A SATELLITE REPEATER COMPRISING SUPERCONDUCTING FILTERS

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ABSTRACT

This contribution deals with the development of a satellite repeater comprising superconducting filters. We show measurements of single devices like narrow-band filters and we also deal with the topics of cryopackaging and cooling. We argue that the implementation of superconducting devices is advantageous.

INTRODUCTION

Since the discovery of high-temperature superconductivity (HTSC) in 1986 [1] much progress has been made towards the realisation of devices benefitting from the unique properties of this new class of materials. In the microwave regime, HTSC suffer Ohmic losses which are about two orders of magnitude lower than those of conventional metals [2]. This allows for the replacement of waveguide resonators fabricated from conventional metals by HTSC resonators in microstrip technology. The latter are much less heavy and voluminous which is especially advantageous for the use in satellite communications. However, for this application one has to bear in mind that a comparison between a conventional system and one comprising superconducting devices has to take the cooling effort into account. The energy required for cooling can be converted into a mass equivalent, which together with the mass of the cooler itself enables a comparison between the two systems.

The present work describes the current status of the development of a satellite repeater to be operated in the C-band. A schematic drawing is depicted in figure 1.

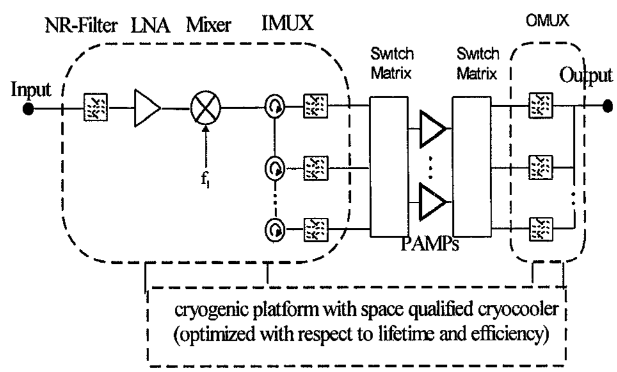

Figure 1: Schematic drawing of a satellite repeater. Superconductors are employed in the noise reduction (NR)- filter, in the channel filters of the input multiplexer (IMUX) and in those of the output multiplexer (OMUX). The other abbreviations are explained in the text.

Superconducting devices are employed on both the input and output section. A superconducting noise-reduction (NR)- filter rejects all signals not within the C-band. The signal is then amplified by a low-noise amplifier (LNA) and divided into a set of channels (input multiplexer, IMUX). This is necessary since the high power amplifiers (PAMPs) show strong nonlinearity which would otherwise be leading to intermodulation and saturation effects. Since the IMUX is placed behind the LNA, dissipative insertion losses in the order of 1-2 dB with respect to the receiver noise figure can be tolerated. This allows to use conventional cryogenic circultors to decouple the channel filters. The channel filters meet specifications in both magnitude and group delay of the transfer function by means of equalizing. The channels are amplified individually and recombined in the output multiplexer (OMUX). Here, superconducting high-power filters are used. These are based on the concept of disk-resonators which show no degradation in unloaded quality factor even at high transmitted power [3]. (For another approach to superconducting output multiplexers, see [4]). Respective measurements on superconducting filters will be shown and questions of cryo-packaging and cooling will be addressed.

HTSC BAND PASS FILTERS

In all the measurements on band pass filters we use high-quality thin epitaxial $YB_2Cu_3O_{7-x}$-films on sapphire wafers [5], [6]. Measurements are performed on a platform firmly attached onto the cold-finger of a Split-Stirling cryocooler. All components (filter, circulator and equalizer in the case of IMUX filters) are mounted in a housing of their own. These housings are connected by standard SMA-connectors. A vacuum chamber that is operated at high-vacuum houses the platform. Electrical connections between the feedthrough in the chamber wall and the devices are made by commercial cables with low heat input. Mechanical feedthroughs allow for the trimming of the filter. With an input power of 70 W into the cooler a temperature of 65 K can be reached on the platform. Experiments show that an improvement of several degrees Kelvin is possible by the use of superinsulation which protects the platform from radiation heat.

The task of the NR- filter is to carve signals within the C-band (3.6 to 4.2 GHz, or 3.4 to 4.2 GHz in the case of extended C-Band) out of all the signals received by the input antenna. Common specifications for this filter include a return loss of -23 dB, requirements on the skirts are less severe. Therefore, a Chebycheff-design with eight resonators was chosen [7] and realized in microstrip geometry. The performance of this filter is shown in figure 2; it is seen that the return loss meets the specification and that the insertion loss is approximately -0.1 dB. An elaborate housing construction ensures stop bands free of spurious modes, with less than -50 dB isolation below and above the passband up to 6.8 GHz (onset of the second harmonic).

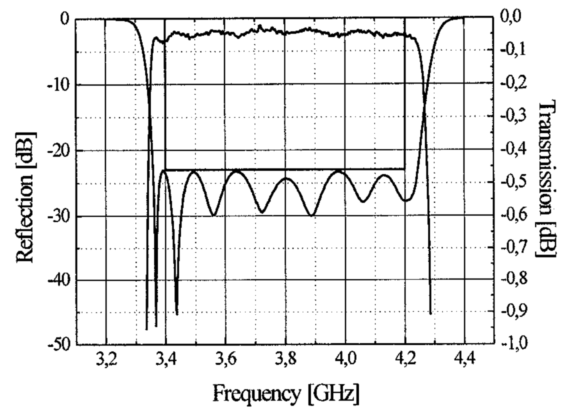

Figure 2: Insertion loss (measurement) and return loss (measurement plus specification) for a NR-filter.

The channel filters in the IMUX are subject to stringent specifications. Considering the required steepness of the skirts, the flatness of the amplitude and the group delay response, one typically ends up with a quasi-elliptic 8-pole filter with external equalizing by means of a 2-pole equalizer. In this design, cross-couplings between non-nearest neighbour resonators provide for poles in the transmission function which sharpen the edges of the passband. These cross-couplings are realized by transmission lines which couple the respective resonators with the required negative sign. Dissipative losses in the filter deteriorate the flatness of the amplitude response, therefore single resonators muss have unloaded Q-values in excess of 8000 at a certain power level. For filters with a bandwith of 36 MHz and an input power of 0 dBm this corresponds to a circulating power in the order of 6 W for a single resonator.

In figure 3 we show the measurement on a channel filter with and without equalizing and compare to specifications. Equalizing is achieved by a reflection-type equalizer attached via a cryogenic circulator to the output line of the filter. The devices are trimmed using commercially available trimming elements combined with low-loss ceramics.

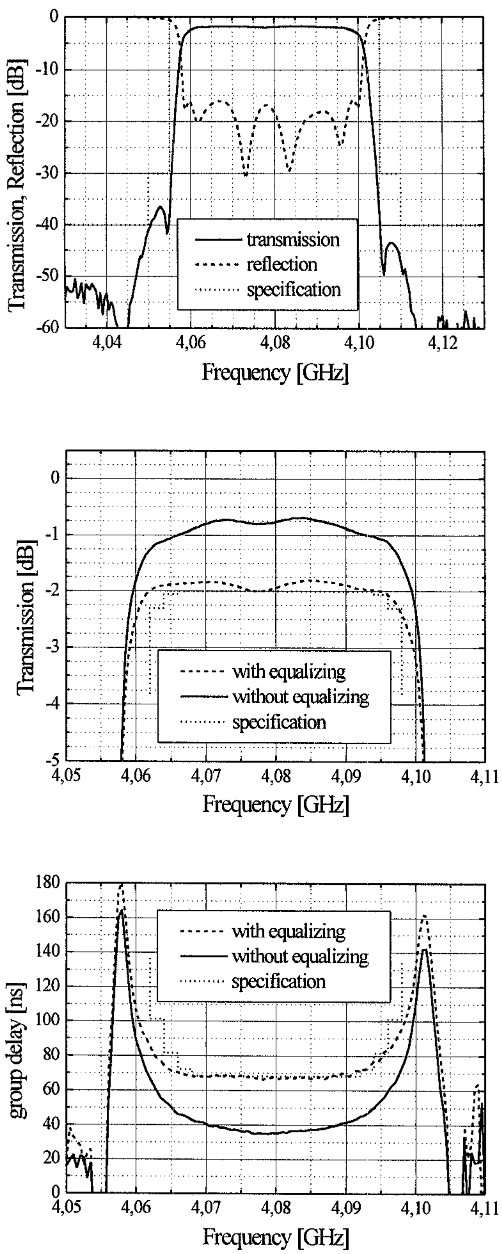

Figure 3: Measurement on a 8-pole channel filter in quasi-elliptical design. Return loss, insertion loss and group delay are shown, with and without equalizing, and compared to specification.

The filter is at a centre frequency of 4.08 GHz, and the specified bandwidth of 36 MHz is matched. The steepness of the skirts is sufficient, and it should be noted that the out-of-band transmission in the whole C-band is below the noise floor of the measuring device which is 70 dB. From the value of attenuation at midband without equalizing one can deduce that the unloaded quality factor of a single resonator is in the order of 8500 [7] (at an input power of 0 dBm). Equalizing introduces losses of about 1.1 dB arising from losses in the equalizer itself, in the circulators and in the connectors. Furthermore, it is seen how equalizing flattens the group delay (the specification for the group delay is an upper bound relative to the lowest value of the group delay measured in the band, and not an absolute value).

The requirements for the sharpness of the frequency response of the channel filters in the OMUX are less stringent and can be met by elliptic 4-pole filters. However, it is required that they exhibit extremely low insertion losses (since losses must be compensated for by cooling) at transmitted power levels of typically some 10 W. This implies that single resonators forming these filter must have unloaded quality factors exceeding 60000 at operating temperature and power level. Measurements on disk resonators clearly demonstrate this requirement can be matched (see figure 4) [3]. These resonators operate in the TM_{010}-mode which carries only radial components of the current and thus avoids 'edge effects' [8].

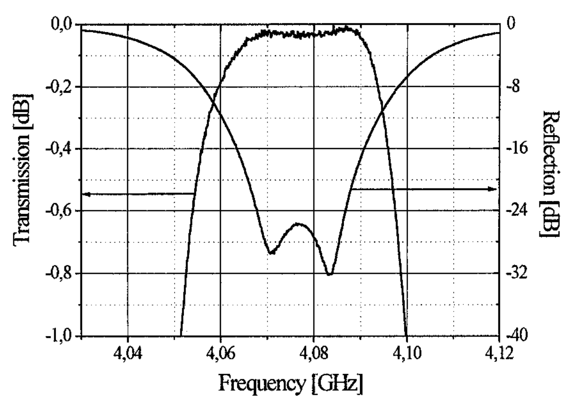

Figure 4: Measurement on a 2-pole filter. From the form of the transmission curve unloaded quality factors of single disk resonators of more than 60000 at 77K and 50 W input power can be deduced.

SYSTEM CONSIDERATIONS

The measurements on filters of the input side of the repeater (NR- and IMUX channel filters) show performances similar to those of their conventional counterparts in waveguide technology. It is the aim to demonstrate with this transponder that a significant advantage is given when employing superconducting filters by the reduction in mass and volume. Since these filters do not need to transmit high power levels, they can be realised in HTSC microstrip technology which offers the highest degree of miniaturisation. The respective architecture of the transponder remains unchanged.

Provided that there will be an increase in the quality of the superconducting films (i.e. lower losses at the same temperature), one might also think of changing the system architecture. Higher values in the quality factor of single resonators will allow for IMUX filters with steeper skirts, which means that the spectral efficiency of the multiplexer will increase. The spectral efficiency is given by the ratio of the usable bandwith (occupied by channels) to the total bandwith (usable bandwith plus guardbands used to separate the channels) and is limited by finite Q-values.

The picture on the output side (respective channel filters) is a different one: these filters do show a performance superiour to that of conventional filters. Their losses are lower, which transforms into a lower required output power of the PAMPs and thus into a lower DC power consumption. As PAMPs one might use solid state power amplifiers (SSPAs), which typically have an efficiency of 25 - 30%, or travelling wave tube amplifiers (TWTAs), typically having an efficiency of 60%. The latter are used when output power levels of more than 30 W are required, the former cover the range up to 30 W.

To conclude, by the use of filters in superconducting technology as shown above, one saves amplifier power, mass and volume. For one kilogram mass one can estimate the launch costs to be in the order of 50,000 US$. On the other hand, superconducting technology requires all devices to be kept at a temperature of typically 77 K. State-of-the-art coolers have a weight of some kilogram and an efficiency of 5%, and to cool down the devices as well as to compensate for the HF-losses especially in the OMUX, the required cooling power for a repeater is in the order of some Watts. Cooling power and amplifier power can be compared directly to mass by using a typical power-mass equivalence of 5-10 Wkg^{-1}. We believe that we can overcompensate for the additional load by the savings in amplifier power, mass and volume.

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