A MULTI-CHANNEL ROTARY JOINT FOR SPACECRAFT APPLICATIONS

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Abstract

A four-channel coaxial rotary joint has been designed for transferring S- and X-band signals between a spinning satellite and a despun antenna system. Measurements show insertion losses under 0.5 dB, VSWR's under 1.2, and inter-channel isolations exceeding 50 dB.

Introduction

The rotary joint described was developed to provide multi-channel transmission of microwave signals between a spinning satellite in synchronous orbit, and a set of despun antennas mounted thereon, positioned to illuminate a fixed portion of the earth. Originally the device was designed to accommodate three X-band signals in the 7 to 8 GHz range; a fourth S-band 2-GHz was added later. Required characteristics were minimum insertion loss, maximum isolation between channels, low VSWR, small size and weight, and avoidance of sliding contacts. The maximum power to be transmitted was 20 watts.

A review of possible design approaches[1,2] led to the selection of a concentric coaxial line configuration for the main body of the rotary joint, with integral transitions to waveguide at both ends for minimum overall system losses. A sketch of the basic design layout is given in Figure 1, including the motor-drive assembly, which incorporates the bearings supporting the two sections of the joint. The principal design features of the rotary joint are described in the following sections.

Coaxial Line Sizes

Sizes of the individual coaxial lines were chosen for maximum impedance levels (for ease of matching) consistent with the following constraints:

(1) adequate wall thicknesses for structural rigidity;

(2) minimum choke gaps of 0.020 inch for reasonable machining tolerances;

(3) maximum outer diameter of 2.00 inches for reasonable bearing size (to reduce friction);

(4) minimum diameters to eliminate higher-order modes wherever possible.

The final design was such that only a single higher-order mode would propagate in one X-band channel. The impedance levels of the individual channels varied between 15 and 35 ohms.

Chokes

Non-contacting quarter-wave type chokes were used between channels to provide maximum isolation with minimum VSWR over the operating bands[3]. The maximum VSWR contribution calculated for the chokes was 1.10, which occurred in the S-band channel with the widest bandwidth requirement of 30%. Calculated isolation between channels was in excess of 50 dB, except for one pair of X-band channels whose bands were separated by about 10%. In this case, the choke lengths were chosen to maximize isolation for the channel carrying the higher-power transmitter signal, to maintain 50 dB isolation into the receiver channel; isolation at the receive band dropped to 40 dB.

A special problem exists in the choke between the X-band and the outer S-band channel, where the respective frequency bands are widely separated. Interaction effects were avoided by introducing resistive loading between separate choke sections for the two bands. This proved quite effective, as measured isolation at both X- and S-bands was in excess of 50 dB.

Output Transitions

Ridge waveguide transitions were used to couple out of the concentric coaxial lines in all channels; they provided the following advantages:

(1) ease of impedance matching to the low-impedance coaxial sections;

(2) elimination of added shunt chokes, which appear inevitable with any other type of off-center coaxial feeds;

(3) elimination of rotating choke in center conductor of concentric coaxial assembly, by employing non-contacting transition at one end.

The individual channel designs[4] utilized multi-section quarter-wave ridge transformers from the impedance of the coaxial section to that of half-height rectangular waveguide, with additional stepped transformers to full-height guide. The S-band and the outer X-band channels utilize dual ridge-waveguide feeds, with separate outputs which are combined in hybrid junctions. This technique provides the following advantages:

(1) doubles the minimum ridge waveguide impedance required for matching to the low-impedance (15 ohm) coax;

(2) avoids higher-mode excitation of the coax due to feed symmetry;

(3) provides loading of the higher mode by the termination on the fourth hybrid port.

Individual outputs from the S-band channel were by means of separate transitions to dual coaxial lines, and a coaxial form of hybrid was used. The X-band hybrid was a Magic-tee in half-height waveguide, as seen in Figure 2.

Matching

Separate test fixtures were constructed to match out each channel transition. Special problems were encountered in determining the match condition of the dual-fed channels prior to matching, since the only legitimate impedance data occurs when both of the dual inputs are fed in the same phase. This problem was overcome by referring impedance measurements to the coaxial sections, using one of the balanced transitions (one end of the rotary joint) to feed the other, and terminating the balanced outputs in a pair of matched loads. The effect of the input transition was then calibrated out of the measurement by use of an automatic network analyzer, allowing real-time optimization of the adjustable matching circuits.

Experimental Model

An experimental model of the four-channel rotary joint was fabricated from aluminum, and is shown in Figure 2, mounted in its motor-drive assembly. The design is such that the rotating coaxial sections extend through the bearings, with waveguide transitions emerging from both ends. A separate view of the two end sections of the joint is pictured in Figure 3, where the concentric coaxial choke sections are easily seen, as well as the X-band hybrid. Figure 4 depicts a disassembled view of the joint, with the dual S-band coaxial outputs in evidence, as well as the design philosophy of making the individual channels separately replaceable for ease of incorporating new designs and modifications - such as a UHF channel in place of the S-band, which is currently under development.

Measurements on the experimental model showed excellent characteristics in the two center channels - under 1.15 VSWR and 0.3 to 0.5 dB loss over the desired 3% to 5% bands. Loss in the third S-band channel is somewhat higher, approaching 0.75 dB, partly because of the added hybrid loss; however, VSWR is under 1.2. The outside S-band channel exhibits approximately the same loss over a 15% band, with a somewhat higher VSWR. The "WOW", or variation of characteristics with rotation, is nearly unobservable. Isolation between channel is generally in excess of 50 dB, as calculated. The entire four-channel unit, exclusive of the motor-drive assembly, weighs less than six pounds, which can probably be reduced by one-third using standard weight-saving construction techniques.

The experimental model was subjected to a series of space-qualifying environmental tests, including temperature, vibration, and power-vacuum. No change in characteristics was observed over the temperature range of -20^{o} to $+135^{o}$F., and no damage was caused by swept vibration tests up to a level of 15 g's. No evidence of multipacting was observed at normal operating power levels in a vacuum of 10^{-5} Torr. Calculations show that the minimum-loss X-band channel (#2) should be able to carry up to 200 watts without multipacting. At this power level, dissipation in the joint would be only about 12 watts.

Conclusions

A four-channel version of a non-contacting rotary joint suitable for spacecraft applications has been built and evaluated. It incorporates three X-band and one S-band channels, which are designed as concentric coaxial sections with integral chokes and waveguide transitions. Tests showed excellent electrical characteristics over bandwidths of 3% to 15%, and over a wide range of environmental conditions, thus demonstrating the feasibility of using this type component as a basic element in a spin-stabilized satellite application.

Acknowledgments

Mechanical details of the rotary joint design were ably handled by Mr. Richard Arnold.

References

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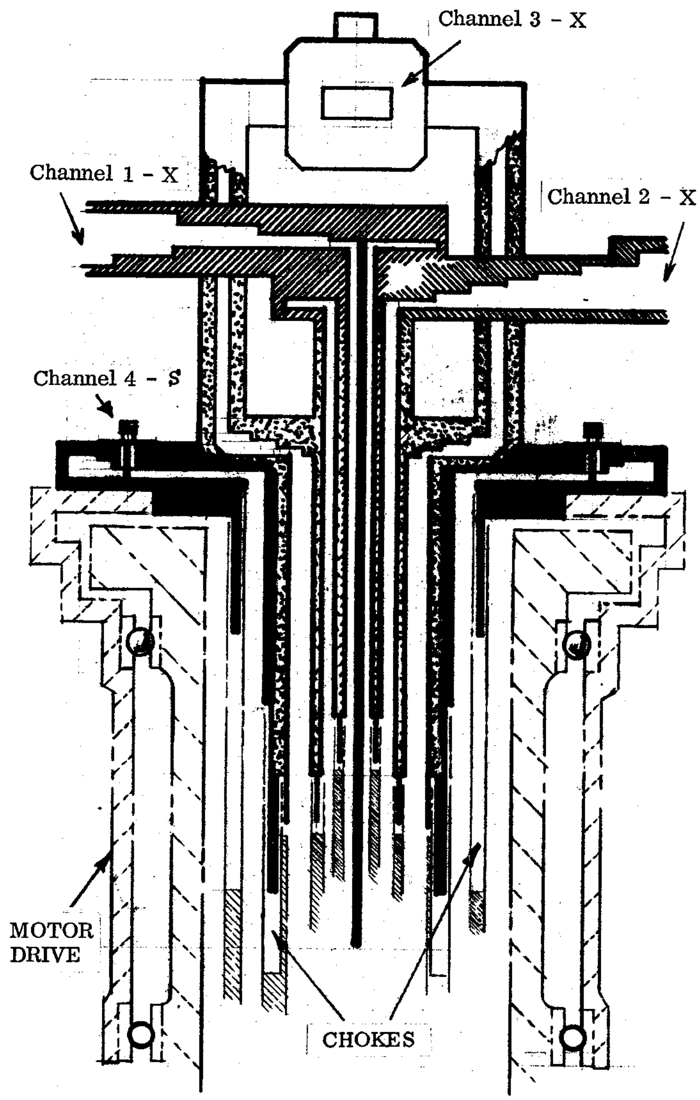
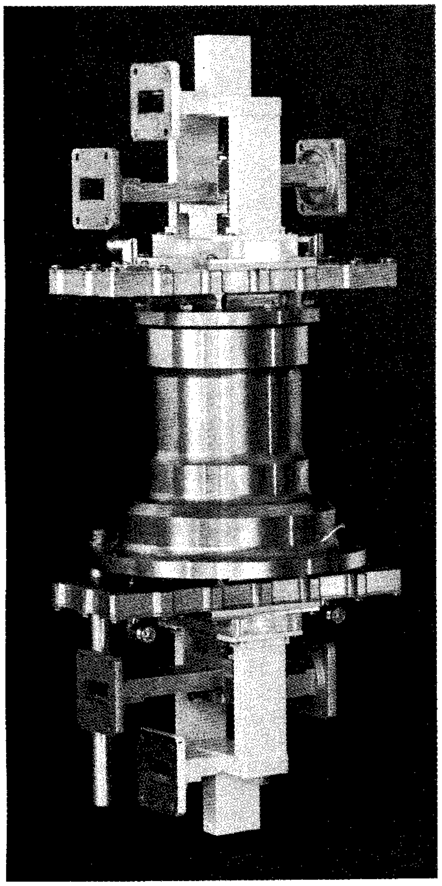


FIG. 1. DESIGN DETAILS OF ROTARY JOINT



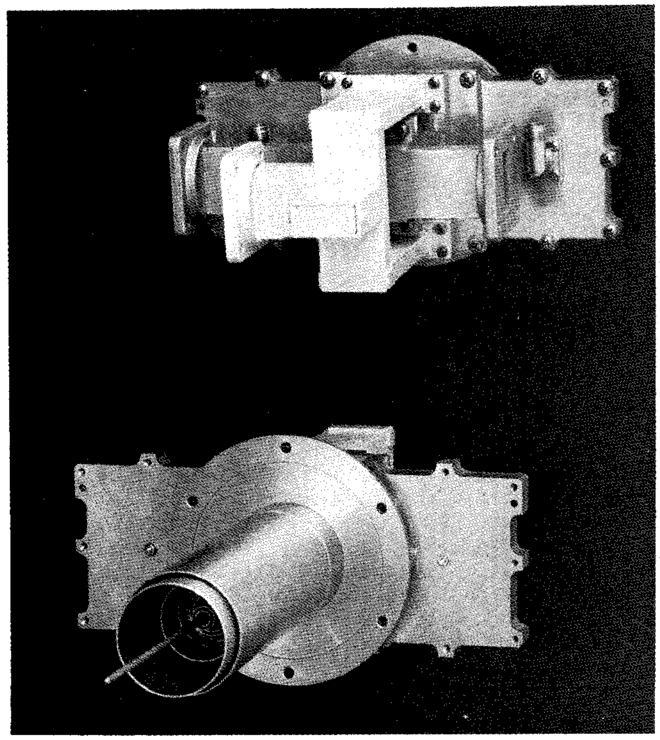


FIG. 3. END-SECTION ROTARY JOINT ASSEMBLIES

FIG. 2. ASSEMBLED 4-CHANNEL ROTARY JOINT

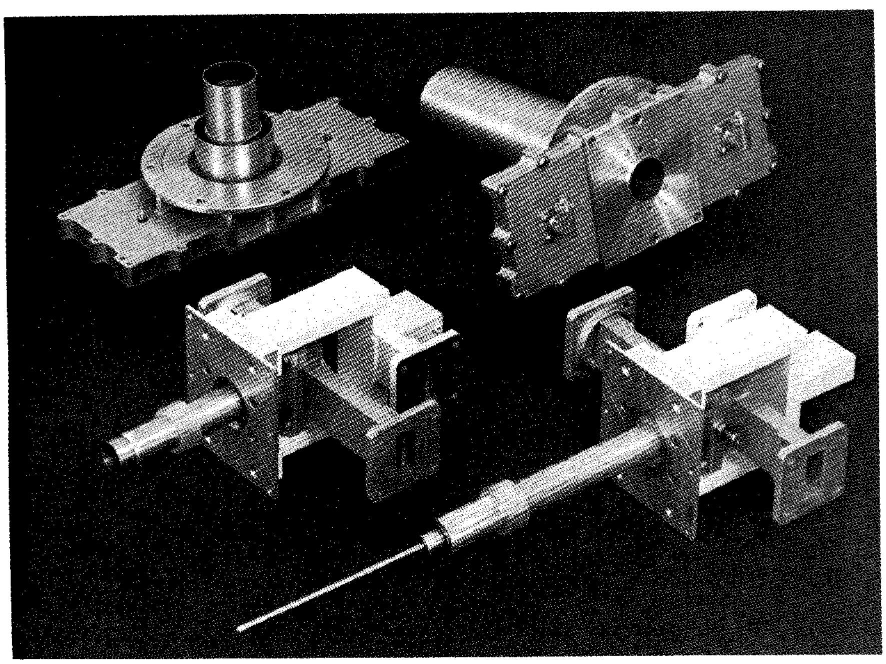


FIG. 4. DISASSEMBLED ROTARY JOINT