Analysis of Hammerhead Probes in a Rectangular Waveguide

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***Abstract*—We present the analysis of hammerhead probes with different geometrical sizes in a rectangular waveguide. In order to investigate coupling efficiency, we vary the widths and thicknesses of the head and its handle. The results show that the probe gives higher return loss when the widths of the structure are relatively smaller, i.e. the head is of the same size and the handle is smaller than the core of the coaxial cable. Experimental measurements show that the impedance of the probe increases in corresponds to the width of the head. The poor performance found in the probe with a larger size can therefore be attributed to the impedance mismatch between the probe and the cable. It can also be observed that the probe with a thicker head and thinner handle exhibits the highest return loss and largest bandwidth. Indeed, by carefully adjusting the geometry of the hammerhead probe, the coupling efficiency is found to be better than conventional rectangular microstrip and coaxial probes. The thick head hammerhead probe gives about 22.72 dB and 31.36 dB higher peak return loss than those of the rectangular microstrip and coaxial probes. Although the bandwidths of the thick head hammerhead probe and the rectangular microstrip probe are similar, i.e. approximately 22.18 GHz, its bandwidth is about 5.88 GHz wider than the conventional coaxial probe.**

***Index Terms*—Bandwidth; Coaxial Cable; Coupling Efficiency; Hammerhead Probe; Rectangular Waveguide; Return Loss.**

I. Introduction

In radio receiver systems, the incoming signal is typically coupled to the mixer circuit via waveguide to probe transition [1 - 3]. Since signals from distant sources are extremely faint, it is therefore of primary importance to ensure that signal loss can be minimized before reaching the mixer circuit. The efficiency of the system is essentially determined by how well the wave is coupled to the probe. For a highly efficient system, it is desirable to achieve full-wave coupling. In other words, all incident waves are to be coupled to the probe, while, at the same time, reflected waves are to be eliminated. This can be done by designing a probe with the input impedance Z_{in} matches the characteristic impedance Z_0 of the cable connecting to the mixer circuit.

Rectangular microstrip probes have been commonly implemented in the millimeter and submillimeter waves frequencies for waveguide to probe transition [4 – 10]. Despite its prevalence, Leech has proposed in [11] to use a hammerhead probe as an alternative for wave coupling instead. It is to be noted, however, that the effectiveness of using this probe was not discussed in detail. Hence, it is not certain if the hammerhead probe is capable of performing equally well, if not better than, the conventional rectangular microstrip probe. It would certainly be interesting to study the coupling efficiency of the proposed hammerhead probe. In this paper, we investigate the coupling efficiency of the hammerhead probe in a rectangular waveguide. To determine the optimum performance of the probe, we vary the geometry (i.e. its widths and heights) of the probe and analyze their return losses. We shall demonstrate in the subsequent section that with careful adjustment on the geometrical structure, the hammerhead probe is capable of giving better performance than the rectangular probe.

II. Design of the Hammerhead Probe

Figure 1 depicts the geometrical structure of a hammerhead probe in a rectangular waveguide with width a and height b. The probe is connected to a coaxial cable with centre core diameter d. The cable allows signals coupled to the probe to be fed to the mixer circuit.

In our study, we first vary the widths of the handle w_1 and head w_2 of the probe. We compare and analyze the return losses of the system for 2 different cases. For case (i), we set $w_1 = 0.5d$ and $w_2 = d$ and for case (ii), we set $w_1 = d$ and $w_2 = 2d$. Once the widths which give better performance are found, we then evaluate the effect of the heights on wave coupling. By fixing the widths w_1 and w_2, we vary the heights of the handle h_2 and head h_3 while retaining the total height of the probe h_1. To assess the viability of the hammerhead probe, we subsequently compare the return loss obtained from the hammerhead probe with optimum parameters with that of the conventional rectangular probe.

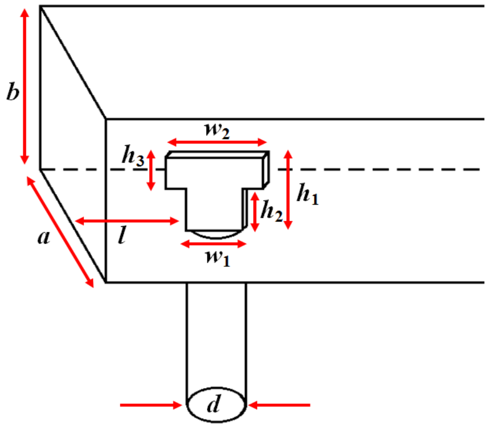

Figure 1: Hammerhead probe antenna in a rectangular waveguide

III. Results and Discussion

In [12], the configuration of a probe in a waveguide has already been carefully designed for full-wave coupling to a 50 Ω coaxial cable. Hence, we adopt identical parameters as those in [12], with the rectangular probe replaced by the hammerhead. The size of the waveguide $a \times b$, height h_1, distance of the probe from the backshort l, diameter of the core d and thickness of the probe are given respectively as 2.286×1.016 mm^2, 0.6072 mm, 0.6093 mm, 0.2286 mm and 0.1 mm. The return losses of the probes with different geometries are then computed using Finite Element Method (FEM) via Ansoft's High Frequency Structure Simulator (HFSS). Figures 2 and 3 show respectively the geometrical structures drawn using HFSS for case (i) and (ii) in Section 2. For case (i), the widths of the handle w_1 = 0.1143 mm and head w_2 = 0.2286 mm; whereas for case (ii), w_1 = 0.2286 mm and w_2 = 0.4572 mm. The height for both cases are the same, i.e. the total height h_1 = 0.6093 mm, handle height h_2 = 0.3593 mm and head height h_3 = 0.25 mm.

Figure 4 depicts the comparison of return losses for both structures. From the figure, it can be seen that the peak return loss in case (i) outperforms that in case (ii) by approximately 5 dB. In the design of receiver systems in radio telescopes, it is desirable to keep the return loss high. According to the system designed for the ALMA telescope [13], the return loss is kept above 20 dB. Hence, by taking 20 dB as the reference, it can be observed from the figure that the bandwidth for case (i) is about 6.4 GHz. On the other hand, the return losses for case (ii) are all below 20 dB throughout the frequency range. This is to say that the probe with a smaller hammerhead performs much better than that with a larger size. According to the experimental measurements found in [11], the impedance of the probe increases along with the width of the head w_2. This is to say that, as w_2 increases, the input impedance of the probe tends to deviate from its initial 50 Ω. Hence, the poor performance found in the probe with a larger size can be attributed to the impedance mismatch between the probe and the cable.

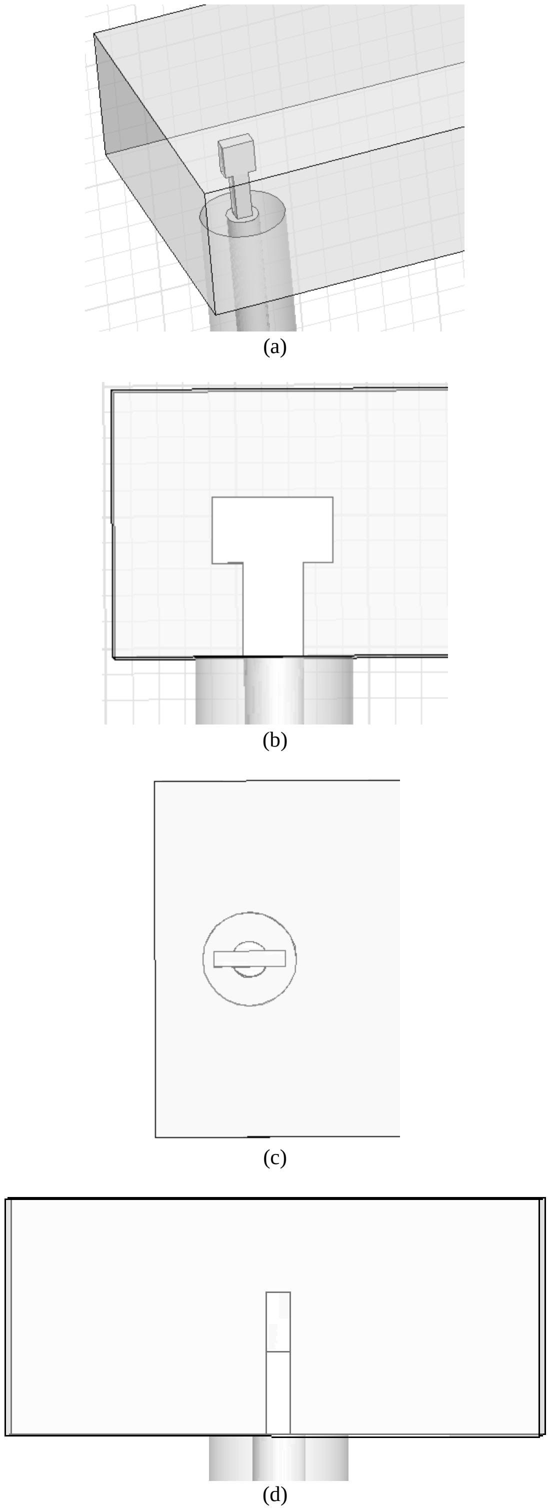

Figure 2: The (a) arbitrary, (b) side, (c) top and (d) front views of a hammerhead probe in a waveguide, with the width of the head the same size and the handle half the size of the coaxial core

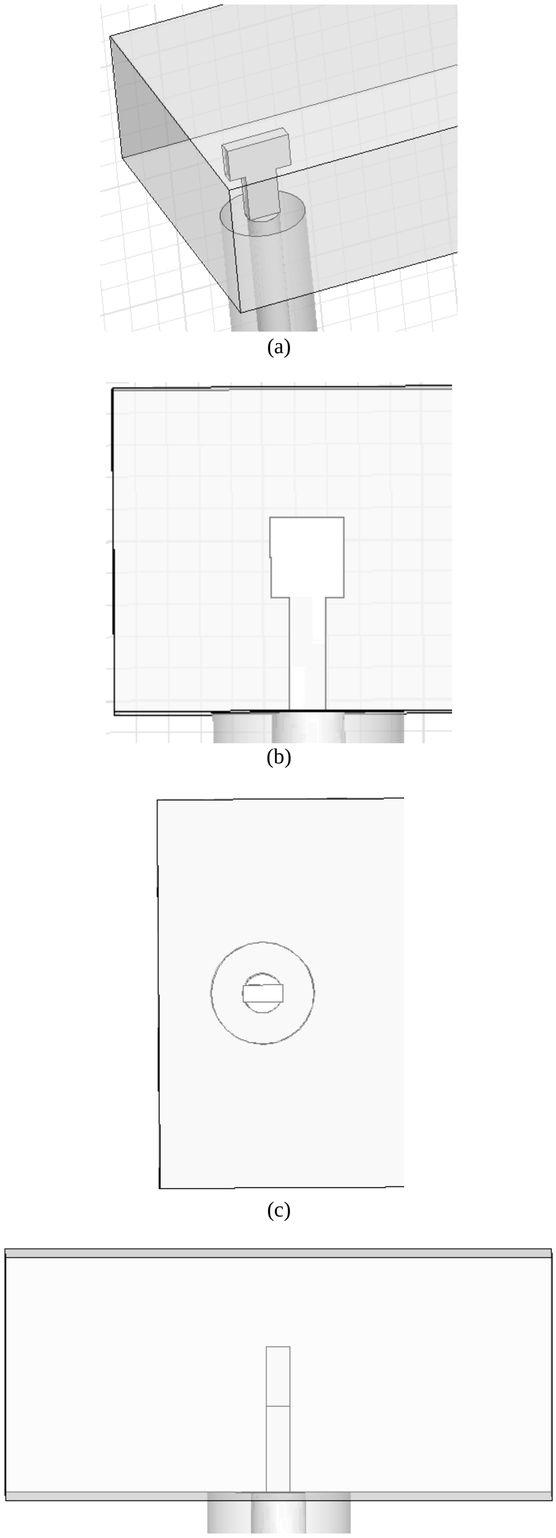

Figure 3: The (a) arbitrary, (b) side, (c) top and (d) front views of a hammerhead probe in a waveguide, with the width of the head twice the size and the handle the same size as the coaxial core

By fixing the widths to be at w_1 = 0.1143 mm and head w_2 = 0.2286 mm and the total height h_1 = 0.6093 mm, we subsequently adjust the heights of the handle h_2 and head h_3. Again, we compare the performance of the probe for 2 different cases. For case (i), we adjust the height of the head to be only 10% of the total height so that the probe has a thick head and a thin handle (i.e. $h_2 = 0.9h_1$ and $h_3 = 0.1h_1$). In contrast to case (i), the probe in case (ii) has a thin head and a thick handle (i.e. $h_2 = 0.1h_1$ and $h_3 = 0.9h_1$). Figures 5 and 6 show the return losses for both cases. It can be seen from the figures that the probe with a thicker head gives significantly better results than that with a thinner head. The return losses of a conventional rectangular probe with width × height × thickness = 0.2286 × 0.6093 × 0.1 mm^3 and that of a conventional coaxial probe with radius = 0.1143 mm and height = 0.1 mm in a waveguide are also plotted in the figure [12] for comparison. The bandwidths of both the rectangular probe and the thick head hammerhead probe are similar – both bandwidths are approximately 22.18 GHz while that of the thin head hammerhead and coaxial probes are narrower, i.e. about 10.78 GHz and 16.30 GHz, respectively. It is apparent from Fig. 5 that the thin head hammerhead probe shows consistent lower return loss than the conventional microstrip and coaxial probes. The thick head hammerhead probe, on the other hand, gives about 22.72 dB and 31.36 dB higher peak return loss than those of the rectangular microstrip and coaxial probes, respectively. The result therefore suggests that the thick hammerhead probe outperforms the two conventional probes.

It is worthwhile noting that the sizes of both the hammerhead and rectangular microstrip probes in comparison here are similar. The hammerhead probe is only distinguished from the rectangular probe with the presence of a notch at the base, forming the handle of the hammer. It is therefore interesting to see from the figure that the thickness of this notch actually affects the resonant frequency f_r of the original rectangular probe. As can be observed from Figure 5, f_r tends to shift towards lower frequencies when the thickness of the notch h_2 increases; when h_2 decreases, on the other hand, f_r tends to shift towards higher frequencies. The thickness of the notch or handle clearly affects the input impedance Z_{in} and the resonant frequency f_r of the probe.

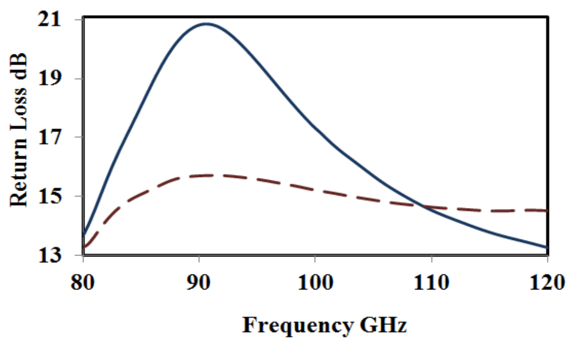

Figure 4: Return losses of the hammerhead probes with different handle width w_1 and head width w_2. Solid line: w_1 = 0.1143 mm and w_2 = 0.2286 mm; dashed line: w_1 = 0.2286 mm and w_2 = 0.4572 mm

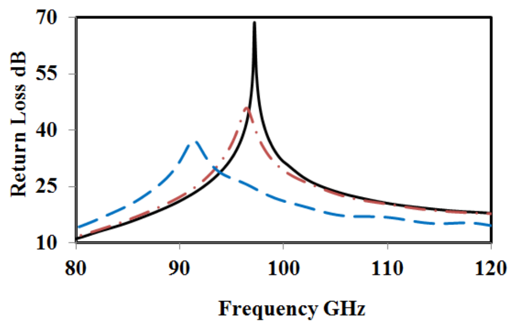

Figure 5: Return losses of microstrip and coaxial probes with different geometries. Solid line: hammerhead probe with handle height h_2 = 0.06093 mm and head height h_3 = 0.54837 mm; dashed-dotted line: rectangular microstrip probe; dashed line: coaxial probe.

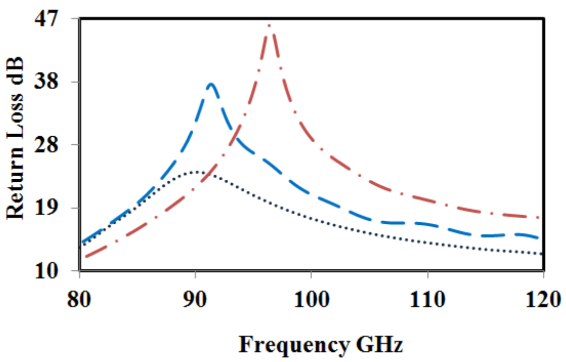

Figure 6: Return losses of microstrip and coaxial probes with different geometries. Dotted line: hammerhead probe with h_2 = 0.54837 mm and head height h_3 = 0.06093 mm; dashed-dotted line: rectangular microstrip probe; dashed line: coaxial probe.

IV. Conclusion

We have performed an analysis on the coupling efficiency of hammerhead probes in a rectangular waveguide. In order to ensure sufficiently large bandwidth and high return loss, the width of the head is to be identical with the diameter of the cable and its height is to be thicker than the handle. The results also indicate that with careful adjustment on the geometrical structure, the hammerhead probe may perform better than the conventional rectangular microstrip probe. This is particularly true when the height of the hammerhead is to larger than its handle.

Acknowledgment

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