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Wideband Compact Dielectric-less Launcher of an X-band Ferrite Faraday Rotator

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Abstract— A compact dielectric-less launcher for a ferrite filled circular waveguide operating as a Faraday rotator for high peak-power applications is presented.

The launcher consists of a 2-section $\lambda/4$ transformer, the first one is an empty quad-ridge waveguide while the second is a ferrite partially filled circular waveguide in such a way that the same ferrite rod is used for both Faraday rotator and launcher transformer and no additional dielectrics and glues are required. The launcher is integrated between two dedicated OMTs, in order to access arbitrarily to both V and H polarizations.

Preliminary measurements prove the effectiveness of the architecture proposed.

Keywords— Faraday Rotator, Power Switch, Ferrites, Quad-ridge waveguides.

I. INTRODUCTION

A High-power microwave switch is mostly based on Faraday rotator that is made up of a cylindrical waveguide filled by a magnetized ferrite.

In fact, a linearly polarized wave entering the magnetized ferrite is split into two equal-amplitude counter-rotating circularly polarized waves, each one propagating with its own propagation constant, let say β_+ and β_- .

Actually, right-hand and left-hand circularly polarized waves are the normal modes of the waveguide in presence of a longitudinal magnetic field on the ferrite and propagate along the structure without changing character.

For a ferrite of length l , the phase shift of the two waves is $\beta_{\pm}l$. So, when the two waves recombine at the end of the active region, namely the one with nonzero magnetization, the resulting wave is still linearly polarized but the polarization is rotated by an angle $\vartheta = (\beta_+ - \beta_-)l/2$.

So, rotation depends on the difference between β_+ and β_- , whose determinations require the solution of a transcendent equation.

To have an immediate idea of the mechanism, it is expedient to consider the case of a plane wave propagating within a magnetized ferrite, where $\beta_{\pm} = \omega\sqrt{\varepsilon(\mu \pm \kappa)}$, where

$$\mu = \mu_0 \left(1 + \frac{f_0 f_m}{f_0^2 - f^2} \right); \quad \kappa = \mu_0 \frac{f f_m}{f_0^2 - f^2}; \quad f_0 = \gamma \mu_0 H_0; \quad f_m = \gamma \mu_0 M_s$$

Both β_s depend on the ferrite material saturation magnetization M_s , waveguide cross-section, operating frequency f and the applied longitudinal magnetic bias field H_0 . In latching -mode operation, maximum rotation is reached when B-static is at the limit values of the major hysteresis loop remanent magnetization points.

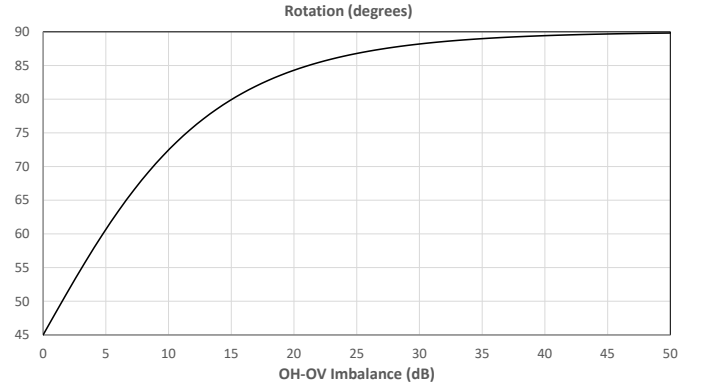


Fig. 1 – Faraday rotator, rotation as a function of the imbalance between the two linear polarizations

The numerical values of β_+ and β_- are interchanged when the direction of the applied magnetic bias field is reversed.

In the best latching Faraday Rotators available on the market the transformer between ferrite filled and empty circular waveguide makes use of ceramic nonmagnetic cylinders (actually there are two adapters, one for each ferrite end).

In other solutions that do not require additional dielectrics and glues, which represent some criticality in operative conditions, matching is obtained by tapering the ferrite cylinder ends. The main drawbacks of the last solutions are the extra length, often excessive, and some fragility, due to the acuminate shape.

Other transformers have been proposed which do not contain additional dielectrics and are based on quad-ridge empty waveguide transformers.

However, a not negligible drawback of the latter is that the response is quite sensitive to the contacts between ferrite and ridge waveguide and good matching requires high degree of planarity and orthogonality. In addition, such contact represents a point of fragility in operative conditions, when vibrations are present. Finally, there can be some limitation to

the power handling capability due to the fact that in the quad-ridge section closer to the ferrite filled waveguide the gaps between opposite ridges are normally quite small.

In this paper an improvement of the quad-ridge architecture is proposed, in which the section of the quad-ridge transformer facing the ferrite filled waveguide is replaced with a circular ferrite partially-filled waveguide. This solution is attractive because: 1) the elimination of both ridges with small gaps/abrupt edges and the contact between ridge and ferrite strongly attenuates the risks of discharge in the adapter region, 2) no additional dielectrics are necessary: it is just required a slightly longer ferrite 3) no sharpened ferrites are used, thus making fabrication easier 4) there are no small gaps, glues and other weakness points.

The replacement of the quad-ridge section closer to the ferrite filled circular waveguide has by a partially filled circular waveguide, allows to eliminate both the contact between ridges and ferrite and teflon or plastic gasket disks to absorb vibrations;

In addition, ferrite cylinder diameter has been increased in order to 1) increase the rotation per unit length, thus reducing the ferrite length and widening the band, 2) reduce dispersion in view of decreasing the variation of rotation with frequency and consequently increasing the isolation 3) make the ferrite waveguide less sensitive to mechanical errors, thus improving the manufacturing process, 4) avoid the onset of higher modes in the operational band, thus making less sensitive the response 5) increase the ferrite heat radiating surface.

II. DESIGN

The final scheme of the improved quad-ridge transformer is shown in Fig.2, where the constituent five blocks are pointed out, namely EWC-QR (transition between Empty circular and Quad-ridge waveguide), $\lambda_g/4$ quad-ridge waveguide section, QR (transition between Quad-ridge waveguide and not-magnetized ferrite partially filled circular waveguide), $\lambda_{\text{mbag}}/4$ partially filled circular waveguide section, PF-FC (transition between not-magnetized ferrite partially filled circular waveguide and fully filled circular waveguide).

Note that, because of the quadrilateral symmetry, the transformer features same response for both TE_{11V} and TE_{11H} polarizations and that the coupling with the TM₀₁ mode, in propagation within the output ferrite circular waveguide is not excited.

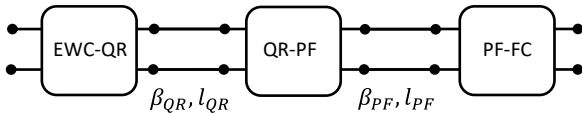


Fig. 2 – Black box scheme of the 2-section transformer designed, adapting the empty circular waveguide to the ferrite filled circular ferrite.

In addition, the quad-ridge transformer has been integrated in a compact OMT with the aims of minimizing losses and improving the power handling capability, by eliminating not-strictly necessary flanges. The OMT has been designed yet taking into account that the device would have been fabricated

by clamshell technology and each half would have been worked by milling machine.

The design of the feeder has been carried out starting from the elementary blocks, namely the OMT's and the two section adapters. The feeder has been designed to work in the frequency range 8.6-9.5 GHz.

A perspective view of the designed feeder with the integrated 2-section adapter is shown in Fig 3.

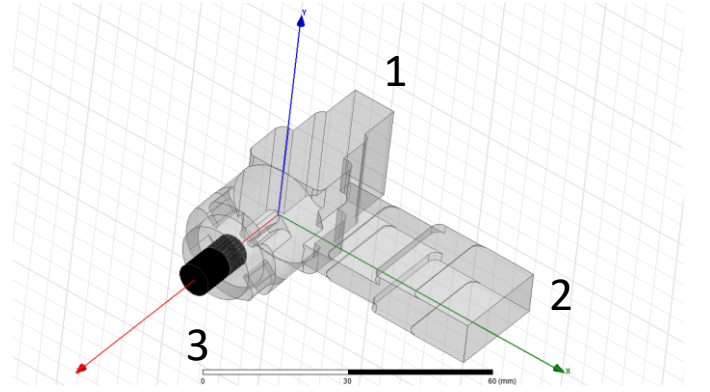


Fig. 3 – Perspective view of the compact dielectric-less OMT feeder (only air (grey) and ferrite (black) are shown). The inputs are rectangular waveguides, the output is the fully filled circular waveguide operating with both TE_{11V} and TE_{11H} modes. Port 3 is the multimodal port of the ferrite filled circular waveguide in which three modes, TE_{11V}, TE_{11H}, TM₀₁ propagate in the operational frequency range.

Fig 4 shows a section of the OMT from which it results that the length of the two-section adapter is less than 12mm. It can be also observed the presence of a small region (a few tenths) where ferrite rod and quad-ridge waveguide superimpose.

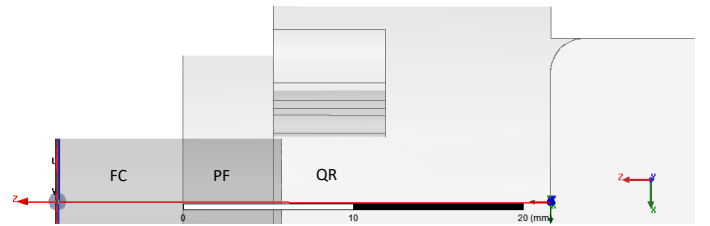


Fig. 4 – Longitudinal section of a portion of the OMT feeder with some details of the adapter part.

This is done to eliminate the possibility of a section of empty circular waveguide below cut-off.

It is observed that the OMT has only one symmetry plane ($y=0$, in Fig.3), which precludes the excitation of the TM₀₁ mode in the ferrite filled circular waveguide from port 2.

On the contrary, port 1 is weakly coupled to the TM₀₁ in the FC, with the QR waveguide section acting as a modal suppressor.

III. RESULTS

The Simulated reflections at the rectangular ports of the designed feeder of Figs. 3 are shown in Fig. 5.

The isolation between the ferrite filled circular waveguide TM01 mode and port 1 is higher than 45 dB, while the one with port 2 is theoretically infinite, as shown in Fig.6. This proves that the quad-ridge section works correctly and attenuates such undesired coupling.

The peak RF Electric field in the feeder is less than 20 kV/m while the RF Magnetic field in the ferrite is 62 A/m (0.78 Oe), both calculated for 1 W average input power.

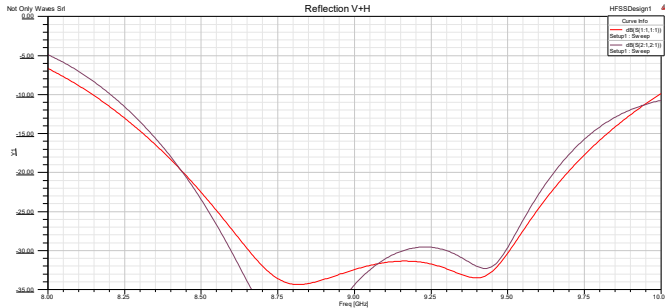


Fig. 5 – Reflections of the feeder of Fig.3 simulated considering an $\epsilon_r=15$.

The fabricated Faraday Rotator, formed by two mirrored feeders and the metallized ferrite rod in between, is shown in Fig.6

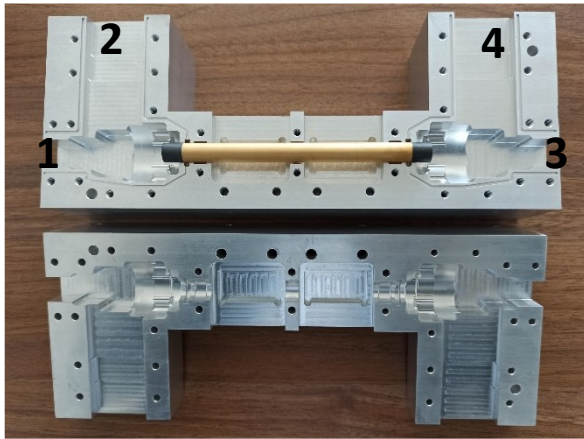


Fig. 6 –The two housing halves of the housing + ferrite rod forming fabricated Faraday rotator.

Some preliminary results have been obtained with a commercial ferrite Trans-Tech TTG1002.

As can be seen the return loss (RL) is lower than what expected, according to the HFSS simulations.

In fact, considering that the ferrite cylinder inserted in between the two feeders is 10 cm long, the minimum RL is 6 dB lower than that of a single feeder, we can estimate that the latter is in the order of 16 dB, against 26 dB of the design.

This is possibly due to the imperfect contacts between the housing and the ferrite cylinder conductive coat, in the region close to the ferrite ends.

Of course, this reflects on the transmission losses too, which are larger than those predicted and change considerably in the band (0.5 dB). Without magnetization the isolation between V

and H polarization is higher than 23 dB in the operative band. In this respect, it is noted that in the operation band there are three propagating modes in the ferrite filled circular waveguide, namely TE11V, TE11H and TM01. While the TM01 is not excited by the H polarization, since, by symmetry, that corresponds to an electric wall in the midplane, it is weakly excited by ports 1 and 3 as this produces a magnetic wall in the midplane which does not prevent the coupling with TM01 in the circular waveguide. This phenomenon appears in Fig. 7 (up) where some abrupt variations due to the resonance of the TM01 are clearly visible. The same does not appear in Fig. 6 (down) which refers to excitation through port 2.

Nevertheless, results prove the effectiveness of the proposed architecture and the feasibility of a rotator without the need of extra dielectric matching elements.

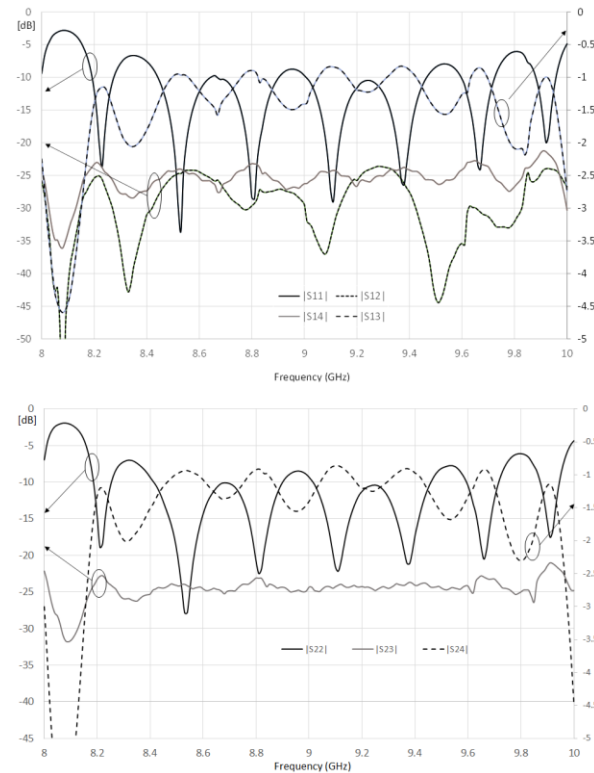


Fig. 7 – Measured scattering parameters of the built Faraday rotator. Ports are numbered as shown in Fig.5.

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