A 30-180GHz Harmonic Mixer-Receiver

B. K. Kormanyos and G.M. Rebeiz

NASA/Center for Space Terahertz Technology
Electrical Engineering and Computer Science Department
University of Michigan
Ann Arbor, MI 48109-2122

ABSTRACT

We have combined integrated circuit antenna technology with microwave circuit design and a back-to-back Schottky diode chip to build a wideband millimeter-wave harmonic mixer-receiver. The design is planar, very simple to build and yields excellent performance from 30-180 GHz. Application areas include wideband early warning systems and search and rescue applications and for extending the range of spectrum analyzers and power meters to the millimeter-wave region.

INTRODUCTION

Millimeter wave harmonic mixers consist of a diode mounted in an E-plane waveguide circuit with an associated LO and IF diplexer. They have limited bandwidth covering only a single waveguide band, and are expensive to build for frequencies above 110 GHz. Also, their conversion loss figures are high for frequencies above 75 GHz because they use a single diode operated as a harmonic mixer. We have developed a new harmonic mixer with a better conversion loss and broader bandwidth than any available waveguide mixer. The receiver covers 5 waveguide bands in a single design (26.5-40, 40-60, 60-90, 90-140, 140-220 GHz) and we have measured its performance up to 140 GHz. The harmonic mixer is quasi-optical. That means the RF energy is coupled via an integrated antenna and not through a guided transmission-line structure. The harmonic mixer consists of a back-to- back Schottky diode chip placed at the apex of a wideband log-periodic antenna. The back-to-back diodes have an asymetrical I-V curve. In this case, only odd harmonics are generated by the diodes using the LO pump voltage and the mixing happens with the 2n'th harmonic of the local oscillator (x2, x4, x6, ...). This configuration allows efficient even- subharmonic mixing of the RF signal and results in a much lower conversion loss than a single diode. The IF and LO channels are diplexed using planar microstrip filters placed at the outer edge of the antenna. The receiver can be built for submillimeter-wave frequencies by monolithically integrating the antenna with a diode pair.

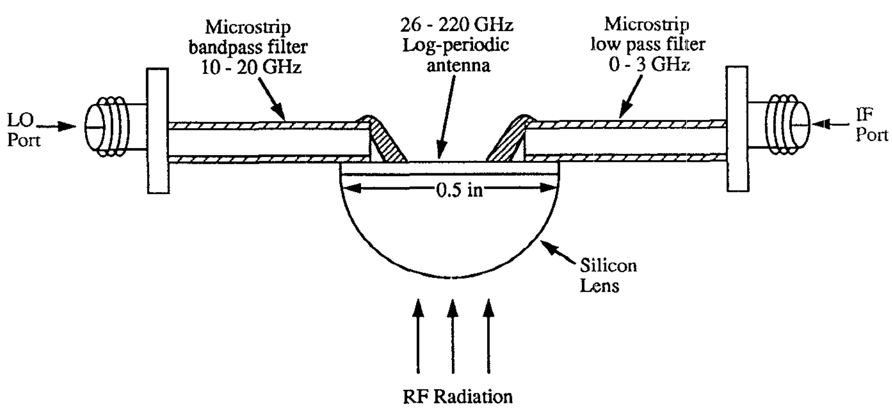

Figure 1: Quasi-optical harmonic mixer-receiver using a planar log-periodic antenna on a substrate lens

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ANTENNA AND MIXER DESIGN

The antenna is a planar self-complementary log-periodic antenna [1] with $\sigma = 0.707$ and $\tau = 0.5$ designed to cover the 26.5 to 220 GHz band. The antenna does not have any teeth covering 10-20 GHz and therefore does not radiate the local oscillator signal which is injected from the antenna edge. The log-periodic antenna is placed on the back of an extended hemispherical lens to eliminate power loss to substrate modes. The dielectric lens also enhances the pattern in the direction of the dielectric and increases the gain.

Recently, in an exciting development experimentally pioneered by Buttgenbach [2], the patterns of spiral and log-periodic antennas showed a marked improvement when placed behind the aplanatic focus of a hyperhemispherical lens. At the optimal position, the patterns are diffraction limited by the substrate lens, and therefore very high gains can be achieved by simply increasing the size of the lens. A theoretical analysis is currently being developed at CalTech and the University of Michigan. It is believed that a uniform phase distribution results on the apperture plane of the lens from an antenna placed at the optimal position. It may be possible to achieve similar patterns with the use of an appropriately designed elliptical lens [3], and this is now being investigated at the University of Michigan.

A 0.5in diameter silicon lens is chosen for the harmonic mixer. This yields about a 1.0λ aperture at the lowest frequency of operation (26 GHz) and a 9λ aperture at 200 GHz. The antenna input impedance is independent of frequency and equal to 75Ω on a silicon lens. This impedance does not introduce a large mismatch between the antenna and the back-to-back diodes.

The anti-parallel diode chip is supplied by the University of Virginia and silver-epoxied at the apex of the antenna. The chip is 10mils long by 5 mils wide. The mixer is essentially two GaAs surface channel diodes [4] integrated in a back-to-back configuration. The surface channel process yields a low parasitic capacitance due to the removal of the GaAs layer between the anode and the cathode. The resulting series resistance and zero- bias junction capacitance is 11Ω and 4fF, respectively. The total parasitic capacitance for the diode is estimated at 9fF, thereby yielding a cutoff frequency of 1 THz. A non-linear mixing program was written at the University of Michigan for the analysis of subharmonic mixers. The program is based on the harmonic balance method [5]. The program takes into account the asymmetrical I-V curve of the back-to-back diodes. See the December issue of IEEE MTT for further details. The program indicates that the RF mismatch between the antenna and the diode pair should be less than 1.5 dB. No RF matching network is used between the antenna and the diode chip. The calculated SSB conversion loss at 36 GHz and 60 GHz are 7.2 dB (x2) and 15.4 dB (x4), respectively. The corresponding IF impedance is around 70Ω and therefore no IF matching network is needed.

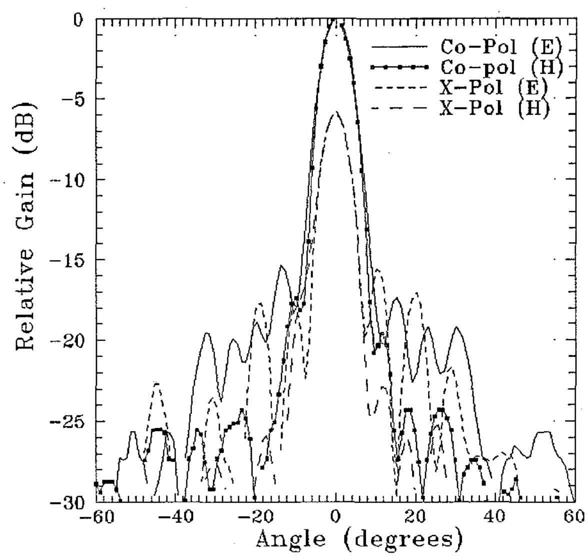

Figure 2: 180GHz antenna pattern for the planar log-periodic antenna at the optimal position on a substrate Lens

LO/IF DIPLEXER DESIGN

As stated earlier, a microstrip diplexer is integrated just after the antenna terminals. The IF filter is a low pass filter with a corner frequency of 3 GHz that exhibits a very low impedance for frequencies above 10 GHz. The LO filter is a bandpass filter covering the 10-20 GHz band. A wideband local oscillator is needed in order to achieve good frequency coverage at the second harmonic, x2 (20-40 GHz) and fourth harmonic, x4 (40-80 GHz). For higher frequenciers, the local oscillator range necessary for complete coverage is between 10 and 15 GHz (for example: x6: 60-90 GHz, x8: 80-120 GHz, ..). A bandpass filter containing only open and short circuit stubs is designed using Kuroda's identities. It exhibits a very low impedance in the IF band (0-3 GHz). Both filters were constructed on Duroid RT/6006 ($\epsilon_r = 6.15$), see [7], and the measured filter responses agree well with theory (Fig. 3). The IF filter loss is less than 0.4 dB up to 3 GHz and the LO bandpass filter loss is about 2-3dB in the 10-20 GHz pass band.

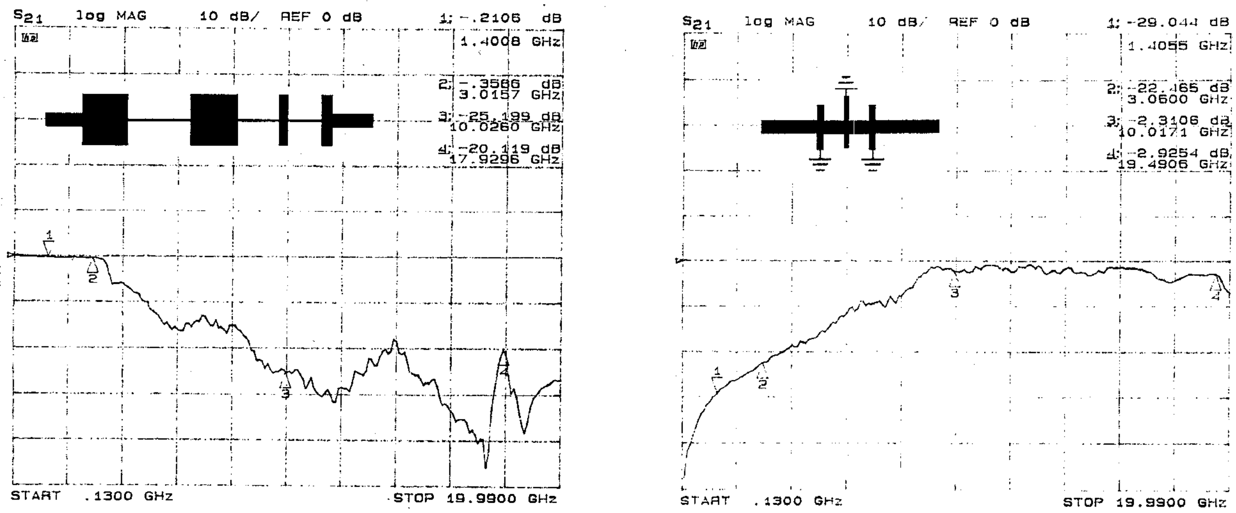

Figure 3: Measured S21 of the microstrip lowpass and bandpass filters used in the diplexer

MILLIMETER-WAVE MEASUREMENTS

The harmonic mixer is part of the quasi-optical family of receivers and therefore its conversion loss can be defined and measured in a variety of ways. In this work, the conversion loss is defined as the power received at the IF channel in a 50Ω load divided by the total plane-wave power incident on the lens aperture (area = 1.26cm^2). This is a "systems" definition and includes all loss components in the harmonic receiver. It is a term that lets the user relate the IF power to the total RF power (or plane-wave RF power density) incident on the lens. The conversion loss includes the electromagnetic coupling efficiency of the log-periodic antenna on an extended hemispherical substrate to a plane wave (aperture efficiency estimated at 80%), the mismatch between the plane wave impedance and the silicon lens (1.55dB), the loss in the silicon less (estimated at 0.4 dB for 100 GHz [6]), the RF mismatch between the antenna and the diode chip (0.9dB typical), the intrinsic diode conversion loss, the IF filter loss (0.2 dB at 1.4 GHz) and the IF mismatch between the diode chip and the IF load.

The RF power was generated using an HP8350B sweeper and harmonic multipliers up to 100 GHz, and Gunn diodes with waveguide doublers for frequencies above 100 GHz. The power density at the location of the lens was measured using an Anritsu power meter with a calibrated standard-gain horn antenna. The local oscillator was generated using an HP83624A synthesized sweeper. The measured conversion loss did not vary for IF frequencies between 0.1-3 GHz and a 1.4 GHz was chosen for most frequencies. The back-to-back diodes required a local oscillator power of 30-80 mW for optimal operation. The upper and lower sideband conversion loss were very similar due to the wideband nature of the antenna and the local oscillator band-pass filter. The measured conversion loss is shown in Figure 4. It exhibits a 9.2dB conversion loss at 34 GHz, and a 35dB loss at 140 GHz. These resutls are about 20 dB better than the best available commercial devices due to the excellent diode chip used and the subharmonic mixing advantage. The results at 36 GHz and 50-60 GHz agree reasonably well with predicted results when antenna coupling efficiency is considered. No measurements were done at 180 GHz because we accidentally burned the diode chip when making the 140 GHz experiments. However, from the measurement trends, we expect that the performance at 180 GHz will be similar to the 140 GHz results. This receiver has been extensively used with an HP spectrum analyzer for high-performance millimeter-wave power and frequency measurements.

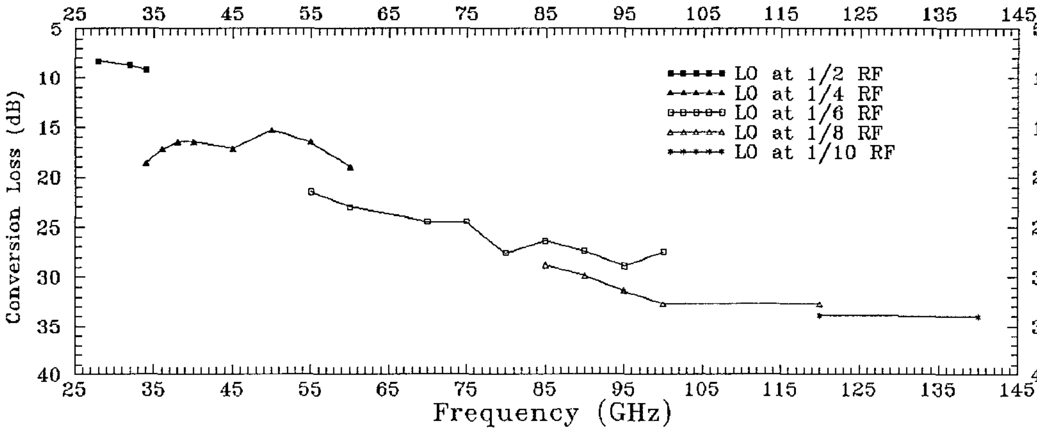

Figure 4: Measured SSB conversion loss of the wideband harmonic mixer-receiver

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[7] Duroid is a trademark of Rogers Corporation and we thank Rogers for their donation of the microwave substrate.