# Use of Nano-Grids in a Waveguide

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***Abstract* — A new concept of passive waveguide circuits is presented. It is based on a combination of the standard rectangular waveguide with a metal uniform linear polarization grid of nano thickness. The grid is deposited on a polymer foil and inserted into the waveguide, allowing it to rotate between two opposite flanges. The concept is demonstrated on a T-junction with an adjustable ratio of the output powers, and on a variable reflection attenuator. The two circuits were designed, manufactured and tested. The measured characteristics compare well with the computer simulations, and have confirmed the expected behavior of the two circuits.**

***Index Terms* — Power dividers, power combiners, power control, waveguide attenuators, waveguide T-junctions.**

## I. Introduction

The interaction of a linear polarization plane grid consisting of straight conductive thin parallel wires with a linearly polarized wave incident perpendicularly to the grid plane has been known for many years. When the vector of the incident electric field $\mathbf{E}_i$ is perpendicular to the wires, the wave passes through the grid with negligible loss, and the transmitted wave saves the orientation of the polarization plane (yz) of the incident wave, i. e., $\mathbf{E}_t = \mathbf{E}_i$, as shown in Fig. 1a. If the grid diverts from its original orientation ($\vartheta = 0°$) by an angle $\vartheta$, the magnitude of the transmitted wave is $\mathbf{E}_{t\perp} = \mathbf{E}_i \cos\vartheta$, and its plane of polarization ($\mathbf{E}_{t\perp}$z) is rotated by the same angle $\vartheta$ from the plane of polarization ($\mathbf{E}_i$z) of the incident wave, as shown in Fig. 1. When an additional polarizer, letting through a wave polarized in the plane (yz), is located behind the grid, the amplitude of the transmitted output wave is $\mathbf{E}_t = \mathbf{E}_i \cos^2\vartheta$. When $\mathbf{E}_i$ is parallel to the wires ($\vartheta = 90°$), the magnitude of the transmitted wave falls practically to zero.

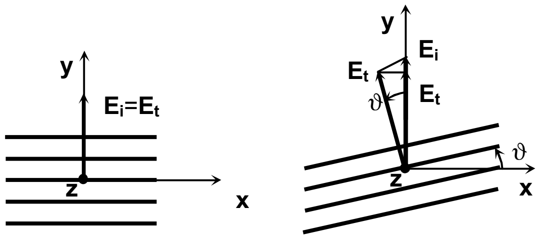


Fig. 1 Set up of the linear grid with the incident and transmitted wave.

These observations are utilized for producing an attenuator with variable output power and for a T-junction with a variable ratio of output powers. The attenuator and the T-junction in the H plane have been designed and manufactured. Theoretical expectations are compared with measured characteristics. Their good agreement gives a chance to produce a new class of variable circuits realized in waveguide technology.

## II. Design of the T-junction

Waveguide T-junctions are used for power dividing and combining, transmitted power control or impedance matching [1]-[3]. Their two appearances are sketched in Fig. 2. A T-junction consists of a main guide with ports 1 and 2, and a side guide with port 3 connected in parallel in the H plane, or connected in series in the E plane to the main guide. We will now observe a T-junction in the H plane, which has two planes of symmetry, $F_1$ and $F_2$. An inductive diaphragm located in the main guide lying in the plane $F_2$ improves the impedance matching of the T-junction, widens its frequency band and ensures equal output power at port 1 and 2 when port 3 is fed.

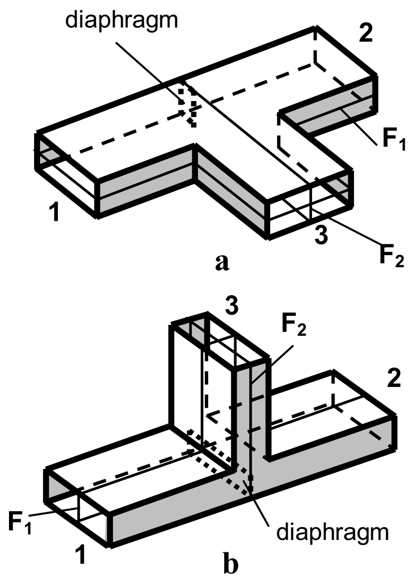


Fig. 2 Compensated T-junction in the H plane (a), and in the E plane (b).

However this modification of the junction, known as a compensated T-junction, does not allow any additional change of its parameters, particularly a change of the output power ratio. A new concept of the junction removes this drawback. The metal polarization grid is inserted under an angle of 45° in the main guide. The grid rotates round its axis perpendicular to the grid-plane, as shown in Fig. 3. Assuming a lossless junction, the power incident on the grid passes, if the conductors of the grid are perpendicular to the **E** field direction of the dominant mode in the rectangular waveguide. The power is reflected when the grid conductors are parallel with **E**. For other orientations of the grid conductors, i. e., apart from the two cases mentioned here, part of the power passes through the grid while the rest of the power is reflected under the incident angle, i. e., 45°.

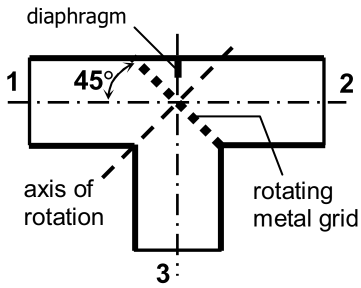


Fig. 3 Arrangement of the rotating grid in the T-junction.

The polarization grid must rotate freely in the cavity between two opposite flanges inclined by 45° to the main and side guide axes. The junction was therefore supplemented by a high frequency grooved choke.

We checked the function of the new T-junction at the CST Microwave studio (MWS) electromagnetic simulator, observing its scattering matrix elements in the frequency band from 8 to 12 GHz. Then the same was observed simultaneously with optimization of the inductive diaphragm size. It turned out that the depth of the diaphragm insertion and its thickness are not critical. The metal polarization grid was made by photo etching a gold layer 60 nm in thickness deposited on a polyethyleneterephthalate foil 50 μm in thickness. The width of the metal strips and also of the slots between them was 100 μm. MWS confirmed the anticipated operation of the junction. In the model of the junction in this case the grid wires were conductively connected to the waveguide walls. When the grooved choke was added to the junction model, the grid wires remained open-circuited at the waveguide circumference allowing rotation of the grid. A T-junction was designed and manufactured [4]. Using the network analyzer, its scattering matrix elements were measured.

## III. Design of the Attenuator

Attenuators control the output power level necessary for signal processing. They are of fixed or variable type. Variation of the attenuation can be effected by mechanical movement of its most important functional part, or can be controlled electronically. Mechanically controlled attenuators are of either absorbing or reflection type [5]. A typical reflection attenuator has a coaxial input and output section with a cylindrical waveguide in between, with an evanescent wave and adjustable length [2]. Variation of the attenuator length excludes its use in the fixed transmission line set-up. This drawback eliminates a new concept of a reflection attenuator with a rotating metal polarization grid, as follows.

Let the dominant mode propagate in the rectangular waveguide. The mode has a linear polarization in the plane perpendicular to its wider walls. The metal polarization grid is inserted in the cross-section of the waveguide between the two flanges, as schematically shown in Fig. 4. The incident power reflects and transmits according to the turn aside of the grid, as was explained in the introduction. Consequently, the reflection coefficient changes considerably with the turn of the grid, but the output power varies in the ideal case from its maximum to zero. A high frequency choke was added in the junction of the two opposite flanges, between which the grid was located in order to prevent leakage of power and minimize the influence of this discontinuity on the attenuator characteristics. CST MWS checked the operation of the variable attenuator for the two extreme positions of the grid. The output power is proportional to $\cos^2\vartheta$. The metal grid was made, as in the case of the T-junction, with the same strip/slot size on the polyethyleneterephthalate foil sputtered by gold. Again the attenuator was manufactured and its scattering matrix elements were measured by the network analyzer [6]-[7].

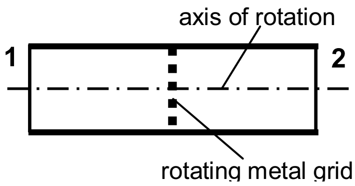


Fig. 4 Placement of the turning nano-grid in the WR90 waveguide.

## IV. Measurements, Results, Discussion

In measurements of the reflection and transmission coefficients we used a matched load with VSWR<1.08 from 8.5 to 12.5 GHz. Two coaxial/waveguide adaptors connected back-to-back in series had reflection losses less than -30 dB and insertion losses less than -0.2 dB in the 8.2-12.5 GHz band. Further details for specific situations are provided below.

### *A. T-junction*

Division of the output powers is frequency dependent in the 8-12 GHz band, as the calculated patterns in Figs. 5 and 6 indicate. The depth of the inductive diaphragm insertion was chosen 6 mm. It turned out that uniform allocation of the grid strips/slots provided practically the same results as the non-uniform grid performance. Consequently the uniform grid was fabricated and used. Acceptable agreement between the measured and simulated frequency-dependent scattering coefficients was recorded. The change in the power ratio $P_2/P_3$ with the angle of the grid at 10 GHz is shown in Fig. 7. The addition of compensating elements into the respective guides is recommended in order to lower the reflection losses.

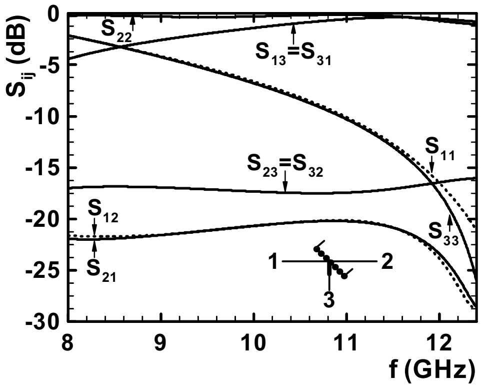


Fig. 5 Scattering coefficients of the new T-junction when the grid wires have a vertical orientation.

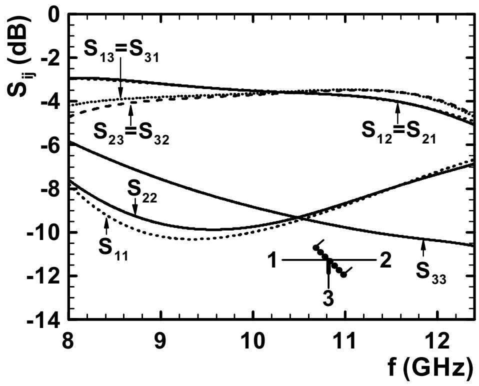


Fig. 6 Scattering coefficients of the new T-junction when the grid wires have a horizontal orientation.

*B. Attenuator*

The attenuator was measured in the same equipment set-up as the T-junction. The measured transmission coefficient of the attenuator is plotted in Fig. 8, along with the same quantity calculated for an ideally lossless circuit. The function of the attenuator was saved from 7.5 to 12.5 GHz. The highest achievable attenuation decreases with frequency. Consequently, at higher frequencies a denser grid is needed in order to maintain the same attenuation.

## IV. Conclusions

Combining waveguides and super thin metal polarization grids enables the design of circuits with improved characteristics, in particular a fluent variation of one of their significant parameters. Careful, especially mechanical design and realization ensures their correct, reliable and reproducible operation. Manufacturing this class of circuit does not require hi-tech investments. Present-day machine tools and standard photolithography are sufficient to produce the bodies of the circuits and polarization grids. Rotary movement of the controlling elements replaces linear movement, and enables such circuits to be installed into fixed length transmission channels.

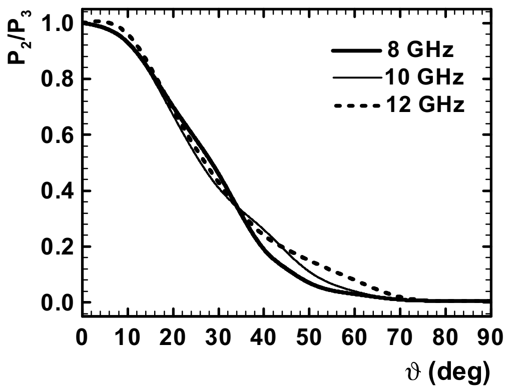


Fig. 7 Ratio of the output powers $P_2/P_3$ from the T-junction fed into the first port.

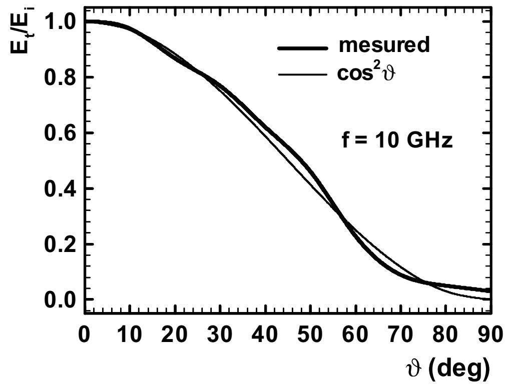


Fig. 8 Measured and calculated transmission coefficient of the attenuator.


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