Cryogenic Test of Marki BT-0024SMG

Nathan Holman

Department of Physics, University of Wisconsin-Madison, 53706

(Dated: January 2020)

Abstract

We characterize the cryogenic performance of the Marki 0024SMG surface mount bias-T by measuring the full scattering parameter matrix from 50 kHz to 18 GHz and the step response of the DC port in the time domain. In general, the bias-T performs extremely well at 1.6 K with low insertion loss (< 3dB above 8 MHz) from the RF input and fast settling time (< 100 μs) for the DC input. These properties, in addition to is robustness against repeated fast thermal cycling makes it a viable component for use in cryogenic device test and measurement printed circuit boards. We note compared to room temperature performance, the DC port isolation experiences a modest reduction in effectiveness and a corresponding increase in speed. This is possibly due to a reduction in the inductance at the DC port from a lowering of the relative permeability at cryogenic temperatures of the material used in the RF choke element. Performance may be improved through use of additional RF choke components at the DC port such as superconducting inductors or cryogenically compatible resistors.

I. MEASUREMENT SETUP

The BT-0024SMG was provided by Marki Microwave in a brass connectorized test package with three stainless steel 2.4mm connectors. The test package was mounted on a cryogenic probe stick and connected by three hand formable coax with no explicit attenuation and is shown in Figure 1. The stick was inserted into an Oxford Instruments Teslatron™screening station and allowed to thermalize to 1.6K over several hours via helium exchange gas. Using a network analyzer, we measured the full scattering matrix of the device using pairwise measurements from 50 kHz to 18 GHz. During each pairwise measurement, the third port is terminated at the top of the probe with a 50Ω SMA termination. Rise time measurements of the DC port were done by applying a 2 Vpp, 100 Hz square wave generated using a Textronix AFG 3022B. A Tektronix MDO3014 mixed domain oscilloscope is used to measure the response out the RF+DC port. Loss of the coax is characterized at both 300K and 1.6K allowing us to decouple transmission loss from the device performance. For the purposes of our measurements, we label the RF in port as port 1, the RF+DC port as port 2, and the DC in port as port 3.

II. 300 K DATA

Figure 2 shows the full 3-port scattering matrix data taken at 295 K (often referred to as 300 K in cryogenic device literature). For these data that cable loss is not subtracted. Notably, for S32 (S23) a large standing wave structure is present thorughouth the entire 18 GHz span. Additionally, a more prominent standing wave structure is also observed at higher frequencies after a resonance feature at around 2 GHz.

To account for cable loss we performed measured two coax joined by a barrel connector. The upper left panel of Figure 3 shows the transmission data and is fit well by a power law which we use to background subtract the loss from the device transmission data. Small deviations in the real data from the power law fit arise from standing wave structure due to small impedance mismatches between connectors and are generally less than 0.3 dB across the range measured. Standing wave structure in the subtracted data is likely due to cabling and may be suppressed somewhat with the incorporation of an attenuator for the RF input cabling typically used to thermalize the lines.

Figure 4 shows a zoom in at lower frequencies of the transmission spectra for both subtracted and raw data. We observe a strong standing wave structure present in the S31 room temperature data. The S21 transmission reaches its 3dB point at around 300 kHz in our setup.

Figure 5 shows the step response of the DC port of the Bias T exposed to a 100 Hz square wave with a 2 Vpp amplitude. The response exhibits a fast and slow portion similar to what is reported in Marki-Microwave's technical notes. The fast portion saturates at around 1 μs and the slow portion saturates around 2 ms.

III. 1.6 K DATA

All data shown was taken after a total of six thermal cycles from 300K to 1.6K (approximately 4 hours to cool, 1.5 hours to warm) and no changes in the SMD component's performance were observed indicating the part can tolerate rapid thermal cycling.

Figure 6 shows the full 3-port scattering matrix data taken at 1.6 ± 0.01 K. For these data that cable loss is not subtracted. Notably, for the parameters involving the DC port (e.g. S13,S23 etc), a second sharp dip can be seen at low frequencies compared to its room temperature counterpart. Additionally, a more prominent standing wave structure is also observed at higher frequencies. The exact origin of these changes is unclear but likely related to the reduced isolation of the DC port.

To account for cable loss we performed a separate cool down of the stick with two coax joined by a barrel connector. The upper left panel of 7 shows the transmission data which is fit well by a power law which we use to background subtract the loss from the device transmission data. Small deviations in the real data from the power law fit arise from standing wave structure due to small impedance mismatches between connectors and are generally less than 0.2 dB across the range measured. Standing wave structure in the subtracted data is likely due to cabling and may be suppressed somewhat with the incorporation of attenuation at the RF input port typically used to thermalize the lines.

Figure 8 shows a zoom in at lower frequencies of the transmission spectra for both subtracted and raw data. We observe a reduction in the standing wave structure present in the S31 room temperature data but the inclusion of a resonance-like feature around 710 MHz. The S21 transmission reaches its 3dB point at around 7.5 MHz. This is due to increased leakage out the DC port of the device at low temperatures.

Figure 9 shows the step response of the DC port of the Bias T exposed to a 100 Hz square wave with a 2 Vpp amplitude at 1.6 K. Similar to the room temperature response, it exhibits a fast and slow portion with a general speed up of 5-10x over the room temperature performance. The fast portion saturates at around 200 ns and exhibits ringing in the response. The slow portion saturates around 80-100 μs. Likely the increased speed of the DC port is due to a reduction in the RF isolation circuit inductance corroborated by an increase in the 3dB insertion loss point for the S21 and an increase in the S31 scattering parameter at low frequencies.

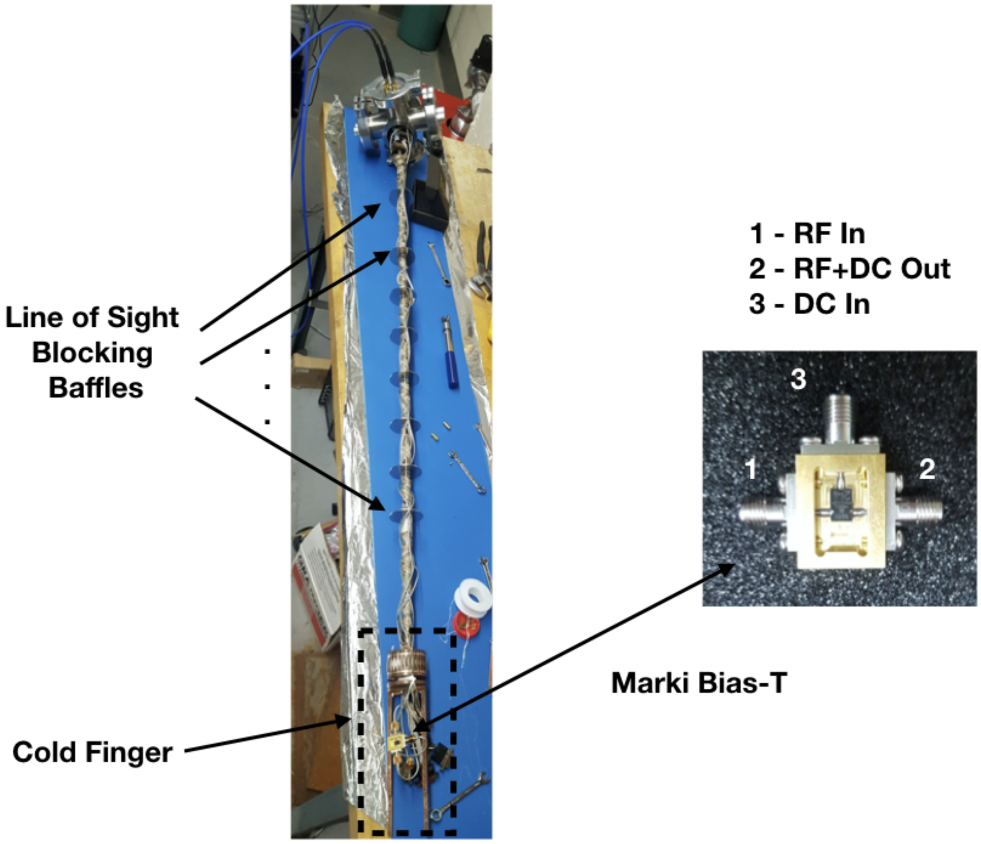

FIG. 1. Left is an image of the probe stick used for all data shown. Baffles block thermal radiation line of sight to the cold finger from 300K and allow for a base temperature of 1.6 K as measured by a thermometer on the cold finger. Right shows the Bias T as packaged by Marki-Microwave as well as our indexing of the three ports for all scattering matrix measurements.

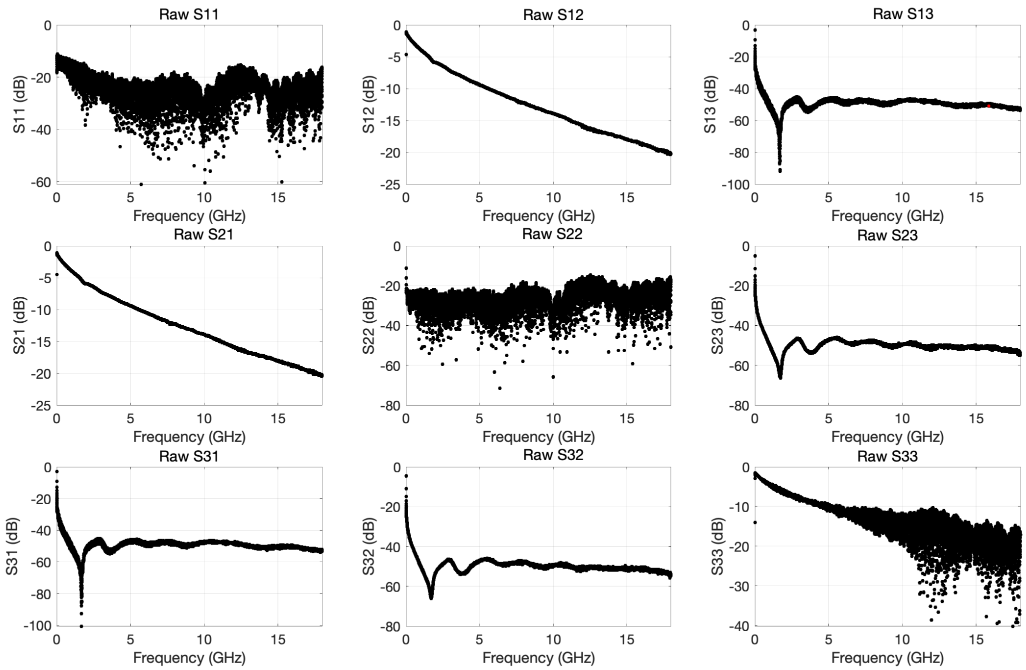

FIG. 2. The full 3-port scattering matrix measured at 300 K. No cable loss subtraction is present in these data and most of the loss in the S21 data is from intrinsic cabling loss at microwave frequencies.

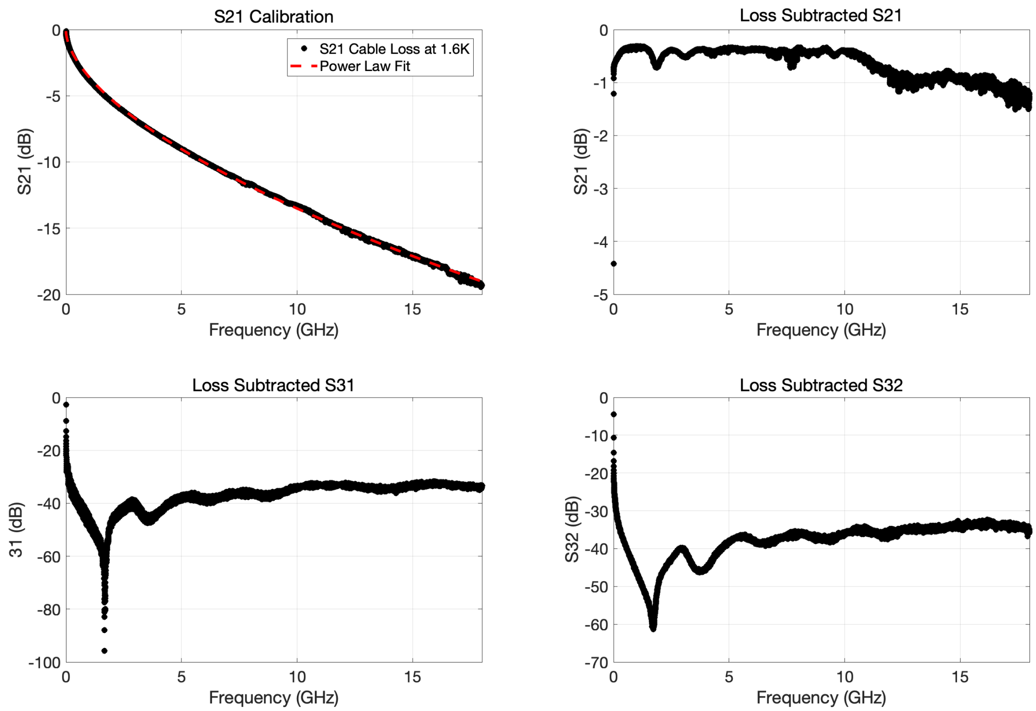

FIG. 3. Calibration of cable loss and loss subtracted transmission data of the device at 300K. We note the loss is higher than at cryogenic temperatures and the background standing wave structure is slightly larger for these data than in the cryogenic data.

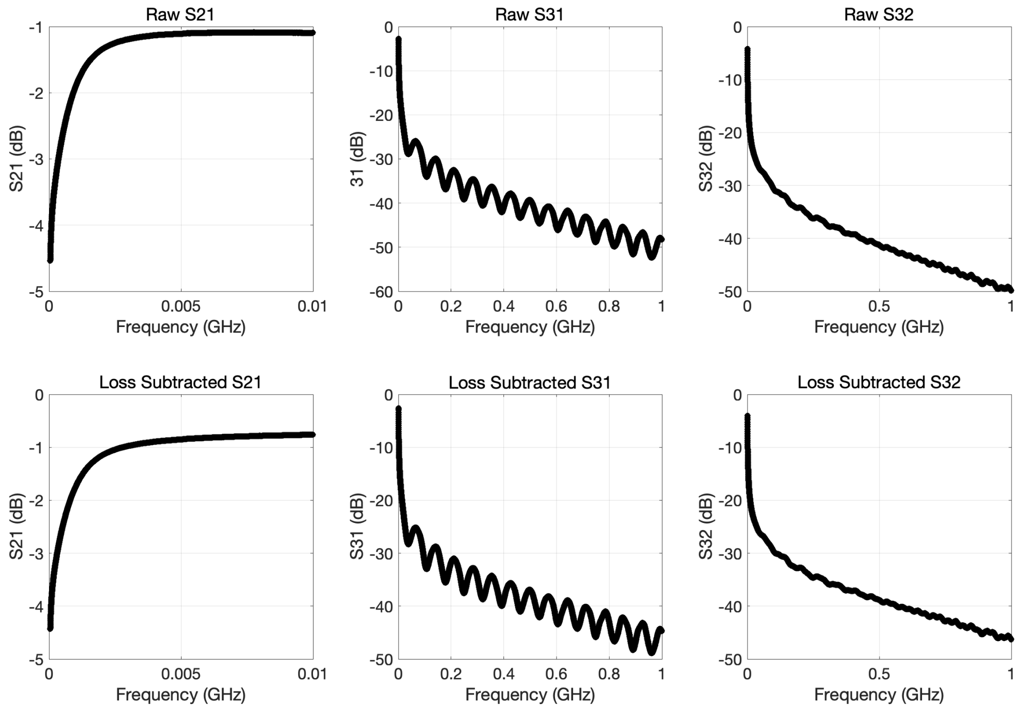

FIG. 4. Low frequency transmission response of the bias T at 300K. Note the S31 spectrum exhibits rapid oscillatory behavior likely due to the inductor-capacitor resonance between ports 1 and 3.

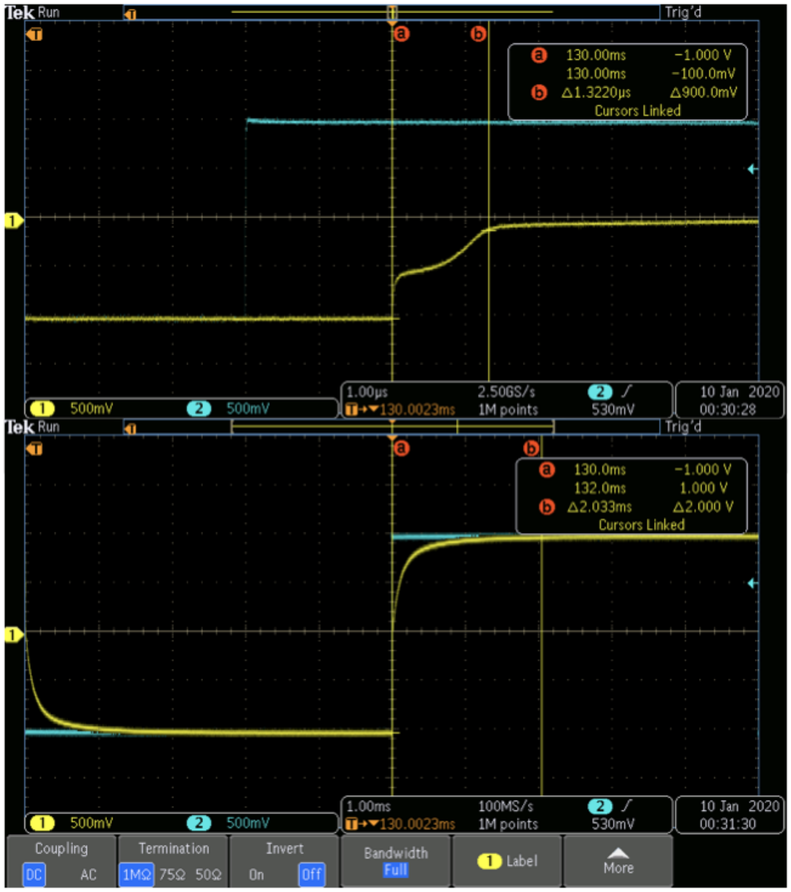

FIG. 5. In yellow is the step response of the DC port (blue is the raw AFG output). We observe a fast and slow portion for the rise time of the device that saturate around 1 μs and 2 ms in our setup.

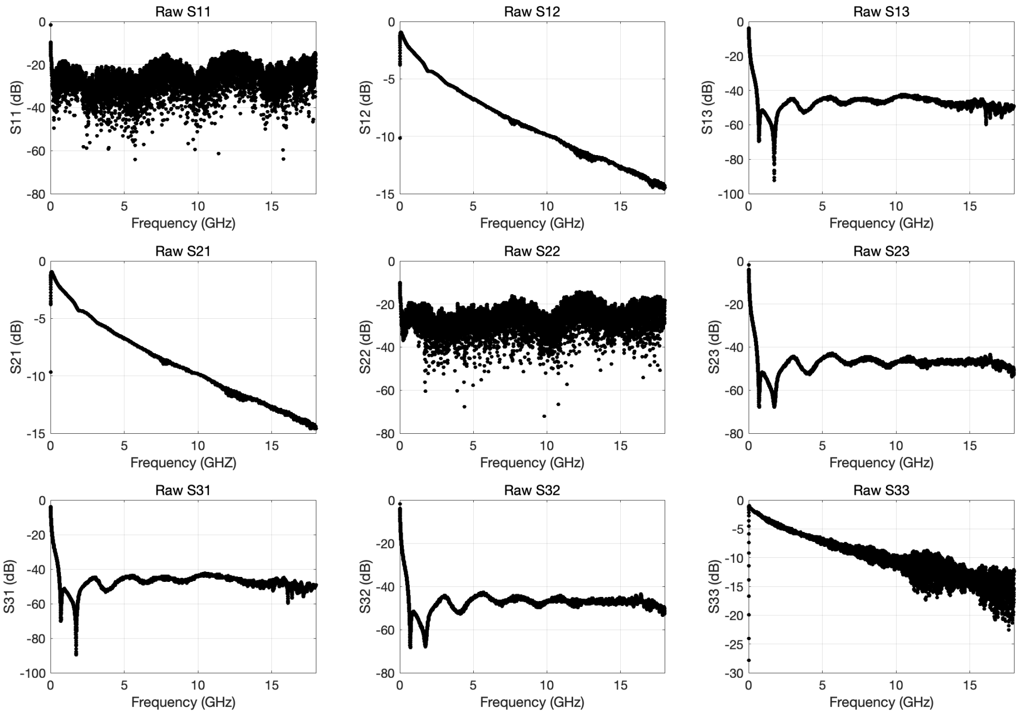

FIG. 6. The full 3-port scattering matrix measured at 1.6 K. Note the transmission loss is lower than the room temperature measurements due to a reduced microwave loss at cryogenic temperatures.

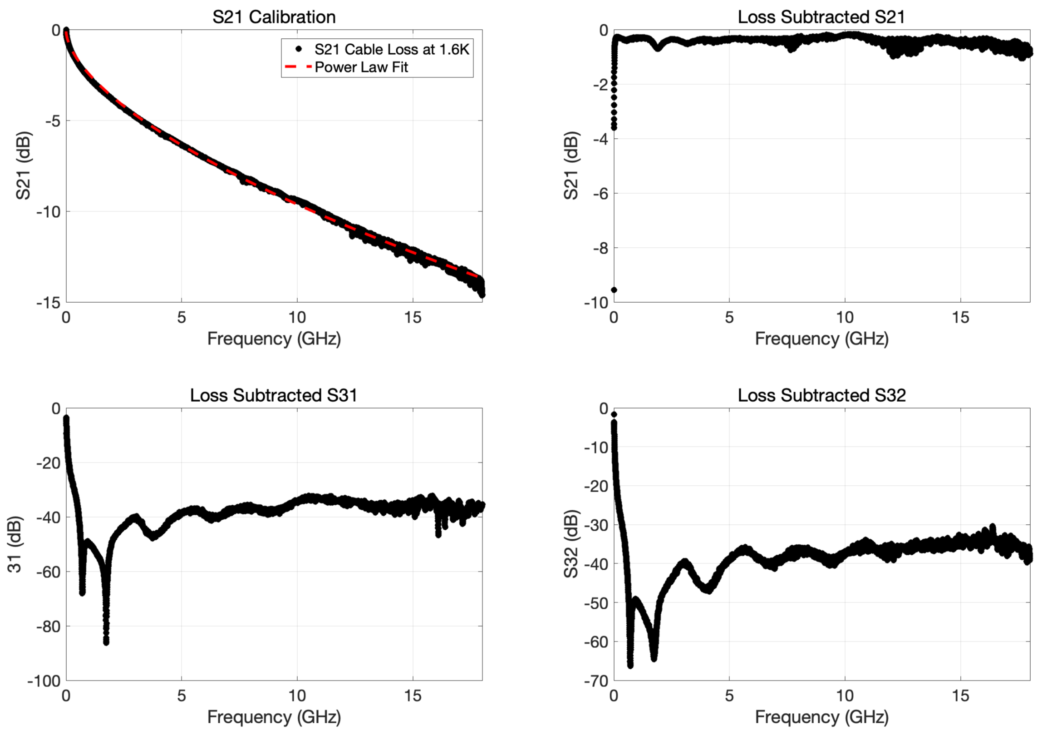

FIG. 7. Calibration of cable loss and loss subtracted transmission data of the device.

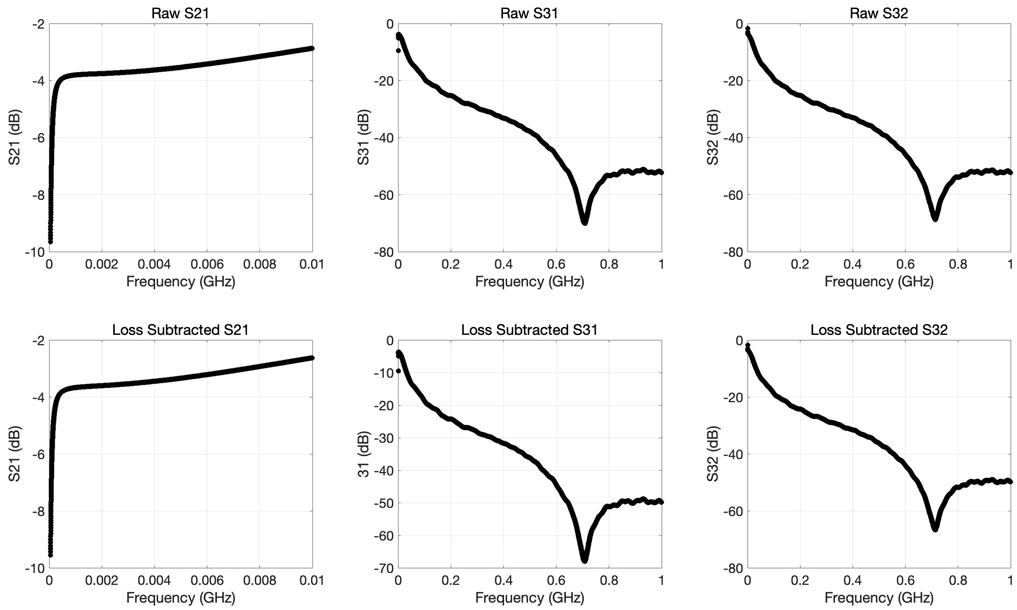

FIG. 8. Low frequency transmission response of the bias T at 300K. Large resonance features are observed in both the S31 and S32 data at cryogenic temperatures. They likely arise from a change in the self resonance frequency of the DC isolation circuit.

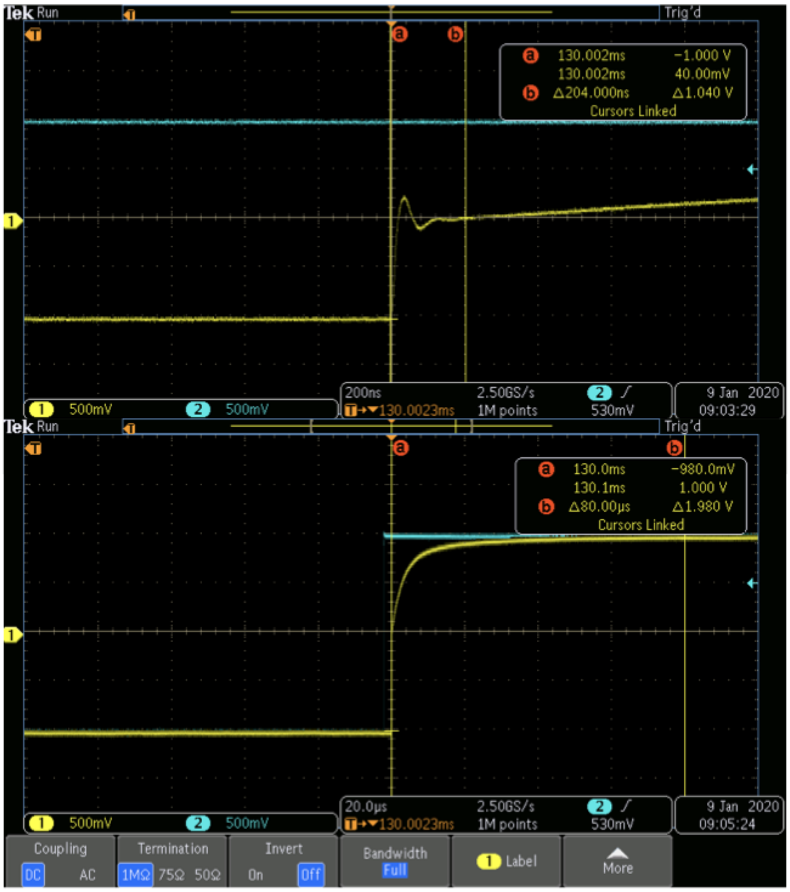

FIG. 9. In yellow is the step response of the DC port at 1.6 K (blue is the raw AFG output). The fast portion is 5x faster than the room temperature performance saturating at around 200 ns. The full rise occurs around 80-100 μs mark.