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Proposal for the Development of a Low-Static Microwave Switch

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The low loss, good match, and electrical symmetry of mechanical microwave switches makes them the prime choice for use with sensitive amplifiers and mixers, and in equipment for measuring the characteristics of low-noise semiconductor and superconductor devices. Unlike solid-state microwave switches, which have high insertion loss, mechanical switches can be used on the input of low-noise amplifiers, and at the front-end of ground stations and cellular systems. They can be used to switch in stand-by receivers in the event of a failure, and in multi-band instrumentation they can be used to connect front-ends for different wavebands to a common IF channel. Fig. 1 shows a setup for accurate measurement of the noise and conversion loss of a millimeter-wave mixer operating at 4.2 K. The mechanical switch between the mixer and IF stage allows accurately known hot (20 K) and cold (4 K) loads to be connected directly to the IF stage within the 4.2 K environment.

Unfortunately, the electrostatic discharge generated by the action of most mechanical microwave switches has ruled out their use in many of the applications for which they would otherwise be ideally suited. This static is generated by the friction between the moving reeds (RF center conductors) of the switch against the plastic guide pins which keep the reeds aligned in their channels. The discharge can be seen easily if the switch is operated while connected directly to the input of an oscilloscope capable of capturing moderately fast transients; a spike > 1 volt is observed in many cases, as shown in Fig. 2.

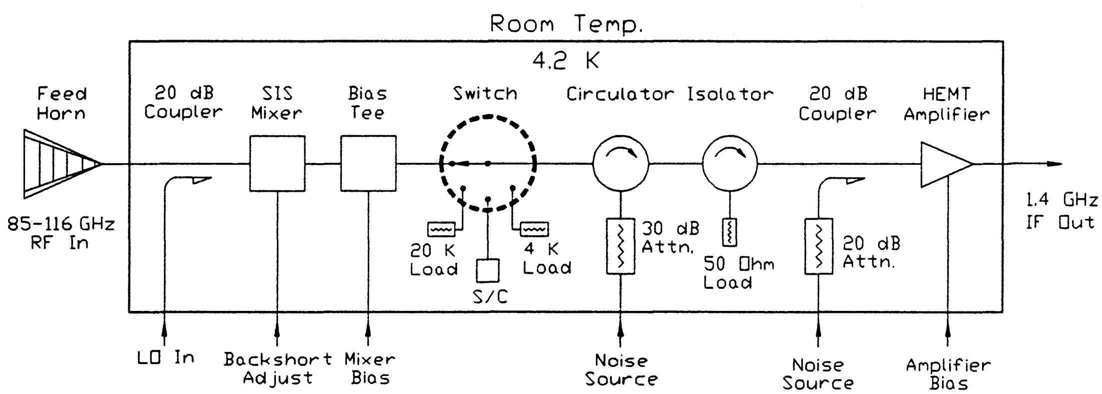

Fig. 1. Accurate measurement of noise and conversion loss of a millimeter-wave mixer requires hot and cold calibration loads to be connected to the IF amplifier using a low-loss switch [1].

In 1984, with the assistance of M. Okano at Dynatech/UZ, we modified a standard SP6T SMA switch to avoid these switching spikes which had hitherto been responsible for the destruction of many SIS mixers. A grounded 10 kΩ chip resistor was connected by a 0.25" long 0.002" diameter beryllium copper spring wire to each moving reed (Fig. 3). The wires, mounted in channels machined in the cavity plate of the switch (Fig. 3), form short high-impedance transmission lines, and are sufficiently flexible not to restrict the movement of the reeds. The return loss of the modified switch was > 26 dB over 0-2 GHz, which is comparable with that of the unmodified switch. Above 2 GHz, however, the modifications caused the VSWR of the switch to degrade rapidly.

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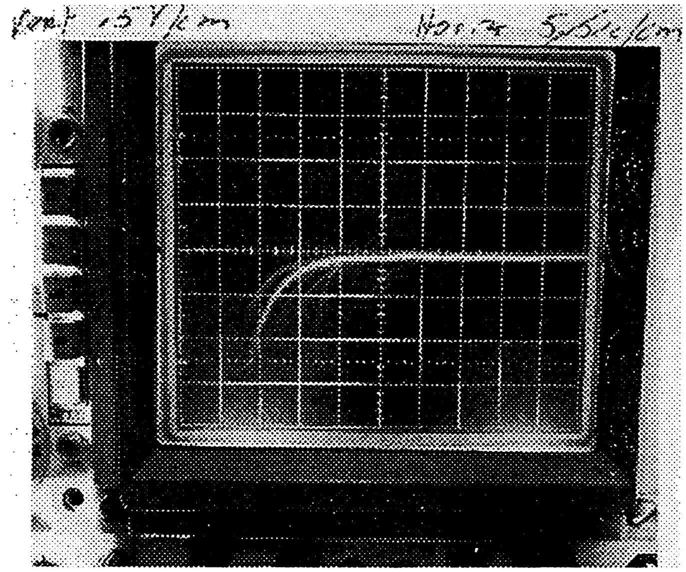

Fig. 2. Typical discharges, measured with a switch connected directly to the oscilloscope. Scales: 0.5 V/div, 5 μsec/div.

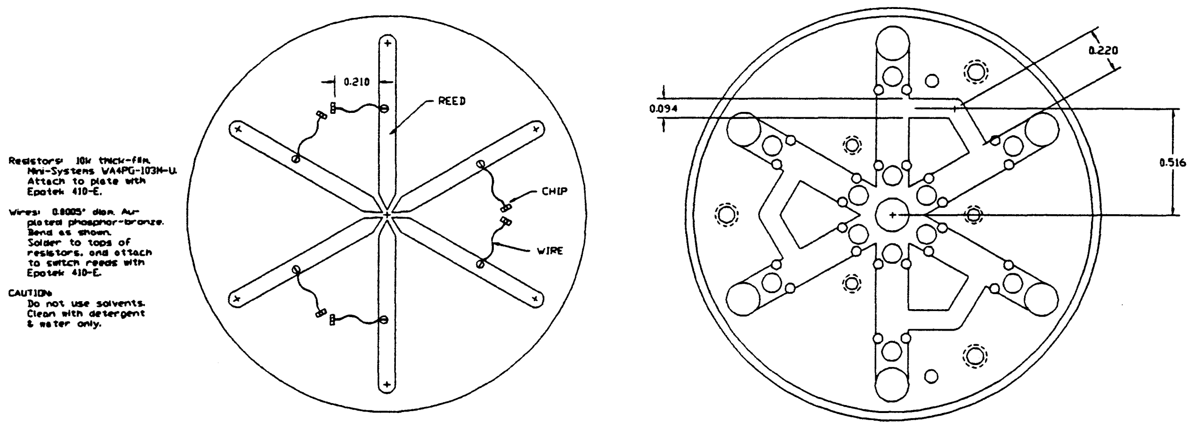

Fig. 3. Showing (left) the 10 kΩ chip resistors connected to the reeds by flexible wires, and (right) the cavity plate modified to accommodate the static suppressor circuit. This configuration is acceptable at frequencies below ~2 GHz.

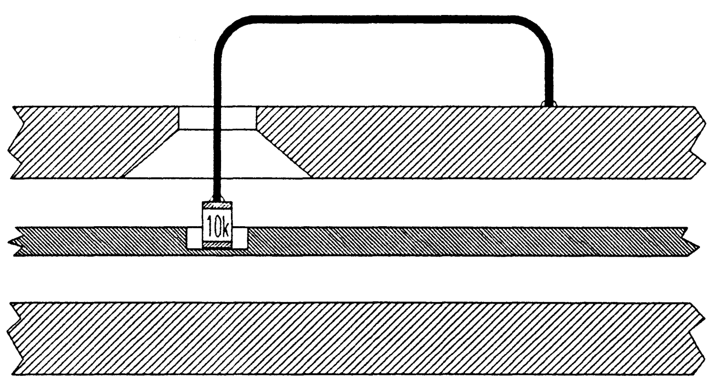

Fig. 4. The modified static suppressor circuit in which the 10 kΩ resistor is mounted on the reed of the switch.

During the last year we have developed an improved anti-static circuit which should allow operation of microwave switches to 12.4 GHz. One of us (PN) suggested that, as before, a 10 kΩ bleeder resistor be connected between the reed and the housing, but for high frequency operation the resistor should be mounted directly on the reed, with the grounding wire passing through a hole in the top of the switch housing, as depicted in Fig.4. Negligible RF current flows the resistor, and its added capacitance to ground is compensated by the conical opening above it. The return loss with this arrangement is shown in Fig. 5.

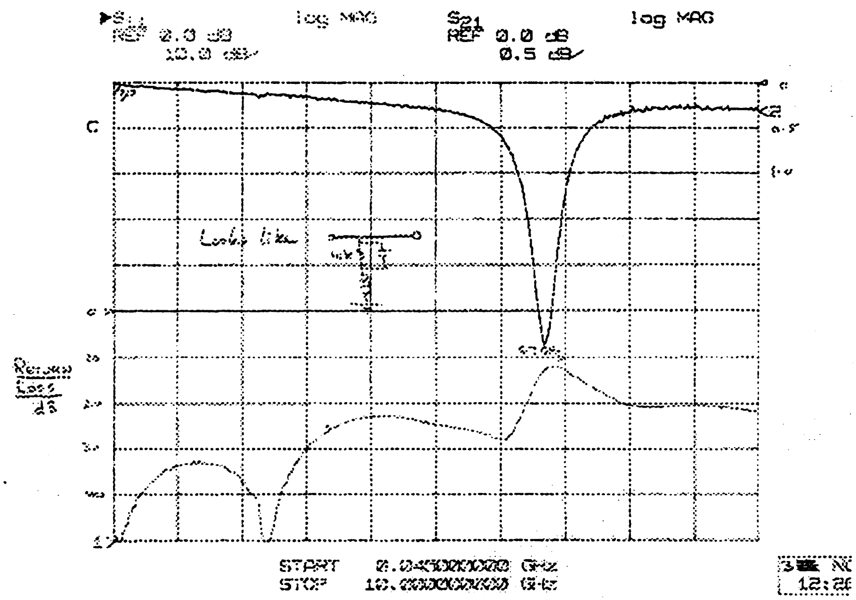

Fig. 5. Return loss of switch with modified static suppressor circuit with single resistor.

The 2-GHz bandwidth of the old design has been increased to 6 GHz, but a resonance is evident at 6.7 GHz. We supposed the resonance to be caused by the parallel capacitance of the chip resistor. If this were in fact the case, adding a second resistor at the grounded end of the spring wire, as in Fig. 6, should increase the resonant frequency by a factor √2. This is seen to be the case in Fig. 7. Fig. 8 shows the return loss of the unmodified switch, for reference. By appropriate design of the static suppressor circuit, we expect to be able to extend the useable range of the switch to > 12 GHz.

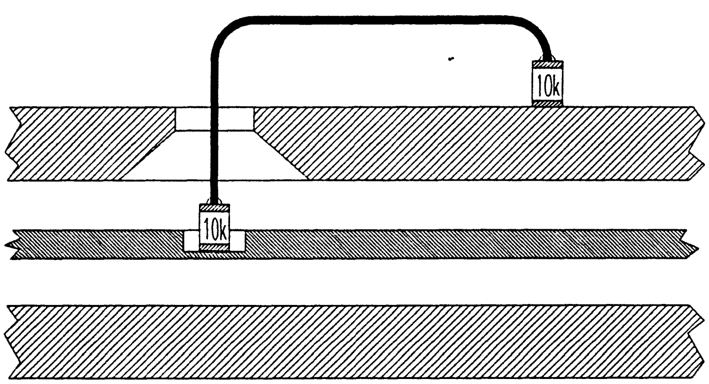

Fig. 6. The modified static suppressor circuit using two 10 kΩ resistors.

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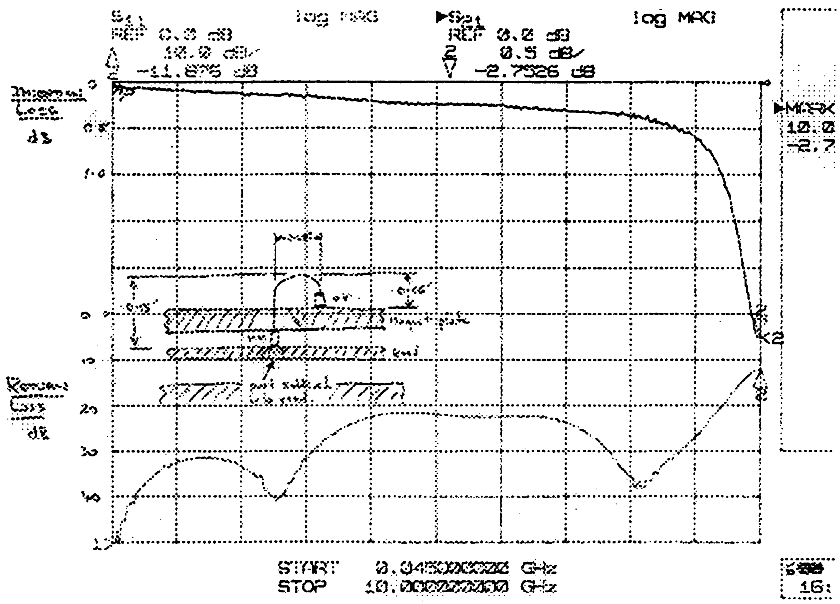

Fig. 7. Return loss of switch with second modified static suppressor circuit with two resistors.

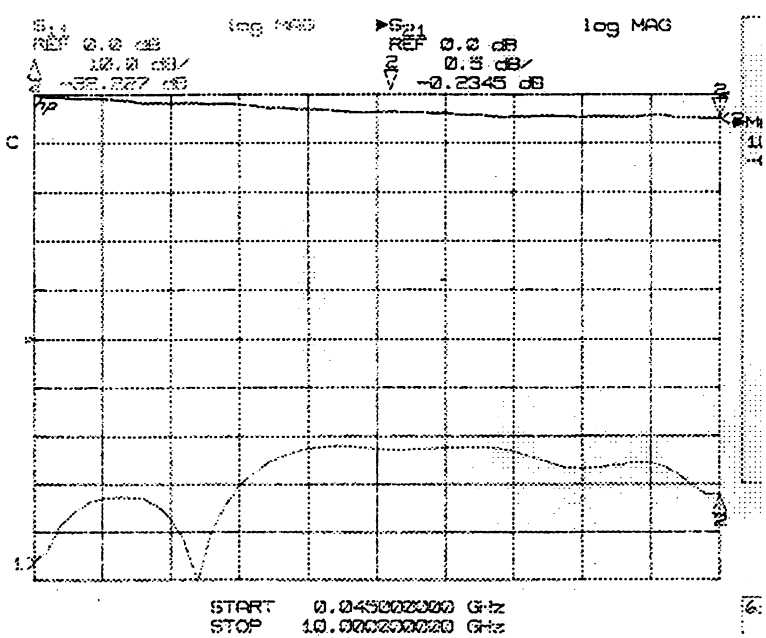

Fig. 8. Return loss of un-modified switch (for reference).

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Proposed Improvements

(i) Static Suppressor Circuit

The resistors used in the experiments described above were MSI type WA56PG-103J-U. These are thick-film resistors on an alumina substrate 0.045" (L) x 0.030" (W) x 0.011" (T). It is now possible to buy smaller resistors (0.040" x 0.020") which should have lower capacitance. These are available from State-of-the Art, Inc., and IMS. If necessary, the resistors can be made on a fused quartz substrate* ($\epsilon_r = 3.8$, as opposed to $\epsilon_r = 9$ for alumina), which should ensure that the resonance mentioned above is moved well above 12.4 GHz. (Note that *thin-film* chip resistors should not be used, since, to achieve high resistance values, the resistance element is a long thin meander line whose capacitance and/or self-resonant frequency will be detrimental in the present application.)

(ii) Switch Mechanism

As many applications for static-free microwave switches are at cryogenic temperatures and in a vacuum, some simple modifications to the mechanical design are desirable to ensure reliable operation and efficient cooling. We have found that the operation of Dynatech and other latching switches at 77 K or 4 K is not reliable unless adjustments are made to the height of the magnet plate above the rocker assembly. We expect permanent magnets to maintain their strength at cryogenic temperatures, and some appear to become stronger. The difficulty we have experienced is a result of differential expansion between the threaded brass rods supporting the magnet plate and the pole-pieces of the magnets. If the threaded rods were made of a metal with an appropriate expansion coefficient — possibly stainless steel — this problem would be overcome.

The following general characteristics are desirable in a switch for operation in a vacuum and at cryogenic temperatures:

(i) The mechanism should be of the latching type. This allows zero power dissipation except when actually switching — an important consideration in a cryogenic system.

(ii) Logic, indicator, suppressor, and cut-out circuits using silicon semiconductor devices should be omitted from switches intended for cryogenic operation. Carrier freeze-out prevents silicon devices from operating at 4 K.

(iii) The case should be vented; or there should be no case. A sealed, but not hermetic switch is likely to leak gas slowly into the surrounding vacuum.

(iv) Separate *set* and *reset* connection should be provided for each section of the switch. Some switches use a common reset line which energizes all reset coils simultaneously. The high current required can damage the thin high-resistivity wires used in cryogenic systems to reduce heat loading.

(iv) We have found that the magnet plate requires its own heat-strap. Without a heat strap, its thermal time constant can be hours in a vacuum cryostat, even with the cavity plate well heat sunk. For this reason, we always attach a copper braid to the magnet plate through a slot in the switch case. The other end of the braid is attached to the refrigerator cold plate. Holes should be provided near the rim of the magnet plate for attaching a heat strap, and the case should have an appropriately positioned opening to accommodate the braid (or the case can be omitted). Alternatively, a protruding lug could be provided for cooling the magnet plate.

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* NRAO has purchased fused quartz resistors from MSI.

(v) For compatibility with existing equipment the following are desirable:

- Dimensions: The mounting plate should be square, max. 2.25 x 2.25 in, with clearance mounting holes in the corners. Height 2.6 in max. from top of base plate to rear of case.
- Power: 28 V, 140 mA.
- Connectors: SMA compatible.
- Minimum number of positions: At least 4 positions are required (SP4T). However 5 or 6 positions would allow greater flexibility if they can be accommodated with the antistatic design.

Reference

[1] S.-K. Pan, A. R. Kerr, M. J. Feldman, A. Kleinsasser, J. Stasiak, R. L. Sandstrom, and W. J. Gallagher, "A 85-116 GHz SIS receiver using inductively shunted edge-junctions," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-37, no. 3, pp. 580-592, March 1989.

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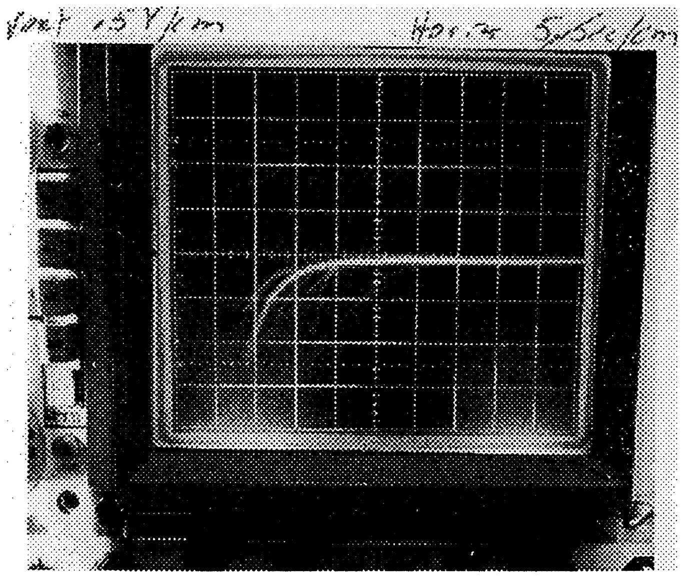
Development of a Low-Static Microwave Switch

Low-loss microwave switches are crucial to accurate measurement of the noise and conversion properties of millimeter-wave mixers. Unfortunately, the electrostatic discharge generated by the action of standard mechanical microwave switches is sufficient to damage Schottky or SIS mixers. This static is generated by the friction between the moving reeds (RF center conductors) of the switch against the plastic guide pins which keep the reeds aligned in their channels. The discharge can be seen easily if the switch is operated while connected directly to the input of an oscilloscope capable of capturing moderately fast transients; a spike > 1 volt is observed in many cases, as shown in Fig. 1.



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The 2-GHz static-free switch was fine while the IF of our millimeter wave receivers was in the 1-2 GHz band, but with plans for a higher IF on the MMA, probably 4-12 GHz, we need a static-free switch covering that band. To this end, we have been working with Dr. Peter Novak of Novak Corp., a switch designer whose cryogenic switches have been used in many VLA receivers. He has suggested an improved static suppressor circuit, of which a prototype has given a frequency range of ~9 GHz (Fig. 2). We believe it is now possible to extend the frequency of this switch to > 12 GHz. Dynatech Corp. has expressed an interest in making such a switch as a commercial product, and are now working with Novak to modify one of their existing designs.

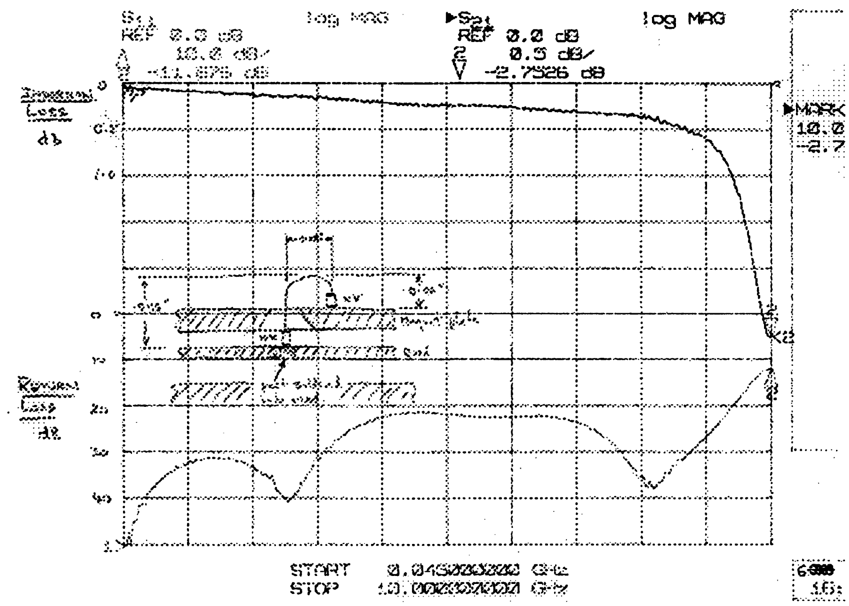

Fig. 2. Return loss of switch with second modified static suppressor circuit with two resistors.