AN OPTICAL SWITCH FOR HIGH TEMPERATURE SUPERCONDUCTING MICROWAVE BAND REJECT RESONATORS[1]

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ABSTRACT

A method for optically switching High Temperature Superconducting (HTS) band reject resonators is presented. Fast low loss switching of HTS filter elements enables digital selection of arbitrary pass-bands and stop-bands. Patterned pieces of GaAs or silicon are used in the manufacture of the two terminal photoconductive switches. Fiber optic cabling is used to transfer the optical energy from an LED to the switch. The fiber optic cable minimizes the thermal loading of the filter package and de-couples the switch's power source from the RF circuit. This paper will discuss the development and implementation of the optical switch and it's integration into a switched filter and switched filter-bank.

INTRODUCTION

The development of switchable and highly selective bandstop filters with low insertion loss will minimize receiver interference problems in dense signal environments. YIG filters have been used in this capacity. The main limitation of YIG filters for use in front end filtering is their insertion loss. Cascading even a few YIG filters will degrade the noise figure of a receiver considerably. There is also a considerable size penalty associated in using several YIG filters. Circuits manufactured using HTS exhibit lower conductor losses than do conventional materials. Thin film HTS circuits are small in size and weight and also offer higher Quality (Q) factors thus giving improved filtering performance. This improvement in filtering performance translates into a higher probability of signal identification or precise rejection.

This paper will focus on the switching aspect of the Switchable Band Reject Filter [1] made by Superconductor Technologies, Inc (STI). An HTS compatible switch is developed which is compatible with HTS resonators. The switch is integrated with the HTS resonators to form a switched filter. Numerous filters are cascaded in series to produce a band reject filter-bank of many contiguous channels. These contiguous channels are capable of being configured in many possible combinations of pass and reject bands.

SWITCH MODEL

Circuit analysis of the switch and resonator models is performed using two programs: an in house program called Nodal© [2], and Touchstone© [3] by HP-EESOF. Filters using half-wavelength folded hairpin resonators are designed by methods such as those in [4]. The filters are cascaded [1] and have minimal insertion loss. Switching is achieved by altering the capacitance of the resonator gaps. The switches were originally modeled as a piece of bulk semiconductor with ohmic contacts. Computer analysis of the switch model integrated with a resonator showed that the contacts did not need to be alloyed in order for the switch to function as needed with the resonator. This was due to the large capacitance of C_2 ($\approx$10 pF) which is virtually a short circuit at 10 GHz. By not alloying the contacts an extra processing step could then be avoided. The equivalent circuit model for the resonator and switch is shown in Figure 1. C_1 ($\approx$.05 pF) is the capacitance between the patterned metal pads of the switch and R_b is the resistance of the bulk semiconductor in the dark and illuminated states. C_g ($\approx$ .08 pF) is the capacitance of the coupled ends of the stripline resonator and C_{sh} ($\approx$ .08 pF) is the shunt capacitance of the resonator pads. The resonator pads capacitance values were derived from SONNET© software's Xgeom and EM [5] and verified by measurement.

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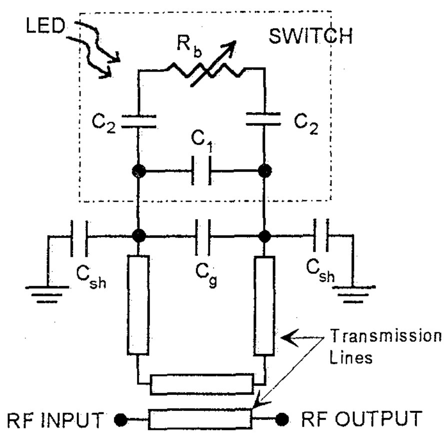

Fig. 1 Equivalent circuit for photo-switch and resonator.

The method of switch attachment entailed gold wire bonding the two-terminal switch to the pads on the coupled ends of the HTS resonator (see Figure 2.).

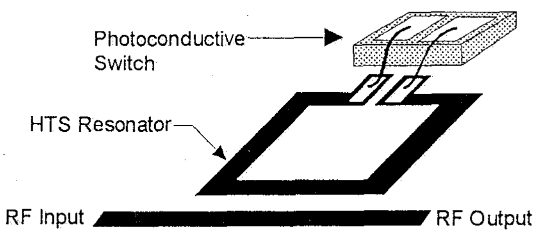

Fig. 2. Layout of patterned switch and resonator.

The model shows that the dark state of R_b must be >10 Megohms in order for the switch to contribute minimal degradation to resonator Q. For a switched loss of approximately .03 dB, the illuminated resistance needs to be <20 ohms. The switched loss is defined as the difference between the loss 80 MHz away from the resonant frequency in the reject state and the worst case loss in the pass state in the defined pass band corrected for return loss ripple. Figure 3 is a simulation from a Nodal model consisting of three switches and three resonators.

SWITCHING METHOD

Fiber optic cables are used to deliver photons to the photo-switch. Optical switching is more attractive than electrical switching because it avoids the

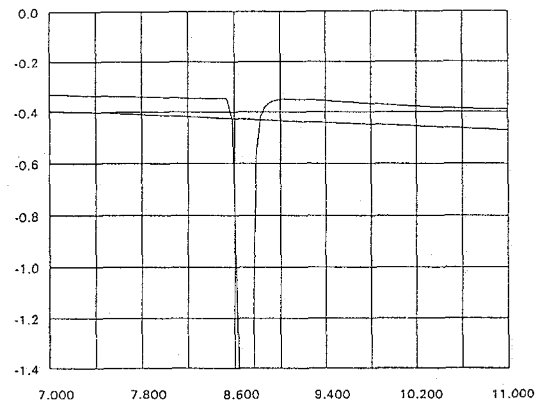

Fig. 3. Nodal simulation of switched filter.

complications associated with having electrical bias and switching-signal connections on each resonator, and also avoids the additional heat conduction that would be associated with the use of electrical conductors. Any extra heat load associated with the device translates into longer cooldown times. There is also no outgassing associated with the glass fiber optic cables. Excessive outgassing can shorten the insulated vacuum time of a dewar.

An LED with an operating wavelength of 880 nano-meters is used to illuminate the GaAs switch and an 860 nano-meter wavelength LED is used in the case of the silicon switch. The fiber optic cable is positioned intimately with the switch so as to allow for maximum light transfer from the fiber to the switch. For every photon that reaches the GaAs switch, an electron hole pair is created because GaAs has a direct bad gap. It requires two photons to create an electron hole pair in the silicon switch because silicon has an indirect band gap. The first photon moves the electron to a higher energy state and the second photon breaks it loose.

SWITCH MATERIAL SELECTION

The two materials used to make the photo-switches are GaAs and high-resistivity silicon. Both photoconductive materials exhibit a high dark state DC resistance and a low illuminated state DC resistance. When cooled to 77 Kelvin, the dark state resistance increased as predicted [6] by the following equation

$$n_i(T) = 2\left(\frac{2\pi kT}{h^2}\right)^{3/2}(m_n m_p)^{3/4} e^{-Eg/2kT} \qquad (1)$$

due to a decrease in the intrinsic carrier concentration. This increase in resistance minimizes resonator Q degradation.

SWITCH FABRICATION

The switches are manufactured from GaAs and n-type silicon wafers. They are fabricated by first patterning a wafer with photo-resist and then sputtering the metal contacts. The GaAs contacts are made from Ni, Ge, and Au. The silicon contacts are made by first depositing Ti/W onto the wafer for good adhesion. Then Au is sputtered to allow for good bond adhesion. The photo-resist is then lifted off and the wafer is thinned to .005 inches and diced to .015 by .025 inches. The switches are attached to the HTS circuits using polyimide and then gold wire bonded to the coupled ends of the resonator.

MEASURED RESULTS

The circuit is first tested using an HP 8720 Vector Network Analyzer. The packaged filter is bolted to a copper block that is submerged in liquid nitrogen. The measured insertion loss and return loss of a three-section switched filter incorporating GaAs switches is shown in Figure 4. The switched loss of the filter is approximately .1 dB worst case. This translates into less than .04 dB per resonator. The silicon switches exhibited a slightly higher switched loss. By increasing the current to the LED that is used to deliver the photons to the silicon switch, the switched loss did improve.

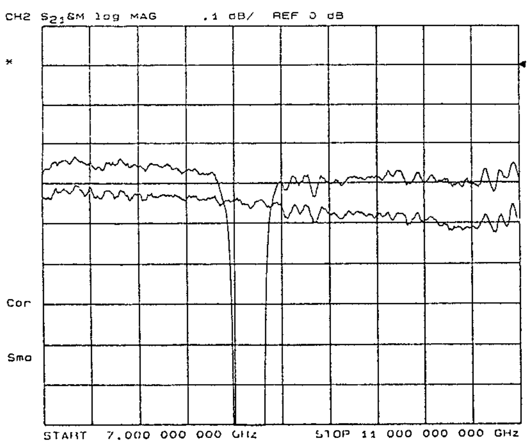

Fig. 4. Switched response of 3-section filter.

From these results, it is shown that our modeled data correlates very closely with the measured data.

Next, switching times are measured. The switching times of the GaAs switch are approximately 8 micro-seconds from the dark state to the illuminated state and approximately 700 micro-seconds from the illuminated state to the dark state. The slower switching time (illuminated state to dark state) is due to the deep traps in the GaAs which electrons enter and exit until they finally recombine. This creates a non-exponential decay characteristic and slower switching times. The silicon switches exhibited well defined exponential decay with a single time constant. Switching times of less than 5 micro-seconds were measured on the silicon devices (see Fig. 5).

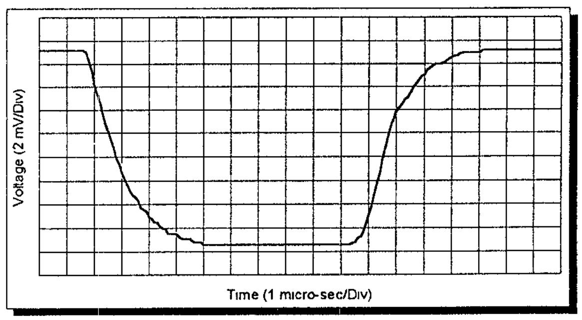

Fig. 5. Switching speed of silicon switch.

Some work has been done using an FET to switch a microwave circuit [7]. However, the FET's and PIN diodes we tried de-Q'd the folded hairpin resonators due to their low DC resistance.

CONCLUDING REMARKS

The work presented in this paper forms the basis for continued development in the area of switchable HTS filter banks. We have demonstrated a fast switch (silicon) which can be integrated with HTS resonators to form filters. The three-section HTS band reject filters can be optically switched with low insertion loss (GaAs) and can be cascaded to form filter banks. Figure 6. shows the switched response of a 16 channel filter bank. Digital control of the band reject filters allows the user to arbitrarily define any reject or pass band within the filter bank. Further development is required to enable one type of switch to meet all the necessary requirements.

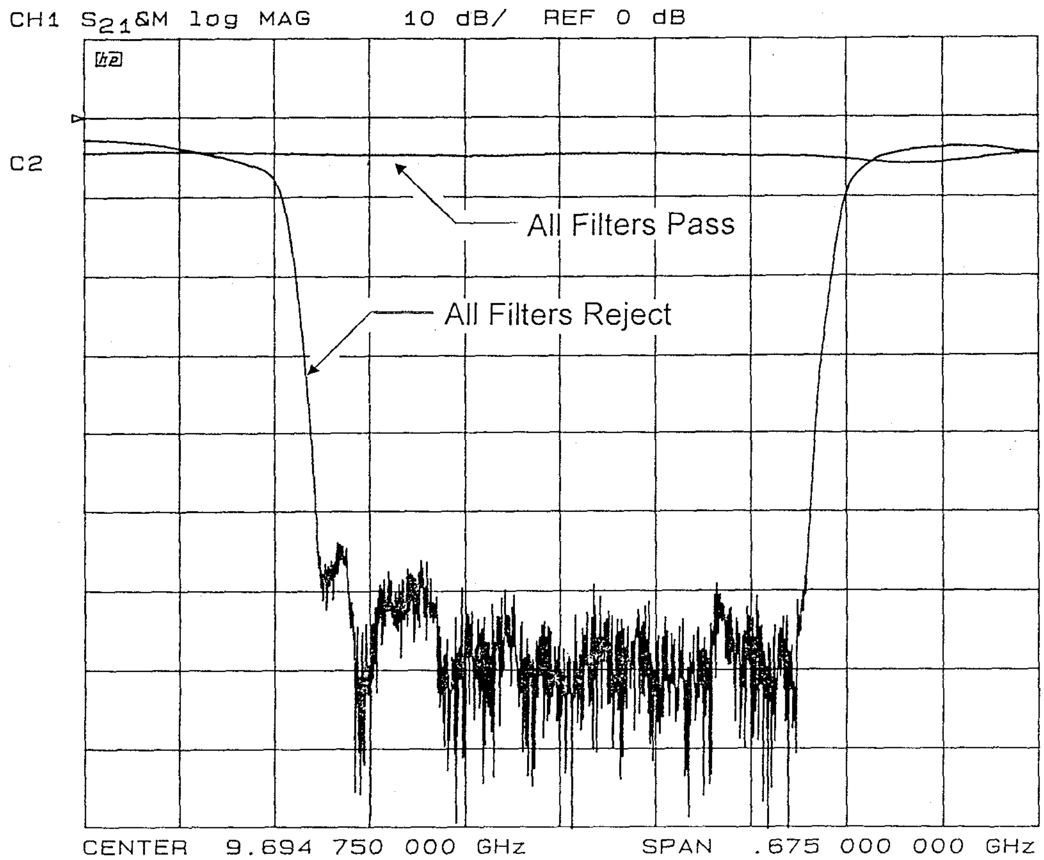

Fig. 6. 16 channel switched filter bank response.

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