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Measurements of 2320-2345 MHz Bandstop Filters Fabricated using a High-Temperature Superconductor

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Introduction

This report describes tests performed on a pair of bandstop filters intended for possible use in the GBT 1.73-2.60 GHz (S-Band) receiver front-end. The filters are specified to provide rejection of the downlink signals from satellites providing Satellite Digital Audio Radio Services (SDARS – i.e. Sirius and XM radio). The filters were designed and fabricated by the ***Emerging Device Technology Research Group***, University of Birmingham, UK, headed by Professor Michael J. Lancaster. This group has extensive experience in design of HTS filters, including filters for radio astronomy applications.[1] The six-pole elliptical filters are fabricated using YBCO thin-film on a $LaAlO_3$ substrate. The titanium housing of each filter is 1.7 X 4.0 X 4.7 cm. Design and fabrication of the filters will be fully described in a separate paper.

The following performance goals were set for the filters:

Passband Frequency Range: 1700-2700 MHz (exclusive of notch)
Notch Rejection Frequency Range: 2320-2345 MHz
Notch Rejection: 40dB minimum
Notch 1dB Bandwidth: 40 MHz maximum
Passband VSWR: 1.25:1 max (exclusive of notch)
Phase match (2 units): +/- 5 degrees. This specification applies inside the passband frequency range, and outside the notch 1dB bandwidth. A constant delay difference between units is acceptable.
In/Out Connectors: SMA, 50 ohms
Operating Temperature Range: 10-20 K. The units shall not be damaged by thermal gradients of 310K to 10K in one hour, and 10K to 310K in two hours.
Quantity required: Two units.

The filters have been tested in the NRAO laboratory at Green Bank, WV, using a closed-cycle refrigerator to cool to 17 K. Stainless steel 085 coaxial cables approximately 20 cm

[1] G. Zhang et. al., "A Superconducting Microstrip Bandstop Filter for an L-Band Radio Telescope Receiver", Proceedings in 35th European Microwave Conference Digest, October 2005.

long were used to provide thermal isolation to the filter input and output ports, as shown in Figure 1. A vector network analyzer was used to measure the filter S-parameters; full two-port calibration was done at the filter ends of the SS cables, at room temperature.

Test Results

The two filters are designated BSF 1 and BSF 2. Because of the nature of the YBCO film, the filters have no measurable signal transmission at room temperature. Figure 2 through Figure 4 show the transmission[2] and reflection properties of BSF 1 at 17 K. A reference plane offset of 724.9677 psec has been inserted to obtain nominally flat phase response in S21. Note that the rejection at 2320 MHz is not quite -40 dB, but other parameters easily meet the performance goals.

Figure 5, Figure 6, and Figure 7 show the BSF 1 S21 parameter at 60K, 86K, and 89K. These plots were taken as the filter warmed up after the refrigerator was turned off, and shows slight change in response at 60K; at 86K the notch has shifted downward by about one-half the notch bandwidth, and at 89K the filter is not usable.

The curvature in transmission phase as the frequency approaches the reject band causes increase in the group delay, as is shown in Figure 8. This curve is obtained by taking the numerical derivative of the S21 phase outside the notch -1dB points. Note that this characteristic is not specific to a HTS filter; any filter will exhibit non-linear phase near the band edges.

Figure 9 and Figure 10 shows the S21 and S11 parameters of BSF 2, with the BSF 1 parameters overlaid for comparison. Figure 11 shows the difference between the two filters' S21 parameter magnitude and phase. While the second filter does not quite meet the S11 goal (1.25:1 = -19 dB), the insertion phase and amplitude match of the filters are excellent.

In addition to the above measurements, the filters were checked for microphonics (refrigerator modulation) using an amplified noise source and a power detector. No evidence of modulation was seen. The literature mentions that at high power levels, HTS transmission lines can exhibit non-linear behavior[3,4]. We performed a two-tone, 3rd order intermodulation test on BSF 2 and saw no intermodulation products above our detection limit of -65 dBc with the two tones at +5 dBm at the filter output. This level is significantly higher than expected in operation. Finally, we did four cooldown – warmup cycles on each filter and saw no significant change in performance.

Conclusions

The HTS bandstop filters deliver performance better than the design goals, with a couple of minor exceptions. The intention is to install these filters following the cooled

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[2] A separate measurement of the change in loss in the cryostat coaxial lines showed that their loss decreased by 0.14 dB upon cooling. This value should be subtracted from the filter S21 measurements.
[3] G. L. Matthaei and G. L Hey-Shipton, "Concerning the Use of High-Temperature Superconductivity in Planar Microwave Filters", IEEE Trans. On MTT, Vol. 42, No. 7, July 1994
[4] R. B. Hammond et. al., "Intrinsic Limits on the Q and Intermodulation of Low Power High Temperature Superconducting Microstrip Resonators", Journal of Applied Physics, Vol. 84, No. 10, 15 November 1998

amplifiers in the GBT S-band receiver, and it appears they will do a good job of reducing the level of the SDARS signals. When the filter is installed, the receiver will not be usable between the notch -1 dB frequencies, approximately 2314 – 2356 MHz. However, reduction of the SDARS signals in the downstream signal processing paths should improve observation quality in general.

The logical next step is to perform system tests after installation of the bandstop filters in the GBT S-band receiver, as soon as this work can be scheduled.

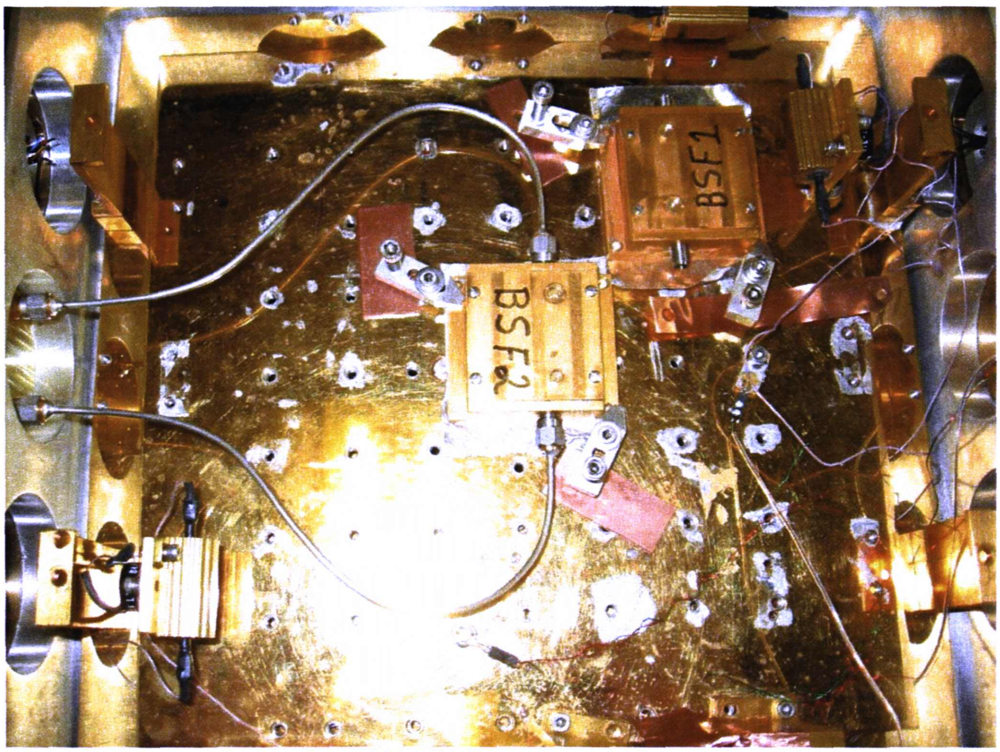

Figure 1: Photo of the bandstop filters in the test cryostat.

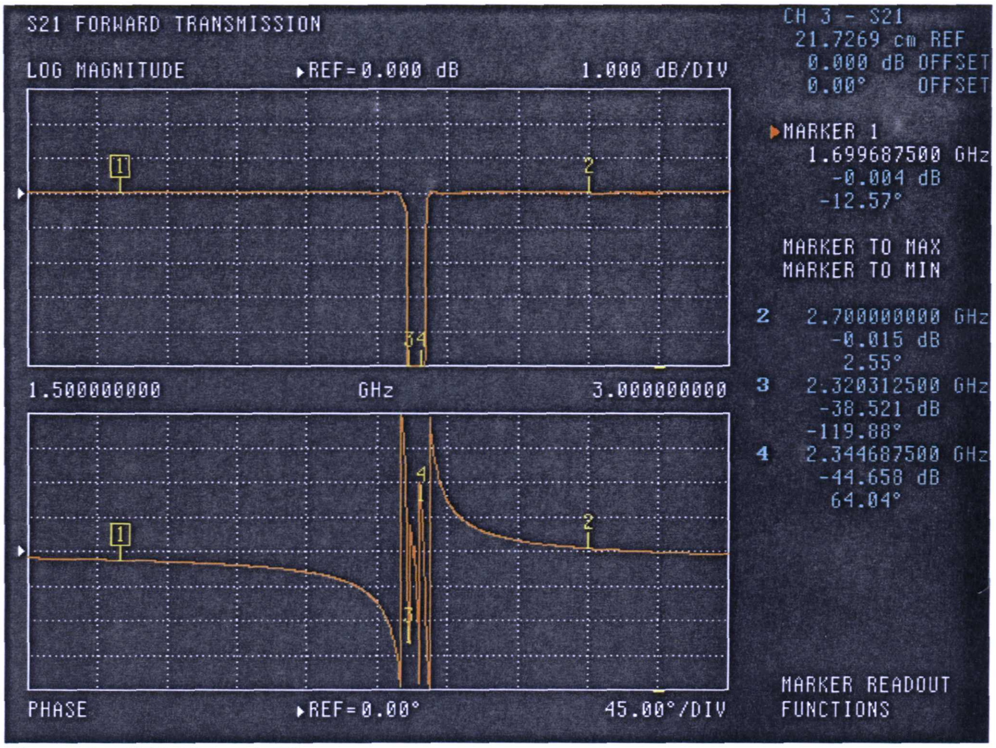

Figure 2: BSF1 S21 at 17K.

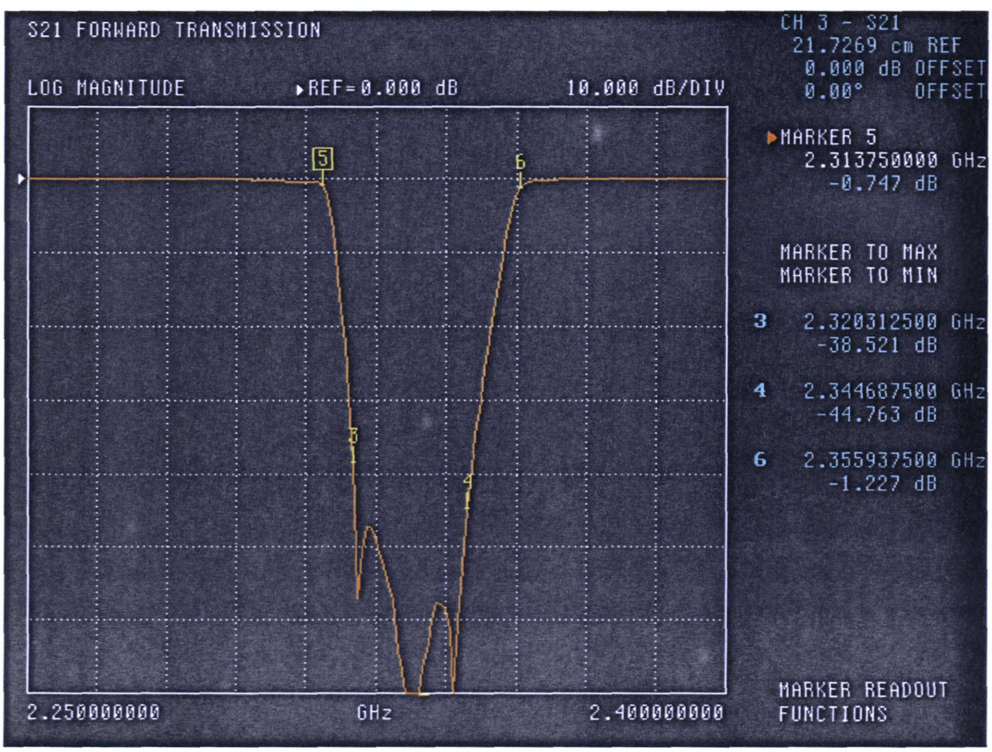

Figure 3: BSF1 S21 magnitude zoomed to notch, at 17K.

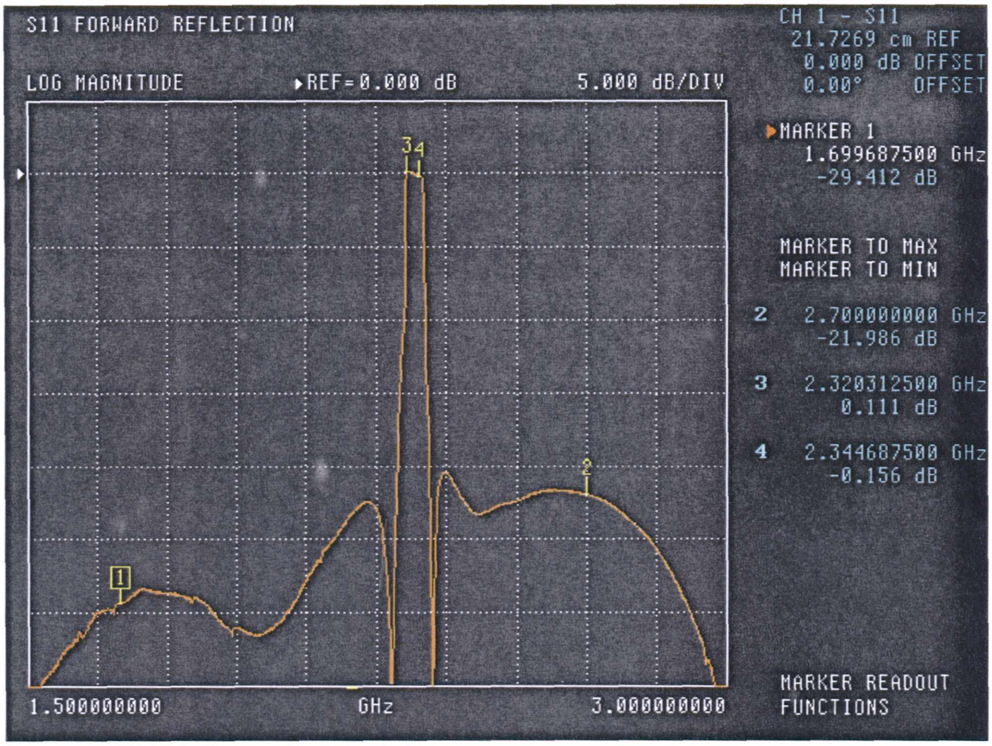

Figure 4: BSF1 S11 magnitude at 17K.

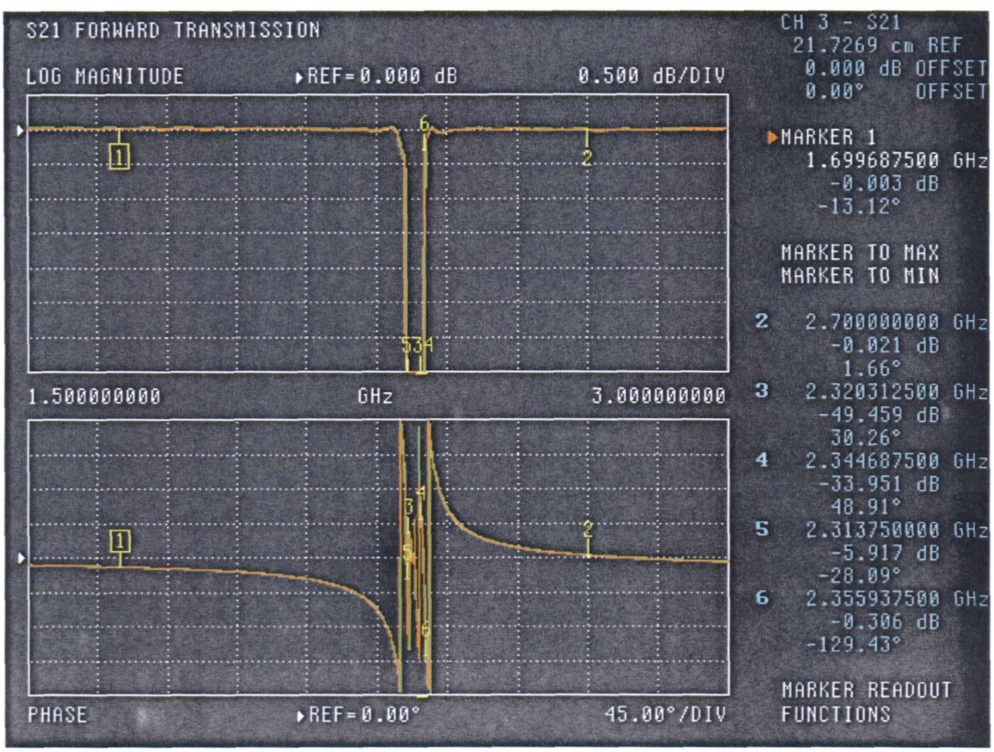

Figure 5: BSF1 S21 at 60K. Green trace is 17K data.

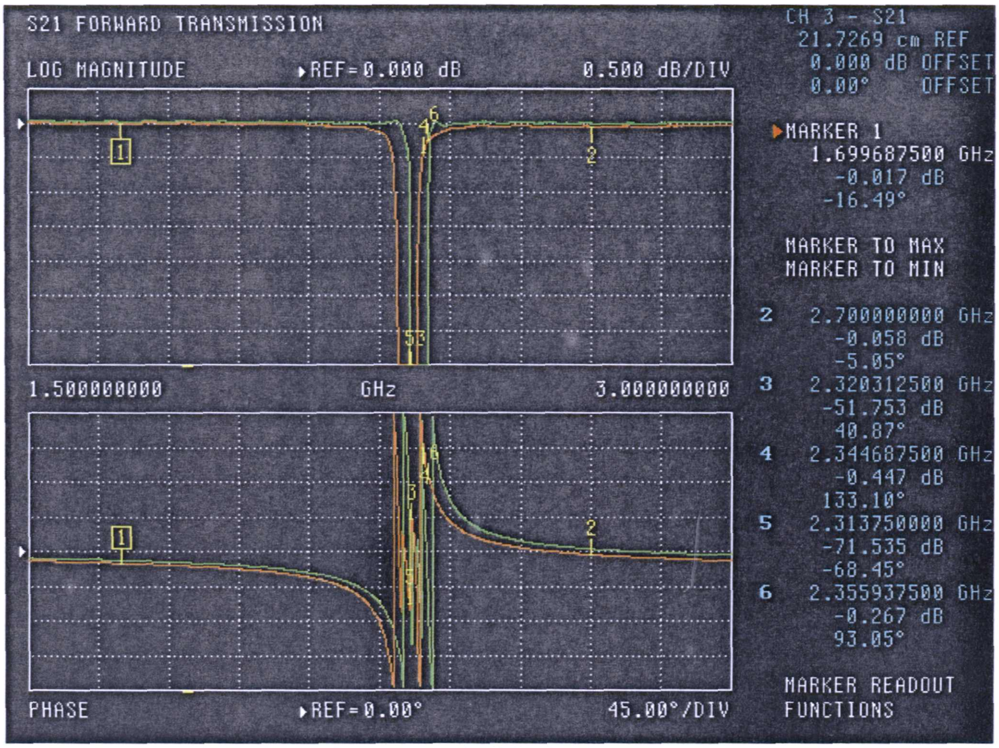

Figure 6: BSF1 S21 at 86K. Green trace is 17K data.

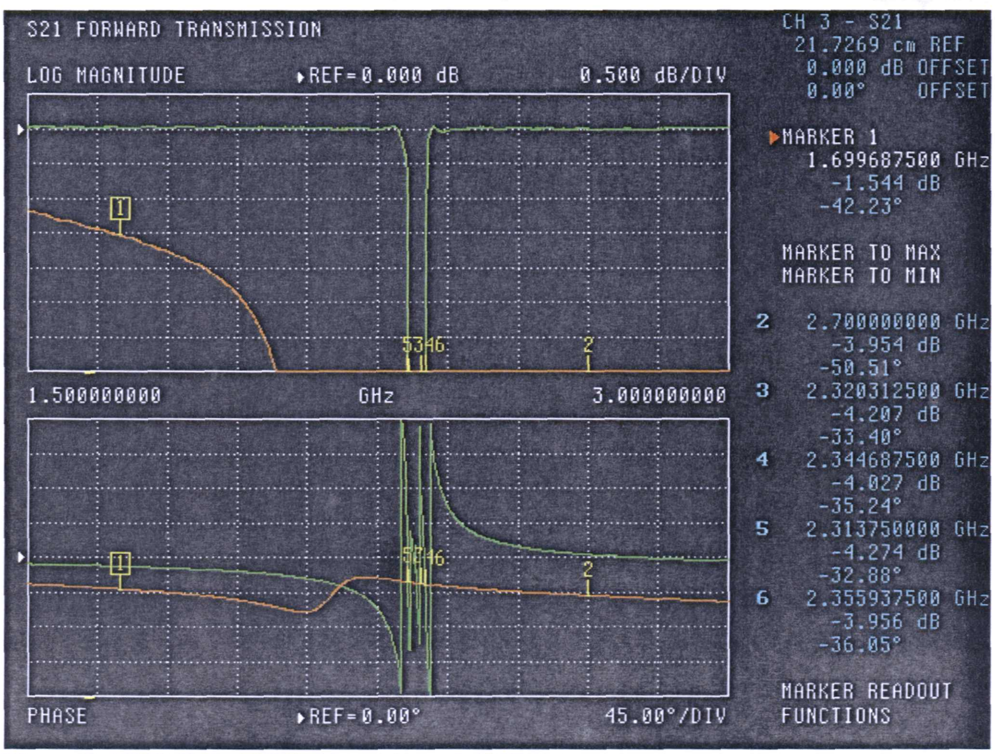

Figure 7: BSF1 S21 at 89K. Green trace is 17K data.

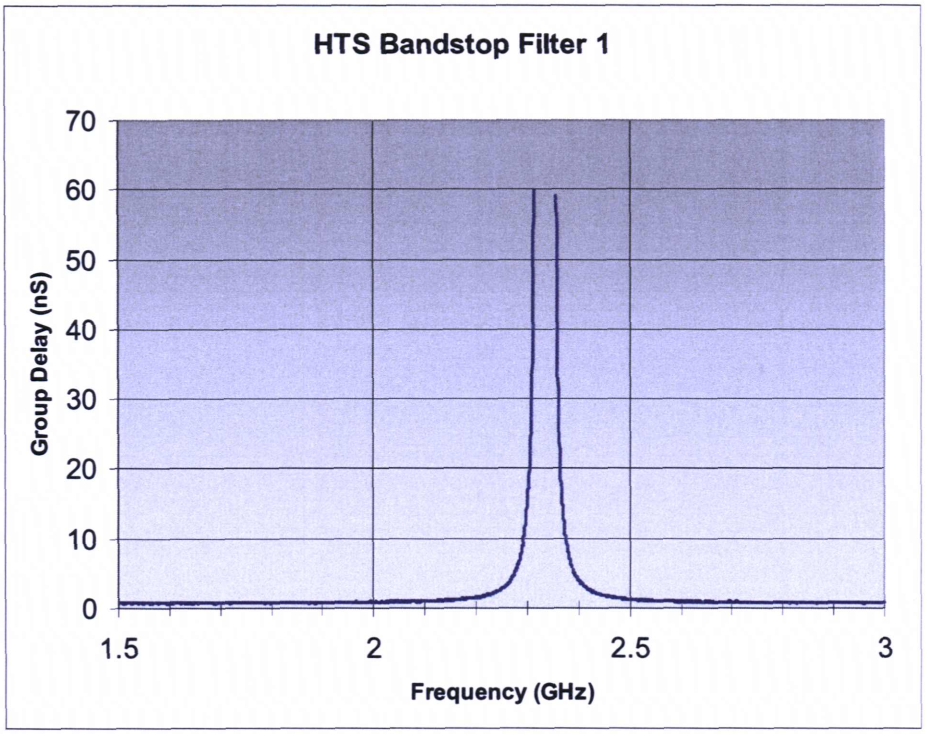

Figure 8: BSF1 Group Delay

Figure 9: Orange – BSF2 S21 Data. Green – BSF1 data. Both at 17K.

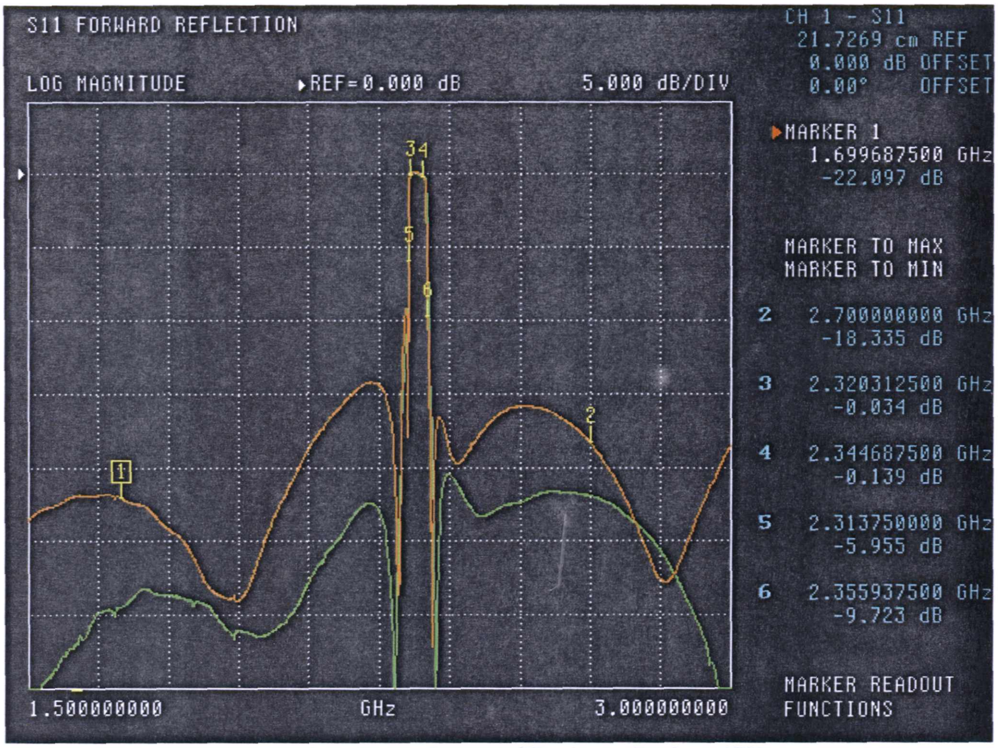

Figure 10: Orange – BSF2 S11 data. Green BSF1 data. Both at 17K.

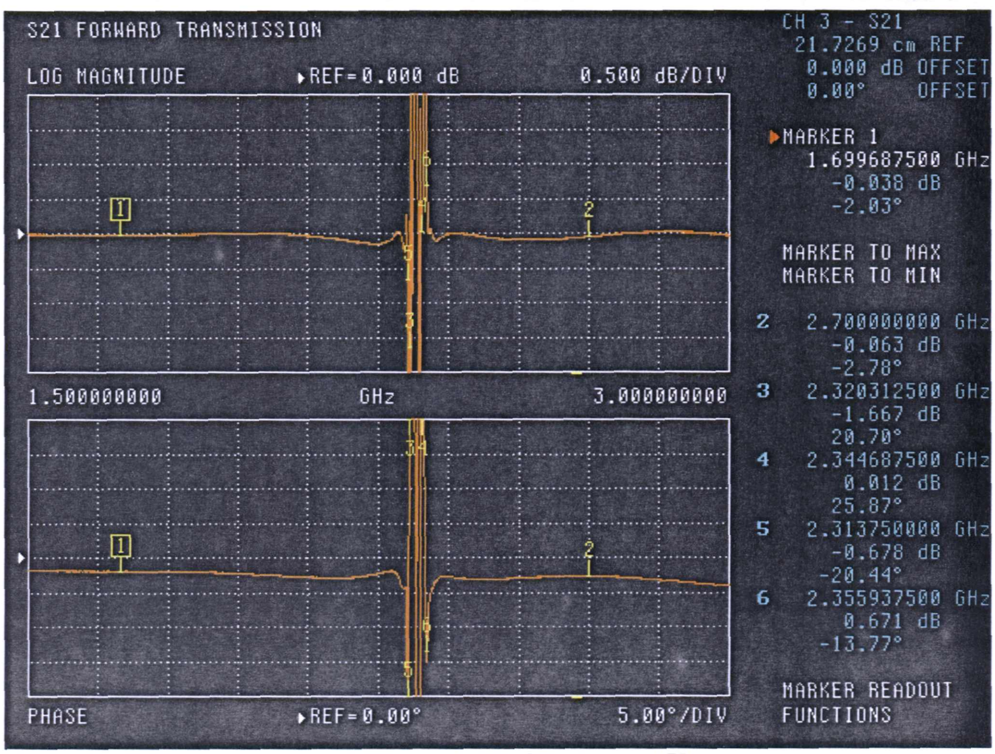

Figure 11: Difference between BSF1 and BSF2 S21 data at 17K.