RECENT EFFORTS ON PLANAR COMPONENTS FOR ACTIVE QUASI-OPTICAL APPLICATIONS

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Abstract

Quasi-optical components are coming to the aid of microwave circuit designers who are seeking smaller size, fewer parts, and higher efficiency. Several novel sources and receiving mixers using both diodes and FETs have been developed, and are discussed in the framework of isotropic conversion loss or gain, quantities that were developed to measure the unique properties of these components.

I. Introduction

Compact, simple, and efficient: these words describe many of the new quasioptical microwave components developed over the last several years. Quasioptical components are compact because many interface connections are eliminated; usually, direct connections are made on a single planar substrate. Quasioptical components are simple because several functions such as impedance matching, frequency selectivity, and radiation can often be performed by the same planar circuit element. Finally, the efficiency of quasioptical components can approach the efficiency of the active device itself because no lossy lines intervene between the device and the antenna. In this paper we review a number of planar quasioptical sources and receivers which have been demonstrated recently. Before we describe them in detail, it will be helpful to define some performance criteria that are unique to quasioptical components.

When one tries to apply conventional measures of performance to quasioptical components, an immediate problem arises: there is usually no well-defined RF input port (for mixers) or output port (for oscillators). Rather, free-space radiation is transmitted or received directly by the component. Since conversion loss for mixers is defined in terms of the available power at the RF port, an alternative definition of conversion loss has been defined for quasi-optical mixers [1]. The concept of isotropic conversion loss L_{iso} is illustrated in Fig. 1. When the quasi-optical mixer is irradiated by a given RF field, it will downconvert this input to an IF output at an available power P_{if} as shown in Fig. 1(a). The isotropic conversion loss L_{iso} is defined as

$$L_{iso} = \frac{P_{iso}}{P_{if}} \quad (1)$$

where P_{iso} is the RF power that would be received if the receiver circuit were replaced by a fictitious isotropic antenna under the same measurement conditions, as shown in Fig. 1(b). The quantity L_{iso} takes into account the effects of the mixer's antenna gain as well as its conversion loss to give a number that is easily measured. Sometimes the inverse of isotropic conversion loss is more convenient to use, so isotropic conversion gain for receivers is defined as $G^R_{iso} = 1/L_{iso}$.

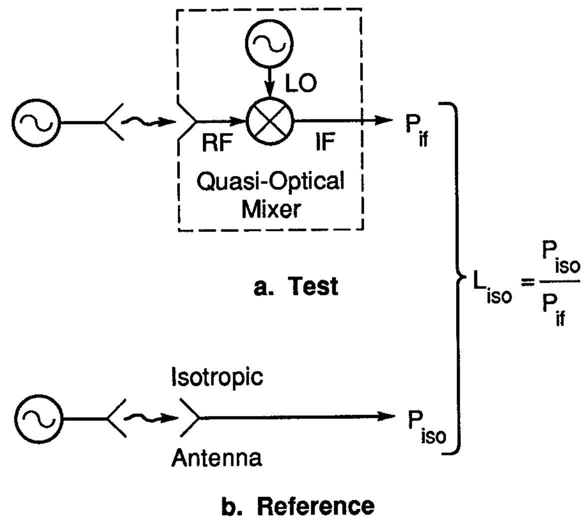

Fig. 1. Isotropic conversion loss L_{iso} for a quasi-optical mixer.

In a similar way, a quasi-optical oscillator with no well-defined RF output port is characterized by isotropic dc – RF conversion gain G^T_{iso}. In Fig. 2(a), a quasioptical oscillator converts a fraction of the dc input power P_{dc} to radiated RF power, and in the far-field direction of maximum radiation power P_T is received. Replacing the actual source with a fictitious 100% efficient source driving an isotropic antenna results in a power P_R at the receiver, and the isotropic dc – RF conversion gain is defined as

$$G^T_{iso} = \frac{P_T}{P_R} \quad (2)$$

If the quasi-optical source's antenna has considerable gain in the direction of measurement, G^T_{iso} can exceed unity despite a device efficiency of less than 100%.

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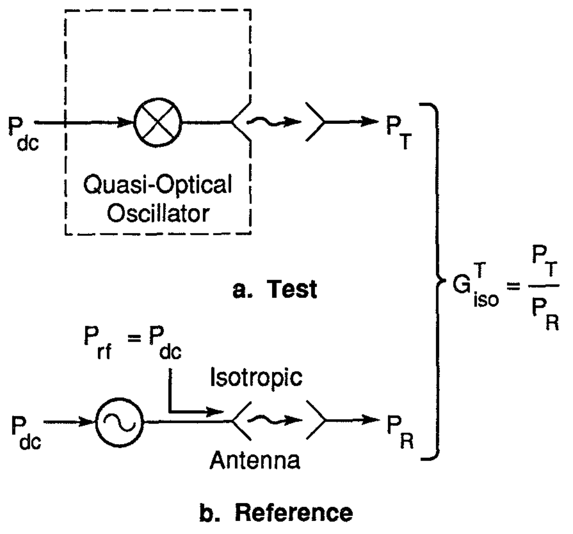

Fig. 2. Isotropic dc–RF conversion gain G^T_{iso} for a quasi-optical oscillator.

II. Periodic- Structure Quasioptical Components

A. Periodic Patch Oscillator

The periodic structure shown in Fig. 3 will be recognized by many antenna designers as a microstrip patch array. Designers of such arrays are aware of a stopband showing high VSWR that occurs at a wavelength that approximates a full period of the array. At this frequency each patch is approximately $\lambda_g/2$, and so is each coupling line. The design of this oscillator [2] uses this normally undesirable stopband to establish the oscillation frequency of the active device, in this case an FET. In circuits built to operate at 9.5 GHz, the actual oscillation frequency was within 5% of the design value. An oscillator using a 12–element array showed a G^T_{iso} of 2 dB, and a 17–element array gave a G^T_{iso} of 9 dB.

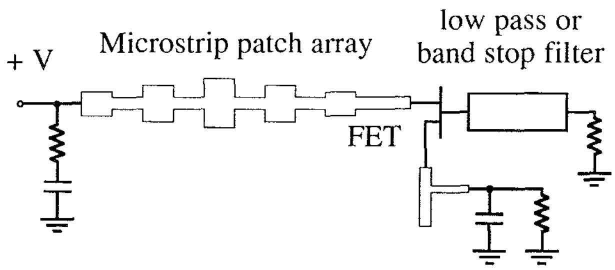

Fig. 3. Periodic patch oscillator (from Ref. [2]).

B. Coupled Rampart Line Oscillators

The rampart line [3] looks like a square wave in microstrip. Fig. 4 shows the mitered bends of a coupled pair of rampart lines. By proper design of the element lengths and coupling, a stopband can be made to appear that will cause the FETs to oscillate in a push-pull (or odd) mode. In this mode of operation the radiation is polarized perpendicularly to the axis of the array. A G^T_{iso} of up to 6 dB was measured for an X-band oscillator running in this push-pull mode [4]. The same basic circuit radiates the second harmonic in a polarization parallel to the long axis of the array, and operation in this mode produced a second-harmonic G^T_{iso} at 19.7 GHz of 0 dB [5]. By adding a receiving antenna to pick up reflection of the transmitted signal from a target, a very simple Doppler radar may be constructed [5].

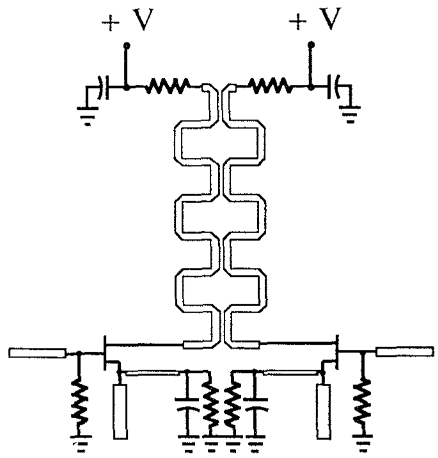

Fig. 4. Coupled rampart line oscillator (from Ref. [5]).

III. Components Using Slots

A. Quasi-optical Frequency Multipliers

The difficulty of frequency multiplication using diodes arises from the low efficiency and limited power-handling capability of a single device. Consequently, workers such as Hwu et al. [6] have spread the power out to a large number of diodes and recombined the harmonic power with various quasi-optical methods. One of the first solutions to this problem was demonstrated by Camilleri and Itoh in 1985 [7]. Slots in a conventional waveguide's broad wall were bridged by multiplier diodes, and good radiation patterns were measured from an eight-diode array doubling to 70 GHz. More recently Nam et al. [8] have achieved the same object by means of a microstrip line which meanders over slots in its ground plane so as to excite each slot's diode in the correct phase. This circuit is shown in Fig. 5.

B. Planar Slot Oscillator using Resonant Tunnelling Diode

The resonant tunnelling diode (RTD) has been observed to oscillate at frequencies as high as 420 GHz [9]. As fabrication methods improve, these devices will be built into planar quasioptical systems. A first step in this direction has been taken by one of us (Stephan) in an experiment shown in Fig. 6. An RTD in a custom quartz package was placed across a slot in the copper coating of a dielectric sheet. The diode and its bias circuit oscillated in X-band, but when a concave reflector was placed opposite the dielectric so as to form a quasi-optical resonant cavity, the RTD's oscillation frequency came under the control of a TEM_{00q} cavity mode and the oscillation spectrum improved. Further work is needed to extend these and other techniques into the submillimeter range opened up by the advent of the RTD.

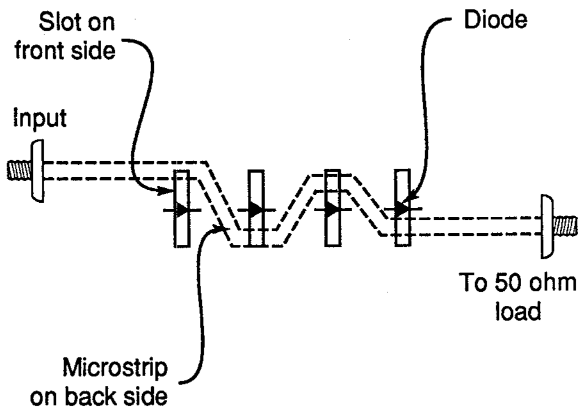

Fig. 5. Frequency multiplier using microstrip-fed slots and spatial power combining (adapted from Ref. [8]).

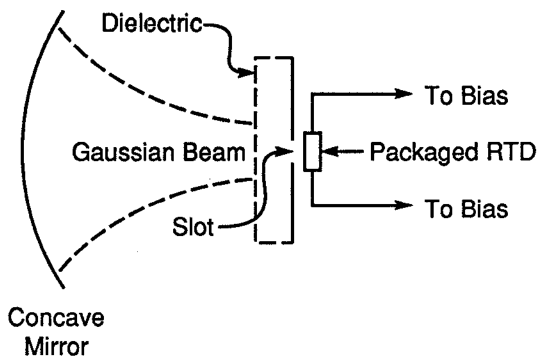

Fig. 6. Planar slot oscillator with resonant tunnelling diode (RTD) coupled to quasi-optical cavity.

C. *Coupled-slot Receivers*

When two lines are connected together at either end as shown in Fig. 7, a two-mode structure results. An incoming RF signal with its electric field perpendicular to the slots' long axes will excite the even mode, while a local oscillator driving the central metal strip through a via hole will excite the odd mode. The designer of a coupled-slot mixer chooses to locate the nonlinear elements (diodes in Fig. 7) so that the proper levels of both RF and LO power are available for mixing. The IF signal path is isolated from the global ground by a thin break in the metal surrounding the coupled slots. As described by Hwang et al. [10], the LO source can be either a Gunn oscillator or an FET, and in a later version [11] the diodes were replaced by self-oscillating HEMTs and MESFETs, eliminating the separate LO circuit. (Note: in Ref. 10, the definition of L_{iso} in Eqn. 1 has P_{IF} and P_{iso} reversed). This last HEMT mixer demonstrated a value of G^R_{iso} of up to 4.5 dB with an associated noise figure of 6.5 dB at 11.87 GHz. A similar quasi-optical mixer called the slot-ring mixer [12] was developed earlier, but requires a quasi-optical LO feed which can be a disadvantage in some cases.

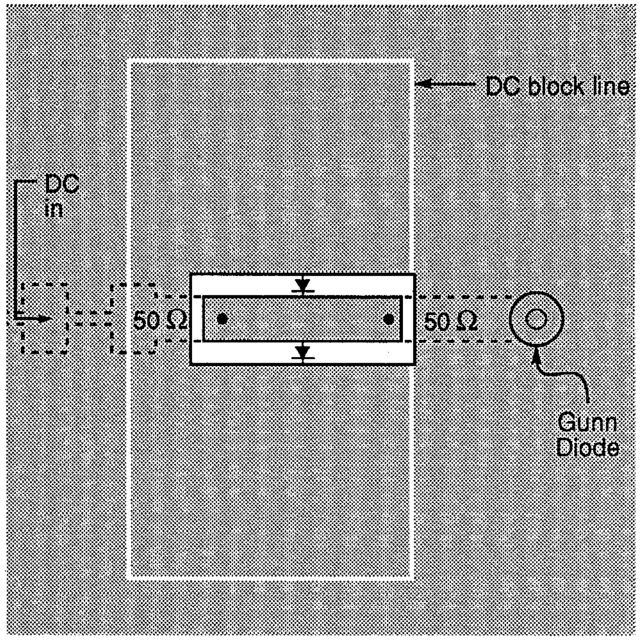

Fig. 7. Coupled slot quasi-optical receiver (adapted from Ref. [10]).

IV. The Ultimately Simple Microstrip Ring Transceiver

As a final example of simplicity in active quasi-optical components, we present the microstrip-ring transceiver of Fig. 8. Counting the two FETs, the RF bypass capacitor at the split in the ring, and the microstrip circuit itself, there are only four microwave parts of any kind. Yet with the assistance of two IF transformers, this circuit simultaneously acts as a dual-polarization receiving antenna, local oscillator, resonator, and balanced mixer, and produces independent co-polarized and cross-polarized outputs with an isolation exceeding 20 dB! A value for L_{iso} of 5.6 dB was measured at 6 GHz [13,14].

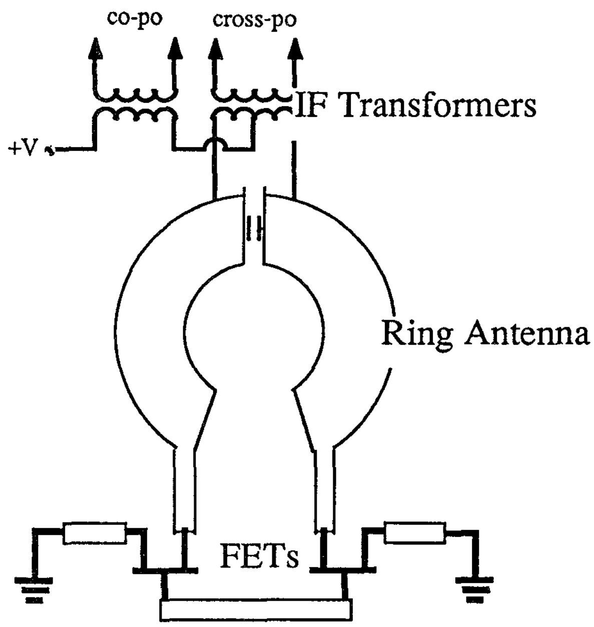

Fig. 8. Microstrip-ring transceiver (from Ref. [13]).

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