DESIGNING COMMERCIALLY VIABLE MM-WAVE MODULES

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ABSTRACT

Millimeter-wave module manufacturing has become a commercial reality but many challenges related to cost still remain. A practical integration methodology that uses a novel wide-band microstrip-to-rectangular waveguide transition at 77GHz is presented. EM based tolerance analysis shows that deleterious resonance can cause significant signal degradation. Accurate EM simulations and re-sampling techniques are useful for improved design and cost reduction.

INTRODUCTION

In the past few years, considerable resources have been devoted towards commercial manufacturing of mm-wave modules. The production of LMDS CPE [1] unit at 26-29 GHz has shown that high volume, 2000 units/week/line, is feasible. Recently a 77 GHz pulsed-Doppler Radar module was demonstrated in a short period of less than two year and was a resounding first pass success [2]. These projects have highlighted – and solved – some of the problems in mm-wave commercial manufacturing.

Commercial manufacturing of mm-wave modules requires reduced cost and ease of manufacturing. Since the wavelength at high frequency is small, tolerance and variations play a major role. In addition, the existence of higher modes complicates simulation and design. Moreover, integration methodology is a major issue for high-speed automated pick-and-place processes. As a result of these pressures, special design considerations are required.

This paper considers the approach required for commercial mm-wave module. A novel transition for 77GHz that considerably simplifies manufacturing is introduced. Impact of tolerance on a simple band-pass filter is used to show the type of EM modeling required for commercial mm-wave components.

COMMERCIAL MILLIMETER-WAVE MODULE

Overall module cost is the primary consideration for the mm-wave circuit design and the make-up of the circuit blocks for LMDS and automotive applications [1,2]. The current GaAs processing is still at 4 inch and the yields are still orders of magnitude lower than that of Silicon. In addition, in mm-wave region tolerance and modeling accuracy directly effects yield thus impacting cost. Projection of cost estimates of the mm-wave chips is difficult to make because of the lack of reliable data. Figure 1 presents an estimate of a GaAs mm-wave chip versus size based on an expected per wafer cost of $2K for a 100-mm wafer, without testing. While the exact

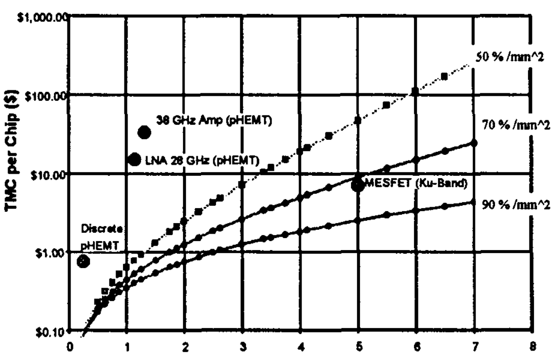

Figure 1. Expected GaAs Chip cost versus area for 50%, 70% and 90% yield per mm^2.

numbers would depend on the foundry economics, it is safe to assume that completely integrated solutions based on one or two chip

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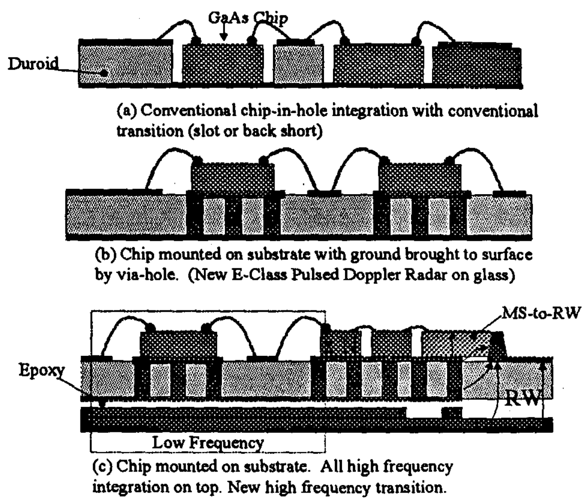

Figure 2. Three methods for integrating mm-modules.

using GaAs are somewhat unrealistic. Even with optimistic assumptions of the chip size (~ two chips with total area of 10-12 mm^2) the price remains exorbitant and with a large uncertainty; therefore, a one or two chip solution is non-commercial because of the yield considerations and the price risks.

The manufacturing costs of the RF modules for LMDS and automotive radar have to be less than a hundred dollars. Therefore, smaller chips (< 3 mm^2) will need to be integrated on a cheaper medium. Figure 2, shows three possible methodology of including the chips

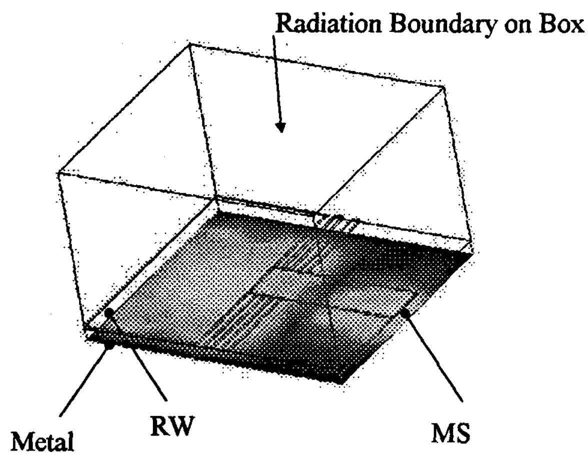

Figure 3. A new method of converting microstrip mode to rectangular mode.

on an integrating substrate. The first method is difficult to manufacture because of the inclusion of the GaAs chip inside a hole. However, this is the method currently used for many applications as it allows shorter bond lengths although it is very labor intensive. The second method has a frequency limitation due to via-hole and bonding. In soft-substrate previous work has shown that highest frequency of operation is around 25 GHz, while in Glass 90 GHz has been found to be practical [2,3].

Finally, the third method, introduced

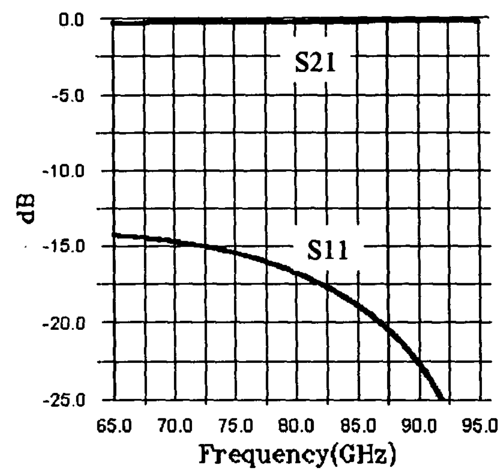

Figure 4. HP HFSS simulated performance of the MS-to-RW. Simulated radiation loss is less than 0.25 dB.

here, allows for high operation of frequency as all the bond wire transitions from integration substrate to chip mounted on substrate are done at lower frequencies. The high frequency interconnects are between chips mounted on top and can be very low in inductance and easy to manufacture. However, it requires a new microstrip to rectangular waveguide transducer.

TRANSITION FOR MM-WAVE MODULES

Figure 3 shows a novel microstrip to rectangular wave guide transducer [2,5], and Figure 4 presents a simulate performance on Duroid. Once transformed to rectangular mode the energy can be transferred to a rectangular waveguide in the base metal or beneath the

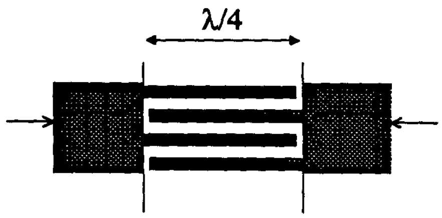

Figure 5. A commonly used band-pass filter at 77 GHz

Duroid substrate. This transition is practical for 50 GHz and higher applications. The working of this transition can be explained by considering the waveguide to be made up of a parallel plate waveguide (PPW) with ¼ wavelength grounded strips from the edge to ground. In Duroid, PPW with 50-ohm VI-impedance is about 600um and the quarter wavelength about 700 um at 80 GHz giving a total waveguide dimension of about 2000um. This waveguide transition can be bent [2] or transferred to another layer as shown in Figure 4, and the simulated radiation loss is 0.2 dB with 13dB return loss from 50-90GHz.

For lower range of operation at 28-32GHz, a DC blocked transition usable for mm-wave application using coaxial and matched inductance to microstrip is feasible [5]. The simulation and design of this transition will be explained in more detail in the conference. These transitions are critical for inexpensive packaging technology such as powdered metal packages [2]

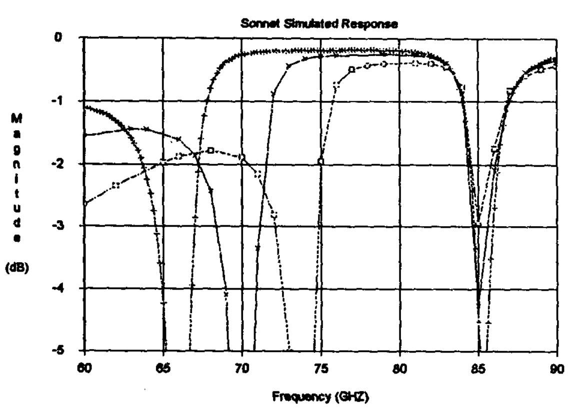

Figure 6. Simulated frequency response of the filter.

and header packages [1].

MM-WAVE PASSIVE COMPONENTS

In addition to the integration issues, tolerance also plays a major role in the choice and design method. Moding can increase the sensitivity of the circuit. Moreover, there is a need to continuously reduce circuit size. Figure 5 shows a simple bandpass filter implemented in Duroid. This filter or its derivative form in figure 8 has been used in many applications. However, these filters can cause considerable signal loss [8].

Figure 6 shows the EM simulated filter response under variance of +/- 25um per edge.

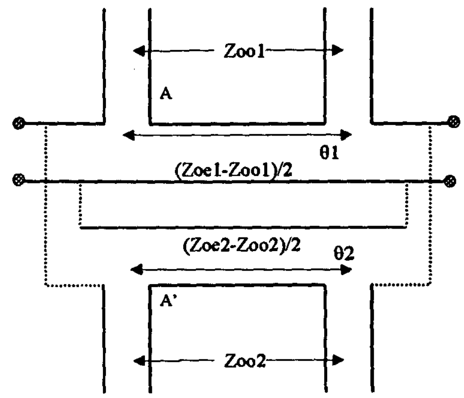

Figure 7. An equivalent circuit to explain the transmission nulls in figure 6.

Considerable variation in pass-band loss occurs and, at extremes, (when substrate variations are also accounted) an extra 2 dB loss occurs due to deleterious pass-band nulls. The high impedance point can be explained by considering the equivalent circuit in Figure 7 derived from [8] generalized to multiple parallel lines. The stubs A and A' are parallel resonant creating an open in the pass band at particular frequencies. Figure 8 shows a filter that has intrinsic symmetry [2,4], and theoretically no parallel resonance. Unfortunately, in actual use, the structure looses symmetry due to process variations and, often the current on the feeding line is non-symmetric due to bend etc causing in-band resonance [2,4].

A filter with just two fingers and an impedance transformation avoids the parallel

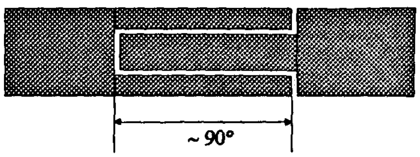

Figure 8. Another structure that can cause problems

resonance. The net result of the modification is that the filter loss and size increases; however the, filter is more tolerant to process variations.

Since loss and size drives up the cost of module, tighter tolerance to less than 10-um is preferred. In addition, semi-lumped filters show tremendous promise for reduced size with better performance. These will be explained in detail.

DESIGN AND ANALYSIS TECHNIQUES

The design of commercial mm-modules has many challenges related to multi-moding, tolerance issue, simulation accuracy and yield centering. EM simulators are required to accurately simulate the moding and high frequency effects. Simple bends in Duroid can give as much as 0.25 dB loss. In addition, box resonance in closed box simulation can influence the solutions, confusing the simulated result. The FEM method applied to microstrip can provide errors up to about –35dB due to slow convergence. In spite of these problems proper use of EM simulator can greatly improve design quality.

However, EM simulations of the passives have to be combined with non-linear simulations to conduct system level simulation for successful working of the mm-wave module. This puts added stress on EM simulators and parametric models have to be used to simulate higher than 4th order. For example, the LMDS module was simulated using a combination of EM simulator, harmonic balance, circuit elements and behavioral models. This multi-dimensional modeling was required for accurately predicting the inter-modulation distortion of the transition-LNA-filter-mixer-transition-IFA chain. Once good models are achieved, considerable improvement in yields are possible by simple techniques such as bonding length control in the LNA-filter assemblies, diode placement and proper choice of bias capacitors in IFA. Finally, since measurements have a statistical nature, re-sampling techniques are required to improve decision process once the module is in production. An example will be demonstrated at the conference.

CONCLUSIONS

Problems and some of the solutions of mm-wave manufacturing have been presented. While considerable strides have been taken in the manufacturing and design of mm-wave modules, significant development in design methodology and circuit compaction is required before mm-wave modules can become a commercial reality.

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