Gap Waveguide Components for Millimetre-Wave Systems: Couplers, Filters, Antennas, MMIC Packaging.

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1. Introduction

Gap waveguides were first presented in [1] as an alternative guiding technology especially attractive for frequencies over 30 GHz up to THz. At those frequencies, the current technologies show some deficiencies regarding to the performance, integration ability, or product cost. Planar technologies, such as microstrip and coplanar, are often chosen due to their good integration ability and manufacture simplicity, but they suffer from higher losses with increasing frequency as well as from the presence of cavity resonances when encapsulated. Hence, hollow waveguides are usually resorted for low-loss applications, in spite of their difficulty for integration with active components and a high manufacturing cost. The need of new transmission line technologies for mm- and sub mm-wave systems is leading to the apparition of alternative technologies. Substrate Integrated Waveguide (SIW) technology has been widely used for high-frequency applications [2], but it exhibits significant losses at increasing frequencies due to wave propagation in substrate. Gap waveguides, on the contrary, support waves in the air gap between two metal plates. One of the plates is provided with a texture, in the form of a bed of nails, to create a high impedance condition at the surface, which in turn forces a cut-off for the parallel-plate modes [3]. On the same plate, there are metal ridges in between the nails providing a path to the waves so that fields are confined to the air gap between the ridges and the metal plate on top. This propagation path can alternatively be provided by a microstrip line lying on the bed of nails, or by a groove in between the nails. An interesting application using similar technology can be found in [4] where a multi-layered phased array antenna developed in Japan was presented.

On the other hand, RF front ends of cellular radio base stations for point-to-point microwave links often make use of microstrip lines to interconnect different components. But for low-loss passive components the use of waveguides is usually resorted. For instance, for full-duplex systems, the diplexer is a critical component, since it separates the TX and RX channels and connects them to a common antenna port. The diplexer filters are normally constructed with iris filters in waveguides to fulfil the stringent requirements regarding to the low-loss and high roll-off, and they represent a significant product cost. Moreover, these filters contribute to increase the size and complexity of the system, as they must be connected to the electronic modules, which contain active components and MMICs, mounted on a PCB and interconnected with microstrip lines. An additional problem comes out at high frequencies when those circuits are packaged, since metal walls and absorbers are the techniques commonly used. Therefore, new solutions have to be investigated for radio links at mm- and sub mm-wave frequencies. In this paper, the use of gap waveguide technology is proposed as a possible solution. On one hand, gap waveguides have been used to package microstrip circuits without creating cavity resonances [5]. On the other hand, they can be used as transmission lines to realize passive components like filters and couplers [6]. In this way, by making use of these two functionalities, gap waveguides can provide complete integration of all parts of the system. Passive and active circuits can be integrated in the same module; even the antenna can be included. This is actually one of the main advantages of gap waveguide technology, to provide system integration between two parallel-metal plates, which do not require any conducting contact between them. As a result, the system becomes more compact and the manufacturing difficulty and cost are reduced notably.

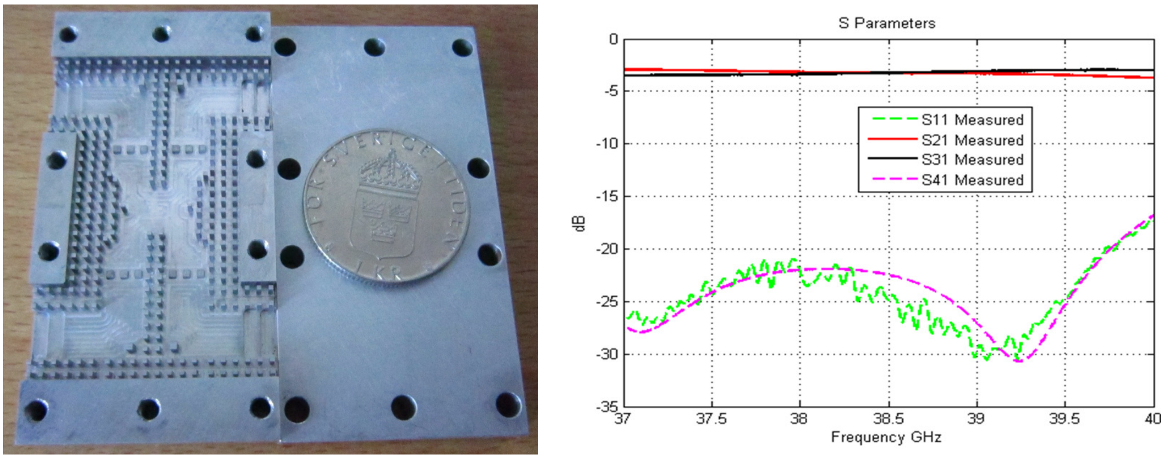
This paper presents the progress made so far on the design of passive components and MMIC packaging demonstrated for RF front ends for microwave links at 38 GHz using gap waveguide technology. Initial designs are made at the microwave band for validation and measurement purposes, and for comparison with existing technology. But it is for millimeter- and sub millimeter-wave applications where gap waveguides represent a promising solution.

2. Couplers

A short-slot hybrid coupler at 38 GHz in groove gap waveguide with the specifications shown in Table 1 was designed on the basis of the techniques used for waveguide couplers. The Riblet short-slot hybrid coupler was constructed by placing two groove gap waveguides side by side and removing a section from the center pins separating both waveguides. The length of this section determines the coupling. Indentations were provided by adding extra pins to the sidewalls of the coupling section in order to match the phase of higher order modes. A pin in the centre of the coupling section with reduced height was in addition used with same purpose. Pucks, pins of reduced height and increased size, were introduced before and after the indentations for a good match at all ports. H-plane 90° bends were used in order to get the required distance to mount standard flanges (WR-28) at the coupler ports. Fig. 1 shows the prototype and measurement results. 4% bandwidth for ± 0.25 dB amplitude imbalance between the two output ports can be seen. A phase difference of ± 2.5°, and return loss and isolation better than 20 dB over the entire band were obtained.

Table 1: Specifications for the 3 dB hybrid coupler

Frequency band	37-40 GHz
Coupling	3 dB
Isolation	20 dB
Return loss	20 dB



(a) (b)

Figure 1: (a) Coupler prototype; (b) Measured S parameters.

3. Filters

A narrow-band band-pass diplex filter for radio links at 38 GHz in gap waveguide technology with the specifications shown in Table 2 was designed. The stringent specifications of these filters regarding to the low loss and high selectivity require a number of resonators with high value of the quality factor (Q). This high Q is provided by waveguides. Groove gap waveguide resonators have been shown to provide values of Q comparable to those provided by rectangular waveguides [7]. Hence, groove gap waveguide resonators were chosen for this design. A general technique for designing coupled-resonator filters was used, which is based on coupling coefficient (K) of intercoupled resonators and the external Q of the input and output resonators. The coupling between adjacent resonators and the coupling from the input/output resonators to the external network (WR-28) is done through ridges, whose dimensions determine the values of the filter parameters (*K* and *Q*). The optimized design and manufactured prototype can be seen in Fig. 2 and Fig. 3a. The band-pass filter is fabricated between two metal plates leaving an air gap between them, allowing airing and cooling. Measurements show a minimum in-band insertion loss of 1 dB and agree quite well with simulations (Fig. 3b).

Table 2: Specifications for the 38 GHz diplex filter

Passband	37.058-37.618 GHz
Stopband	38.318-38.878 GHz
Insertion loss	1.5 dB
Attenuation	70 dB
Return loss	17 dB

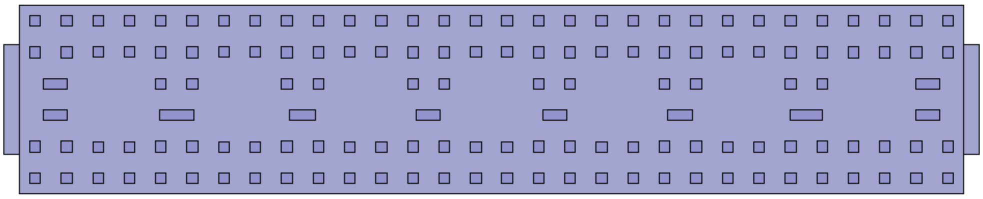


Figure 2: Sketch of the optimized 7th order diplex filter using groove gap waveguide resonators.

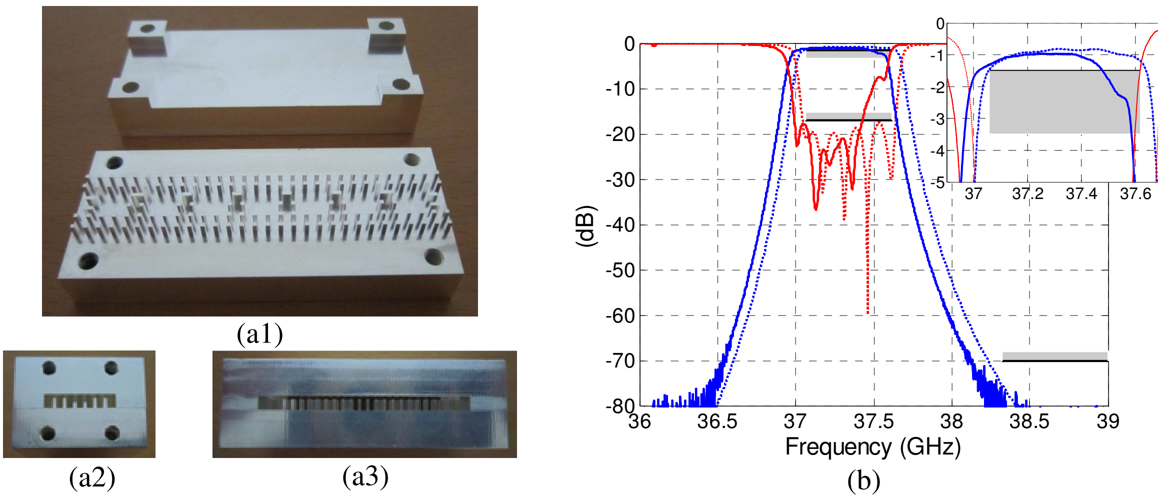
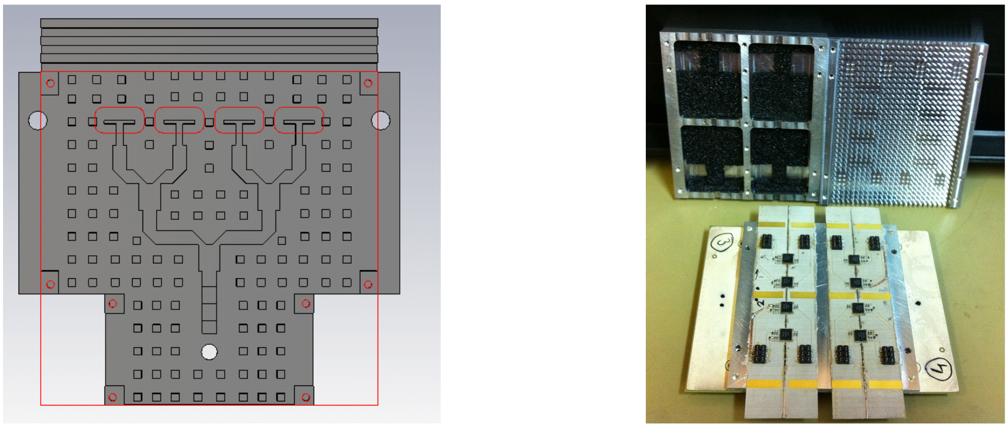


Figure 3: (a) Photos of the silver-plated prototype: (a1) Top and bottom plates (with holes to assemble both parts), (a2) Front view, (a3) Side view (with no sidewalls); (b) Filter responses: measured (solid line) and simulated (dotted line). Specifications are also shown for reference.

4. Antennas and MMIC packaging

New antenna designs in gap waveguide technology are now being developed in order to get complete system integration. High gain and directive antennas are required for radio links. Hence, we are looking into slot arrays and cylindrical reflectors. Gap waveguide distribution networks are used to transmit the power to the radiating elements or to generate linear phase fronts (see Fig. 4a).

Gap waveguide technology was used to package the active microwave circuits of the RF front end for 38 GHz radio link. Validation was done by measuring the isolation between the TX and RX amplifier chains, and the maximum stable gain of a single amplifier chain (see Fig. 4b). Stable gain higher than 60 dB in 6.5 × 7.3 cm^2 was obtained for a chain of 4 amplifiers with maximum gain of around 18 dB each. A TX-RX isolation higher than 80 dB is needed in practice in order to avoid performance degradation due to undesired crosstalk and feedback loops leading to oscillations and system instability. This is fulfilled by the separation of eight rows of pins between TX and RX chains.



(a) (b)

Figure 4: (a) Distribution network in ridge gap waveguide; (b) MMIC packaging using conventional method, metal walls and absorbers (left lid) and using gap waveguides (right lid).

6. Conclusions

Design of passive components (couplers, filters and antennas) and MMIC packaging validation intended for RF front ends for microwave links at 38 GHz using gap waveguide technology have been shown. The use of this technology allows all-in-one integration of receiver, transmitter, and diplexer including the antenna into one mechanical unit. These initial designs and studies have been made at the microwave band for validation and measurement purposes, and for comparison with existing technology. They represent the first step towards the application of gap waveguides to millimeter-wave systems, where gap waveguides could have a large potential.

Acknowledgments

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