A High-Power Rotary Waveguide Joint*

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Summary—A conceptually new type of contactless multichannel rotary waveguide joint is described. Power handling capability without pressurization exceeds that of the associated waveguides.

Electrical features include elimination of impedance and phase variations with rotation, exceptionally low loss and power leakage. Operation is possible over a 10 per cent frequency band with a maximum VSWR of 1.15.

Experimental results on a *C*-band model are given. Both electrical and mechanical design features are presented for a compactly folded design for operation at multimegawatt peak powers.

Introduction

Since most radars employs mechanically scanned antennas, there is usually a requirement for a high-frequency rotatable connection between the antenna and the remaining components of the radar. In pulsed radars, this rotatable connection or "rotary joint" frequently has to conduct relatively high peak-power levels.

Design improvement on the usual types of rotary joints have generally kept pace with increases in radar performance requirements. However, as available power has now increased into the multimegawatt range, electrical performance requirements have become increasingly difficult to meet with further improvements in conventional types of rotary joints.

A high power radar development at Bell Laboratories presented some unusual requirements for the rotary joint. A peak-power capability in the multimegawatt range was required without pressurization or cooling (except for normal indoor ventilation). Furthermore, it was required that the design permit stacking three such rotary joints, each having equal high-power handling capability, on a common axis to enable power to be transmitted simultaneously from three separate transmitters to three separate antennas on a common rotating mount. These requirements are adequately met by a radically new design.

In the description which follows, details of the design of this rotary joint will be described and some of the results of electrical tests on *C*-band models will be given.

Description

As shown in Fig. 1, a series of binary power splitters divides the input rectangular waveguide into sixteen rectangular waveguide sections having TE_{10} fields of equal amplitude. All path lengths are made equal to achieve equal phase between the sections. The cross section of the sixteen waveguides is then changed by slightly flaring one E dimension of the guide to form a keystone segment, as shown in Fig. 2. The E dimensions of the guide gradually change to arcs of a circle. This allows complete alignment of the segments. The flaring of the transitions does not materially change the waveguide fields and the larger E dimension of the keystone is less than $\lambda_c/2$; this prevents the propagation of higher modes. The sixteen segments are arranged circularly to approximate the circular TE_{01} mode shown in Fig. 3.

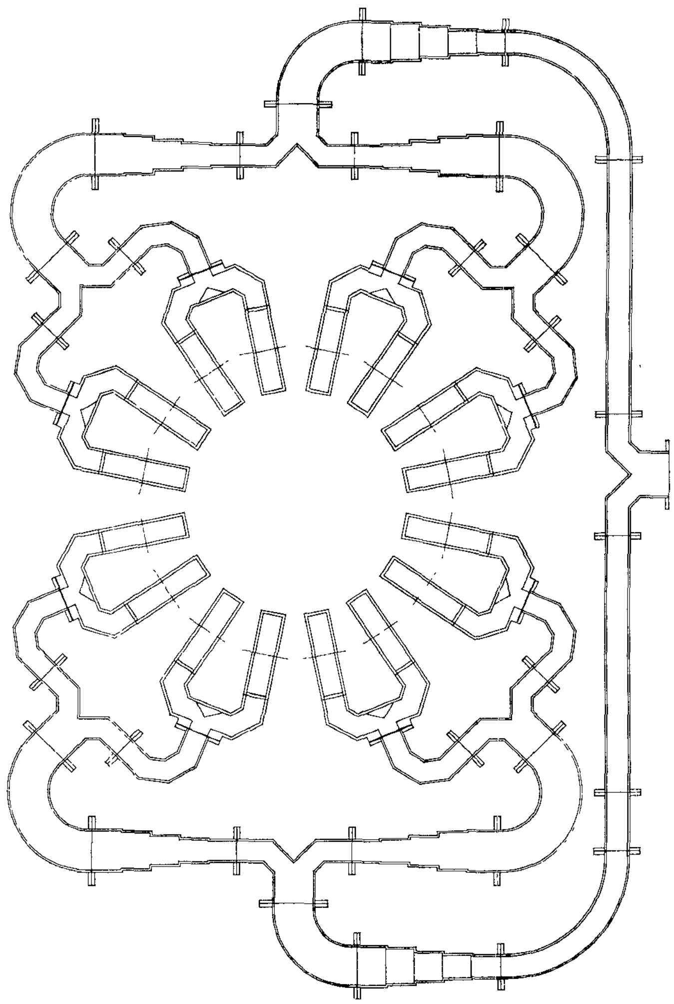

Fig. 1—Drafting layout of folded design feed arrangement.

Thus the rotary joint is analogous to a waveguide mode converter. The rectangular waveguide feed, TE_{10} mode, is converted to a circular TE_{01} mode for transmission across the rotating interface, and then reconverted to the rectangular TE_{10} mode for output. The conversion makes use of the fact that the the electric and magnetic fields of a rectangular guide, Fig. 4,

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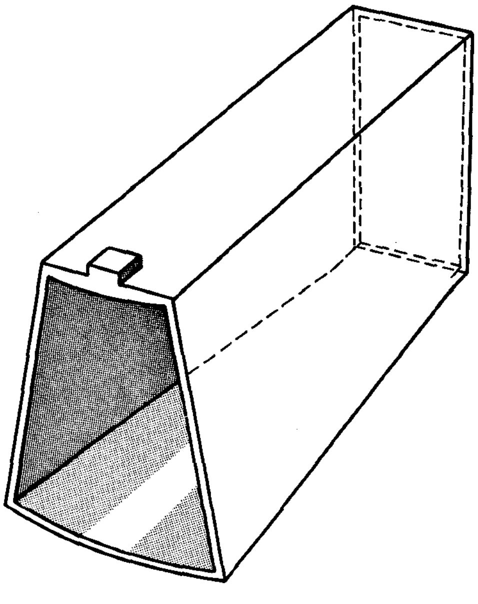

Fig. 2—Transition from rectangular waveguide to segment of a circle.

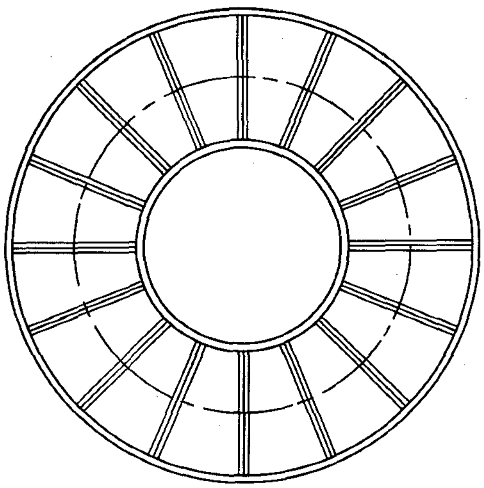

Fig. 3—Combination of segments to form circular TE_{01} mode. Shown is the center hole that allows other waveguide feeds to pass through.

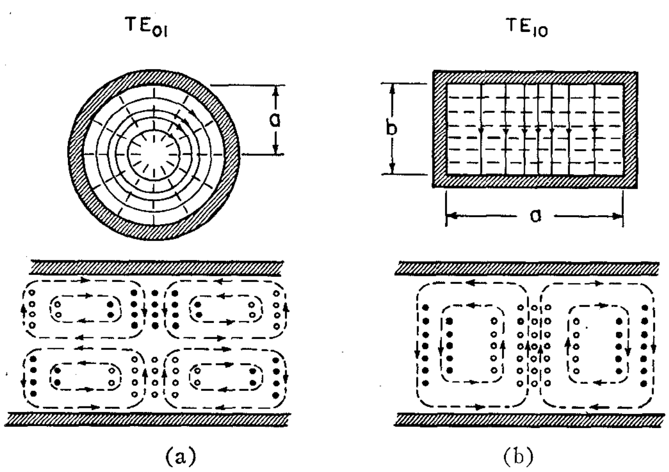

Fig. 4—(a) Circular TE_{01} mode. (b) Rectangular TE_{10} mode. Electric and magnetic fields.

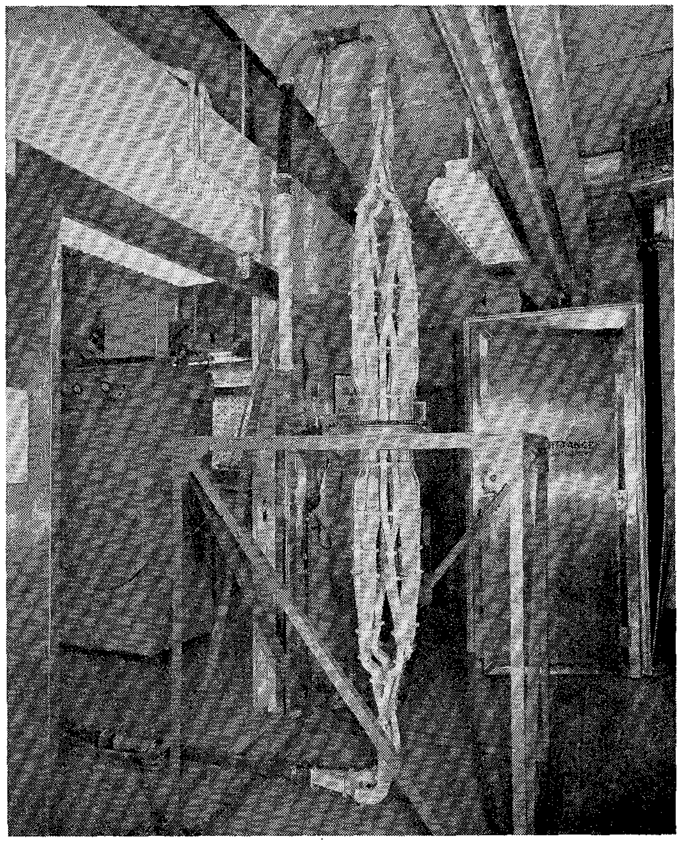

Fig. 5—*C*-band feasibility model.

transmitting the TE_{10} mode are very similar to a segment of the circular TE_{01} mode.

The waveguide configuration differs from the normal circular TE_{01} waveguide in that a center hole now exists. This allows a multichannel capability as waveguide feeds can pass through to identical joints axially mounted.

Septa, which taper to knife edges at the interface of the joint, are placed on the flat formed by the adjacent keystone sections. The knife edge minimizes disturbance to the fields at the interface of the joint when it is rotating.

The circular mode generated is propagated across a small gap to an identical rotating section and reconverts in inverse sequence to a single rectangular TE_{10} output. No RF leakage occurs at the gap because the electric fields close on themselves in the circular TE_{10} mode existing at the interface. Thus no longitudinal currents flow across the gap and no choke joints are required.

Scale Model

A *C*-band feasibility model, Fig. 5, was built utilizing axial stacking of *Y* power splitters to feed the sixteen keystone transitions. Twists of different angles and left or right twists were used for alignment of the splitters. This arrangement, though bulky, insured excellent phase relationship between the individual segments of the circular interface. In this model, a gap of 0.005 inch was maintained at the interface. Results of tests on this model were excellent. The input VSWR indicated no resonances occurred over a 10 per cent bandwidth. The variation of an input VSWR of 1.015 while rotating the joint was less than 0.001. For higher readings of input VSWR no change was perceptible during rotation. The attenuation throughout the entire rotary joint was only 0.01 to 0.07 db higher than the theoretical value for a straight section of waveguide, the same path length as through the test model. After pressurizing the input and output waveguides and splitters, the model handled in excess of three Mw over the 10 per cent bandwidth with no breakdown. There was no breakdown upon rotation at this power level. No RF leakage was detected at the interfaces at a -60-db level.

Prototype

A compact folded design was developed to make the joint more usable (Fig. 6). The feed system is a series of waveguide T power splitters connected by E plane bends and arranged circularly in a plane orthogonal to the rectangular end of the transitions. Fig. 1 is a drafting layout of this feed arrangement. The T power dividers used at the input and as the second and third splitter in the series are a full E dimension input to two half E waveguide outputs. The double reflection corner is used for matching.

A four step binomial impedance transformer is used to convert from the one-half E dimension output of the splitters to the full E input of the next two splitters. These transformers were tested at a power of 1.4 Mw across a 10 per cent bandwidth without breakdown.

The fourth splitter, Fig. 7, was designed for compactness of the joint. It is a combination one-half E dimension T, two $101\frac{1}{4}°$ E plane reflection corners and two 90° H plane reflection corners. This splitter feeds the rectangular end of the transitions. The matching devices of this lumped arrangement are also shown.

Two of these splitters were built to determine the reproducibility of the matching and to test the transitions. The VSWR across the bandwidth, within measuring accuracy, was the same for both splitters using the same matching devices.

New transitions were required due to the half E output of the fourth splitter. The keystone segments are the same size as the full E waveguide model to allow other waveguide feeds to pass through the center hole. Thus the flaring is more severe and the length becomes critical. The minimum length which met design requirements, including the length of the knife edge septum, was determined to be approximately 2 λg.

Each component of this feed system was matched out in C band and the maximum VSWR of any individual component was 1.05 over a 20 per cent bandwidth. The input VSWR for this arrangement was calculated to be 1.3 over a 10 per cent bandwidth.

The design requirement for this rotary joint was a maximum VSWR of 1.15 over a 10 per cent bandwidth.

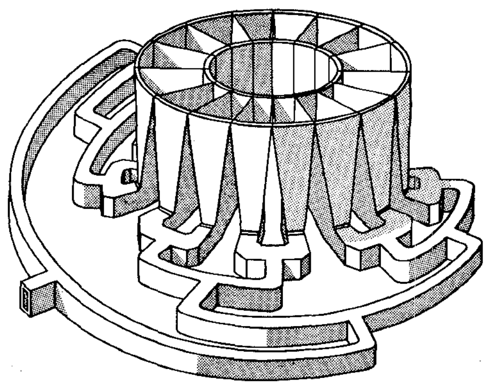

Fig. 6—Feed arrangement of folded design.

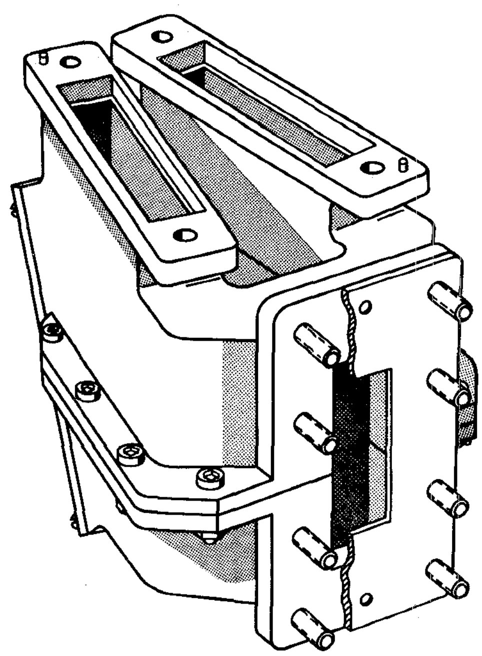

Fig. 7—Fourth splitter of folded feed design

The large number of components in the feed system made it difficult to achieve this requirement. Therefore, a portion of the VSWR was canceled by the following procedure. The input was offset from the center of the feed arrangement by one quarter-wavelength. A one quarter-wavelength section was added between the fourth splitters and the tapered transitions on the same side of the feed system as the offset. This configuration was used in both the stationary and the rotating halves of the joint. Thus, between these two quarter-wave sections, about $\frac{3}{4}$ of the VSWR was canceled over the 10 per cent bandwidth.

The maximum input VSWR now becomes the value of the input splitter plus about $\frac{1}{4}$ of the value of the components between the quarter-wave steps times two, because the input VSWR is the sum of the stationary and rotating sections. As the keystone transitions have a reflection coefficient close to zero, they do not add to the value obtained. With this arrangement, the input VSWR is within the design requirements of a maximum of 1.15.

Features

The principal features of this rotary joint design are as follows. The power handling capability is in excess of that of the main waveguide itself. As the power level in each element at the interface is $\frac{1}{16}$ of the input, the joint does not have to be pressurized. The large hole through the center permits two or more rotating antennas to be independently fed from a corresponding number of fixed transmitters which may operate on different frequencies with different or variable power outputs. The joint is free from electrical resonances and from higher order waveguide modes. There are no ripple effects or commutation in input impedance characteristics with rotation. All sliding or other electrical contacts are eliminated. There is no radiation leakage because of the uniform 360° closed field. It is amenable to very broad-band operation. The field pattern is similar to the field pattern associated with the TE_{01} mode in a circular waveguide, but with the advantage that higher order modes cannot propagate in this structure. The system can also be used as a power adder by adding the outputs of several synchronized klystrons. For example, four klystrons could be paralleled by connecting each to the input of the third level splitters.

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A Harmonic Rejection Filter Designed by an Exact Method*

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Summary—**An exact design procedure for band-stop filters is used to design a transmission-line filter with one point of perfect match at a fundamental frequency and one point of infinite attenuation at a harmonic frequency. This design method is based on the mapping of the response of a low-pass prototype into that of a transmission line filter. Here a three-element Chebyshev filter is chosen as the prototype and the otherwise general procedure is adapted for the special case of rejection of the second harmonic.**

Introduction

A HARMONIC REJECTION filter has, ideally, zero attenuation at the fundamental frequency, and infinite attenuation at a harmonic of the fundamental frequency. Although the pass band and stop band of the harmonic rejection filter might be narrow, they are always widely separated. Thus, the band-stop filter design theory that is used must be accurate over very wide bandwidths. Band-stop filters with narrow stop bands have been developed before,[1] and general design formulas of very good accuracy for this case have been given. The band-stop filter design method given here, however, is a special application of an exact design procedure[2] that is not limited theoretically with respect to bandwidth. This exact design procedure applies to a broad class of microwave band-stop filters. The main feature of this method is a table of easy-to-use formulas for one- to five-element (or stub) transmission-line filters. Each such filter is based on a low-pass prototype whose element values are used in the table of formulas.

Second-Harmonic Rejection Filter

A transmission-line filter which has theoretically zero attenuation at a chosen frequency ω_V and infinite attenuation at $2\omega_V$ is shown in Fig. 1 together with the computed attenuation L_A in the stop band, and the computed VSWR and attenuation in the pass band. The filter consists of a symmetrical arrangement of three open-circuited stubs in shunt with the main line. All stub lengths and stub separations are exactly one-quarter wavelength long at the second harmonic frequency. The impedances of the stub and of the connecting lines were found by first choosing a three-element, low-pass, prototype circuit and then applying appropriate exact design formulas,[2] as explained below. The low-pass prototype is of the Chebyshev type with two points of zero attenuation in the pass band and

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