Increasing Stop-band in Gap Waveguides using Inverted Pyramid-Shaped Nails for Slot Array Application Above 60GHz

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Abstract— **This paper presents a proposal for a slot array antenna for frequencies above 60 GHz. Also, The array is using the new air gap waveguide as a feeding structure. Here we present a new structure for the parallel plate stop-band based on replacing the uniform cross sectional nails with inverted pyramidal shaped pins. This new type of pin is more suitable for micromachining and manufacturing of gap waveguides above 60 GHz. The wider parallel-plate bandwidth achieved with this new type of pins makes it suitable for integration of very wideband active MMIC circuit with gap waveguide without package resonance problem. Once the RF circuitry is integrated with gap waveguide, the slot arrays can be easily built by having slots on the top metal wall of the gap waveguide thus enabling low cost integrated antenna solution at frequencies above 60GHz.**

I. INTRODUCTION

The need for higher data rates and greater bandwidth has resulted in large interest and research in millimeter-wave systems. But designing millimeter wave antennas and their integration with the high frequency planer electronic circuits has always been a challenge for the antenna researchers. Researchers are interested to integrate and package antennas with as many components and electronic circuits as possible so as to achieve higher performance and cost effective solutions for mass production. The most established way of integrating an antenna is to use a printed antenna [1-4]. In this approach, the antenna can be part of the main PCB substrate or can be a suspended antenna bonded with the feeding line as is shown in Fig.1.

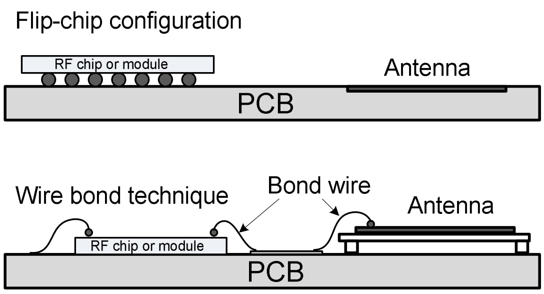

Fig.1 Integrated printed antenna

These types of printed antennas can be very compact and low cost single element antenna solution. But these types of single element antennas suffer usually from high dielectric losses at millimetre wave frequencies. The antenna input matching can be worse due to the length and inductive behaviour of bond wires. Also, the efficiency of these antennas can be quite low due to the use of substrates with high dielectric constant such as alumina or silicon substrate which are common for mm-wave frequency band. Besides these negative factors, when an array of printed antenna is built for high gain or multiple beam application, the antenna efficiency goes down even more because of increased losses in feeding network. The steps and discontinuities in the feeding network also tend to give spurious radiation resulting in higher side lobe level and higher cross-polar level in antenna patterns.

Planar waveguide-type slot array antennas do not suffer from the above disadvantages, and is therefore an attractive candidate for millimetre wave applications requiring high gain [13-14]. But till now waveguide slot arrays have not been used much in commercial products due to high manufacturing costs of standard rectangular waveguide at high frequency. Apart from the cost of waveguide array itself, the integration of high frequency MMIC with rectangular waveguide is also very challenging at high frequencies [5].

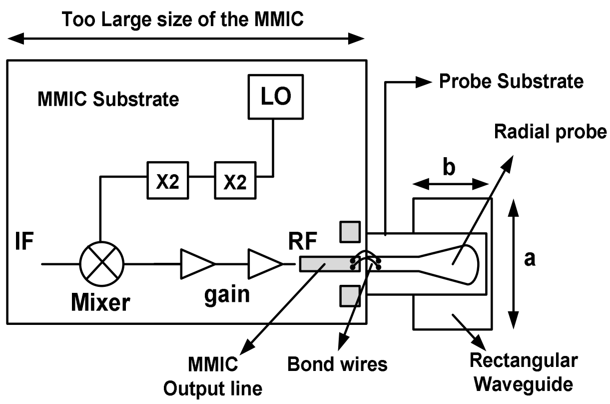

Fig.2 Top view of probe type transition

Present probe type coupling technique between MMIC and rectangular waveguide is shown in Fig. 2. The problem of the existing solution is the need of the separate piece of small sized substrate for the probe to prevent waveguide modes from leaking into the circuit cavity. This requires bond wire interface with considerable inductance at higher frequency. Also, due to the complexity of multifunctional MMIC and the size of the MMIC, the resonance problem occurs very easily when packaged. So, a new packaging solution is really one of the most critical parts in designing integrated antennas at millimetre wave frequencies.

To address these issues mentioned above, recently evolved gap waveguide technology mentioned in [6-9] can be applied very successfully. The recently demonstrated low loss gap waveguide technology is very advantageous in this concern due to the fact that gap waveguide can be designed free of dielectric and thus free from dielectric losses. Detail theoretical study of the dispersion characteristics, theoretical bandwidth study as well as the rapid lateral field decay properties for this metamaterial based waveguide can be found more details in [10-11]. Apart from this, gap waveguide technology has been demonstrated to stop the cavity modes and stop spurious radiation from discontinuity in microstrip line circuits [12]. Moreover, gap waveguide itself is similar to that of a planar technology and can be fabricated or realized by micromachining techniques thus enabling integration of planar high frequency electronic circuits. All the microwave circuit components integrated with gap waveguide will be naturally isolated from each other and will not require additional packaging. In addition, an array antenna based on the gap waveguide can be designed easily by having slots on the top metal plate similar to that mentioned in [17-18]. This is shown in Fig. 3. The feed network needed for an array can also be built easily with the help of ridge gap waveguide concept. The concept of gap waveguide technology with other radiating elements was demonstrated in [15]. Thus the integrated gap waveguide slot array antenna will be a good candidate for high gain application or multiple beam antenna application. The presented work in this paper deals with new packaging solution based on gap waveguide concept for integrated antenna system.

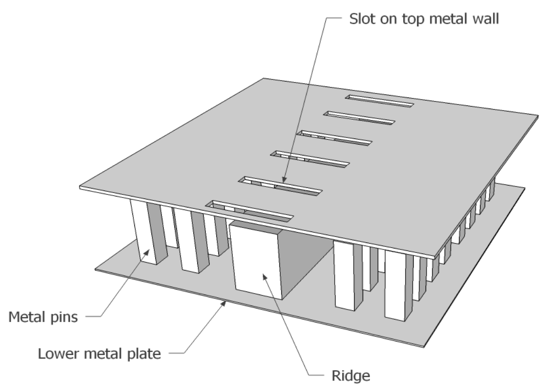

Fig.3 Concept of slot array based on ridge gap waveguide

II. Need for Wideband Packaging Solution for Integrated Antenna

Apart from these antenna performance and integration related issues, there are some additional complex packaging issues to deal with while considering the integrated antenna concept. Often, spurious radiation from discontinuities or interconnections causes substrate-mode propagation and coupling of EM energy among different circuit components. This leads to the shielding problems and oscillation of RF circuits and can destroy the performance of the whole system. These effects are very difficult to model and are usually revealed only during measurements [4] and [16]. Also, cavity resonances show up easily due to relatively large size of the MMIC itself. If GaAs substrate is used for the MMIC, the half wavelength is about 0.5 mm at 80 GHz. So, it is impractical to think of making the MMIC small enough and suppress the cavity modes by shrinking the size of the cavity. Usually, at lower frequency range, ferrite absorbing materials are used to dampen these high Q cavity resonances. But these absorbing materials become less absorptive at millimetre wave frequencies. Also, due to the complexity of the whole MMIC itself and unknown source of resonance, it is difficult to determine a priori the optimum absorber location as well as the placement. Another problem is that - the LO power level is significant and some spurious mixing products can appear in the operating band which can also destroy the performance of the circuit. The new packaging solution based on gap waveguide concept for integrated antenna system is considered as the solution for the above mentioned problems.

In the previous works of gap waveguide, square pins with $\lambda/4$ height were used to realize the required PMC condition. The available parallel plate stop bandwidth achieved with this square pins was about 2:1. Also, it is mentioned in [3-5] that this parallel plate cut-off bandwidth depends significantly on the height of the air gap between the textured bottom plate and the upper smooth metal plate. It is observed that there are manufacturing issues, which complicates the integration problem at high frequency. Especially, the problem is the bond wires used for interconnectivity. These bond wires stick up in different parts of the circuit and restrict the upper metal pin lid to be placed close on top of the bottom layer as is shown in Fig. 4. This reduces the parallel plate stop band for the square pin surface. So, there is a need for studying other types of geometries to increase the parallel plate cut-off bandwidth.

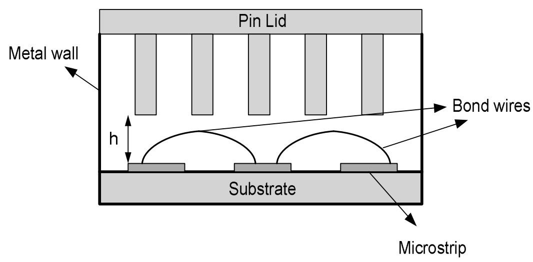

Fig.4 Pin lid with the bond wires in the circuit.

III. Comparison of Parallel Plate Stop-Band Between Square Pin and Inverted Pyramidal Pin

The MMIC to be integrated with gap waveguide slot array antenna is active over a very wide frequency band 30-120 GHz as mentioned in [5]. The first cavity mode due to the (3.5×2.35) mm^2 size of the MMIC was found to be appearing at 67 GHz. Thus resonance free packaging solution needed for the MMIC has to cover a significant frequency range 67 - 120 GHz which is more than 50 % relative bandwidth.

To design a gap waveguide based packaging solution for this MMIC, at first the parallel plate stop band is analysed for regular square pin surface. When studying the unit cell dispersion diagram for the regular square pin the dielectric of the MMIC was considered. Also, the height of the bond wires was taken into consideration. A GaAs substrate with a thickness of the 50 µm was taken into account and the height of bond wires was considered to be 250 µm. Apart from this, 50 µm additional clearance spacing was considered for tolerance purpose. The pin dimension was chosen to be 0.43×0.43 mm^2. The height and the period of pin were chosen to be 0.75 mm and 1 mm, respectively. This is shown in Fig. 5. The dispersion diagram obtained for this unit cell of square pin is also presented in Fig.6.

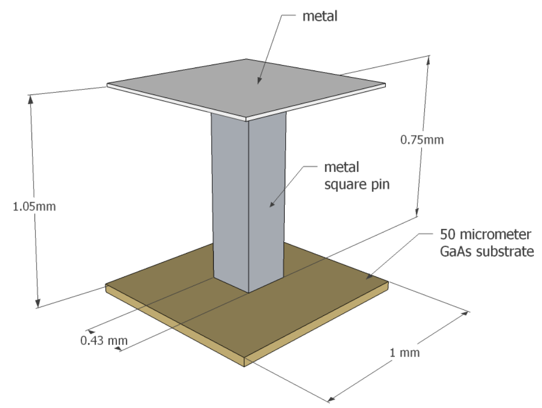

Fig.5 Unit cell for the square pin.

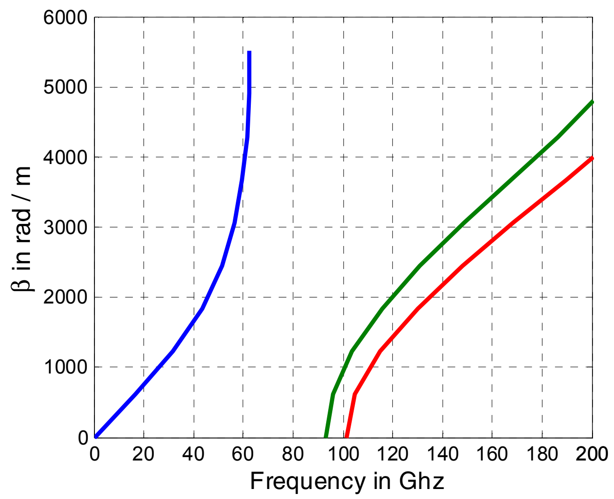

Fig.6 Dispersion diagram for the unit cell square pin

As is seen in Fig. 6, for the above mentioned square pin geometry, the parallel-plate stop-band is obtained between 62-92 GHz. This is not enough to be used for packaging and integrating this MMIC with gap waveguide. For this reason new type of geometry is investigated.

The newly investigated geometry had the inverted pyramidal shape shown in Fig. 7. The overall length for this inverted pyramidal shaped pin is kept also the same as the regular square shaped pin.

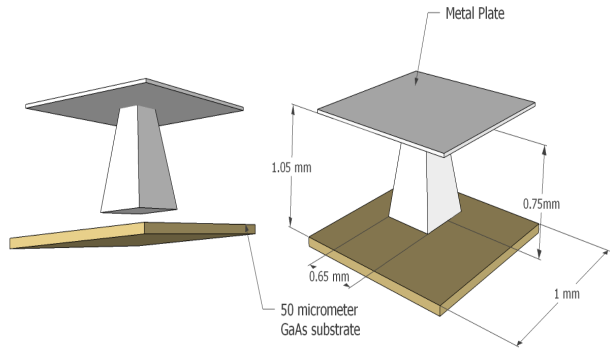

Fig. 7 Unit cell for the inverted pyramidal pin.

The dispersion diagram for this geometry is shown in Fig. 8. As is seen in Fig. 8, this new geometry was able to provide a parallel plate stop band from 59-120 GHz.

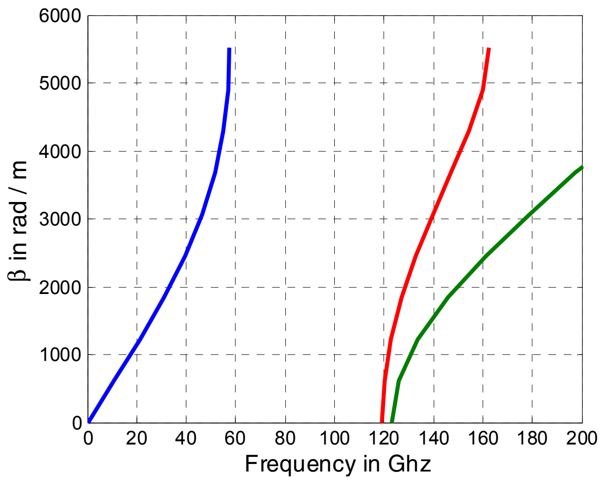

Fig.8 Dispersion diagram for the unit cell inverted pyramidal shaped pin

We now compare the parallel plate cut-off bandwidth for regular square pins and newly proposed inverted pyramidal shape pins first. It is observed that the inverted pyramidal pin shapes give relatively larger parallel plate stop band. In both cases, the dispersion diagrams for a unit cell is obtained taking into account the dielectric and required air gap to place bond wires in the real circuit. The fractional bandwidth of parallel plate stop-band for square pins is 43 %. But in case of the pyramidal shape pins, the fractional bandwidth of stop-band is 66 %. So, this inverted pyramidal shape geometry is more suitable for integrating and packaging of the wideband MMIC with gap waveguide due to its wide stop band. At this point, the scope of the paper is limited to only the band gap study of the newly proposed inverted pyramidal shape pins. The micromachining of this newly proposed shape and integration of the complete MMIC with gap waveguide will be discussed in details in future.

IV. Conclusion

The integrated antenna has been one of the major research topics for millimetre wave frequency bands. In principle, the antenna alone can show good performance but when the MMIC is integrated with the antenna, the performance of the complete system can be destroyed due to the packaging problems such as cavity resonance, spurious radiation coupling to substrate modes etc. So, it is of utmost importance to consider the packaging and integration issue of the RF circuit while designing the integrated antenna. The newly evolved gap waveguide technology is the standalone technology which can be used to build high gain planer slot array antennas as well as able to coup with the problems of integration and packaging of RF circuits. But due to the complexity of the bond wires required for the interconnectivity, the regular square shaped pins were not providing the big enough parallel-plate stop band for wideband RF circuitry packaging. For this reason, a new inverted pyramidal shaped pin was investigated. It was found that, this new shape can provide the required parallel-plate stop band over a very wide frequency range from 60-120 GHz. After this, proposed inverted pyramidal pin can be easily used to obtain the PMC condition required for the gap waveguide packaging of the previously mentioned MMIC and also for ridge gap waveguide for building the feed network and the slot array.

Acknowledgement

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