Septum polarization transformer

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Compact Duplexer – Polarizer with Semicircular Waveguide

The Septum polarizer

OK 1 DFC

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Abstract:

Feed for parabolic dish with circular polarization

I had in last time problem with feed in my dish. As a first type of feed I have use VE4MA. All worked normally up to my power increasing. With new PA (TH338-1kW out) started problem with a hybrid 90°. My interesting was turn to the system witch used Franta OK1CA. I started find some technician materials and theory about Septum polarization transformer. Advantages I saw in very easy production and set upping, second advantage was that system save 1,5 dB on RX and TX sites because cables are going directly to the feed connectors. I had first prototype finished on the spring 1999 and tested his parameters with very good success and results. Noise of the sun was increase from 9,2 dB to 11,5 dB by my small 3,8m dish. My best result is 3rd place in single category ARRL EME 1296 MHz and 96 different initials include WAC. Many other details you can see on my web page www.qsl.net/ok1dfc. This web include also Excel sheet for technical parameters calculation. You can use this SW for each frequency. Only one parameter you must write. This parameter is frequency in MHz. Construction was presented on EME 2002 conference Praha as a lecture.

Zdenek OK1DFC

Communications

Compact Duplexer-Polarizer with Semicircular Waveguide

Roger Behe and Patrice Brachat

Abstract—Circularly polarized antennas such as C-band space communications antennas are generally fed by rotationally symmetric structures radiating the two strongly decoupled orthogonal polarizations. A light, compact, and high-performance device able to generate circularly polarized waves in a circular waveguide, is discussed.

I. Introduction

Several technologies are currently used to excite high purity left-hand or right-hand circular polarizations in a circular waveguide.

The association of several distinct devices such as orthomode transducers (OMT), polarizers and square-to-circular waveguide transitions is too bulky for tightly packed feed arrays (multibeam or contoured beam antennas).

The use of a probe excitation in a circular waveguide requires hybrid circuits in coaxial or microstrip technology. Unfortunately, these circuits introduce significant losses (0.5 dB) and show poor isolation performances.

The stepped septum in a square waveguide [1], [2] is a very interesting device. It is an extremely compact element which handles the tasks of both the OMT and the polarizer. It appears difficult to increase the compactness of this component. The solution proposed here involves eliminating the square-to-circular waveguide transition required by the output-port cross section of this device, and keeping a circular cross section throughout.

A. Description of the Component

The OMT-polarizer is composed of a circular waveguide (Fig. 1) divided into two identical parts by a metallic septum. The originality of this unit is the use of two semicircular waveguides. Each semiguide is excited by the fundamental mode of the electric field orthogonal to the septum. This excitation may be realized in line or orthogonally with a probe (coaxial input) or via slot coupling (rectangular waveguide input for high power use). Due to the asymmetry of the septum, the linearly polarized guided modes in the semicircular waveguide are converted into guided modes in the circular waveguide. With an appropriately stepped septum, each input part excites two orthogonal $TE_{11_\perp}$ and $TE_{11_\parallel}$ modes in the circular waveguide with approximately equal amplitudes. If the septum is thin, the mode perpendicular to the septum is not affected by the ridge. By contrast, this will increase the phase velocity of the other mode. By adjusting the length of each step, a shift of 90° is obtained for the relative phase between the two modes. Excellent circular polarization is thus achieved.

B. Development

Designing this device requires knowledge of the guided modes in a circular waveguide including an asymmetric ridge. For a homogeneous waveguide we must obtain the eigenfunction and the eigenvalues of the Helmholtz equation:

$$\nabla^2\phi(x, y) + \Lambda\phi(x, y) = 0 \tag{1}$$

$\phi(x, y) = E_{0z}(x, y)$ and boundary condition $\phi = 0$ cf. TM mode

$\phi(x, y) = H_{0z}(x, y)$ and boundary condition $\partial\phi/\partial n = 0$ cf. TE mode.

The eigenvalue Λ is related to the propagation constants in free space ($k_0^2 = \omega_0^2\epsilon\mu$) and in the waveguide ($K_g$) by the equation:

$$\Lambda = k_0^2 - K_g^2 \tag{2}$$

with Green's identity we can reformulate (1)

$$\int_S (\nabla\phi)^2\, ds \Big/ \int_S \phi^2\, ds = \Lambda \tag{3}$$

where S is the cross section of the waveguide.

It has been proven that when ϕ is a solution to the wave equation, the functional of ϕ (3) is stationary. This is formulated using a finite element method [3]. We then obtain the matrix eigenvalue problem:

$$A\bar{\phi} = \Lambda B\bar{\phi}. \tag{4}$$

Finally (4) is solved with an iterative overrelaxation method [3].

A program has been written to compute the normalized cutoff frequencies $\lambda_{C_\perp}$ (respectively, $\lambda_{C_\parallel}$) of the $TE_{11_\perp}$ (respectively, $TE_{11_\parallel}$) for different ridge heights (cf. Fig. 3) as well as the associated transverse field distributions (cf. Fig. 2).

For each section of the septum we can deduce the dispersion curves and obtain the relative phase between the two orthogonal modes:

$$\Delta\phi = 2\pi\,\Delta l\left(\frac{1}{\lambda_{g_\parallel}} - \frac{1}{\lambda_{g_\perp}}\right).$$

The length of each section is adjusted in order to achieve the final 90° relative phase. The last adjustments are done experimentally with a HP8510 vectorial network analyzer.

C. Measured Performances

Two experimental units were designed. One device was built with a 53.5 mmm diameter circular waveguide to operate in the 3.7–4.2

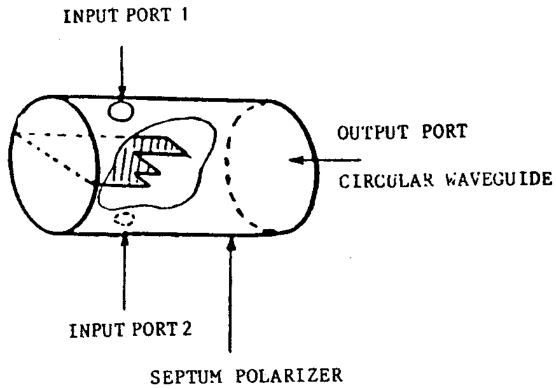

Fig. 1. Septum in circular waveguide.

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[1] Patent pending.

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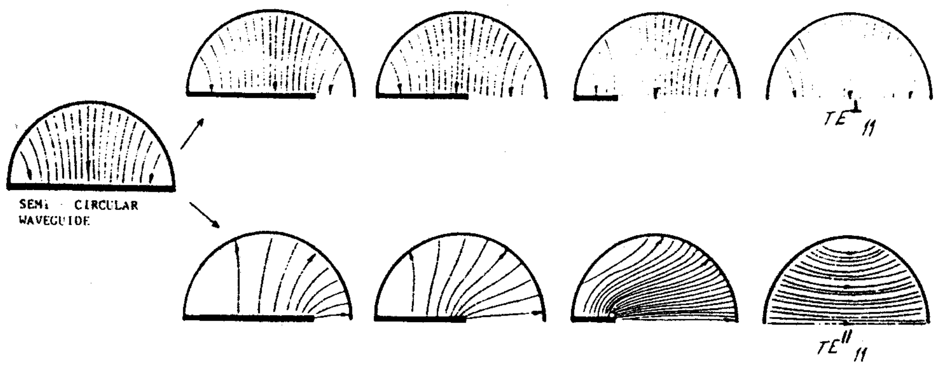

Fig. 2. Excitation of orthogonal modes in semicircular waveguide (computed transverse field distribution).

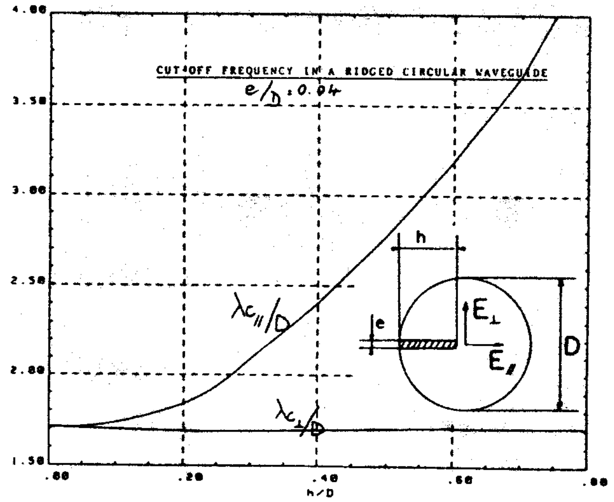

Fig. 3. Cut-off frequency in a ridged circular waveguide.

GHz band. The coaxial input ports (low power application) are realized with O.S.M connectors (cf. Fig. 4), and the probes are matched to the semicircular waveguide with standing wave ratio < 1.1. The ellipticity of the unit is less than 0.25 dB over the entire band.

Another device was designed for the 5.925–6.425 GHz band. The output port is in a circular waveguide (35 mm diameter) and the input ports in a rectangular waveguide (WR 137) (high power capability).

Coupling with the circular waveguide is realized by two slots located at 12° on each side of the septum plane. The matching of the rectangular waveguide input ports, achieved by a resonant iris, is excellent (cf. Fig. 5).

Concerning the ellipticity (cf. Fig. 6), we obtained less than 0.14 dB from 5.75 up to 6.5 GHz. This was measured on the HP8510 network analyzer, connecting the device under test to a rotating load equipped with radial probes. As for the isolation we measured less than −28 dB from 5.85 to 6.6 GHz. It was not optimized, but is seems harder to improve in the circular waveguide than in a square waveguide (less than −40 dB). This is probably due to the coupling of the TM_{01} mode, whose cut-off frequency, in a circular waveguide, is closer to that of the TE_{11} fundamental modes.

II. Conclusion

We have designed a new compact duplexer–polarizer for application to the feeding of rotationally symmetric horns. Two prototypes were built. The SWR and ellipticity performances are extremely good (less than 0.15 dB ellipticity over 15% bandwidth).

The experimental development was facilitated by the computation of the dispersion curves and of the transverse field distribution

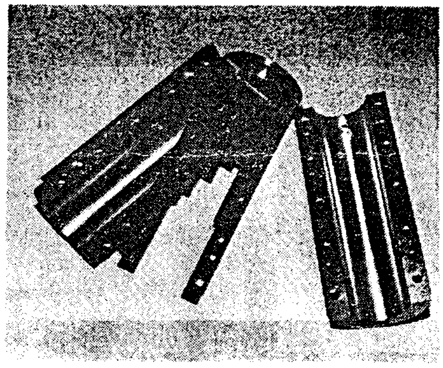

Fig. 4. Prototype no. 1: probe excitation (coaxial input).

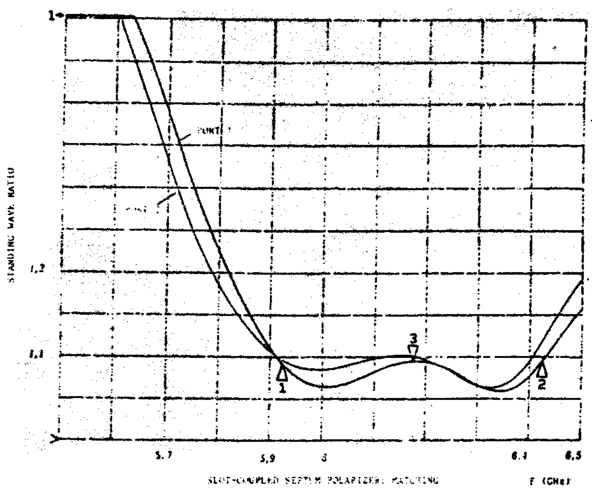

Fig. 5. Slot-coupled septum polarizer: matching.

associated with the two fundamental guided modes propagating in the different sections of the septum waveguide.

However, the exact analysis of this unit with rigorous methods has yet to be done. The isolation performance can then be improved and the element can be made more compact.

Two methods appear well suited to solve this problem.

- On one hand, modal analysis [4], in which the different guided modes propagating in each section of the unit are first computed. The continuity conditions on each transition involve the formulation of the complex excitation coefficient for each propagating mode at the output ports and the reflection coefficient for each mode at the input port. The difficulties associated with this method are principally numerical (mixing of circular and rectangular parts in the cross section of this element prevent expressing the propagating modes analytically). Computational speed remains its main virtue.

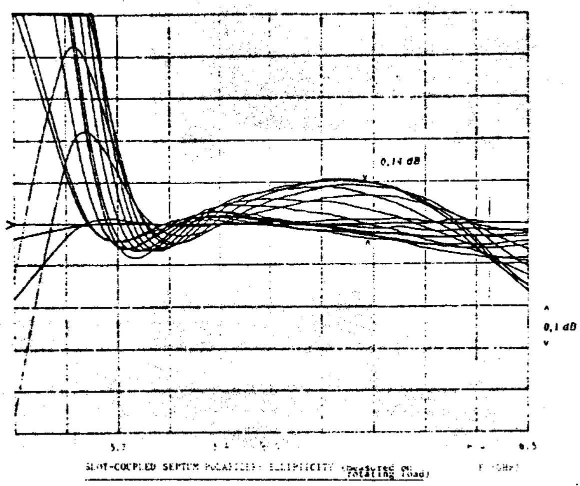

Fig. 6. Slot-coupled septum polarizer: ellipticity (measured on rotating load).

• On the other hand, the integral equation formulation can be used to solve a tridimensional problem. A surface finite element technique provides the numerical solution [5]. Yet, numerical difficulties arise (sampling a volume with boundaries between circular and rectangular elements, matrix dimensions, computation time). However, the accuracy resulting from the global solution of the problem outweighs the computational complexity.

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Backscatter RCS for TE and TM Excitations of Dielectric-Filled Cavity-Backed Apertures in Two-Dimensional Bodies

Paul M. Goggans and Thomas H. Shumpert

Abstract—Both transverse electric (TE) and transverse magnetic (TM) scattering from dielectric-filled, cavity-backed apertures in two-dimensional bodies are treated using the method of moments technique to solve a set of combined-field integral equations for the equivalent induced electric and magnetic currents on the exterior of the scattering body and on the associated aperture. Results are presented for the backscatter radar cross section (RCS) versus the electrical size of the scatterer for two different dielectric-filled cavity-backed geometries: Nonconcentric circular cylinders and concentric square cylinders.

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I. Introduction

A number of investigators have considered the problem of scattering from conducting objects which are partially or completely hollow (or dielectric-filled) and which have some aperture which allows coupling of external energy to the internal cavity and back out again [1]–[5]. This communication presents results which complement those presented in [4] and [5] but address different geometries. Emphasis here is on the backscatter RCS only. When the frequency of the incident energy is at or near one of the internal resonances of the cavity formed by the scattering object with its aperture, the resulting exterior scattered field exhibits rather unusual behavior. In addition to internal resonances, other resonance mechanisms can significantly affect the scattered field.

This communication presents the backscatter radar cross section (RCS) solution for two specific examples: 1) A circular cylinder of infinite length which has an infinite length slot aperture along one side. The cavity inside the cylinder is dielectric-filled and is also of circular cross section. The two cylinders (external and internal) are of different radii and their respective longitudinal axes are parallel but not collocated. The aperture "size" is determined by the angle, ϕ_a, formed by two line segments which emanate from the center of the exterior cylinder and pass (outward) just along the two edges of the aperture, and 2) a square cylinder of infinite length which has an infinite length slot aperture along one side. The cavity inside the square cylinder is dielectric-filled and is also of square cross section. The two square cylinders (external and internal) are of different cross sectional area and their longitudinal axes coincide. The aperture is 1/5 of the dimension of the side of the external cylinder, and it is centered in one side. The radar backscatter is calculated for both transverse electric (TE) and transverse magnetic (TM) polarized plane waves which are incident directly onto the aperture. The dielectric inside the interior cavity is assumed to be linear, isotropic, and homogeneous, and to have a relative permittivity $\epsilon_r = 2$ and a relative permeability $\mu_r = 1$.

II. Formulation

Consider the two-dimensional, dielectric-filled, cavity-backed aperture shown in Fig. 1. The approach for determining the scattered fields from the dielectric-filled, cavity-backed aperture utilizes the method of moments technique to solve a set of combined-field integral equations. The development of the equations follow directly from the work of Mautz and Harrington [6]. The resulting set of combined-field, coupled integral equations may be expressed succinctly, for the TM excitation, as

$$\left[-E_z(\mathbf{J}^+) - E_z(\mathbf{M}) - E_z(\mathbf{J})\right]/\eta^+ - H_t(\mathbf{J}^+) - H_t(\mathbf{M}) - H_t(\mathbf{J}) = E_z(\mathbf{J}^i, \mathbf{M}^i)/\eta^+ + H_t(\mathbf{J}^i, \mathbf{M}^i) \quad \text{just inside } A \text{ and } S^+ \text{ in free space} \tag{1}$$

and

$$\left[E_z(\mathbf{J}^-) + E_z(\mathbf{M}) + E_z(\mathbf{J})\right]/\eta^+ - H_t(\mathbf{J}^-) - H_t(\mathbf{M}) - H_t(\mathbf{J}) = 0 \quad \text{just outside } A \text{ and } S^- \text{ in dielectric.} \tag{2}$$

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Antenna Designer's Notebook

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THE SEPTUM POLARIZER is a microwave antenna component whose usefulness has been recognized by a few, but many antenna engineers seem to be unaware of its existence. The purpose of this DESIGNER's NOTEBOOK page is to introduce this interesting component to our new readers and perhaps to remind our old timers of its potential applications.

DESCRIPTION

Figure 1 illustrates the basic form of the septum polarizer. At

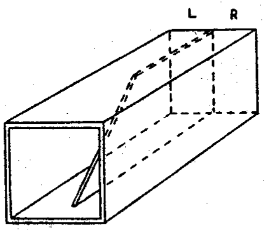

Figure 1. Sloping septum polarizer.

first glance it looks like a three-port device, with two adjacent rectangular waveguide ports at one end, and a square waveguide at the other. In between, the broad wall common to the two rectangular waveguides is tapered (or stepped) to form what may be thought of as a single-ridged waveguide transition. The square waveguide really constitutes two ports because it can support two orthogonal modes, therefore the septum polarizer should be analyzed as a four-port device. With a properly designed septum, this device becomes a waveguide hybrid with some interesting and useful properties applicable to waveguide circuits as well as to antennas.

A signal fed into one of the rectangular ports is transformed into a circularly-polarized field in the square waveguide, hence the name "septum polarizer." If the signal is fed into the port marked R, right-hand circular polarization (RHCP) results, while a signal fed into port L produces LHCP. Conversely, a circularly-polarized field propagating in the square waveguide (toward the septum) couples to only one of the rectangular ports, depending on its sense, e.g., RHCP couples to port R.

PRINCIPLE OF OPERATION

The operation of the septum polarizer is shown in figure 2. A

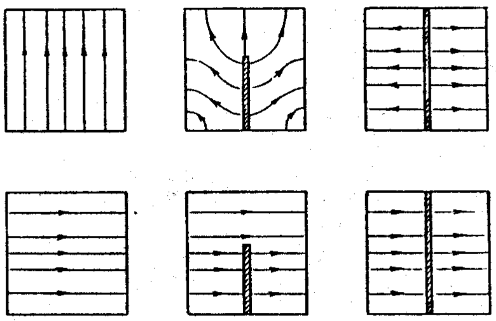

Figure 2. Field transitions.

field component (in the square waveguide) perpendicular to the septum transforms into two even-mode signals in the rectangular ports as shown at the bottom of figure 2; a parallel component transforms into two odd-mode signals. If both components exist simultaneously, cancellation can occur in one rectangular port, provided the amplitudes are identical and the phases are correct.

For example, if a RHCP field is propagating toward the septum, its two orthogonal components will be as shown in figure 3, with

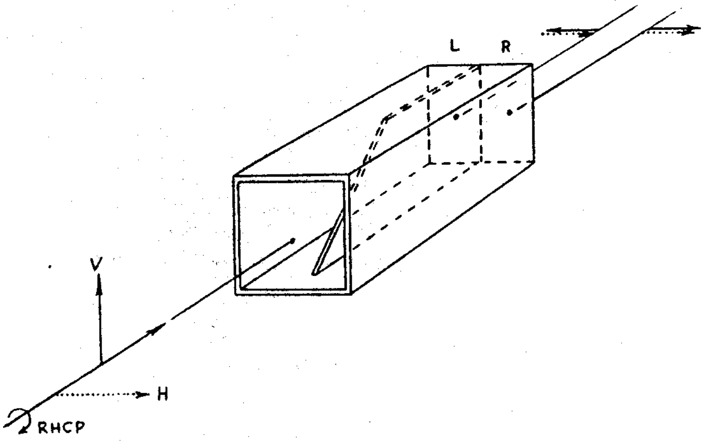

Figure 3. Polarizer operation.

the vertical component leading the horizontal by 90°. The septum region is equivalent to single-ridged waveguide to the vertical component, and it is delayed in phase relative to the horizontal. A properly designed septum makes this differential delay equal to 90°, resulting in field cancellation in port L and reinforcement in port R.

ORIGIN AND EARLY DEVELOPMENT

Surprisingly, the operating principle of this device is described in the MIT Rad. Lab. Series[1] where it is shown in circular rather than square waveguide and applied to a rotary joint design. Bill Parris of Westinghouse, Baltimore recognized the potential of the septum polarizer for CP antenna applications, and later a 15 percent bandwidth polarizer design was developed by Dan Davis, et al[2] who reported their work at the 1967 AP Symposium. An array of five square radiators showed excellent CP patterns even when phase scanned off boresight. This was achieved by optimizing the slope angle of the linearly tapered septum.

MORE RECENT DEVELOPMENTS

Chen and Tsandoulas[3] of Lincoln Labs designed a broader bandwidth (20 percent) polarizer using a stepped septum design as shown in figure 4. Their paper suggests using arrays of these devices

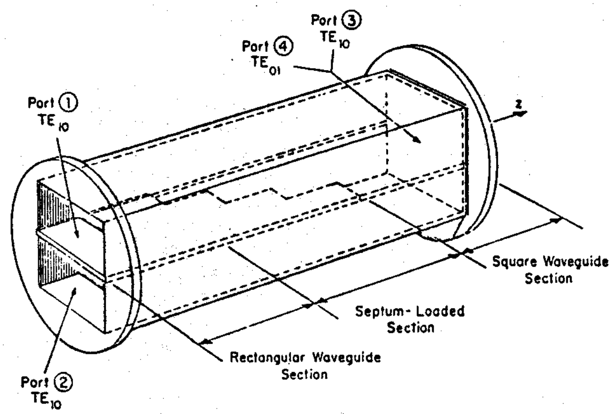

Figure 4. Stepped septum polarizer (from Chen and Tsandoulas).

to produce antennas with polarization diversity, including not only CP but variable angle tilted linear polarizations. Very high purity CP was achieved, with at least 26 dB isolation between orthogonal modes.

Salzberg[4] patented a special septum shape to achieve good isolation and low ellipticity over a wide band. A minimum isolation of 27.5 dB was achieved over a 20.5 percent band, with corresponding ellipticity (axial ratio) of 1.1 dB max.

OTHER APPLICATIONS

The septum polarizer offers a diversity of uses not only for microwave circuits and radiating and/or receiving antennas, but also for measurement applications. At the 1982 APS Symposium in Albuquerque[5] I suggested two possibilities that could be investigated. One is the use of the septum polarizer as a *polarization analyzer.* Looking at figure 3, if a general elliptically polarized wave is picked up by the square port, it is split into its two circular components. The larger of the two rectangular port outputs immediately identifies the sense of the incident polarization, and the ratio of the two signal amplitudes gives the cross-polarization ratio (CPR) from which the axial ratio is easily derived. By measuring the phases of the two signals relative to a reference signal, the tilt angle of the unknown polarization can be derived.

A second use suggested is as a *source of spinning linear* polarization without the need for mechanical rotation and rotary joint. This all-electronic means of achieving spinning linear can be done by phase control of the two equal amplitude signals into the rectangular ports.

CONCLUSION AND CHALLENGE

The septum polarizer is perhaps the most under-utilized waveguide component in our field, and yet it has many potential applications for future antenna designs. I'm sure there are readers out there who have some clever ideas not mentioned here. How about sharing your ideas with us?

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Report of the Division 4 Director

Emerson Pugh

The IEEE Board of Directors took several important actions at its meeting in August. The restructuring of technical societies into ten technically cohesive divisions was formally approved. The impact on Division 4 is substantial with the loss of four of our societies: Components, Hybrids and Manufacturing Technology; Electron Devices; Quantum Electronics and Applications; and Sonics and Ultrasonics. I wish these societies and their members continued success in their new division. Simultaneously, I welcome the Electromagnetic Compatibility Society and the Nuclear and Plasma Sciences Society to Division 4 and am pleased to be able to continue to serve the Antennas and Propagation Society, the Microwave Theory and Techniques Society, and the Magnetics Society as their IEEE Division 4 Director.

In 1984 IEEE will celebrate its centennial year. Each society has special plans to commemorate this event and I urge each member to participate. As an incentive to recruit new members during the last few months of 1983, special centennial gifts are being offered to members who recruit new IEEE members. You will be doing yourself and your friends a favor by urging them to join IEEE at this time. Also, beginning now and during 1984, affiliate members may upgrade their status to full IEEE membership without paying the usual $15 initiation fee -- watch for an official announcement of this program.

Other actions of the board include raising the annual dues by $4 to $52 for all members while keeping the assessment of United States members for professional activities unchanged at $13. A Conference Board had been established to better coordinate conference and exposition activities, which contribute about one quarter of IEEE's total revenues. Finally, consistent with a new IRS regulation of May 1983, the IEEE bylaws were changed to permit sales and order taking at conferences and exhibitions without obtaining prior approval of the Executive Committee.

Important actions by other boards include adoption of a position statement by the United States Activities Board on alien engineers which urges that they practice in their native countries, that they be paid as well as U.S. citizens if they practice in this country, and that only limited exceptions be permitted in the rule that students must return to their own countries for two years before taking employment in the United States. A very significant role has been undertaken by IEEE in the development of standards for unregulated telephone lines in cooperation with the Exchange Carrier Standards Association which was founded on August 1, 1983, to fill the void resulting from the breakup of AT&T.

I look forward to serving as Division 4 Director during the IEEE Centennial year and welcome your comments and suggestions.

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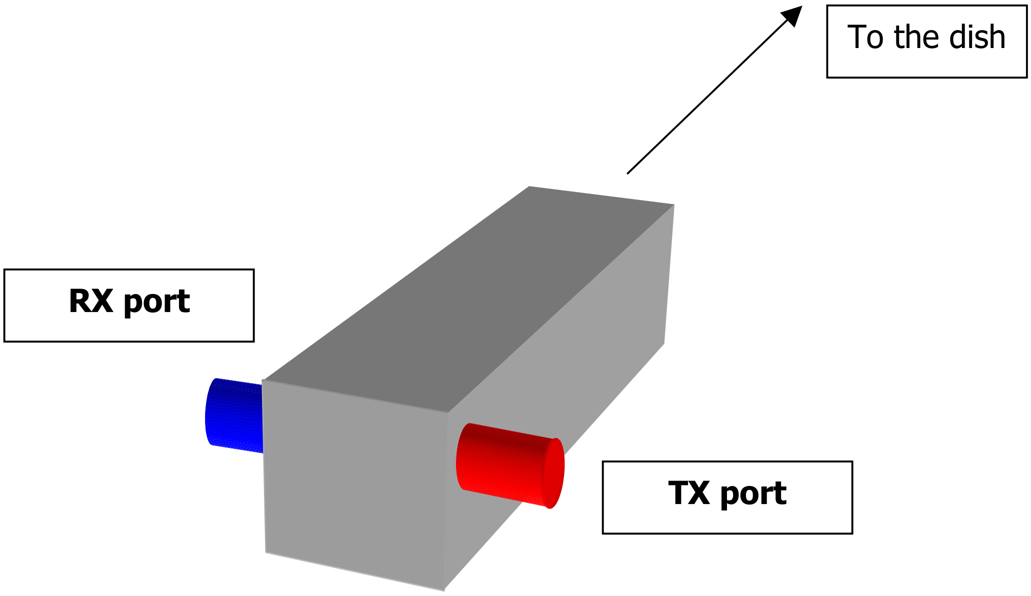
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