AN ANTENNA ARRAY FOR QUASI-OPTICAL FREQUENCY MULTIPLIER APPLICATIONS

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ABSTRACT

Quasi-optical frequency multipliers require antennas providing impedance matching at two frequencies simultaneously. In our case, we use the same antenna for the two frequencies, as a receiving antenna at the fundamental frequency and as a transmitting one at the first harmonic. This paper presents a design approach for planar antennas, which are primarily dedicated to frequency multiplier applications. In the quasi-optical frequency doubler scheme indicated in fig. 1, each of the two slot dipole antennas has to provide impedance matching for the Schottky diode at the fundamental frequency as well as at the output (first) harmonic (Ref. 1). Apart from the correct choice of the antenna dimensions, the optimal values of the impedance can be obtained by varying the thickness of the substrate. The array of two antennas has also to ensure a good gaussian coupling to the input and output gaussian transmission line. First measurement results are also reported on.

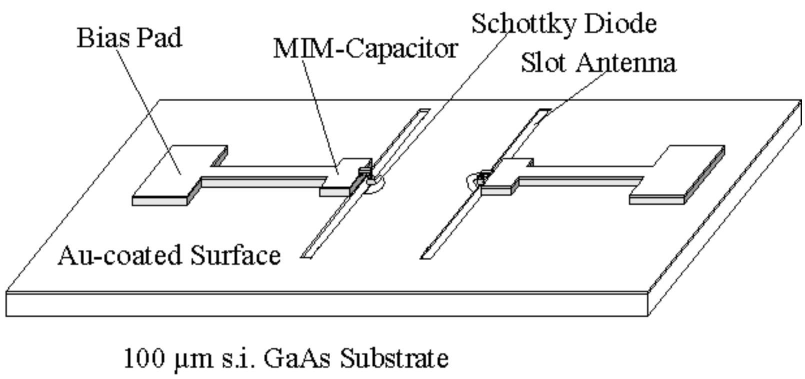

Fig. 1 *Schematic of the basic quasi-optical 300 GHz frequency doubler chip*

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INTRODUCTION

Antennas that readily provide the necessary matching impedance and radiation pattern could significantly facilitate the design of the monolithic integrated quasi-optical frequency multipliers. Additionally, by eliminating the matching circuit between the diode and the antenna, the losses will reduced effectively. The primitive cell of a large size array consists of two slot antennas, which can provide a similar radiation pattern in the E- and H-plane as well. Though this primitive cell will not provide sufficient gaussian coupling efficiency for submillimetre-wave applications, the large size array can easily enhance it considerably (Ref. 2). Since this antenna concept is also valid for quasi-optical subharmonic mixer and imaging arrays applications, this proof-of-the-principle study has been conducted at 18 GHz and 300 GHz (Ref. 3).

In this scheme, the substrate is used as an effective design parameter to primarily provide the necessary matching impedances at the frequencies of interest. Usually the substrate is regarded to as a parasitic element that limits the RF performance of MMIC circuits. While the elementary monolithic integrated multiplier circuit shown in figure 1 will not cater for the required gaussian beam behaviour for low-loss operation, it presents an elementary block for a multielement array with improved gaussian behaviour.

Besides the impact of the permittivity and loss tangent on the impedance and radiation pattern, the substrate mode formation must also be understood and accounted for. Substrate mode propagation translates into direct losses of the incident as well as of the output power. Yet a great deal of research is due in order to account for the substrate mode formation and eliminating them.

The fabrication and measurement of a scaled model of the two-element antenna array is aimed at verifying the input impedance and the bi-directional radiation pattern at 9 GHz and 18 GHz. The bi-directional radiation property renders this planar antenna concept attractive for applications, in which the local oscillator power and received signal are directly fed to the chip without a diplexer. This leads to a further miniaturisation of the systems. The fabrication technique is briefly described, and measurement results are also discussed.

INPUT IMPEDANCE AND RADIATION EFFICIENCY

The input impedance of the antenna is key for an efficient performance of quasi-optical active devices. The condition for maximum power transfer between the antenna and active device requires that the input impedance be the complex conjugate to the impedance of the active device. The substrate thickness can be used as an effective parameter for controlling the frequency response of the antenna (fig. ?). For this purpose, the required matching impedances for typical Schottky diodes were assumed as follows:

$$Z_{in}(f_0) = (20 + j100)\Omega,$$
$$Z_{in}(2f_0) = (20 + j50)\Omega. \qquad (1)$$

The figure shows that the impedance at the fundamental pump frequency and first harmonic can nearly be attained, when selecting the optimal substrate thickness. For further optimisation, the diode parameters can also be altered for best matching condition. This implies, that with this scheme the Schottky diode can directly be integrated at the slot antenna feed, no additional matching circuit being required.

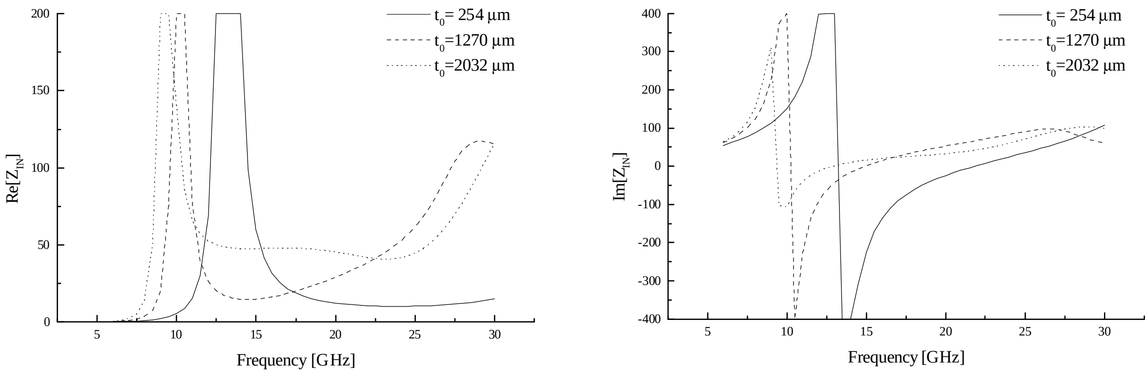

Fig. 2 Real part (left) and imaginary part (right) of the input impedance as a function of frequency for three different substrate thicknesses

The mutual impedance (Ref. 4) as a function of the spacing between two elements in a two-element array is calculated and indicated in fig. ?. For mixer applications, the cross-talk has to be kept at low levels. This can be achieved by choosing the distance between the elements. Using the array theory of antennas, the directivity in the plane perpendicular to the slot antenna can be computed. While the mutual coupling has a minor effect on the self impedance, the radiation pattern has to provide a good gaussian coupling efficiency. This can be obtained by dimensioning the array size for optimal input and output power coupling.

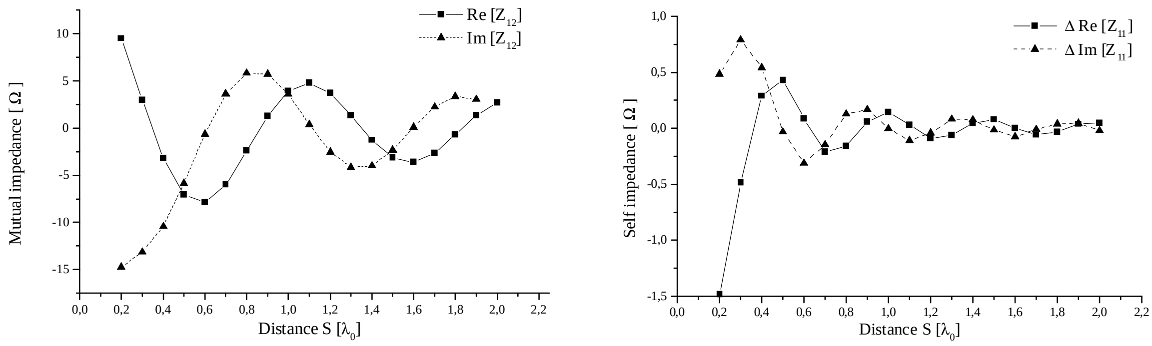

Fig. 3 Mutual impedance (left) and change of self impedance (right) as a function of distance between the elements in the array

The radiation efficiency (Ref. Rutledge) is indispensible indicator for substrate waves. Due to the similarity of the radiation behaviour between the elementary and the presented slot antenna, the radiation efficiency is calculated for elementary antennas with the chosen substrate thickness. The frequencies of operation are indicated on fig. ?. The substrate modes can be reduced by perturbing their propagation (e.g. by patterning grooves well away from the antenna) or by distructive interference (e.g. by optimising the spacing between the elements (Ref. 5)).

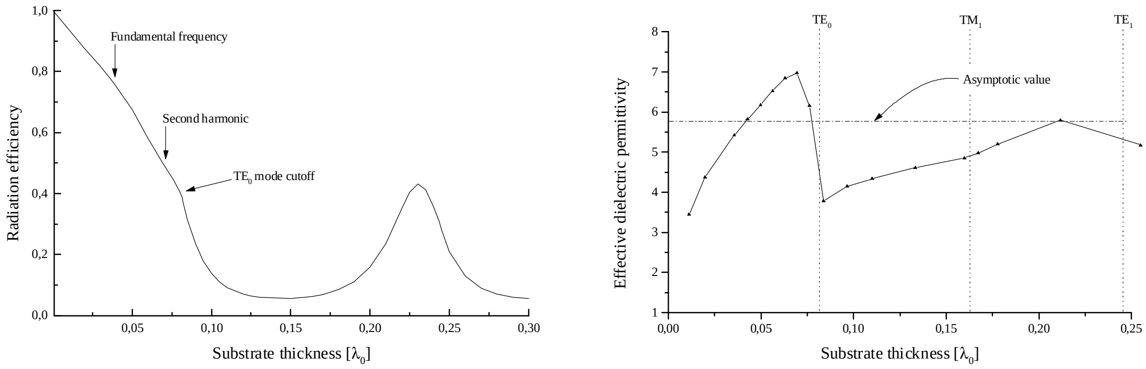

Fig. 4 The radiation efficiency (left) and effective dielectric permittivity (right) of elementary antennas as a function of substrate thickness

FABRICATION AND MEASUREMENT OF THE SCALED MODEL

To verify the above principle, a scaled model of the two-element antenna array was implemented. The circuit was patterned on RT-Duroid substrate with a relative permittivity of ca. 10.5, thickness of 1.27 mm and one sided copper layer of 17.5 µm thickness. The dimensions of the slot antenna were designed to provide an impedance matching for conventional Schottky diodes. The coplanar waveguide feeding the antennas was chosen to have a characteristic impedance of 50 Ω, so that the reference plane of the input impedance can be shifted to the terminals of the slot antenna, when measuring the S-parameters with the network analyser. The width of the inner conductor is 50 µm, and that of the slots of the coplanar waveguide 40 µm. The dimensions of the slot antenna are 5660 x 400 µm². A taper was introduced at the SMA-connector to provide sufficient space for the solder bump, while keeping the characteristic impedance at 50 Ω. The theoretically calculated input self impedances at the antenna terminals at the fundamental and first harmonic are:

$$\begin{aligned} Z_{in}(f_0) &= (23 + j230)\Omega, \\ Z_{in}(2f_0) &= (21 + j43)\Omega. \end{aligned} \tag{1}$$

The circuits were patterned using UV lithography. Using a 1,1 µm thick negative photoresist, the circuit was exposed and developed. The substrate was then Au electroplated to a thickness of ca. 1 µm. After a cleaning the substrate with Acetone, the Au mask was used to selectively spray etch the 17.5 µm copper layer using acidic iron chloride at 55 °C. The underetching in the copper amounted to ca. 12 µm, while the Au mask was still kept even after the etch. The substrate was subsequently glued to a brass frame. The SMA-connectors were mounted and soldered to the coplanar waveguide.

OUTLOOK AND FUTURE APPLICATIONS

It has been shown, that this topology is suited to match nonlinear varactors and varistors without additional matching networks. In particular, for quasi-optical circuits and systems this translates into significant increase of reliability and reduction of complexity. In the following two corner applications for the above mentioned antennas are proposed.

Fig. 3 indicates the measurement setup of a quasi-optical frequency multiplier (Ref. 3). The pump power is provided by the horn antenna attached to the BWO. The gaussian beam is focused to the frequency multiplier chip. The input and output filters (Ref. 6) are used to form a standing wave with its peak in the chip plane while slightly changing the input impedance of the slot antenna at the respective harmonic (Ref. 7). The output power is collected by a horn antenna, which is attached to a mixer and a spectrum analyser.

Figure 4 depicts a scheme for a compact quasi-optical radiometer setup. Whereas the pump power is fed to one side of the chip, the received signal is incident to the other side. The IF signal is filtered and guided on the chip surface for external signal processing. The chip, filters and LO source can easily be sealed in a casing as shown in the figure.

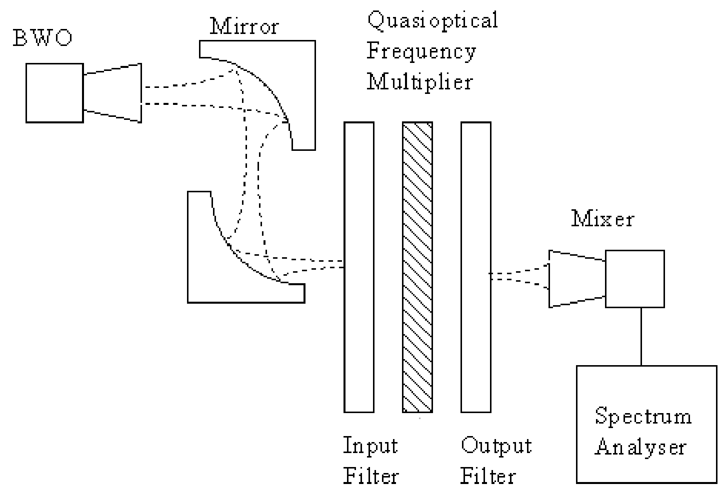

Fig. 5 Measurement setup of a monolithic integrated quasi-optical frequency multiplier chip.

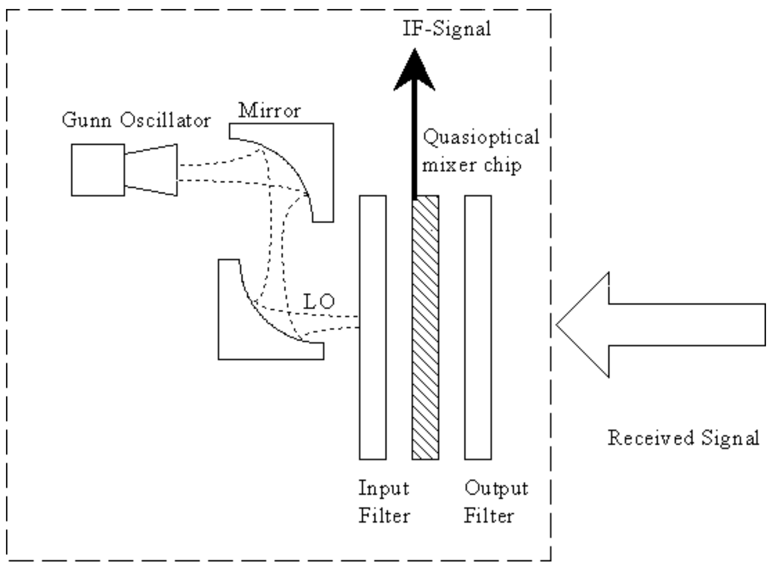

Fig. 6 Schematic Setup of a compact quasi-optical radiometer

CONCLUSION

A novel antenna concept for quasi-optical monolithic integrated multipliers and subharmonic mixers has been proposed. This planar antenna provides the necessary impedance matching to the conventional nonlinear varactors, dispensing with matching circuitry which add to the complexity of the system. The bi-directional property renders this antenna type attractive for specific applications, in which the local oscillator side is separated from the receiving side. The extension of the elementary array into a large size array ensures an improved gaussian coupling to quasi-optical waveguide systems. The parasitic substrate modes, which directly contribute to the system losses, can be reduced either technologically (e.g. grooves in the substrate far from the antenna) or by designing a suitable array geometry (destructive interference of substrate modes).

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