SUBHARMONICALLY AND FUNDAMENTALLY PUMPED SLOTLINE QUASIOPTICAL MIXER

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ABSTRACT

A slotline dipole quasioptical mixer has been designed and tested at 35 GHz. This quasioptical mixer has circuit elements that can act as inefficient antennas without adversely affecting mixer performance, showing another reason why the isotropic conversion loss is important for the characterization of quasioptical mixers.

INTRODUCTION

The high directivity and broad bandwidth of receivers at frequencies above 140 GHz are particularly attractive features for space based radio link applications. Operating at high frequencies also enables many mixers to be combined into compact imaging arrays that are prohibitively large at lower frequencies. In order to address this future need, quasioptical receivers combining both optical and microwave techniques must be developed with an emphasis on low cost, planar design, and compact size, taking full advantage of the size benifits offered by waveguide approaches, and the cost savings offered by optical techniques.

Quasioptical mixers and mixer arrays for use above 100 GHz will require substantial amounts of LO power in a regime where high power sources are not readily available. Alternatives to fundamentally pumped mixers above 100 GHz are biased fundamentally pumped mixers and subharmonically pumped mixers. Bow tie subharmonic mixers have recently been investigated by Stephan and Itoh [1]. We present a novel approach at 35 GHz that uses a slotline dipole antenna with a planar IF output that can be scaled to higher frequencies and is suitable for array applications.

CIRCUIT DESIGN AND LAYOUT

Computer aided design facilitated the development of the 35 GHz slotline quasioptical mixer. The circuit layout, shown in Figure 1, exhibits four different transmission line media: slotline for the dipole antenna, coplanar waveguide (CPW) for the transition from slotline to microstrip, waveguide for the introduction of the local oscillator (LO) signal, and microstrip for the IF output. Existing programs were used to calculate the microstrip and CPW impedances, and standard formulas were used to design the IF filter. A program for calculating

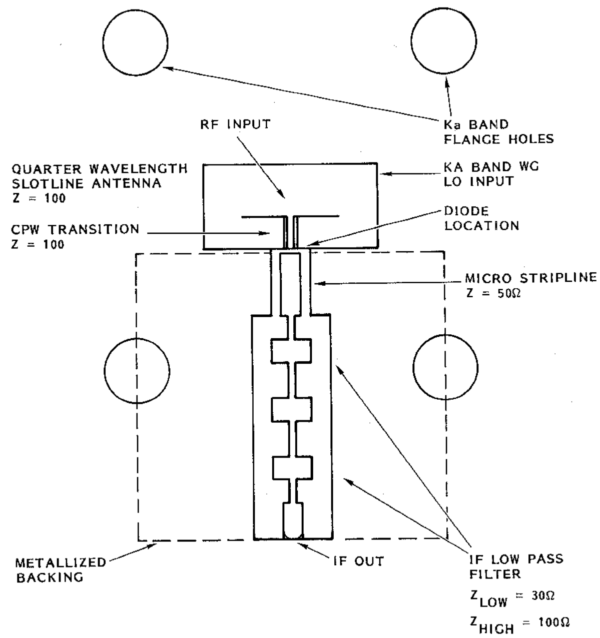

Figure 1. 35 GHz Circuit Layout

the impedance of slotline - especially for substrates with small dielectric constants - was written based on Cohn's article [2] because standard formulas are designed for high dielectric constants. High dielectric substrates are often preferred for slotline, where radiation losses must be avoided. In this application a low dielectric constant has certain advantages; it radiates very efficiently.

The half wave slotline dipole antenna and the CPW transmission line were fabricated with an arbitrary impedance of 100 ohms. This design differs from others [3] because a high impedance line was used as opposed to a low impedance one. A single diode, or a pair of anti-parallel diodes, are located at the junction between the CPW line and the microstrip line. Hence, this configuration can be used as a fundamental or subharmonic mixer. The backside of the substrate was metallized to ensure a good ground plane. To reduce LO power in the fundamentally pumped mixer mode, a bias tee was used to introduce a low bias current to the diode. The filter is a standard seven section Chebyshev high

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impedance/low impedance lowpass filter [4]. The circuit was mounted on a standard Ka band flange with nylon screws for mechanical support.

A single half wave dipole antenna was chosen for the quasioptical mixer, as opposed to an array antenna, because the focal point of a lens can be small, and because most imaging applications require a small area for the receiving antenna. The spot size of a spherical lens is larger than our current antenna area. But other lens designs will result in a diffraction limited spot size, rather than the geometrically limited one we now encounter. For a quasioptical receiver to be optimized, the antenna and the spot size should be comparable. A two inch lens is very close to the limit of Gaussian Optics [5] at 35 GHz, but at 140 GHz, classical optics will hold.

All features of this design can be scaled to 140 GHz. This requires the use of a thinner substrate material, and a carefully designed IF filter. Most of the features, such as the dipole antenna, the CPW transmission lines, the microstrip transmission lines, and the filters scale well, but the size and electrical properties of the diodes do not scale well. Some degradation in the electrical performance must be accepted, unless special diodes are used. To accommodate the size of the diodes (Alpha DMK6606A), a constant impedance transformer, shown in Figure 2, was designed using an interesting property of CPW. For a given impedance, any number of center widths and slot widths can be found. This makes it possible to go from a narrow spacing, required for coupling the CPW line to a half wavelength dipole antenna, to a wider spacing, required for mounting beamlead diodes. The use of a computer generated ruby cutting station makes this transformer possible. Another attractive quasioptical mixer design [1] using a slotring resonator, instead of the closely related slotline mixer design described in this article, can be scaled to higher frequencies by taking advantage of higher resonant modes. The width of the slotring channel becomes too small for commercial diodes, but the design could be used in monolithic applications on GaAs substrate material. The slotline dipole quasioptical mixer described here can be scaled for use on either low dielectric constant substrates, or high dielectric constant materials.

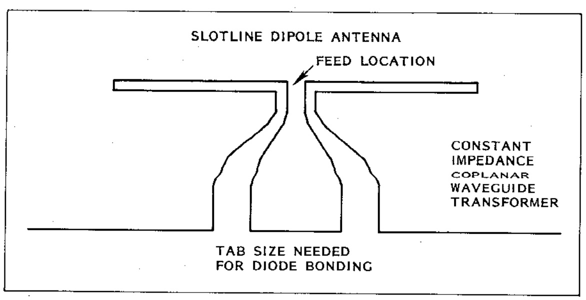

Figure 2. Constant Impedance Transformer

This mixer layout is very compact despite the use of an optical element. This arrangement gets around the use of a bulky diplexer for the LO port of the mixer because the LO power is introduced by a waveguide, allowing a compact overall design. The lens is comparable in size to a standard gain horn, but its cost is significantly less. Suitable combination of waveguide, microstrip, and optical techniques can result in a compact low cost receiver.

PERFORMANCE

The angular dependence of the dipole antenna alone, and the quasioptical mixer was measured at the operating frequency of 35 GHz. Both plots in Figure 3 are normalized to their maximum directivity. The radiation pattern of the dipole antenna alone agrees well with the theory, but the directivity of the quasioptical mixer has been increased by the presence of the waveguide behind the slotline and degraded by the perturbations from the IF filter and the nylon mounting screws. Preliminary measurements on 94 GHz designs show that care must be taken in the design of the IF filter.

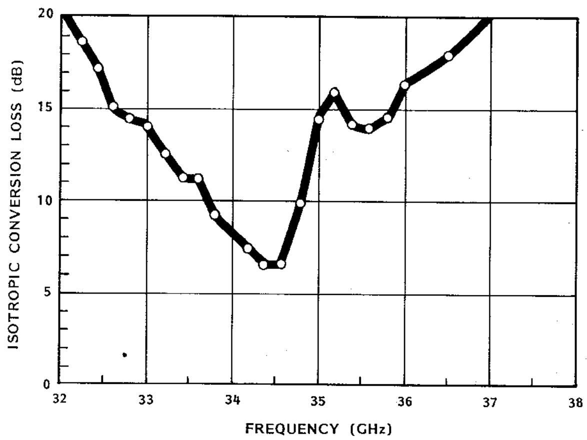

Figure 3. Isotropic Conversion Loss and Direct Power Absorption vs Angle

The conversion loss as a function of frequency, shown in Figure 4, exhibits a low conversion loss over a 2 GHz bandwidth. It has been shown that the isotropic conversion loss [1] is the most appropriate for use in the testing of quasioptical mixers, but we caution the reader not to misinterpret it as the conversion loss. Similar results were obtained with a biased single diode, and with a subharmonically pumped configuration. One problem that is encountered in the test of quasioptical mixers that is not encountered with standard waveguide mixers is LO leakage. The total rejection of an IF filter in microstrip is limited by radiation and other leakage effects to about 40 dB. This is enough for a standard mixer where the input power is around -10 dBm, but for a quasioptical mixer

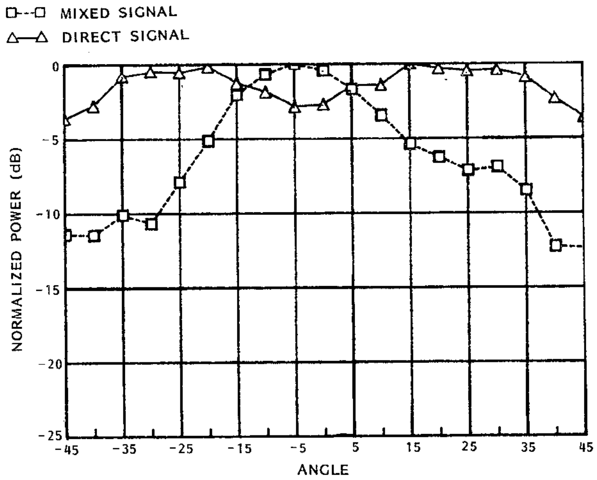

Figure 4. Isotropic Conversion Loss vs Frequency of a Fundamentally Pumped Slotline Dipole Quasi-optical Mixer

where the effects of free space attenuation reduce the input power, signals of -40 dBm are input into the mixer. Standard HP power meters can detect down to -70 dBm, and LO leakage can exceed the IF signal intensity. This problem would occur in the test of standard waveguide mixers if an input power of -30 dBm were used. In fact, use of a waveguide mixer with a horn will encounter the same problem. This is a problem that occurs in testing only; an IF amplifier is a very good band pass filter.

DISCUSSION

The mixer design presented here has two primary features: it can be scaled to 140 GHz, and it is truly planar. Isotropic conversion loss measurements effectively characterize quasioptical mixers because the antenna is an integral part of the mixer, however, it is important to mention that the ultimate use of the quasioptical mixer is to detect microwave power. An imperfect dipole pattern, such as the one shown in Figure 3, does not prevent the same quasioptical mixer from performing well with a lens, as shown by Figure 5. This points out another reason that the isotropic conversion loss, as proposed by Itoh and Stephan [1], is important: circuit elements themselves can act as antennas. Just as it is impossible to separate the antenna from the mixer, it is impossible to isolate the antenna from the circuit elements of the mixer. A lowpass filter with a rejection frequency F resembles an array of patch antennas with optimum efficiency at 2F. This suggests abandoning a high/low lowpass filter in favor of the CPW IF filter used by Stephan et al. [6], the stub filter used by S.J. Nightingale et al. [7], or the parallel coupled line filters used by Fetterman et al. [8] in array applications.

In conclusion, we have developed a novel planar slotline quasioptical mixer that performs well at 35 GHz. Another reason for the use of the isotropic conversion loss was found; circuit elements

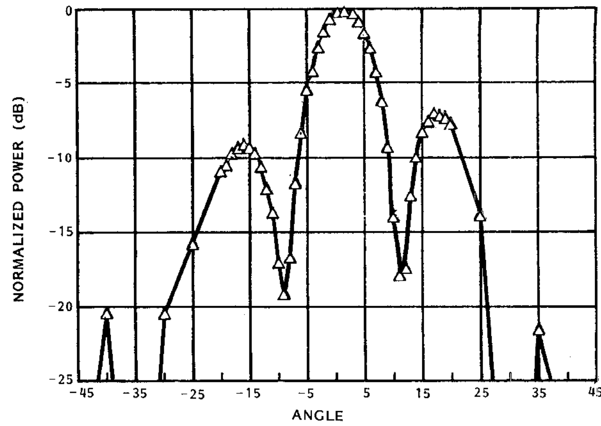

Figure 5. Mixer with Lens Antenna Normalized IF Output Power vs. Angle

have been found to act as antenna elements, so it is not possible to separate the gain of an antenna from the mixer itself. This design can be scaled to higher frequencies, and both fundamentally and subharmonically pumped modes have been tested.

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