DESIGN OF HIGH POWER SUPERCONDUCTIVE OUTPUT MULTIPLEXERS

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ABSTRACT

This paper presents experimental results for a fully integrated high temperature superconductive manifold-coupled output multiplexer. The high power test results indicate that the superconductive multiplexer is capable of meeting the power handling requirements of typical C-band satellite programs. Design considerations related to the implementation and design of high power superconductive multiplexers are discussed in detail.

I. INTRODUCTION

Present HTS technology offers a variety of low power microwave components that can be realized with significant size, weight and performance advantages over comparable conventional components [1]-[5]. However, truly enabling benefits will not likely be derived from the replacement of conventional low power components with their HTS counterparts alone. A comprehensive approach, that combines both low power and high power HTS components into a fully integrated system is required. The development of high power HTS components and subsystems is therefore essential in order to fully realize the benefits of the HTS technology.

The behaviour of HTS thin films under high power operating conditions is quite different from that for low power conditions. Over the past four years, experimental results have been reported confirming surface resistance degradation and non-linear performance of HTS filters operating at modest microwave power levels. However, these results were limited to certain filter geometries and did not truly present the actual picture of the power handling capability of HTS filters in general. More recently, the feasibility of realizing superconductive filters capable of handling 30-50 watts with a third order intercept point of 100 dBm has been demonstrated in [6].

In satellite applications, HTS filters for input and output multiplexers continue to demand attention because of the payoff which results from even minor improvement in parameters such as unloaded Q, size and mass. The operating power of input and output multiplexers can vary from one satellite to another. Typically, input multiplexers operate at very low power levels (milliwatts), while output multiplexers operate at 10-50 watts. The type of multiplexing approach is another key parameter which differentiates input and output multiplexers. While the circulator-coupled approach is widely used in input multiplexer applications it is seldom used in the design of output multiplexers due to its relatively poor insertion loss performance. In [5] the measured performance of a circulator-coupled low-power superconductive input multiplexer has been presented. This paper deals with the performance and design considerations of high power superconductive output multiplexers.

We present in this paper experimental results for a fully integrated 4-channel manifold-coupled superconductive multiplexer employing hybrid dielectric/HTS filters. The superconductive multiplexer is capable of handling 40 watts per channel with no major performance degradation.

II. DESIGN CONSIDERATIONS OF SUPERCONDUCTIVE OUTPUT MULTIPLEXERS

Design Requirements

The number of channels on the manifold can range from 3 to 14, depending on the type of services the satellite is providing. A satellite payload can consist of more than one output multiplexer. Typically, the channel filters for C-band output multiplexers are either 4-pole or 5-pole 1% bandwidth quasi-elliptic filters with two transmission zeros. In contrast to the circulator-coupled approach [5] where there is no interaction between channel filters, channel interaction is quite strong for the manifold-coupled approach. The channel filters must be properly designed to take into account the loading effects from adjacent channels.

Superconductive manifold-coupled multiplexers can be built either by using HTS thin film planar filters or hybrid dielectric/HTS filters. However, in view of the power handling limitations of today's HTS materials, the task of designing a 1% bandwidth 4-pole HTS thin film planar filters that can handle 40 watts at 77 K is quite

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challenging. On the other hand, hybrid dielectric/HTS filters have demonstrated the capability to handle such power levels [6]. At the present time, hybrid dielectric/HTS filters seem to be the optimum choice for high power superconductive output multiplexers.

For a 4-channel output multiplexer with a channel filter peak power of 40 watts, the instantaneous peak power due to the combined signal on the manifold can be as high as:

Manifold peak power = $(4)^2$ x 40 watts = 560 watts.

In view of the extremely high peak power level which the manifold must handle, it is not feasible to construct the manifold using currently available HTS materials. The manifold then must be built using conventional technology.

Passive Intermodulation and Breakdown

In superconductive output multiplexers, passive intermodulation (PIM) products could be generated from the inherent non-linearity of the HTS materials and/or the manifold. Even though the manifold is not made of HTS materials, any micro cracks or voids on the manifold can generate intermodulation products. Fig. 1 illustrates a plot for power out versus power in for a 4-pole hybrid DR/HTS filter. The filter has a third intercept point of more than 100 dBm.

For a typical communication satellite system, the level of any intermodulation products produced by the transmit portion of the satellite which fall within the satellite's receive band has to be at least 20 dB below the power of the received signal. This condition results in a carrier to passive intermodulation (C/I) requirement of anywhere from 100 to 200 dB depending upon the system gain and transmit receiver configuration.

Multipaction and/or ionization breakdown is another problem which could limit the power handling capability of the superconductive high power multiplexer. Multipaction is an electron resonance phenomenon which takes place in components operating in atmospheric pressure lower than 10^{-5} torr. At atmospheric pressure higher than 10^{-5} torr, multipaction cannot occur since ionization is the limiting breakdown condition. However, for satellite output multiplexers ionization is less common than multipaction breakdown as it requires partial pressure conditions which are unlikely to occur in space.

Multipaction represents a possible payload failure mechanism for communication satellites since it can destroy RF components and/or significantly raise noise level. If the superconductive channel filters are not properly designed, their power handling capability could in fact be limited by the multipaction breakdown rather than by the inherent power handling limitations of the HTS materials.

The issue of reliability of the HTS materials under high power conditions is also of concern. While some superconductive filters have initially shown strong power handling capability, in several cases the power handled by these filters has dropped significantly when they are tested again. Inspection has shown that potions of HTS films were missing from the substrate. On the other hand, other filters have consistently demonstrated the same power handling capability over many repeated tests. The effect of continuous prolonged exposure of the HTS films to high power levels is certainly an issue which needs to be thoroughly investigated.

III. EXPERIMENTAL RESULTS

Fig. 2 shows the measured isolation and return loss performance of a 4-channel manifold-coupled superconductive multiplexer. The channel filters are realized using 4-pole quasi-elliptic hybrid DR/HTS filters while the manifold is realized using coaxial lines. A comparison between the superconductive multiplexer and a 3-channel C-band multiplexer built using the conventional waveguide technology is depicted in Fig. 3. The superconductive multiplexer occupies less than 5 % the volume of the waveguide multiplexer.

The overall superconductive multiplexer was tested for high power handling while submerged in dewar of liquid nitrogen. The measured insertion loss of channel #3 under 10, 20, 30 and 40 watts of incident power are given in Fig. 4. No major degradation in insertion loss performance was observed even at an input power of 40 watts. All HTS films used to build this multiplexer were supplied by DuPont.

The insertion loss given in Fig. 4 is the combined overall loss of the manifold and the superconductive filter. The typical insertion loss of a stand-alone 4-pole 1% bandwidth superconductive filter of this type is 0.1 dB. The relatively high insertion loss shown in Fig. 4 is mainly attributed to the insertion loss of the coaxial manifold used in this prototype unit. A number of coaxial T-junctions and straight through connectors were used to construct this manifold. By employing a manifold with no connectors, a channel insertion loss of 0.15 is expected to be achieved.

IV. HEAT DISSIPATION AND COOLING REQUIREMENTS

In designing a superconductive output multiplexer for satellite applications, the insertion loss of the HTS filter is a critical parameter. Any minor improvement in the insertion loss translates directly to a considerable reduction in the required cooling power. As the filter insertion loss increases more power will be dissipated in the form of heat, which in turn could increase the cooling power demand to a level that is significantly high for current cooling technology. This concern is especially critical for multiplexers with a large number of channels.

It can be readily shown that 0.68 watts of heat per channel will be dissipated in an output multiplexer operating at an input power level of 20 watts/channel if the channel insertion loss is 0.15 dB. In view of the achievable efficiency of today's cryocooler, a dc power of 13.6 watts per channel will be required to provide enough cooling to accommodate the rf heat dissipation.

The dc power required by the cryocooler could be offset by potential saving in dc power generated in following two areas:

i) Amplifier dc power: The typical channel insertion loss (filter and manifold) of conventional C-band waveguide multiplexers is 0.4 dB. We have shown that a saving of more than 0.25 dB in the insertion loss can potentially be achieved through the use of HTS technology. For a system with power amplifiers operating at 40 % efficiency, and with rf power of 20 watts/channel, a 0.25 dB improvement in channel insertion loss would result in a saving of 2.7 watts of amplifier dc power per channel..

ii) Heater dc power: Conventional waveguide output multiplexers use heaters in order to minimize the frequency drift over temperature. The objective of these heaters is to ensure that the multiplexer temperature is within the designed temperature range in the case when some of the channels are in the back off mode. A dc power of 2-3 watts per channel will be typically required for heaters implemented on such system. The use of HTS technology could eliminate the need to use these heaters, which represents another area of potential savings in mass and dc power.

V. CONCLUSIONS

This paper has demonstrated the feasibility of designing a manifold-coupled non-contiguous multiplexer that is capable of handling the power requirements of conventional C-band satellite systems. The absolute insertion loss of the channel filter is a key parameter in designing superconductive output multiplexers. A reduction in the channel insertion loss from 0.15 dB to 0.075 dB will reduce the cryocooler dc power from 13.6 watts/channel to 6.8 watts/channel. It will also increase the saving in amplifier dc power from 2.7 watts/channel to 4.6 watts/channel.

Such reduction in the channel insertion loss requires the development of HTS filters with extremely high Q values in the range of 40,000 at C-band. Efforts are currently under way to achieve this goal. The key issue, however, for successful implementation of HTS output multiplexers for satellite applications is the development of small, highly efficient space-qualified cryocoolers.

ACKNOWLEDGEMENT

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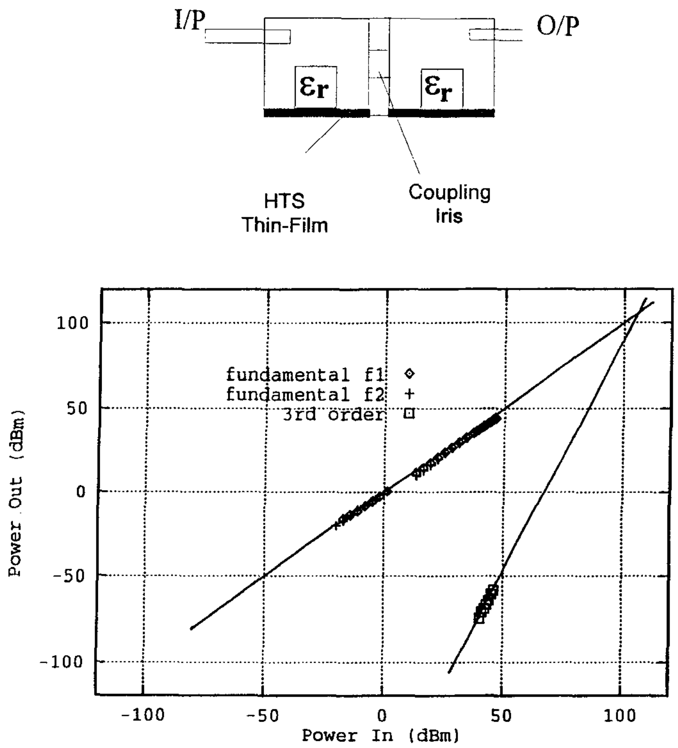

Fig. 1 Passive intermodulation test results for a 4-pole hybrid DR/HTS filter.

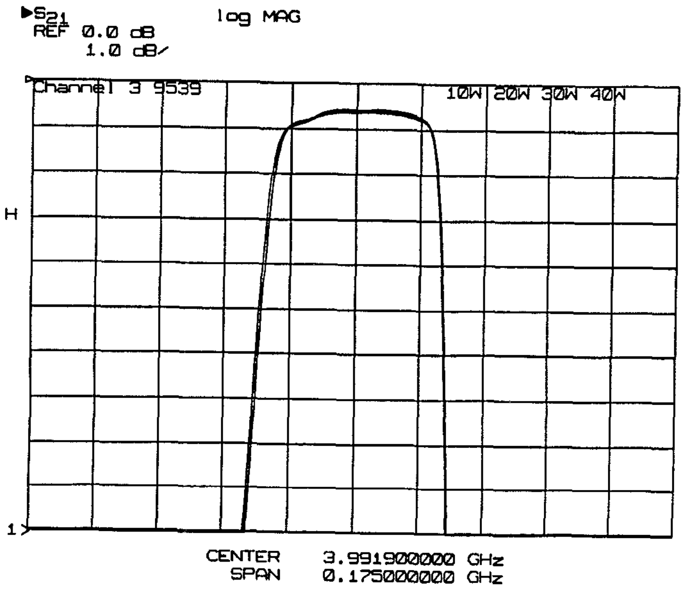

Fig. 4 The measured insertion loss performance of a channel #3 operating under 10, 20, 30 and 40 watts.

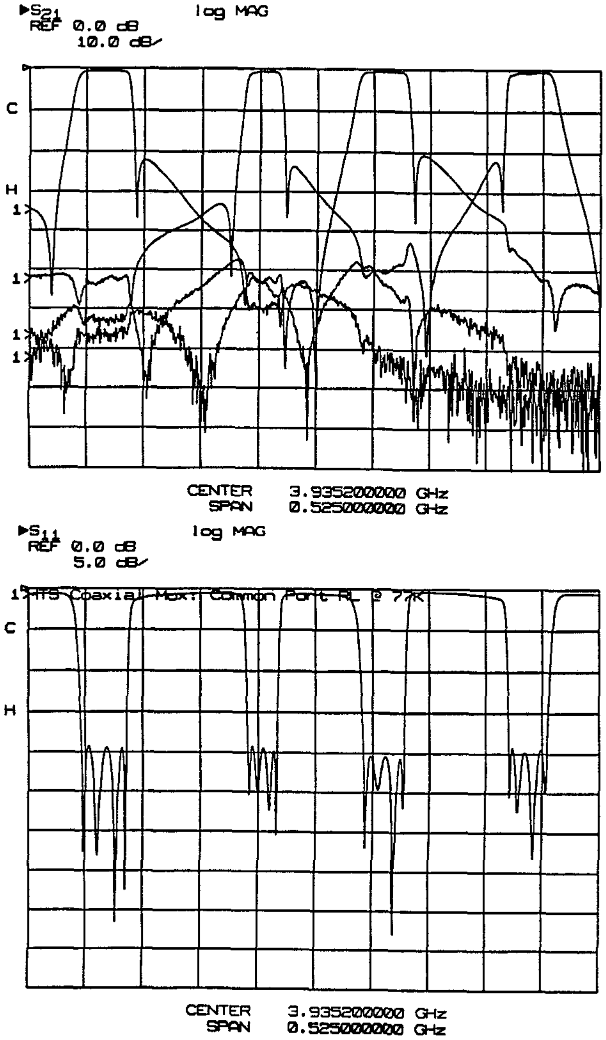

Fig. 2 The measured isolation and return loss performance of a 4-channel superconductive manifold-coupled multiplexer.

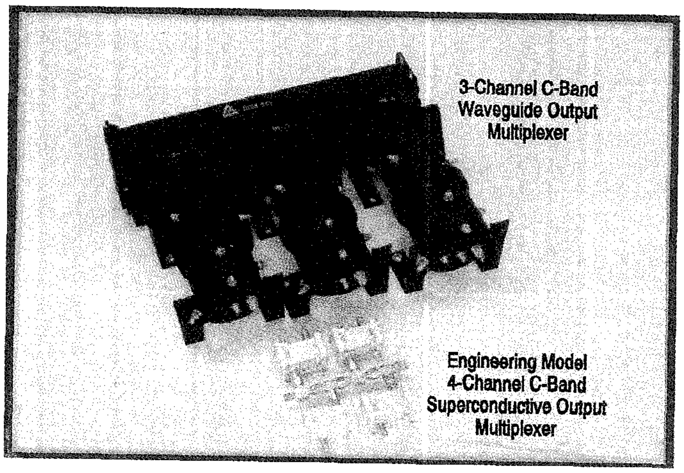

Fig. 3 A comparison between a 4-channel superconductive manifold-coupled multiplexer and 3-channel C-band output multiplexer built using conventional waveguide technology.