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DESIGN OF A CIRCULAR WAVEGUIDE TM_{01} MODE LAUNCHER WITH WIRE LOOP FEED

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Abstract

In Accelerator technology, RF power couplers are important component to couple RF signal to travelling wave structure. Circular waveguide TM_{01} mode is one of the symmetric modes, that is suitable to use for RF coupling. TM_{01} mode launcher is used as an RF coupler in Accelerator technology. Design of a compact circular waveguide TM_{01} mode-launcher is presented in this paper. The design is based on the principle of magnetic field coupling between a wire loop and TM_{01} mode of circular wave-guide. The mode launcher exhibits high efficiency and 3.1% bandwidth at 3.2 GHz frequency with both circular and elliptical loop. Performance of the mode launcher is experimentally verified and simulated S-parameters agree with the measured results. The mode launcher is of compact size and is suitable for efficient excitation of TM_{01} mode in circular waveguide and travelling wave structures. The launcher is also useful for cold testing of high power microwave antennas and Radars.

INTRODUCTION

Circular waveguide is an important component in many applications of microwave engineering. It is used as a transmission device for transfer of microwave signal from one place to another with minimum loss. Transmission loss can be minimized if symmetric waveguide modes i.e. TEM, TM_{01} or TE_{01} modes are utilized. TEM mode can be excited in coaxial waveguides or cables only. In circular waveguide, TM_{01} and TE_{01} modes can be excited. TM_{01} mode cutoff frequency is much lower than TE_{01} mode and therefore it is more suitable for single mode transmission.

The mode excitation is realized with a mode-launcher, which is also referred as mode transducer or mode converter in some papers. The mode launcher is a useful device in different waveguide applications, such as de-signing waveguide rotary joint [1], as CPT (cone penetra-tion test) underground sensor device [2], as mode-launcher and detector in Single Wire or Single Conductor Transmission line (SWTL or SCTL or Gobau-line) communication [3]. TM_{01} mode-launcher is also used for low-power testing of the high-power microwave components [4].

In conventional designs the TM_{01} mode-launcher, a coaxial probe is inserted along the axis of the waveguide. The same end of the waveguide is closed with a metal plate, which also works as ground plane for the feed. The inner conductor of the coaxial feed is extended in different shapes to achieve the impedance matching and wide bandwidth. Center conductor is extended as monopole in [5], to achieve TM_{01} mode excitation. In [6], the coaxial probe is extended in conical shapes (single cone, cone with skirt and bi-conical) for wide-bandwidth TM_{01} mode excitation. In [7], the center conductor is extended in match feed horns to generate TM_{01} mode. A different approach for mode-launcher design is reported in [8], by feeding the circular waveguide through the side wall with rectangular waveguide TE_{10} mode. The center conductor is extended in pagoda shape [9] for TM_{01} mode excitation with wide-bandwidth. A Ku-band TE_{10} to TM_{01} mode converter is reported in [10], where circular waveguide is fed from side wall through rectangular waveguide. This converter has large size in the transverse direction due to multiple waveguides. A multi-stage stepped impedance transformer based mode-launcher is reported in [11]. All the discussed designs are based on electric-field coupling between input feed and TM_{01} mode field.

This paper presents a mode launcher with magnetic field coupling between excitation signal and TM_{01} mode, in next section. Results are discussed in subsequent section and conclusions are summarized in last section.

DESIGN AND CONFIGURATION

Previous designs of TM_{01} mode launcher [6-11] in literature are based on E-field coupling and employ a probe feed at the centre axis of the circular waveguide or rectangular waveguide feed from the side-wall of the circular waveguide. The probe radiates E-field in radial direction towards the waveguide wall and excites or launches the TM_{01} mode. The proposed mode launcher design consists of a wire-loop antenna excitation. The magnetic field or H-field of TM_{01} mode (of circular waveguide) remains

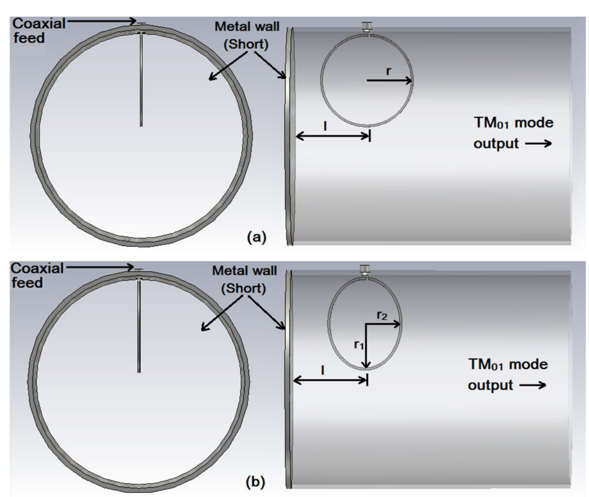

Figure 1: Front view and side view (waveguide transparent) of the proposed mode launcher with (a) circular and (b) elliptical loop feed.

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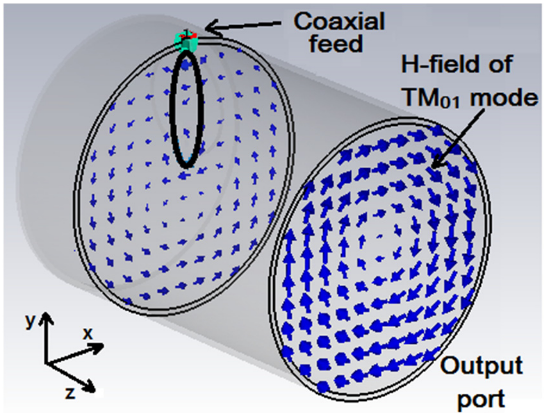

Figure 2: Process of TM_{01} mode generation through magnetic field coupling (waveguide shown transparent).

constant in azimuthal direction at a constant radial distance from centre axis of the waveguide. Therefore the H-field of TM_{01} mode consists of concentric loops parallel to the waveguide inner wall.

A wire loop antenna generates the magnetic field orthogonal to its plane. If a loop antenna is applied inside the circular waveguide such that the magnetic field excited by the loop, couples with the magnetic field of TM_{01} mode, the mode can be excited. Circular and elliptical shaped loop antennas are most suitable to excite the symmetric magnetic field. Square or rectangular loop antennas do not perform well for this application. The proposed launcher designs with circular and elliptical loop feed are shown in Fig. 1. The process of mode excitation and coupling is shown in Fig. 2.

The loop is fed with 50 Ω coaxial cable connected on sidewall of the waveguide. One end of the loop is connected to center conductor of coaxial feed and other end to the outer conductor or waveguide wall. If the waveguide has the diameter D and its axis is along the z-axis, the wire-loop is placed in the yz-plane. The elliptical loop has semi-major axis r_1 and semi-minor axis r_2. The parameter l is the distance of ellipse center from the metal wall (short) end of the waveguide. The distance l is carefully chosen such that the reflected fields meet in phase with the forward propagating field. The circular loop of radius r can be considered as a special case of elliptical loop, where $r_1 = r_2 = r$. The design constraint to estimate initial values of parameters are $2r_1 < D/2$ and $r_2 < l$. The design parameters (r_1, r_2, r and l) are optimized in the simulation process for maximum mode conversion efficiency.

The bandwidth of mode excitation is comparable in case of elliptical and circular loop feeds. The mathematical analysis of wire loop antenna of elliptical or circular shape for non-uniform current is rigorous and can be referred in [12, 13] for the interested readers. The simple principle of matching between loop antenna H-field and H_ϕ component of TM_{01} mode fields is utilized here for designing the mode-launcher.

SIMULATION AND MEASUREMENT RESULTS

The proposed mode launcher is designed and simulated using commercial EM simulation software CST Microwave Studio®. Circular waveguide of diameter D = 9 cm is modeled in the software to achieve results in S-band. The cutoff frequencies of TE_{11}, TM_{01} and TE_{21} modes are 1.95 GHz, 2.55 GHz and 3.25 GHz respectively. TE_{21} mode can only be excited with suitable excitation method and symmetry. Since the required symmetry does not exist, TE_{21} mode will be attenuated. Elliptical and Circular loop feeds are designed and simulated separately to achieve maximum conversion efficiency at 3.2 GHz frequency. The optimized design parameters for both type of feed are summarized in Table 1. A comparable bandwidth of mode excitation is achieved with elliptical and circular feed.

The simulated results with parametric variation of circular feed are shown in Fig. 3. The radius (r) of circular feed is varied as 1.6, 1.8 and 2 cm with constant distance (l = 2.4 cm). With decreasing radius (r), the efficiency peak shifts significantly from low to high frequency. Taking constant radius r = 1.8 cm, the distance (l) of feed centre from metal wall (short) is varied from 2.2 to 2.6 cm. The efficiency peak shifts towards high frequency with increasing distance (l).

To verify experimentally, the mode launcher waveguide is fabricated with Aluminium metal as shown in Fig. 4(a). A bi-conical shape TM_{01} mode detector [6] is connected at the output port of the mode launcher to measure the TM_{01} mode. The length of the waveguide is taken as 10 cm for sustained mode excitation between launcher and detector. The wire loop feeds are formed with a copper wire of 2 mm diameter. An illustration of the measurement setup is shown in Fig. 4(b).

Table 1: Design Parameters of the Proposed TM_{01} Mode Launcher

Type	r_1	r_2	l	f_0
Circular loop	1.8 cm	1.8 cm	2.4 cm	3.2 GHz
Elliptical loop	2.0 cm	1.5 cm	2.0 cm	3.2 GHz

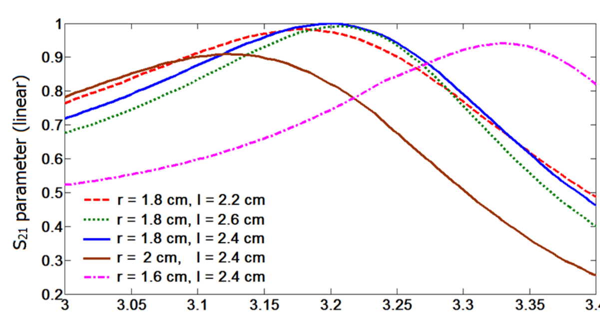

Figure 3: Effect of parametric variation on the S21 parameter of the mode-launcher with Circular loop feed.

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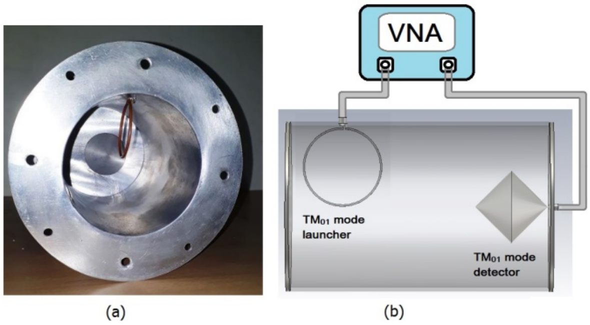

Figure 4: (a) Fabricated circular loop feed mode-launcher with biconical detector. (short metal plate removed for inside view) and (b) Illustration of measurement setup for circular loop feed mode launcher (waveguide shown transparent).

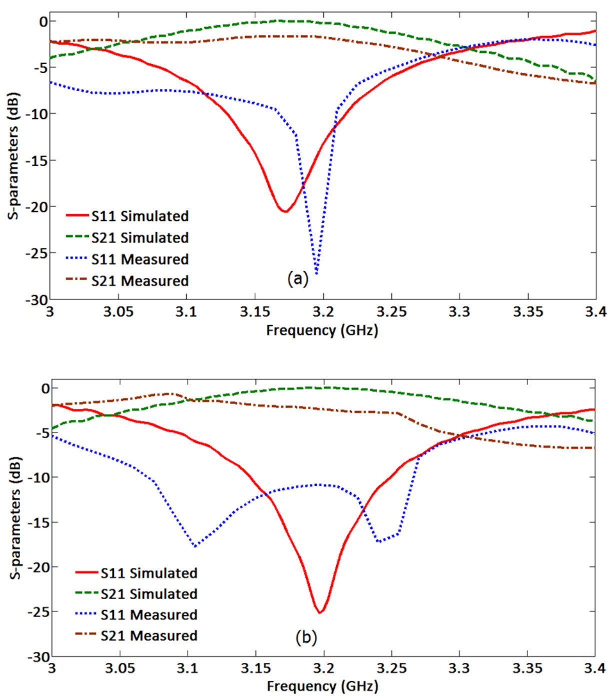

Figure 5: Measured S-parameters of the mode-launcher with (a) Circular and (b) Elliptical loop feed.

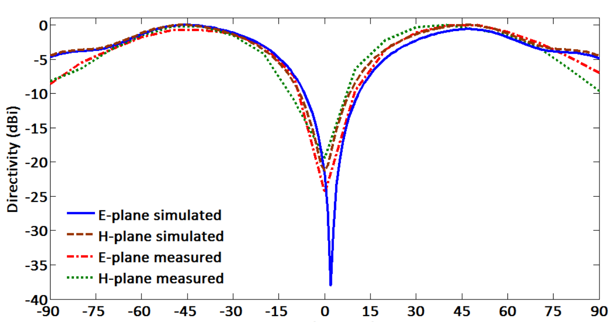

Figure 6: Measured radiation pattern (normalized) for the circular loop feed mode-launcher at 3.2 GHz frequency.

Table 2: Comparison of the Proposed Designs with Previous TM_{01} Mode Launcher Designs

Paper	Length λ	Diameter λ	S_{21} peak (dB)	Coupling Principle
[6]	0.58	1.05	-0.01	E-field
[7]	1.33	0.42	-	E-field
[8]	3.59	0.94	-0.01	E-field
[9]	0.34	0.9	-0.27	E-field
[10]	0.38	0.86	-0.08	E-field
[11]	0.44	1.08	-0.20	E-field
Circular	0.44	0.96	-0.01	H-field
Elliptical	0.37	0.96	-0.01	H-field

The simulated and measured results of S-parameters are plotted and shown in Fig. 5(a) for circular feed and Fig. 5(b) for elliptical feed. It is evident that high excitation efficiency (measured) is achieved in 3.15-3.25 GHz band for circular feed. In case of elliptical feed the efficiency peak is shifted to 3.1 GHz and high efficiency is observed in 3.05-3.15 GHz band. The difference in measured efficiency and simulated efficiency is due to low conductivity (of aluminium) of the fabricated structure and multiple reflections in the experimental setup.

The output mode is also verified by measuring the far-field radiation pattern according to [4, 6] and the normalized pattern is plotted as shown in Fig. 6. The pattern consists of null or minimum (-23 dB) at the center and the 3D pattern is of conical shape. This verifies the efficient excitation of TM_{01} mode at the output port of the mode launcher waveguide. A comparison of the proposed mode launcher designs with previous designs in published in literature, is presented in Table 2. The proposed designs are very compact and highly efficient for mode excitation. The proposed designs are unique due to the principle of magnetic field coupling, compared to the E-field coupling based designs.

CONCLUSION

A mode launcher to excite TM_{01} mode in a circular waveguide is presented in this letter. Efficiency of TM_{01} mode excitation with circular loop feed is more than 90% over the 3.15-3.25 GHz band which corresponds to 3.1% bandwidth. Similar results are also achieved with elliptical shape feed. The launcher has compact shape and exhibits high efficiency of mode excitation.

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