and reflects the period of the switching transients at the drain nodes of the NMOS transistors in the ring oscillator. From eqn. 1 the required capacitance is then 3.3pF and the dynamic resistance through the 1000μm2 diode formed by the e+ source/drain implant with a horizontal sheet resistance of 1000μΩ.

References


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0.1THz rectangular waveguide on GaAs semi-insulating substrate

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Indexing terms: Gallium arsenide, Waveguides, Monolithic integrated circuits

The realisation of a millimetre-wave rectangular waveguide fabricated using traditional monolithic technology is presented. The rectangular waveguide has a cutoff frequency of 100GHz and an operating frequency of 105GHz. The measured performance clearly shows that the dominant TE_{01} mode of propagation is supported.

Introduction: Commercial applications that operate at high millimetric frequencies are becoming increasingly popular. One example is automotive radar that may have a simple forward-looking sensor, for autonomous intelligent cruise control applications, or a more sophisticated scanning antenna, for obstacle detection and collision avoidance applications [1]. In Europe, these radars have been allocated an operating frequency of 76.5GHz. Another example of a commercial application is direct-detection radiometric imaging arrays, demonstrated at 94GHz, used for seeing through fog, cloud, smoke and sandstorms [2].

Rectangular waveguide technology is still the most common transmission line medium used at millimetric frequencies. As operating frequencies increase, the manufacturing tolerances associated with the fabrication of these waveguides must decrease. However, using conventional workshop machining, the mass production of rectangular waveguide circuits is not economically viable. As a result, Philips Microwave (UK) developed injection moulded metalised plastic waveguides, for operation at 94GHz [1]. This technology can provide the necessary dimensional tolerances for use up to ~100GHz.

For the mass-production of future subsystems operating at terahertz frequencies, monolithic technology can provide the necessary submicrometre dimensional control. Micromachined circuits consisting of conducting lines and metalised cavities have been demonstrated using a two-wafer arrangement [3]. Also, pyramidal waveguide horns have been etched into the back of wafers, for realising quasi-optical antenna arrays [4].

This Letter presents the design, realisation and measured performance of a 105GHz rectangular waveguide fabricated using conventional GaAs monolithic technology. This technology enables semiconductor devices such as HEMT, Gunn diode, and IMPATT diode sources, and Schottky diode detectors, to be directly integrated within the rectangular waveguides, while the associated circuitry can be located on the same substrate, alongside the waveguide.

Fig. 1 Cross-section of rectangular waveguide

Fig. 2 Noise at amplifier output with and without guard-ring bias

a Without guard-ring bias
b With optimum guard-ring bias

A substrate noise of 17.5mV peak to peak at 875MHz was generated at the output of the amplifier as shown in Fig. 2. When 4.2μA current was applied to the diode formed by the guard-ring, the noise at the output of the amplifier was reduced to 2.5mV, and the primary component at 875MHz decreased by over an order of magnitude. A significant second harmonic at 1.8GHz appears in the noise, since the substrate current waveform does not have half-wave symmetry. Overall, this is almost an order of magnitude improvement in substrate noise reduction in the analogue section assuming a parasitic resistance of 0.19. Another aspect of the results is that the frequency of the remaining noise is doubled. This effect allows for the possibility of regular filtering at higher frequencies using a second guard-ring.

Conclusion: The isolation of the digital from the analogue sections of the circuit has been demonstrated by creating a variable-tuned filter, resulting in a low-impedance node at specific frequencies. This scheme could have a great effect on making mixed-mode circuits a practical reality.

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Design and realisation: The Physical Electronics Research Group, at King's College London, has developed an experimental multilayer fabrication process for realising novel three-dimensional passive structures. A cross-sectional view of the rectangular waveguide is given in Fig. 1. The top and bottom sections of the structure are made from 1µm thick aluminium metallisation layers, M3 and M1, respectively. Two layers of 2µm thick polyimide are used to separate these metal layers. The side walls of the structure are essentially implemented with plated through-polyimide vias, from M2 to M1 and from M3 to M2. The resulting cross-sectional dimensions of the rectangular waveguide are \( a = 813\mu m \) and \( b = 4\mu m \).

To measure the scattering parameters of the structure, miniature electric-field probes were placed a distance of \( \lambda/4 \) from the short circuit ends of the waveguide. These electric-field probes are realised using 100µm square plated through-polyimide vias, from M3 to M2. As a result, the electric-field probes penetrate the structure to only 2µm. A microphotograph showing the top of the fabricated rectangular waveguide is shown in Fig. 2. The distance between the centres of the electric-field probes is \( P = \lambda/2 = 2.45\mu m \).

By applying traditional analytical expressions [5] to the given dimensions, while using standard material constants for aluminium and polyimide, it can be shown that an ideal section of rectangular waveguide will have the electrical specifications given in Table 1.

Table 1: Calculated electrical specifications for a section of rectangular waveguide

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cutoff frequency ( f_c )</td>
<td>100GHz</td>
</tr>
<tr>
<td>Design frequency ( f_d )</td>
<td>105GHz</td>
</tr>
<tr>
<td>Skin depth ( \delta )</td>
<td>0.26µm</td>
</tr>
<tr>
<td>Attenuation due to guide walls ( \alpha_g )</td>
<td>9.0dB</td>
</tr>
<tr>
<td>Wave impedance ( Z_{\text{eff}} )</td>
<td>649Ω</td>
</tr>
<tr>
<td>Attenuation due to dielectric ( \alpha_d )</td>
<td>7.6dB</td>
</tr>
<tr>
<td>Total attenuation at ( f, \alpha_o = \alpha_g + \alpha_d )</td>
<td>16.6dB</td>
</tr>
</tbody>
</table>

Measured performance: The experimental rectangular waveguide was measured by the Microwave & Terahertz Technology Group, at the University of Leeds (UK), using their W-band on-wafer probing facilities. The probe tips used have a ground-signal-ground configuration. As a result, the structure was measured by probing directly onto the top of the waveguide. The centre contact of the measurement probe tip (i.e. signal) touches the internal electric-field probe of the waveguide. The two outer contacts of the measurement probe tip (i.e. grounds) touch the top metallisation layer (M3) of the waveguide.

The resulting W-band measurements of the waveguide are shown in Fig. 3. The reference impedance was reset, from 50Ω to \(-j(8+32)j\), to compensate for the significant measurement error associated with the nonideal transition between the coplanar waveguide (CPW) transmission line of the probe tip and the rectangular waveguide transmission line. Also, simulations have shown that dielectric filled rectangular waveguides with large values of \( a/b \) can have a low characteristic impedance.

In theory, the insertion loss of a rectangular waveguide has a highpass filter response with a characteristic notch at \( f_c \) (since \( Z_{\text{eff}} \rightarrow \infty \) at \( f_c \)). The input return loss should improve as frequency increases above \( f_c \) and be a maximum at \( f_c \). In practice, the measured insertion loss and input return loss frequency responses exhibit these characteristics. As a result, it can be concluded that the dominant \( TE_{10} \) mode of propagation is clearly supported in this transmission line structure.

The mean level of insertion loss is \(-5.4dB\) higher than calculated. This difference can be attributed to the nonideal CPW-to-waveguide transition at both the input and output ports of the waveguide.

Conclusions and discussion: The design, realisation and measured performance of a rectangular waveguide fabricated using traditional monolithic technology have been presented for the first time.

The high level of insertion loss attributed to the guide walls appears inherent. Thicker metallisation layers would not significantly reduce this level of loss. If gold were used, instead of aluminium, only a modest reduction in this loss would be found. However, the level of insertion loss attributed to the dielectric material can be significantly reduced. In practice, polyimide has one of the highest values of loss tangent out of the many dielectric materials that can be used in monolithic technology. Moreover, the levels of insertion loss, attributed to both the guide walls and the dielectric, can be significantly reduced with a dielectric that has a lower value of permittivity.

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References

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