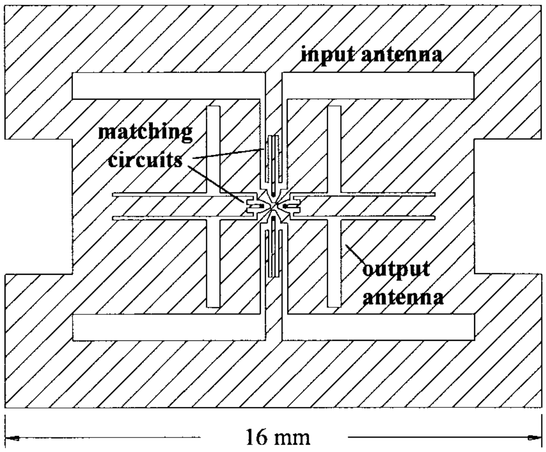

Fig. 2. Parabola feed layout for X/K-band doubler. The circuit is fabricated on a thin quartz substrate and mounted on a stycast-filled ($\varepsilon_r = 3.9$) parabola to satisfy the infinite-thickness dielectric substrate condition. A quad-diode chip is placed at the center and bonded to the tips of the coplanar waveguide center-lines.

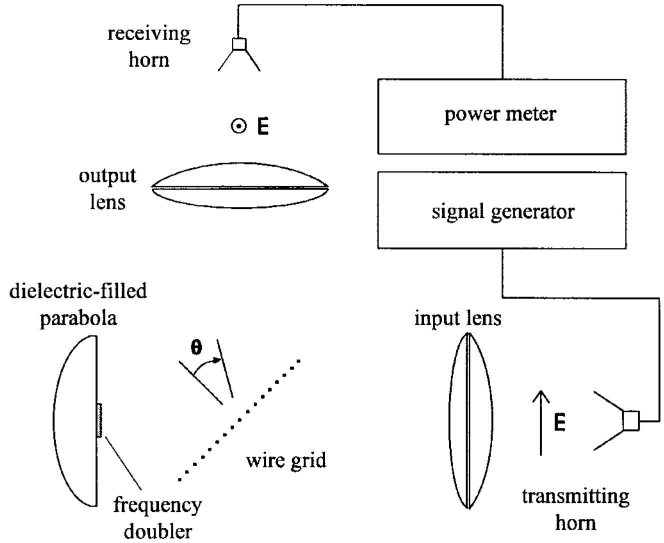

Fig. 3. Measurement setup for the X/K-band doubler. Two lens-coupled standard-gain horns are used to eliminate the diffraction losses in the system. The wire grid reflects the output signal to separate it from the input. The output beam patterns can be measured by removing the output lens and rotating the grid.

were fixed, coupled transmission lines were used along with low- and high-impedance sections to create the neccessary phase delays in the matching circuits. Symmetry is preserved in the matching circuits, and all the ground planes for the matching circuits are joined together at the center of the coplanar waveguide cross-junction underneath where the diodes are placed, in order to inhibit the excitation of slot-line modes.

The overall size of the doubler circuit is minimized to reduce the parabola beam blockage loss. The small circuit size also allows simulation of the diode de-embedding impedances for the whole parabola feed structure on the infinitely thick quartz substrate using HP-MDS. With an input power of 12 dBm for an output frequency of 20 GHz, MDS predicts the conversion loss (which is taken as the ratio of the power transmitted from the output antennas to the power coupled into the input antennas) to be 6 dB for the unbiased quad-diodes, *DMJ2088 X-Band Mixer Quad* by Alpha Industries. The manufacturer's equivalent circuit model for a typical diode used in the *Mixer Quad* contains R_s of 6 Ω, C_{j0} of 76 fF, and $C_{\text{parasitic}}$ of 35 fF. This device, optimized for mixer applications, was used because a suitable varactor diode package was not commercially available. While reverse-biasing the diodes can slightly improve the conversion efficiency, no dc bias circuitry has been incorporated in this particular design to keep the circuit geometry simple.

III. Measurement

The planar circuit was fabricated on a 10-mil-thick quartz substrate (Fig. 2) and glued to the top of a stycast-filled parabola ($\varepsilon_r = 3.9$) as shown in Fig. 3. The radius of the parabola was 4.1 in ($6.94\lambda_0$ at 20 GHz) with a focal length of 2.1 in. A wire grid polarizer was used to through-couple the input signal while reflecting the output beam to the receiver at an angle of 90° with respect to the optical axis of the parabola. The conversion loss measurements were performed by focusing and collecting the Gaussian beam into and from the parabola, with two 11-in-diameter PMMA lenses and standard-gain horns. Calibration measurements performed with the parabola replaced by a mirror, indicated the input path loss between the input feed horn and the parabola to be 2.5 dB at 10 GHz, and the output path loss to be 2.5 dB at 20 GHz. Another calibration measurement, using the parabola with the planar frequency doubler replaced by a mirror of the same size, showed results consistant with a stycast dielectic loss tangent of 0.01, resulting in a calculated stycast loss of 2.3 dB at 10 GHz and 4.6 dB at 20 GHz, assuming no power is reflected at the parabola feed. An additional back radiation loss for the parabola feed of 0.5 dB and Gaussian beam mismatch loss to the parabola of 0.3 dB were also calculated. After compensating for the total system loss (5.6 dB at the input and 7.9 dB at the output), a best slot-to-slot frequency conversion loss of 6.8 dB was measured at the output frequency of 20.3 GHz. The swept frequency measurements [Fig. 4(a)] contained significant resonances due to mismatches in the optical system. The swept power measurement [Fig. 4(b)] carried out at 20.3 GHz indicated that the diodes reached saturation when the power received by the input slot antennas was approximately 12 dBm. The output radiation patterns from the parabola were examined by rotating the polarizer grid without the output lens present. Measured E- and H-plane patterns agree well with the theory down to −10 dB and show a 10-dB beamwidth of 10° for the H-plane and 7° for the E-plane.

IV. Conclusion

We have built and measured an X to K-Band quasi-optical frequency multiplier to test the feasibility of similar circuits at millimeter-wave frequencies. The perfomance of the doubler circuit has been compared with simulation results from MDS with good agreement. A new design for a monolithic 320/640-GHz version using a silicon parabola is now being tested.

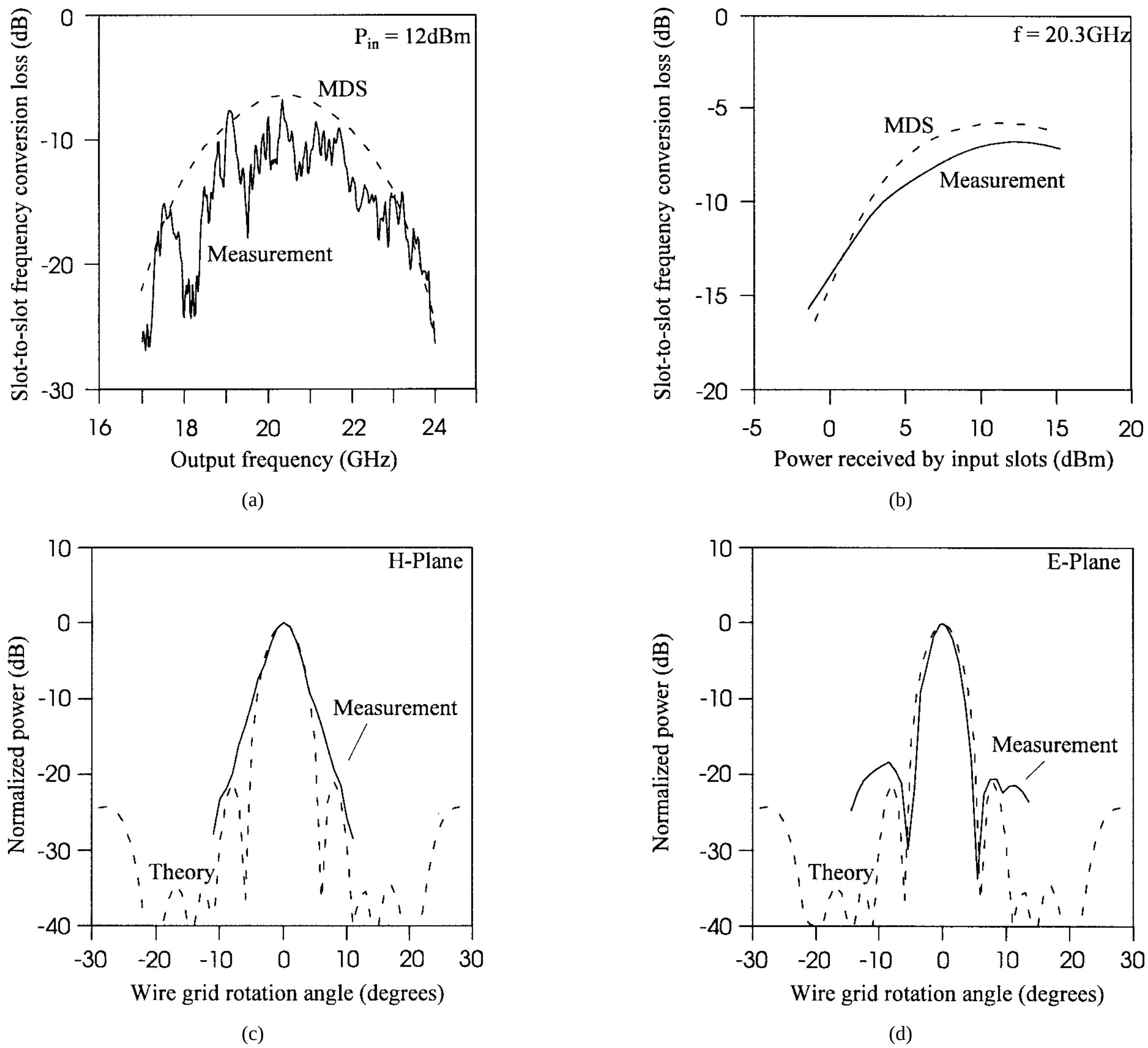

Fig. 4. Measurement results. (a) Slot-to-slot frequency conversion loss versus output frequency with an input power of 12 dBm, (b) conversion loss versus input power received by the input slot antennas at 20.3 GHz, and (c) H-plane and (d) E-plane output power radiation pattern of the parabola. Dashed lines show HP-MDS simulation results [(a) and (b)] and the theoretical pattern calculated for the parabola without the back-side radiation [(c) and (d)].

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