A Novel Split-Waveguide Mount Design for Millimeter- and Submillimeter-Wave Frequency Multipliers and Harmonic Mixers

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Abstract—**A novel split-waveguide mount for millimeter and submillimeter wave frequency multipliers and harmonic mixers is presented. It consists of only two pieces, block halves, which are mirror images of each other. The mount provides parallel and series impedance tuning with two sliding backshorts at both the input and output frequencies while utilizing E-plane arms to provide an in-line waveguide input and output. Its fabrication is much easier than that of a traditional multifrequency waveguide mount. Waveguide losses are minimized by a very compact design with very short input and output waveguides. This mount is especially well suited for planar diodes used with microstrip or suspended stripline RF filters.**

I. Introduction

Waveguide structures are commonly used as mixer and frequency multiplier mounts in millimeter and submillimeter heterodyne receivers used for radio astronomy and atmospheric remote sensing. Frequency multipliers [1] and harmonic mixers [2] require waveguides of at least two different sizes. While a split-waveguide block (where the rectangular waveguide is split along the E-field at the center of the broad wall) is readily designed for a fundamental mixer with a planar mixing diode, e.g., [3], [4], the harmonic mixers and frequency multipliers commonly utilize a crossed-waveguide design in order to accommodate the necessary waveguide flanges and backshort tuning mechanisms. In this case the block has to be built of several pieces, e.g., [5], and electroforming or electro-discharge machining of the crossed waveguide may be required, e.g., [6], [7].

Desirable aspects in these multifrequency, multiwaveguide mount designs are ease of fabrication and assembly, wide tunability of fundamental and harmonic embedding impedances, and low loss. High reliability requires the use of planar diodes as nonlinear elements.

The purpose of this letter is to present a novel mount design which provides these characteristics for both harmonic multipliers and mixers at millimeter and submillimeter wavelengths. The new mount has all tuner waveguides parallel, with all four sliding backshorts in the same plane. E-plane arms, perpendicular to the tuner waveguides, are utilized to form in-line input and output ports. Planar devices are easily mounted on either microstrip or suspended stripline substrates in a channel formed between the tuner waveguides.

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II. Waveguide Mount Description

While we have designed and fabricated frequency doublers, triplers and harmonic mixers utilizing this generic mount design, we only present a doubler (2 × 110 GHz) design here as an example. Figure 1 shows a schematic of the doubler mount. The pump signal is input via an E-plane arm in full height WR-8 waveguide (dimensions 1.02 mm × 2.03 mm) and is coupled to a quartz microstrip probe with the help of two noncontacting sliding backshorts in the tuner waveguide. A planar multiplier diode is located on the microstrip substrate in the output frequency tuner waveguide (WR-4) which has a reduced height (0.28 mm × 1.09 mm). The output signal leaves via another E-plane arm which is aligned with the input waveguide. The distance of the E-plane arms from the probe and the diode is approximately $\lambda_{g,\,\mathrm{pump}}/2$ at the input frequency and $\lambda_{g,\,\mathrm{signal}}$ at the output frequency. Two sliding noncontacting backshorts provide the impedance match at the output frequency. The output waveguide has a built-in channel transformer [8] to match it with a standard WR-4 waveguide. The distance between the input and output frequency tuner waveguides is 2.50 mm, allowing a length of about 2 mm for the RF filter. The filter channel cross-section dimensions are 0.31 mm high × 0.36 mm wide, and the microstrip filter utilized in this design is composed of a 0.152-mm thick × 0.33-mm wide fused-quartz substrate. As shown in Fig. 1, the substrate channel extends across and beyond the output frequency tuner waveguide. This allows dc and RF grounding at the end of a TEM transmission line instead of at the waveguide wall (see e.g., [4]).

The overall dimensions of the block are 29 mm × 14 mm × 19 mm, where 14 mm is the distance between the input and output waveguide flanges. The block is split into two halves of equal dimensions, one half of the block being a mirror image

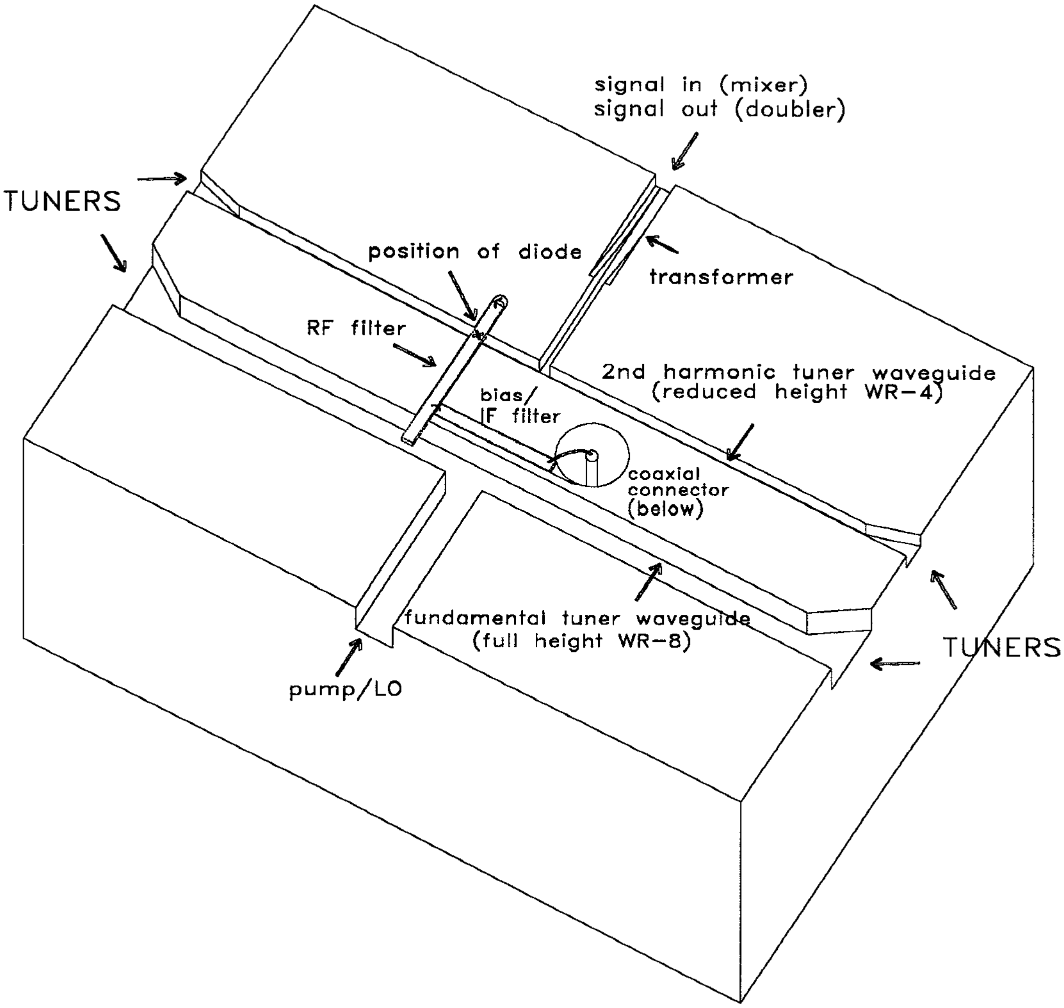

Fig. 1. Schematic drawing showing one half of the 220-GHz doubler/harmonic mixer split-block.

of the other. The bias feed-through, made from a coaxial SMA connector, comes in through the bottom of the lower block half as indicated in Fig. 1. The two closely-spaced backshorts at each end are tuned with a pair of offset micrometer heads supported by a common housing (design adopted from the subharmonic mixer described in [7]).

III. Pros and Cons of This Design

The new split-block design provides improvements over designs performing similar functions in one or more of the following ways.

1) *High Reliability:* Planar diodes have superior reliability to whisker-contacted diodes. This block design is especially well suited for planar devices.
2) *Wide Impedance-Tuning Range:* Both the input and output have two sliding backshorts providing a series- and a parallel-tuning element at both frequencies. It can be shown theoretically and has been demonstrated by scaled model measurements that this configuration allows impedance match over a wide range of impedances at both frequencies. However, the use of several tuning elements does not lessen the importance of correct design of the RF filter and the waveguide coupling probe.
3) *Ease of Fabrication and Assembly:* The block requires only two machined pieces with no electroforming. Since all of the waveguides as well as the substrate channels are in one plane, the block halves can be easily machined using an endmill and/or a slitting saw. Shaving or scribing is also a possible method for producing the waveguide and channel halves and may turn out to be the best procedure at submillimeter wavelengths. In addition, all waveguide surfaces are easily accessible for polishing and plating.
4) *Low Losses:* With this geometry, the total length of the input and output waveguides is reduced to a minimum, decreasing the total waveguide loss.
5) *Readiness for Scaling to Higher Frequencies:* We expect that this mount design can be scaled quite easily to 600 GHz and possibly higher because no sophisticated machining techniques are needed.

One drawback of this design which is common to all blocks with a split along the E-plane wall center, is the requirement for very precise alignment of the waveguides, which otherwise results in poor performance of the sliding backshorts.

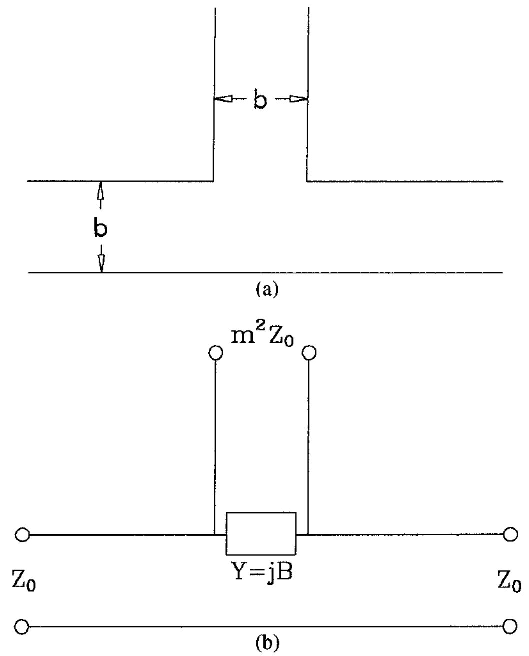

Fig. 2. E-plane T-junction of (a) equal height waveguides and (b) its equivalent circuit.

IV. Discussion

Usually, in multiplier mounts, an E-plane arm is used for realizing a series tuning element while a straight-through waveguide arm is used for power input or output coupling. In this new mount these functions are reversed. Theoretically, the impedance-matching conditions in these two cases are different; Fig. 2 shows an equivalent circuit of a waveguide T-junction. However, graphs [9] (pp. 336–350) show that, in the case of a T-junction of waveguides of equal heights, the shunting susceptance is very small, $B \approx -0.03Y_0$, and the transformer ratio is close to unity, $m^2 \simeq 0.90 - 0.97$. Therefore, for practical purposes, we can conclude that in the case of equal height waveguides the E-plane arm and the straight-through arm are interchangeable for tuning and power coupling.

This generic mount design is equally well suited for a doubler, a tripler, a quintupler (with a symmetric diode characteristic), or a harmonic mixer. A tripler with a Schottky varactor or a quintupler with a diode containing symmetric impedance characteristics requires one idler circuit which can be provided by extending the substrate across and beyond the output frequency tuner waveguide and placing a proper planar tuning circuit there.

Any measurements characterizing the mount require a set of filters and a waveguide coupling probe designed for a given application. The obtained measurement results depend strongly on those designs. Therefore, we have omitted the measurements in this paper which is intended only as a description of the generic mount. We have fabricated a millimeter-wave doubler, tripler, and harmonic mixer with this new mount arrangement and will report on their performance in future publications.

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