A Taper Filtering Finline at Millimeter Wavelengths for Broadband Harmonic Multiplication

T. Decoopman, X. Mélique, O. Vanbésien, and D. Lippens

***Abstract*—The design of a taper filtering finline aimed at simultaneously mode matching and frequency selecting multifrequency signal is presented. Based on the superimposition of a smoothly corrugated taper and a sinusoïdal-shaped filter, a low insertion loss ($L < 0.1$ dB) at W band [75:110] GHz and a high rejected stop band in the third harmonic range (R band [225:330] GHz) are demonstrated. Both sections are numerically optimized using chain matrix techniques and assessed by means of full three-dimensional electromagnetic simulations.**

***Index Terms*—Filters, finline, harmonic multiplication, millimeter waves, tapers.**

I. Introduction

The development of solid-state non linear electronics at millimeter and submillimeter wavelengths faces numerous challenges to fulfill operators' requirements in terms of delivered powers, conversion efficiencies and bandwidths [1]. At these frequencies, limitations arise not only from the device performances but also from the electromagnetic environment, filtering sections and/or impedance and mode matching networks. In this field, harmonic multiplication shows promises to reach the Terahertz gap with the recent development of heterostructure barrier varactors (HBVs) [2], [3]. Few attempts have been done to develop wideband applications, using nonlinear transmission lines [4]. Using discrete devices, the most popular approach is to use waveguide technology at input/ouput, the Archer multiplier block being the basic element of these applications [5], with microstrip type planar circuit for embedding the non linear device and to filter the various harmonics. Excluding limitations due to the device impedance matching, such a topology exhibits a limited bandwidth. In this paper we have chosen a second route, namely the finline approach [6], with in mind the compactness of the circuit and an expected bandwidth higher than 30% at W band in input. Only the first part of the multiplier design is presented here, i.e., filtering taper. Impedance matching considerations are beyond the scope of this letter. In Section II, the method used to optimize the taper design will be developed whereas Section III will present the results obtained using full-three dimensional electromagnetic simulation. Section IV will contain concluding remarks.

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II. Optimization Method

The goal of the method is to develop a taper in finline technology with the following requirements. The input frequency range is between [75:110] GHz (W band) generated in a WR-10 classical waveguide. A finline is designed within this guide to feed a discrete device embedded in a quasi-WR-3 waveguide for the third harmonic ([225:330] GHz range). Compared to a conventional WR-3 waveguide, the height has to be increased (from 0.432 mm to 0.55 mm) in order to lower the finline cut-off frequency below 75 GHz. Moreover, the finline has to filter this harmonic to avoid spurious propagation in the incident waveguide.

To this aim, we develop a four stage approach illustrated in Fig. 1, combining full-three dimensional electromagnetic simulation and a home-made finline optimizer to accelerate the design convergence. First, scattering matrixes for finline with various gap sizes are computed using Ansoft HFSS for the frequency bands of interest and stored in a database (Fig. 1(a)). By this means, characteristic impedances (Z_c) as well as propagation constants (β) are known for each gap value. Second, by the use of this database, a taper section is designed to optimize the power transfer from the WR-10 waveguide to the finline [Fig. 1(b)]. Third, filtering of the third harmonic band is adressed by the superposition of a sinusoïdal shape to the previously optimized taper which period is one half wavelength calculated at the middle of the band (270 GHz) [Fig. 1(c)]. The aim is to create strong impedance variations—thus strong reflection coefficient variations—which are summed up in phase for the third harmonic band. Moreover, it was shown in a strip technology that such smooth filters allows wide band operation [7]. The first two stages make use of a home-made code based on the method proposed in ref [8] but with two improvements: i) a representation in terms of chain matrixes and ii) the possibility to converge toward multiple objectives in separate frequency bands. In short, when targeted values for the reflection coefficient (ρ) are defined for all frequencies of interest, the calculation uses a vectorial representation of ρ to locally modulate the taper shape. A frequency sweep is performed to find the frequency where the magnitude difference between the target and the current value of ρ is maximum. At this frequency, the taper geometry at each mesh point is corrected using a convergence criterion involving the phase difference between the target and the local phase value of ρ. Since it can be shown that at first order, ρ is related to the variation of Z_c, and thus to a finline gap value, the new gap can be deduced. Using the new shape, a frequency sweep is performed and the procedure is repeated until convergence is obtained.

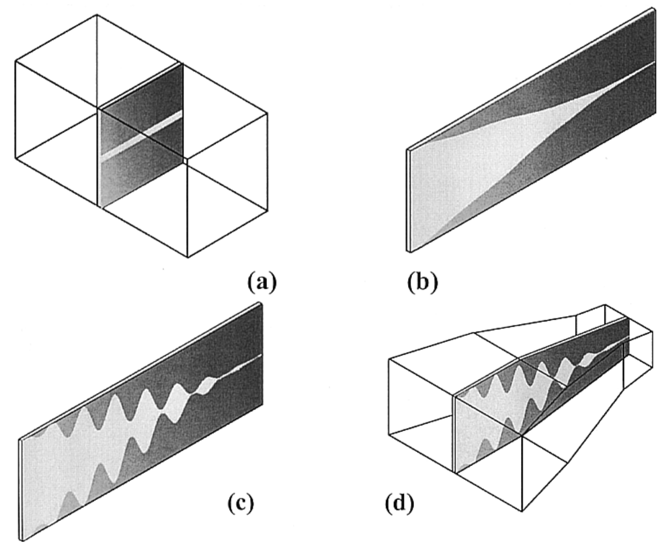

Fig. 1. Illustration of the four optimization stages used for the call design in finline technology.

The fourth step is achieved by full wave multimodal simulations. In fact, our home-made model assumes a monomode regime and higher modes have to be eliminated. Indeed, the WR-10 is multimode above 225 GHz and the third harmonic could propagate on higher modes. To avoid such mode conversion, at least two solutions can be proposed: i) localized insertion of periodically arranged thin metallic wires to avoid the propagation of undesired modes and ii) progressive increase of the guide side dimensions from the quasi-WR-3 to the WR-10 waveguide. As shown in Fig. 1(d), the second solution was preferred, and particular attention was paid to shift the higher order mode cut-off frequencies above 330 GHz.

III. Numerical Results

The first goal of the block design is to optimize the transfer of energy from a WR-10 waveguide to the unilateral finline, inserted in the quasi-WR-3 waveguide. Fig. 2 shows the scattering parameters obtained using the home-made code between 75 and 110 GHz (in dotted lines). Also shown in full lines HFSS results which will be discussed later. High performances are obtained with a reflection coefficient (S_{11}) remaining lower than -30 dB on the whole frequency band whereas as insertion losses (S_{21}) are close to unity ($|S_{21}| < 0.02$ dB). As illustrated in Fig. 3, calculated using HFSS, the tapered finline remains in a passband at much higher frequencies even if S_{21} (> -0.5 dB) and $S_{11}(\sim -20$ dB) parameters are sligthtly degraded.

The second objective is now to filter the third harmonic band using the same finline without highly degrading the previous performances in W band. Usually, low-pass filters in unilateral finline technology are designed using notches periodically spaced along a constant gap section [9]. This could be done within the quasi-WR-3 waveguide behind the taper. Here, to optimize the circuit compactness, we have chosen to superpose filter and taper. Also, rather than notches which lead to a pronounced resonant behavior, detrimental from the wideband viewpoint, a smoother approach based on a sinusoïdal form of the gap has been preferred.

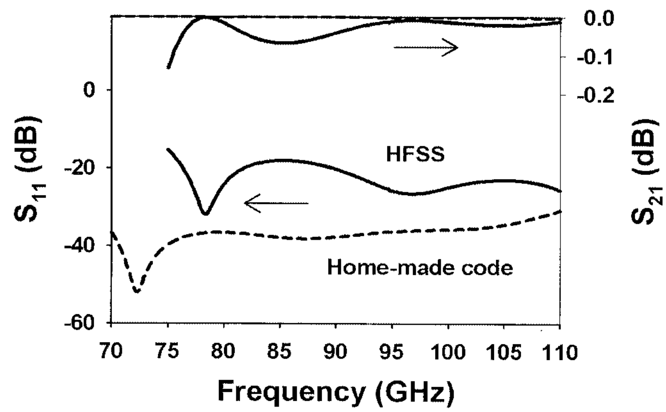

Fig. 2. Scattering parameters of the taper finline transition using the home-made code (dotted lines) and of the taper filtering section with HFSS (full lines) in W band.

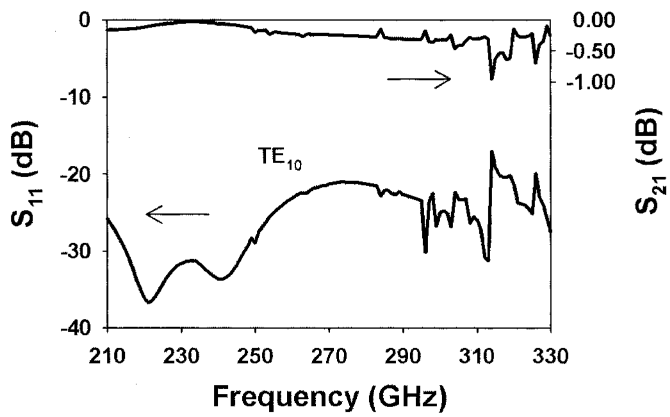

Fig. 3. Scattering parameters of the tapered finline between 225 and 330 GHz.

Fig. 4 illustrates the scattering parameters obtained between 210 and 330 GHz for the sinusoïdal tapered filter. The targeted transmission maximum level has been fixed to -25 dB for the TE_{10} mode and as illustrated the associated S_{11} parameter remains higher than -0.05 dB for the same range. Fig. 5 shows the mapping of the electric field magnitude for two relevant frequencies. As illustrated in Fig. 5(b), filtering occurs over three periods of the sinusoïdal shape with an accumulation of the electric field along its sides. This corresponds to the region where impedance variations are maximum. The impact at lower frequencies, as shown in Fig. 2 in full lines, is a slight degradation of the transfer efficiency with a mean level of S_{11} reaching -20 dB rather than -30 dB for the taper alone. As shown in Fig. 5(a) for $f = 90$ GHz, electromagnetic energy is well directed from the waveguide to the end of the transition, electric field accumulating at the extrema following preferentially the tapering shape.

Fig. 4 gives also the insertion losses obtained for the higher order modes, respectively TE_{20} and TE_{30} using the full wave analysis. Both remain lower than -25 dB between 210 and 330 GHz. To obtain these performances, a careful design of both heigth and width of the waveguide transition between the quasi-WR-3 to the WR-10 has been performed, as shown schematically in Fig. 1(d). First, the quasi-WR-3 width has been kept constant over 0.6 mm till tapering performances begin to deteriorate. Then, a linear shape is used to match WR-10

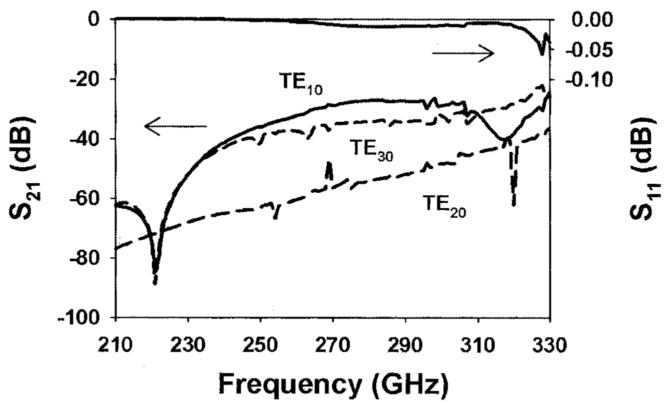

Fig. 4. S_{11} and S_{21} parameters between 210 and 330 GHz for the global taper-filter finline structure. The higher order modes are plotted for S_{21} to show the filtering efficiency.

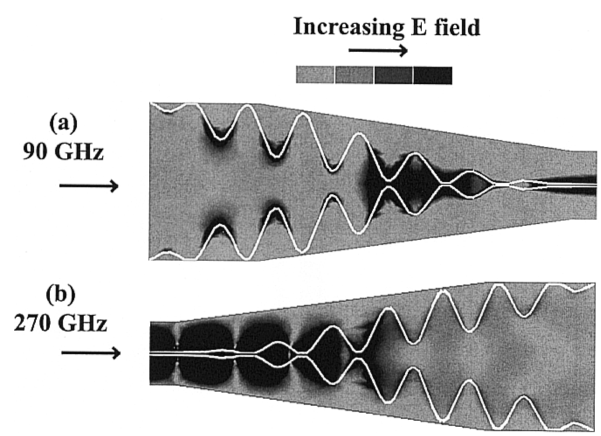

Fig. 5. Electric field magnitude plots at 90 GHz (a) and 270 GHz (b) along the finline transition.

width. Second, the height profile is fixed by the sinusoidal extension of the finline gap. The latter is fundamental for the filter rejection. As a consequence, the WR-10 height (1.27 mm) is reached after 2.5 mm and then kept constant up to the end of the transition over the remaining 0.9 mm.

As a final remark, let us mention that the total length of the designed transition is equal to 3.4 mm which corresponds roughly to λ at the middle of W band. This fulfills the requirement of compactness needed for such applications, with the associated benefit of loss reduction of major concern at mm and sub-mm frequencies.

IV. Conclusion

In summary, the design of a compact and broadband filtering taper in finline technology is presented. The structure combines mode matching (insertion losses lower than 0.1 dB) and smooth filtering (rejection higher than 25 dB) operating simultaneously in W and R bands, corresponding to the third harmonic band.

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