A BROADBAND WAVEGUIDE THERMAL ISOLATOR

J. L. Hesler †, A. R. Kerr ‡ and N. Horner ‡

† University of Virginia Dept. of ECE
Charlottesville, VA 22902
e-mail: hesler@virginia.edu

‡ National Radio Astronomy Observatory *
Charlottesville, VA 22903

ABSTRACT

This paper describes a new, compact, waveguide thermal isolator. The isolator is based on a recently developed microwave bandgap joint, a periodic structure which suppresses microwave fields propagating between two parallel conducting surfaces. When such a structure is placed between a pair of waveguide flanges, the flanges can be separated by a few percent of a wavelength before the leakage and mismatch become significant. The thermal isolator is relatively immune to misalignment and cocking. Simulations and measurements on WR-10 thermal isolators indicate excellent performance over the entire waveguide band. The design is readily scalable to other waveguide bands.

Keywords: Waveguide components, waveguide transitions, thermal isolators

INTRODUCTION

When microwave or millimeter-wave equipment is operated at cryogenic temperatures, it is often necessary to make waveguide connections to it from room temperature. To reduce heat flow along the waveguide, some form of thermal isolation is normally used. Often, a length of thin-walled stainless-steel waveguide is used, but the attenuation of stainless-steel can be unacceptable, particularly at shorter wavelengths. The attenuation can be reduced by plating the inside of the waveguide with a few skin-depths of gold or copper, but this substantially increases the heat flow. An alternative approach is to use an abrupt thermal transition consisting of a small gap between the hot and cold sections of waveguide. Several designs for such thermal isolators have been described [1-3], but these tend to be sensitive to alignment and/or have resonance-free performance over less than a full waveguide band. This paper describes a waveguide thermal isolator which overcomes these drawbacks. The isolator, shown in Fig. 1, uses two flanged waveguide sections, separated by a small gap and supported by a G-10 glass-epoxy tube. It is based on a recently developed microwave bandgap joint, a periodic structure that suppresses microwave fields propagating between two parallel conducting surfaces [4]. When such a bandgap structure is placed between a pair of waveguide flanges, the flanges can be separated by a few percent of a wavelength before the leakage and mismatch become

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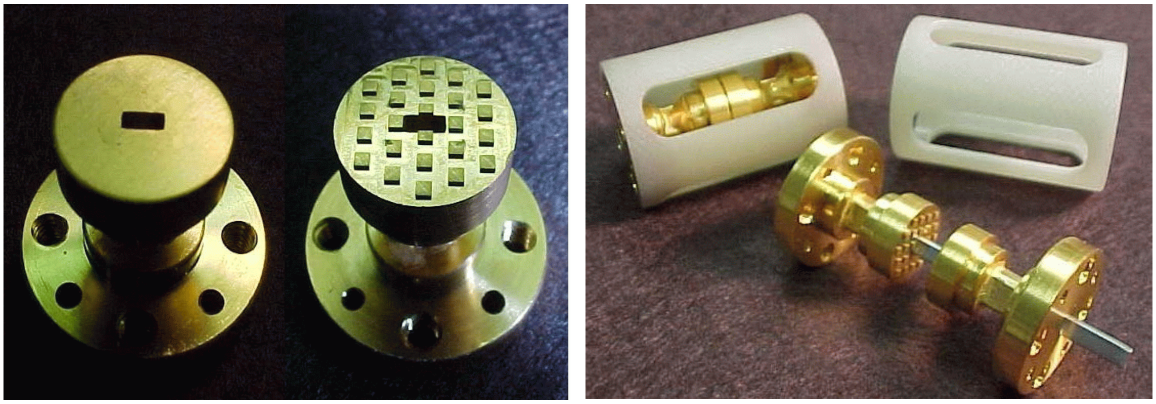
significant. One advantage of this design over other thermal isolators is that it is relatively immune to cocking and misalignment.



(a) (b)

Fig. 1. (a) The two waveguide sections of the isolator, showing the flat flange and the flange with the periodic bandgap structure. (b) The assembled thermal isolator and the individual parts. The waveguide sections are shown on the alignment mandrel used during assembly.

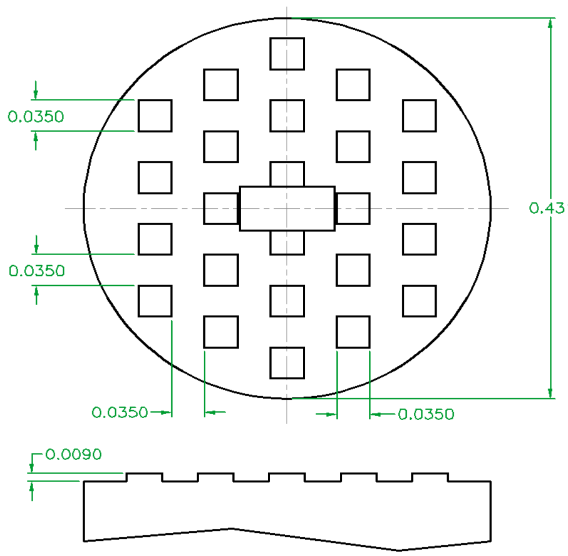


Fig. 2. Details of the periodic bandgap array for WR-10 waveguide (0.100" x 0.050"). Dimensions are in inches. The array is machined on only one side of the gap, the opposing flange being of the same diameter but flat.

DESIGN

An electromagnetic bandgap structure uses a periodic two-dimensional array of reflecting elements with approximately half-wavelength period. In this application, an array of metal posts is machined on the face of one flange of a pair, as shown in Fig. 1(a). Simulations with various array dimensions and gap widths were performed using QuickWave [5]. For the WR-10 (75-110 GHz) design described here, satisfactory results were obtained with 0.035" square pillars and a pitch of 0.070", adjacent rows being staggered by 0.035", as shown in Fig. 2. Simulation indicates that the height of the posts is not critical. All dimensions can be scaled with wavelength for operation in other bands.

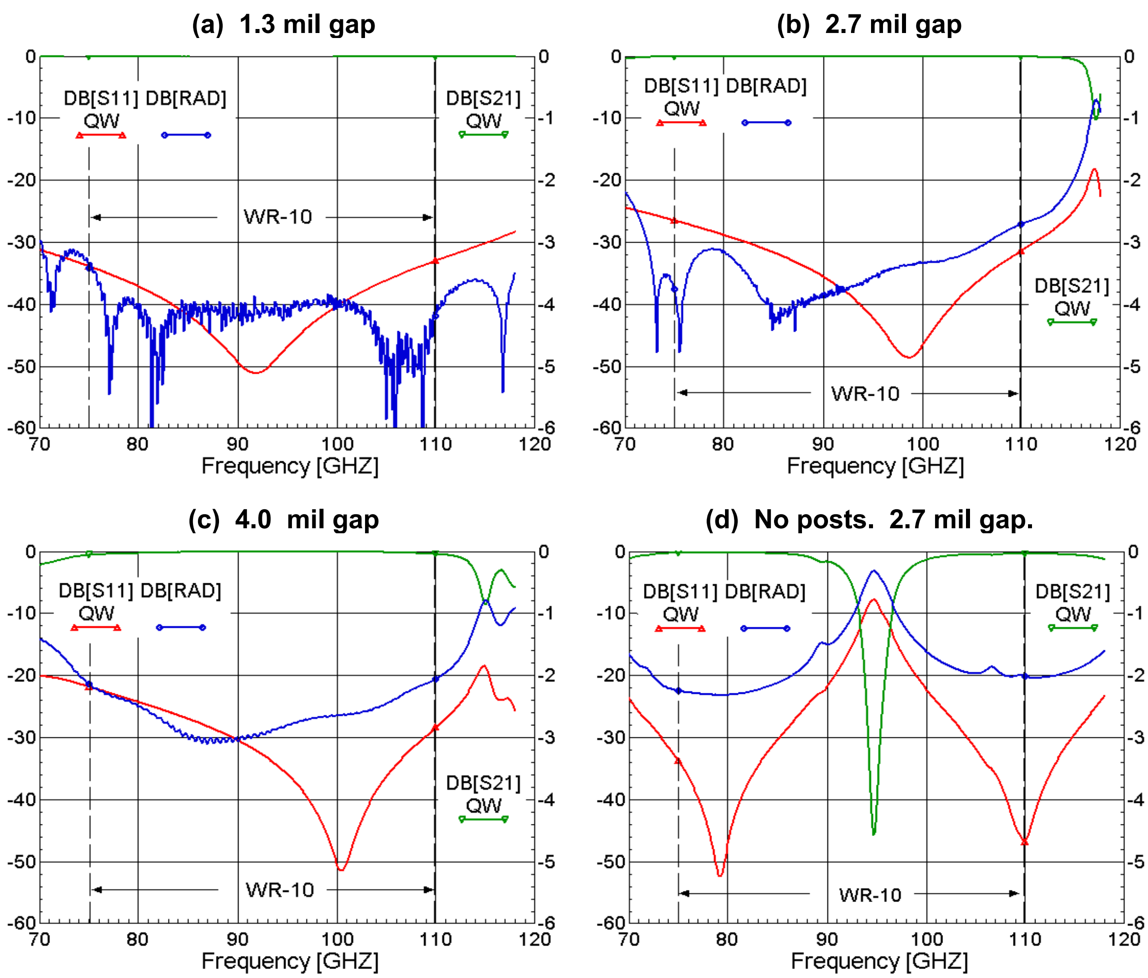


Fig. 3. Characteristics of the thermal isolator with different gap widths. (a) 1.3 mil gap, (b) 2.7 mil gap, (c) 4.0 mil gap, and (d) 2.7 mil gap without the periodic structure. Simulations using QuickWave: |S11| dB (—▲—), |S21| dB (—▼—), power radiated from gap dB (—◆—).

Figure 3 compares the performance of WR-10 thermal isolators using the bandgap array of Fig. 2 with gap widths 0.013", 0.027", and 0.0040", and also an isolator with gap width 0.0027" but without the bandgap array. For small gaps, the performance is nearly ideal. As the gap increases to 0.0027”, the return loss remains better than 25 dB within waveguide band, and with a 0.004” gap the return loss is greater than 20 dB. It is clear that the gap between the flanges can be as large as 3% of a wavelength without serious degradation of the transmission and return loss over the full waveguide band. For the isolator without the bandgap array, a strong transmission minimum is present near the center of the band. It has also been observed that without the bandgap structure, the isolator is quite sensitive to misalignment and gap width, and is particularly sensitive to cocking.

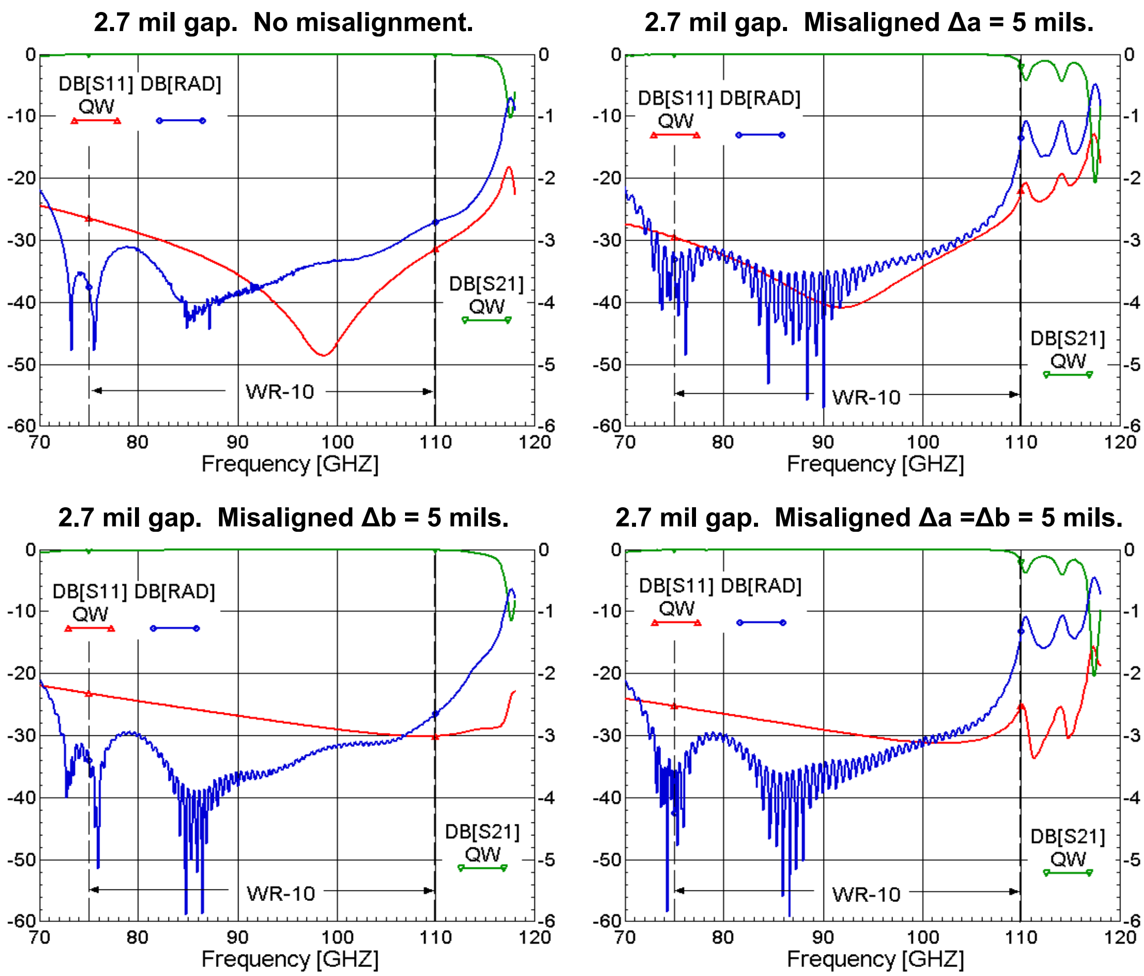
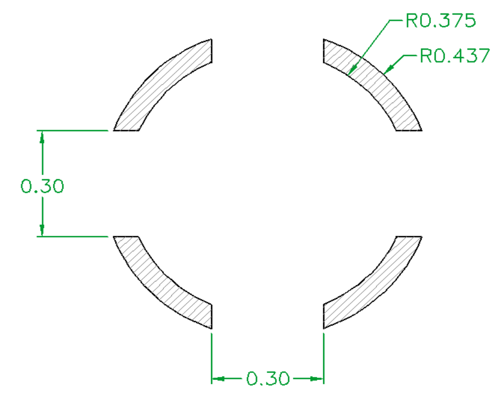
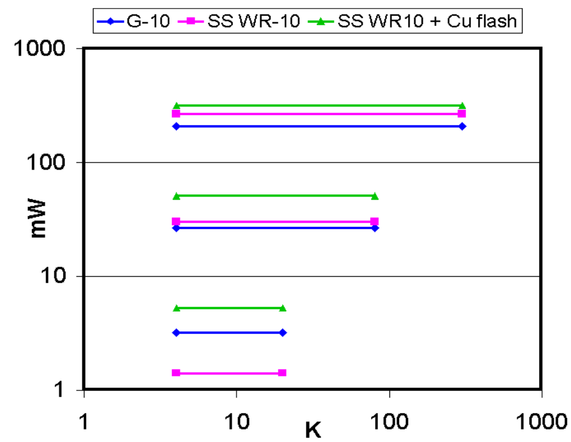


Fig. 4. Characteristics of the thermal isolator with different lateral misalignments. (a) No misalignment (same as Fig 3(b)), (b) 5 mil misalignment in the *a* direction, (c) 5 mil misalignment in the *b* direction, (d) 5 mil misalignment in both *a* and *b* directions. In all cases the gap width is 2.7 mils. Simulations using QuickWave: |S11| dB (—▲—), |S21| dB (—▼—), power radiated from gap dB (—◆—).

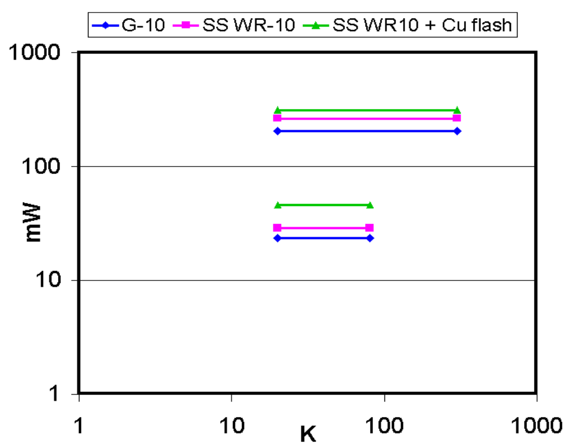
Figure 4 shows the effect of misalignments between the two flanges, and indicates that for reasonable machining tolerances good performance can be maintained.



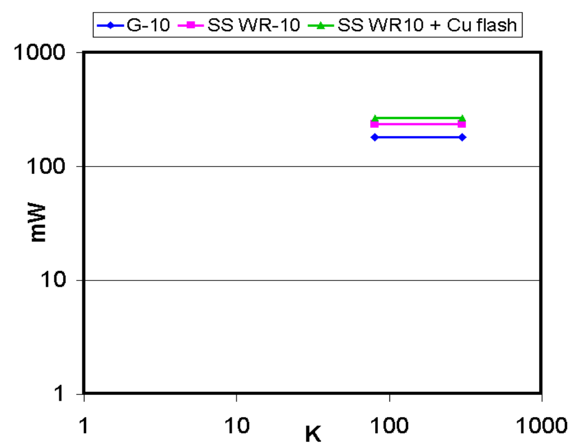
(a) Cross-section of G-10 support. Dimensions in inches.



(b) Cold end at 4 K.



(c) Cold end at 15 K.



(d) Cold end at 80 K.

Fig. 5. Heat flow through the thermal isolator compared with that of plated and unplated stainless-steel waveguides of the same length (1.0"). (a) Cross-section of the G-10 support. The graphs show the heat flow when the cold end is at (b) 4 K, (c) 15 K, and (d) 80 K, for G-10 (—◆—), stainless-steel WR-10 with 10 mil wall thickness (—■—), and stainless-steel WR-10 with 10-mil wall thickness plated inside with 40 μ-in copper (—▲—).

HEAT FLOW CALCULATIONS

To compare the thermal performance of the isolator with that of a comparable length of stainless-steel waveguide, we consider the isolator supported as shown in Fig. 1(b) by a G-10 glass-epoxy tube of inside diameter 3/4" and wall thickness 1/16". Four 0.3" wide slots were machined in the G-10 tube to reduce heat flow. The cross-section of the G-10 support is shown in Fig. 5(a). The stainless-steel WR-10 waveguide has a wall thickness of 0.010", and, in one example, it is plated inside with 40 μ-in of copper. The heat flow was calculated from the thermal conductivity *K*(*T*) of the materials. Figs. 5(b)-(d) show the results of the thermal analysis. It is clear that the G-10 supported isolator is superior except when the isolator spans 4-20 K, in which range the unplated stainless-steel waveguide is superior thermally. For all other temperature spans (4-80, 4-300, 20-80, 20-300, and 80-300 K), the G-10 supported isolator has lower heat flow than the stainless-steel waveguide by a factor of 1.2-1.3. Compared with the copper-plated stainless-steel waveguide, the G-10 supported isolator has lower heat flow by a factor of 1.5-2.0. The RF loss of unplated stainless-steel WR-10 waveguide is ~1 dB/inch higher than that of coin silver waveguide as used in a gap type of isolator.

CONSTRUCTION

The two waveguide sections are glued into a thin-walled G-10 glass-epoxy tube, as shown in Fig. 1(b), using Armstrong A12 epoxy. To maintain alignment while the epoxy cures, a removable mandrel is inserted through both waveguides. Differential contraction between coin silver and G-10 is approximately 0.0012 inches/inch from 300 K to 4 K, so for cryogenic operation, the isolator can be made with no gap at room temperature. (The isolators described here were measured at room temperature, so the desired gap was set with a spacer during assembly.)

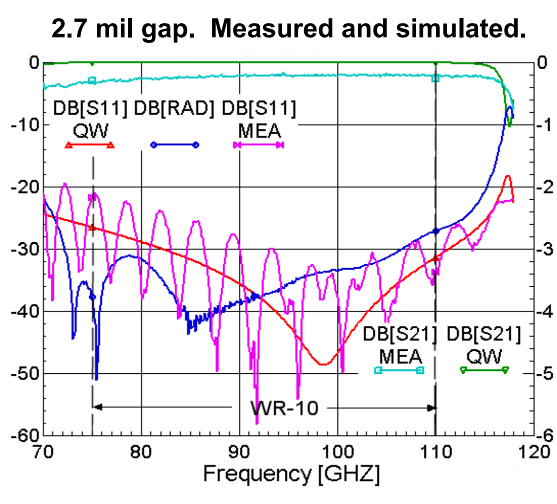


Fig. 6. Measured and simulated characteristics of the thermal isolator with a 2.7 mil gap. Measurements: |S11| dB (—⧗—), |S21| dB (—◘—). Simulations using QuickWave (same as Fig. 3(b)): |S11| dB (—▲—), |S21| dB (—▼—), power radiated from gap dB (—◆—). The ripples on the measured |S11| data are caused by the interaction between the reflections at the two flanges (< -30 dB) and the gap itself.

MEASUREMENTS IN WR-10

Measurements were performed on the WR-10 thermal isolator using an HP8510 vector network analyzer. The measurements, shown in Fig. 6 for an isolator with a 0.0027" gap, agree well with the QuickWave simulations. The ripples in $|S_{11}|$ are caused by the interaction between the reflections at the two flanges (< -30 dB) and the gap itself. The measured midband loss is that of the coin silver waveguide used in the isolator.

CONCLUSIONS

The new waveguide thermal isolator has low return loss and insertion loss over the full waveguide band. It is relatively immune to cocking and misalignment, and does not exhibit the in-band resonances common in other waveguide gap designs. Its insertion loss is essentially that of the coin silver waveguide used in its construction, and is hence much lower than that of a comparable thermal isolator made of thin-walled stainless-steel waveguide. The design is readily scalable for operation in other waveguide bands.

ACKNOWLEDGMENT

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