General-Purpose Fifth-Harmonic Waveguide Mixer for 500−700 GHz

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Abstract — **This paper presents the design of a wide-band fifth-harmonic waveguide mixer. The mixer uses two single planar Schottky diode chips in a balanced-mixer-type configuration. It is designed to operate at 500−700 GHz radio frequency (RF) range applying an InP Gunn oscillator as the local oscillator (LO) source at 100−140 GHz. A novel transition structure is used in the LO waveguide. The mixer block is compact comprising an integrated diagonal horn antenna, two 40-μm-thick quartz circuits, and a coaxial connector. For effortless use in a submillimetre-wave antenna measurement set-up the mixer does not comprise any tuners. Mixer circuits were designed for wide-band operation and were not optimised for a certain frequency. The conversion loss is close to 27 dB at 650 GHz with an LO power of 10 dBm at 130 GHz. The mixer is currently being used for phase-locking of a submillimetre-wave backward wave oscillator in a hologram-based compact antenna test range.**

I. Introduction

At the Helsinki University of Technology, Radio Laboratory we are currently constructing a hologram-based compact antenna test range for 650 GHz [1]. The test range uses a backward wave oscillator (BWO) as a signal source to guarantee an adequate dynamic range. For phase-locking (Fig. 1) of the BWO we have designed and constructed a wide-band fifth-harmonic waveguide mixer using two planar Schottky diodes. The mixer is designed for a wide-band operation (500−700 GHz RF range with 100−140 GHz LO frequency range) without any tuners. This feature makes it very useful in test facilities where frequencies are often changed. Operation can be tuned by changing the LO power level (no biasing). Furthermore, a separate tuning mechanism can be used for optimising LO matching if considered necessary.

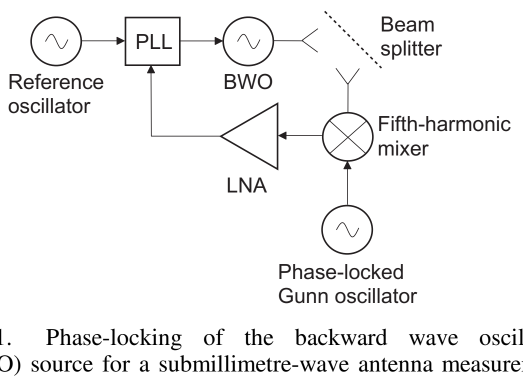

Fig. 1. Phase-locking of the backward wave oscillator (BWO) source for a submillimetre-wave antenna measurement system.

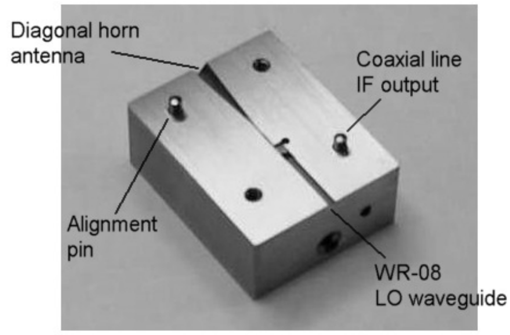

Fig. 2. Fifth-harmonic waveguide mixer block.

II. Mixer Design

A. Mixer Block

Fig. 2 shows one half of the fabricated mixer block with alignment pins and holes for fastening screws. The block is fabricated by using the split-block techniques [2]. It consists of two, almost similar, gold-plated brass block halves. The overall size of the mixer is 20 mm × 25 mm × 20 mm (width, length, and height, respectively). The mixer has an integrated diagonal horn antenna [3], [4] for the RF input (500−700 GHz). Due to a novel transition structure [5] used in the LO waveguide, the RF and LO signals can be fed in line. The LO input (100−140 GHz) applies a WR-08 waveguide (2.03 mm wide, 1.02 mm high) with a standard flange connection. An InP Gunn oscillator is used as the LO source. Fig. 2 also shows the coaxial line output (or its the outer conductor) for the down-converted intermediate frequency (IF) signal. For the easy usage in the antenna measurement system the mixer does not comprise any tuners.

B. Diagonal horn antenna

The diagonal horn antenna is designed to have a length of 11.8 mm and length of the aperture side of 1.5 mm. With these dimensions, the directivity is > 20 dB and 3 dB beamwidth is close to 18°. The diagonal horn antenna is integrated to a 340-μm-wide and 200-μm-high waveguide. Fig. 3 shows a calculated co-polarised power density pattern at 650 GHz. Table I presents calculated and measured values for different planes (*D*-plane is parallel to the aperture side) at 650 GHz. The power density patterns have been measured at *E*- and *H*-planes at 650 GHz. Fig. 4 shows measured and calculated patterns. The measured results are very congruent with

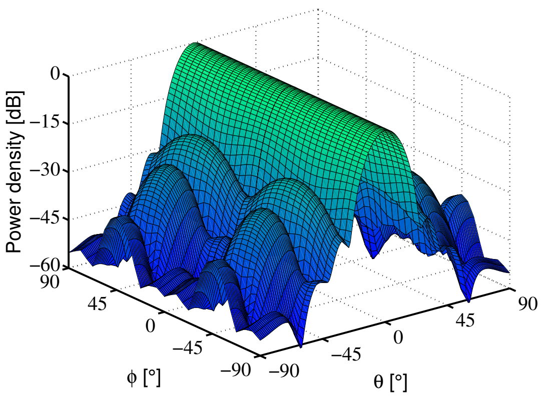

Fig. 3. Calculated co-polarised pattern of the diagonal horn antenna at 650 GHz.

TABLE I
CALCULATED AND MEASURED VALUES OF THE DIAGONAL HORN ANTENNA AT 650 GHZ

	Calculated	Measured
Directivity	22 dB	22 dB
3 dB beamwidth E/H/D-planes	17.9°/17.9°/17.7°	17.8°/17.0°/-
Side lobe level E/H/D-planes	−31 dB/−31 dB/ −19.2 dB	−30 dB/−29.4dB/ -
Cross polarization	−15.7 dB max.	-

the simulated ones. In the measurements, a transmitter antenna is rotated respect to the diagonal horn antenna to simplify the measurement assembly (Fig. 5). The fifth-harmonic mixer works as the receiver front-end. The transmitter comprises a Gunn oscillator and multiplier.

C. Mixer Circuits

Mixer circuit designs are based on the use of two single Schottky diode chips as mixing elements. The mixer applies SC1T5-S20 planar single-anode Schottky diodes (Virginia Diodes, Inc.) in a balanced-type configuration. For the RF signal the diodes are in series whereas for the LO and IF signal in parallel. This configuration is appropriate for fifth-harmonic mixing since mixing products due to even harmonics of the LO are eliminated (if the diodes are identical). These diodes have already been applied successfully in submillimetre-wave mixers, e.g., [6].

The mixer comprises two circuits made on a 40-µm-thick quartz substrate. Fig. 6 gives an overall view on the mixer circuitry. The flip-chip soldered diodes lie side by side in the middle of the smaller circuit (260 µm × 2000 µm × 40 µm). The diode placing is similar to that in balanced mixers. The RF signal coming through the diagonal horn antenna and a short input waveguide section is coupled to the diodes with a waveguide-to-fin-line transition and short fin-line. The input waveguide is 340 µm wide and 200 µm high. The width is 340 µm in order to increase the waveguide cut-off frequency close to 440 GHz and, thus, to present a reactive termination (toward waveguide) for the third harmonic of the LO

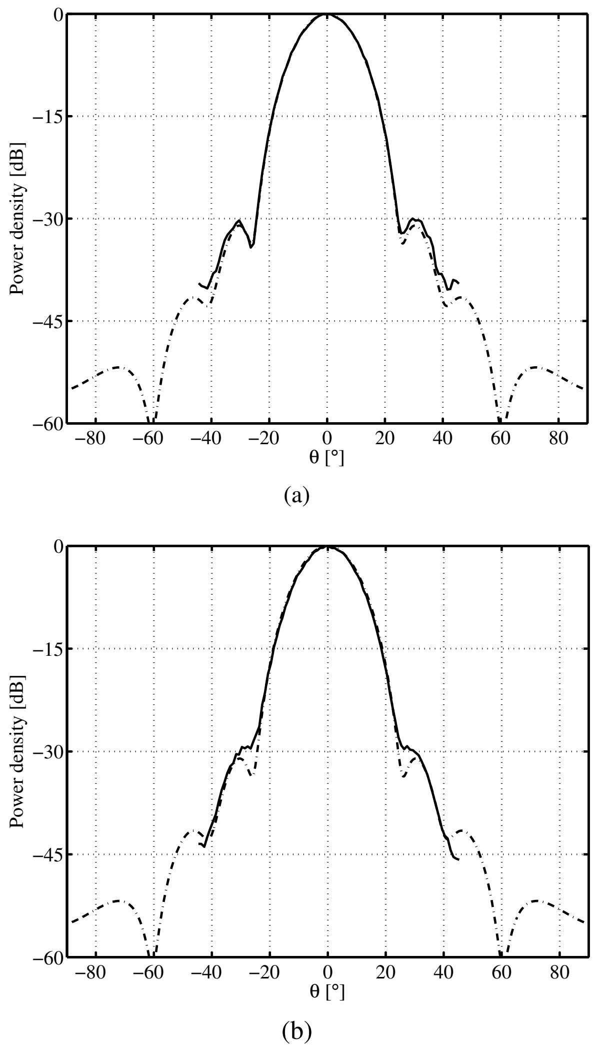

Fig. 4. (a) *E*-plane and (b) *H*-plane power density pattern of the integrated diagonal horn antenna at 650 GHz. Solid line is for the measured and dash dot line for the simulated results.

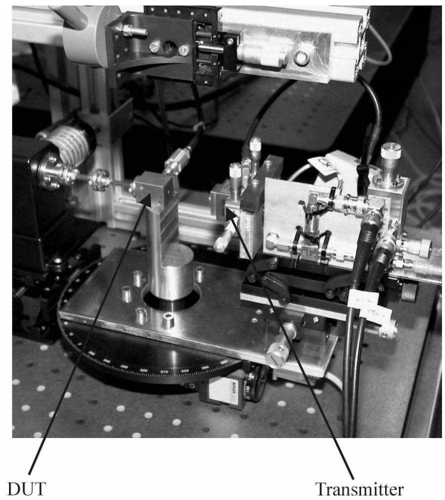

Fig. 5. Antenna measurement set-up.

signal. In addition to the fin-lines and diode mount, this circuit includes a microstrip line bandstop filter to pass only the LO and IF signals and to show a reactive termination for the RF signal and the third harmonic of the LO signal. The RF waveguide extends to the

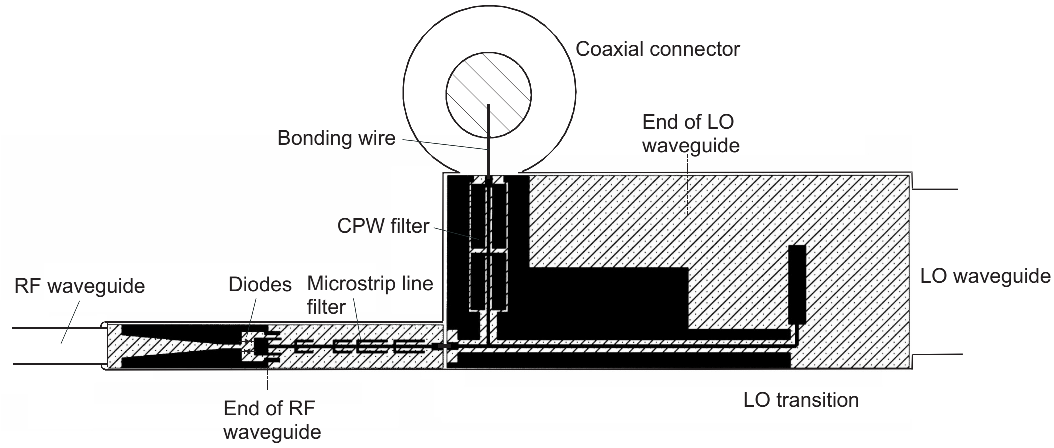

Fig. 6. Fifth-harmonic mixer circuitry comprising two 40-µm-thick quartz substrates.

beginning of the microstrip line section. The other end of the microstrip line is bonded with a gold wire (diameter of 17.5 µm) to the end of a coplanar waveguide (CPW) of the larger circuit. This circuit has a CPW LO bandstop filter for the IF output. The end of the filter is bonded to the end of the inner conductor of the coaxial connector. The filter provides an open termination for the LO signal at the CPW T-junction. The circuit also includes a novel CPW-to-waveguide transition [5] for the LO input. The transition uses a rectangular probe for coupling the TE_{10} waveguide mode. The microstrip line section only includes grounding on the backside of the quartz substrate.

The mixer circuits are designed using a finite-element based electromagnetic structure simulator and circuit simulator (Agilent HFSS and ADS, respectively). The waveguide parts, quartz circuits, and the transitions are designed and optimised with the structure simulator. The circuit simulator is used to simulate conversion efficiency and desirable load impedances of the diodes mounted in the balanced-type configuration with the harmonic balance analysis. In the analysis, the diodes are modelled using the equivalent circuit and parameters presented in [6]. For wide-band operation, the mixer circuits are not designed to give an optimum performance at a certain frequency by reactive matching of the diodes. But instead they are designed to provide purely resistive impedances. These impedances are chosen with the harmonic balance analysis to give a small conversion loss from 500−700 GHz.

D. Mixer Performance

Thus far, conversion loss measurements have been carried out for the fifth-harmonic mixer at 650 GHz. A conversion loss of around 27 dB has been obtained using an InP Gunn oscillator as the LO source with a power level of 10 dBm at about 130 GHz. Based on the combined electromagnetic structure and circuit simulations, a conversion loss of around 20 dB is estimated at 650 GHz. The measured result, although higher than the theoretical one, is acceptable for a fifth-harmonic mixer designed for a wide-band operation without any impedance tuners or IF matching circuit.

III. CONCLUSION

We have designed and constructed a wide-band general-purpose fifth-harmonic waveguide mixer for 500−700 GHz. Two single-anode planar Schottky diode chips work as mixing elements pumped by an LO Gunn oscillator at 100−140 GHz. The LO transition applied in the mixer is based on a novel coplanar waveguide-to-rectangular waveguide transition. The harmonic mixer has been successfully used in antenna measurement instrumentation at 650 GHz.

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REFERENCES

[1] J. Säily, J. Ala-Laurinaho, J. Häkli, T. Koskinen, A. Lönnqvist, J. Tuovinen, and A. V. Räisänen, "Measuring satellite antennas with a compact hologram test range," *IEEE Aerospace and Electronic Systems Magazine*, vol. 17, no. 5, pp. 13−19, May 2002.

[2] A.V. Räisänen, D. Choudhury, R.J. Dengler, J.E. Oswald, and P.H. Siegel, "A novel split-waveguide mount design for millimeter- and submillimeter-wave frequency multipliers and harmonic mixers," *IEEE Microwave and Guided Wave Letters*, vol. 3, no. 10, pp. 369−371, Oct. 1993.

[3] A. W. Lowe, "The diagonal horn antenna," *Microwave Journal*, pp. 117−122, Mar. 1962.

[4] L. F. Johansson and N. D. Whyborn, "The diagonal horn antenna as a submillimeter wave antenna," *IEEE Trans. Microwave Theory Tech.*, vol. 40, no. 5, pp. 795−800, May 1992.

[5] V. S. Möttönen and A. V. Räisänen, "Novel wideband coplanar waveguide-to-rectangular waveguide transition," *IEEE Microwave Theory and Techniques*, to be published, vol. 52, no. 8, Aug. 2004.

[6] J. L. Hesler, "Planar Schottky diodes in submillimeter wavelength waveguide receivers," *Dissertation for the degree of Doctor of Philosophy in Electrical Engineering*, University of Virginia, Jan. 1996, 173 p.