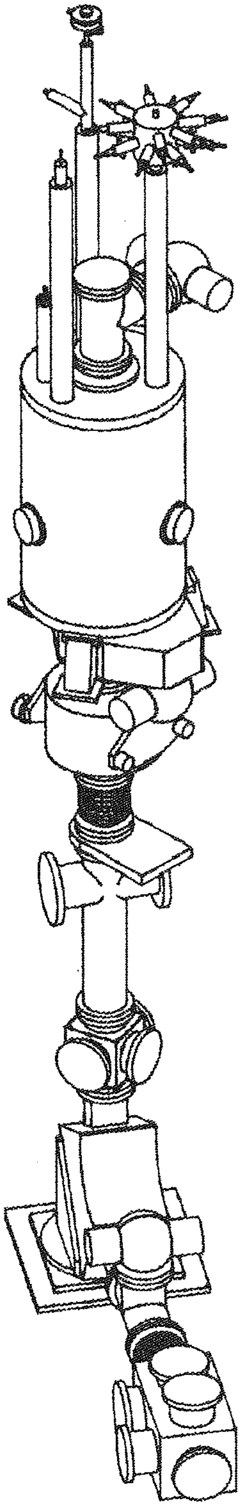
# Michigan State University

## National Superconducting Cyclotron Laboratory



# The Development of 6.4 GHz Waveguide High Voltage Isolators for 30-50 kV Operation of the SCECR

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## 1 Introduction

For the coupled cyclotron proposal at NSCL, it will be necessary to operate the SCECR at a positive bias voltage of at least 30 kV, but possibly as high as 50 kV. At present, the SCECR has been designed to operate in the range of 5-20 kV, the required voltage range for first harmonic cyclotron injection. Of fundamental importance is the question – can the SCECR operate in this higher voltage regime without having to place it on a platform? As a dynamically fed cryogenics device, placing the SCECR on a high voltage platform would be a non-trivial effort.

When one discusses the ion source bias voltage, one is actually referring to the plasma chamber bias with respect to the extraction beamline. The voltage holding dependencies of the SCECR including the source bias are shown schematically in Figure 1. The copper plasma chamber is centered in the bore of the superconducting magnet by the main support insulator. This insulator isolates the plasma chamber from the exit beamline at ground potential, while at the same time, providing a high vacuum connection to the beamline. A Teflon wrapped 'skin' isolates the sides of the plasma chamber from the magnet bore, allowing the magnet, cryogenics and controls to reside at ground potential. The waveguide high voltage joint isolates the microwave transmitter from the positive bias of the plasma chamber. All of these insulation systems must function properly for the SCECR to operate directly at bias voltages of 30-50 kV.

In this paper, we would like to report the development of two microwave high voltage isolation joints for 30 kV and 50 kV operation respectively.

| | **Melting Point** $^\circ$**C** | **Dielectric Constant** | **Dielectric Strength (v/mil)** | **Radiation Limit (RAD)** |
|---|---|---|---|---|
| Kapton Type HN | none | 3.4 - 3.5 | 7700 | $< 5 \cdot 10^7$ |
| Teflon FEP | 260 - 280 | 2.0 | 6500 | $< 10^5$ |

Table 1: Comparison of selected properties of Kapton and Teflon films

(The failure mode of the 30 kV joint actually led to the 50 kV design.) We focus on this element of the SCECR insulation scheme because the present microwave joint design, in use in all three NSCL sources, fails above 20 kV, so it is known that this element will be limiting. Further, we believe that there is sufficient radial space available to increase the skin insulation to required levels, and the main support insulator is already considered adequate for the higher voltage operation.

## 2 The Existing HV Isolation Flange Design

Figure 2 shows the existing microwave high voltage isolation joint design. It has been used for many years in various applications on all three NSCL ECRIS. In this design, two 6.4 GHz (WR 137) circular choke flanges sandwich a 1/16 inch dielectric sheet. This sheet provides the actual waveguide high voltage isolation. Competing requirements combine to set the thickness of this sheet and the choice of material. It should be thin ($\triangle x << \lambda_{6.4}$) to minimize transverse microwave leakage. It should, at the same time, be thick enough to stand-off the nominal ECRIS operating voltage of 5-20 kV. The dielectric material should be transparent to electromagnetic waves in this frequency range. In this design, a 1/16 inch thick Teflon sheet was selected to fulfill these requirements.

Microwave leakage can be enhanced if the mating flanges are mis-aligned. For this reason, the choke flanges are securely dowelled into G-10 holders, which are then aligned by dowelled aluminum clamping rings. The initial alignment to set the dowels is done with the dielectric removed and a waveguide plug inserted between the flanges. The clamp ring is also connected electrically to the grounded waveguide. The flange shown in Figure 2 is intended to be used at 5-20 kV – the ECRIS bias voltage range for 1st harmonic injection into the NSCL cyclotrons. Several of these joints have been built, and some have operated for several thousand hours. At operating

| Joint Type | Radial Gap | Kapton Thickness | Breakdown Voltage |
|---|---|---|---|
| Design A | .987 | 2 x 5 mils | 44 kV |
| Design B | 1.987 | 3 x 5 mils | 57 kV |

Table 2: Critical features of the new isolation joint designs and the breakdown voltages achieved.

voltages of 0-16 kV they have been very reliable – few failures and little if any deterioration is observed over time. Above 16 kV this design is not reliable. Failure has been observed both through the Teflon (flange to flange) and radially along the surface of the Teflon, from the biased choke flange to the bolts that bind the outer aluminum clamp ring.

## 3 Raising the Voltage Holding Limit

In order to raise the voltage limit in our 6.4 GHz high voltage joint design, we felt that it would be necessary to:

1. choose a higher dielectric strength material
2. eliminate the choke flanges using instead flat circular flanges
3. eliminate the straight-line path from the biased flange surface to the clamp ring along the surface of the insulator sheet.

Items #1 and #3 are obvious choices – both should directly raise the voltage limit. In addition, we felt that the sharp edges on the choke flange may also contribute to the initiation of arching, and replacing the circular choke flanges with circular flat flanges should eliminate this effect (item #2).

The standard choke flange / Teflon isolation joint of Fig. 2 can fail with flange-to-flange arcing axially through the Teflon. The ability of the insulating material to exclude the external field is therefore important in raising the voltage holding limit. In order to better understand this issue, we built as a first step a similar design, but replacing the Teflon insulation with Kapton. The resulting new design, Design A, is shown in Figure 3. Table 1 compares some properties of Teflon and Kapton. As can be seen, Kapton has both a higher dielectric strength and a much higher dielectric constant, and this should raise the axial voltage holding limit. In Design

A, there are other design changes as well. Kapton, an organic film, is only available in thin sheets ($\leq$ .005 in.). Design A uses two layers of 0.005 in Kapton Type HN film. With a 0.010 inch gap between waveguide flanges, it is then possible to replace the choke flanges with circular flat flanges without incurring too great a penalty for transverse microwave emission. Also, the G-10 clamp blocks have an added step to break the straight-line gap from waveguide flanges to the aluminum clamp ring. We have built a prototype Design A type flange and tested it off-line to determine the voltage holding limit. As Table 2 shows, the Design A voltage holding limit achieved was 40-44 kV. The main failure mode was radial breakdown from the waveguide circular flange at high voltage, across the Kapton / G-10 interface, to the aluminum clamp ring. Additionally, above 35 kV, sparks in air from the rectangular waveguide at high voltage to the clamp ring were observed intermittently, probably due to corona formation on the waveguide corners. Axial breakdown through the Kapton film from the biased flange to the grounded flange was never observed! The results of the Design A testing suggested that:

1. Increasing the radial distance from the biased flange to the aluminum clamp ring

   and

2. More effectively screening the clamp ring from the biased waveguide

could perhaps result in an isolation flange that would greatly exceed 30 kV, perhaps operating above 50 kV. In Design B, shown in Figure 4, the radial gap between the biased flange and the clamp ring has increased from 0.987 inch to 1.987 inches. The G-10 clamps are also thicker – to shield the biased waveguide from the grounded aluminum clamp ring. For added margin, we also increased the Kapton thickness from $2 \times .005$ in. to $3 \times .005$ in. In testing, we found that Design B could be operated to 57 kV. The failure mode was again found to be radial arcing at the Kapton / G-10 interface. It should be quite adequate for 50 kV of isolation. Design B is pictured dismantled in Figure 5. The three sheets of Kapton film can be seen as well as both circular flat flanges, G-10 clamps and aluminum clamp rings. Figure 6 shows Design B fully assembled with the waveguides attached.

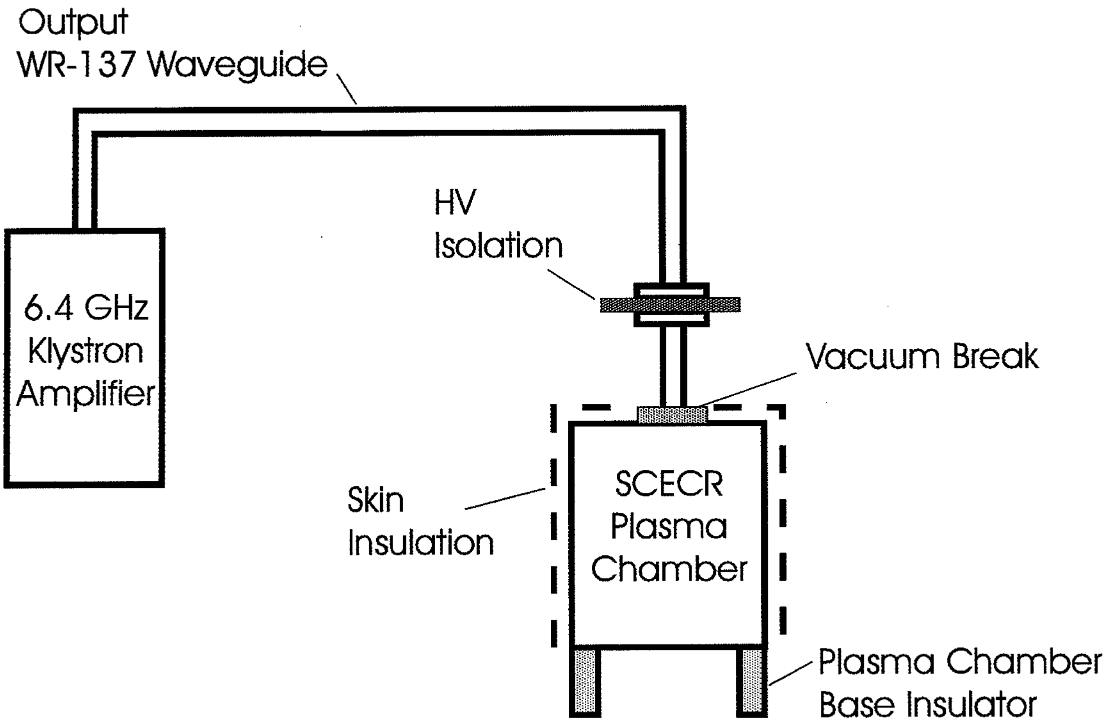

Figure 1: Key features of the high voltage insulating surfaces of the SCECR are shown schematically.

## 4 Summary and Conclusions

Since the completion if the off-line testing, the SCECR has operated for about two months with a Type-A design microwave isolation joint. Beams have been extracted at voltages up to 30 kV without incident. Operating the SCECR above 30 kV (using a Type-B design) requires a higher voltage bias supply and additional radial insulation in the plasma chamber. These further steps require source disassembly but are not considered limiting, hence reliable operation of the SCECR with beam extraction to at least 50 kV, without a high voltage platform, now appears feasible.

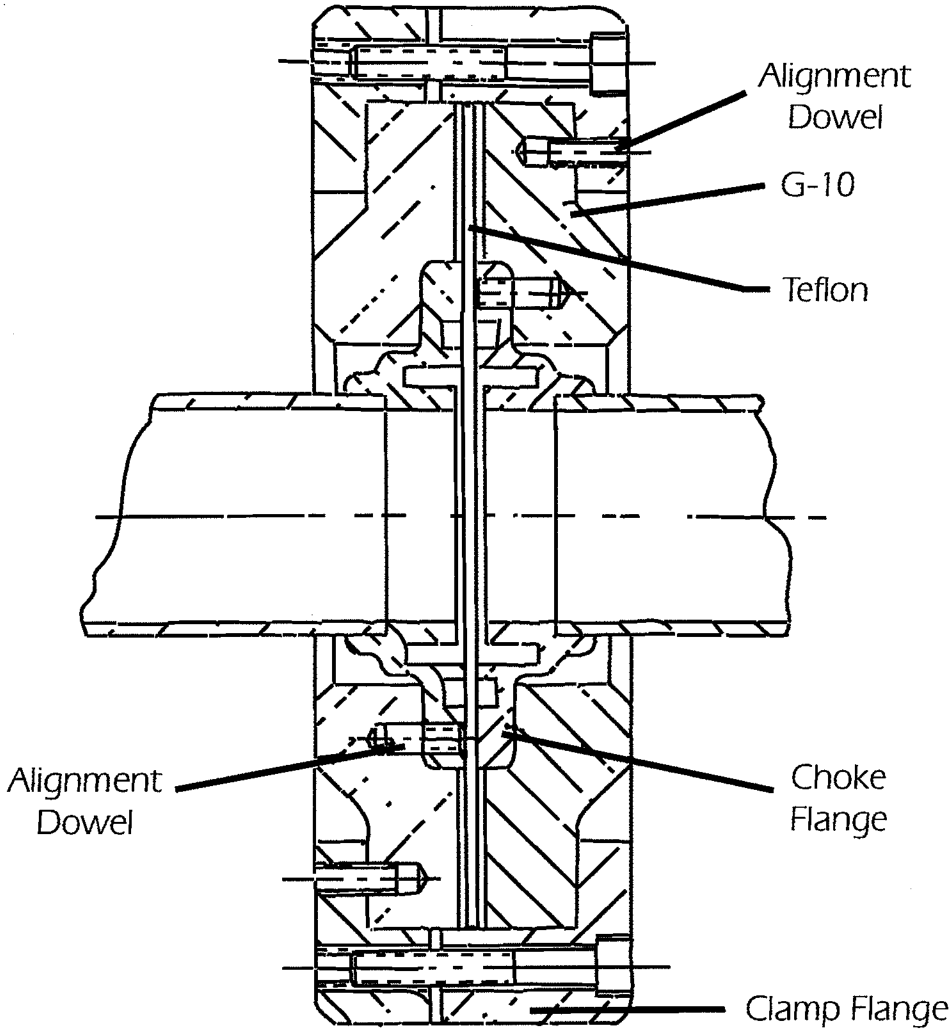

Figure 2: The existing 6.4 GHz microwave high voltage isolation joint design features a Teflon insulator sandwiched between two circular choke flanges.

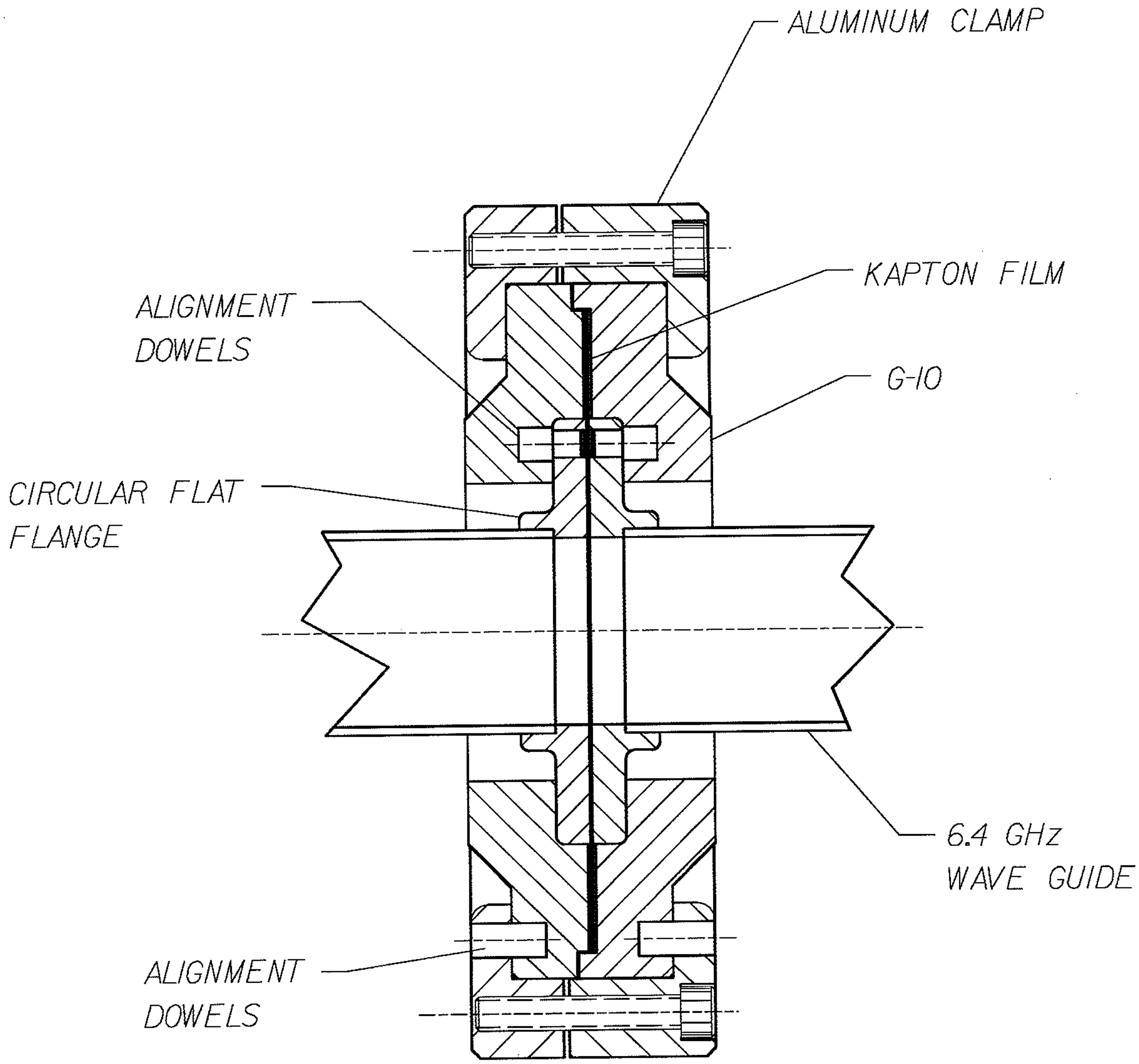

Figure 3: The new type-A design: equivalent to the existing design but with 10 mils of Kapton film replacing the Teflon insulation.

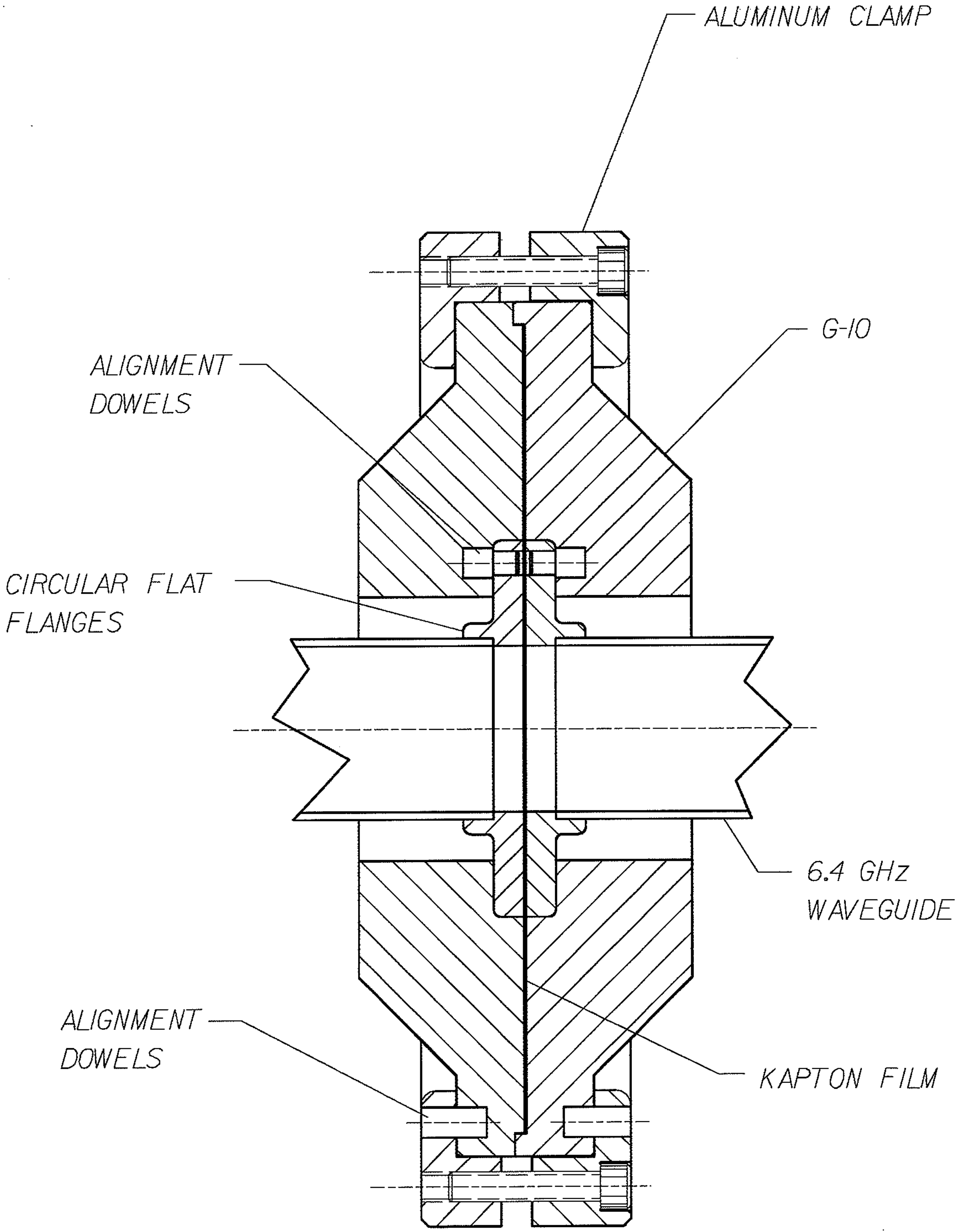

Figure 4: The new type-B design: the radial spacing of the bias flange to the clamp ring is increased, as is the thickness of the G-10 clamps.

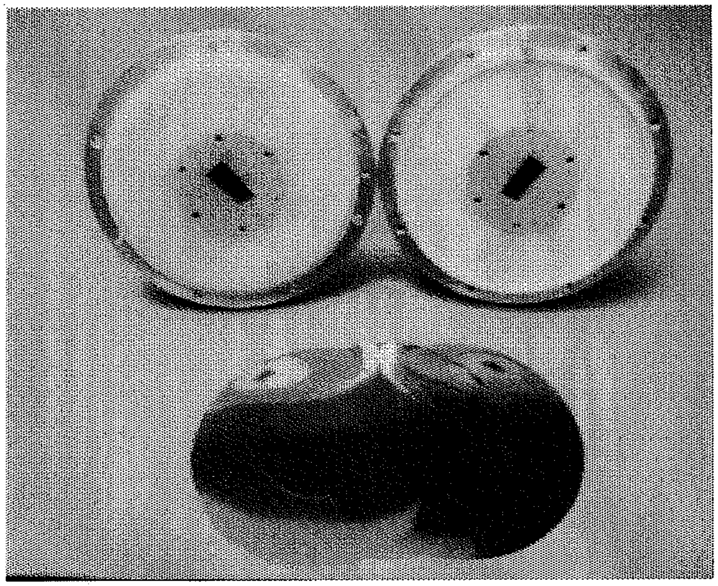

Figure 5: The internal parts of the type-B design are shown.

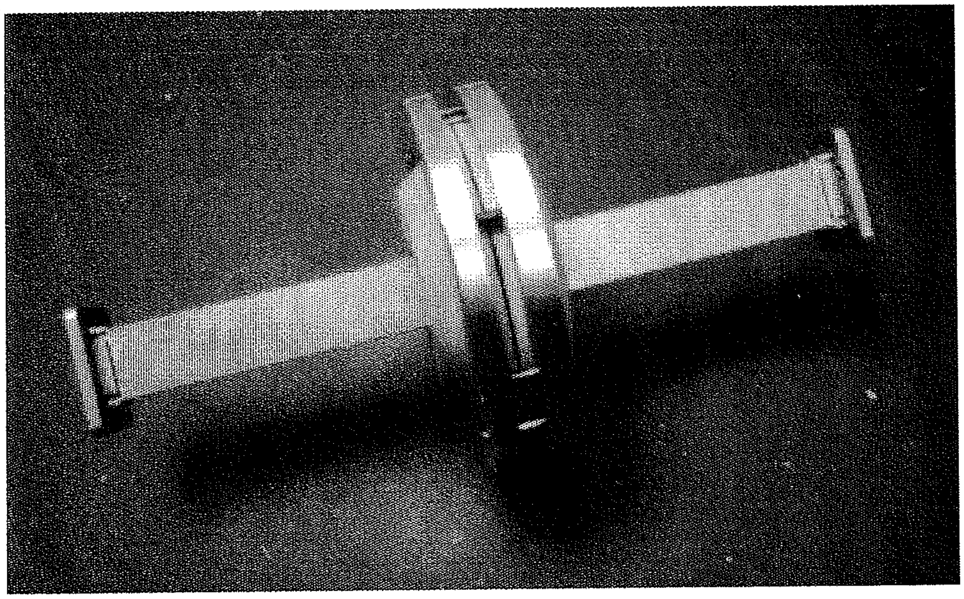

Figure 6: The fully assembled type-B design is shown. To further reduce transverse microwave leakage, if needed, the gap in the aluminum clamp can be covered with metallic foil.