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Measurements of thermal-dependence of 50-Ohm terminators

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July 3, 2017

Overview

The SP4T RF switch "VNA switch" used in the EDGES frontend for VNA measurements employs an OSL set on three of its ports. The load (L) is a 50-Ohm terminator. Current VNA switches are not latching and produce a significant increase in temperature of the switch block near the OSL plane, by as much as 5-10 degrees Celsius if in sustained operation. Recent experience suggests that thermal dependence of the 50-Ohm terminator used on the switch may be a significant source of error in S11 measurements acquired through the system. Hence, we aim here to measure and document the thermal dependence of several 50-Ohm terminators to inform the selection for use in EDGES receivers.

The thermal dependence of the DC resistance of three 50-Ohm SMA terminators was measured in the ASU lab. The three terminators were: Fairview part #ST1819, Mini-Circuits MCL-Anne-50, and the Agilent/Keysight calibration load standard part #85033-60016 (the male 3.5mm connector load that comes with the Keysight 85033E Cal kit). The Fairview and MCL terminators were found to have approximately 10 PPM/degC thermal dependence in S11 between 25-50 degrees Celsius. The Agilent standard had a larger dependence of order 100 PPM/degC in S11 over the same temperature range.

Alan measured several 50-Ohm terminators at Haystack and found a similar range of results. Both ASU and Haystack measurements are summarized below.

Testing procedures

For terminators tested in the ASU lab, each was tested as follows:

- The terminator was connected to an Ohm-meter using a banana to BNC adapter and BNC to SMA adapter.
- A thermal probe (thermistor) was temporarily connected to the terminator using Kapton tape and a Fluke 54(II)B was connected to the thermistor to yield temperature measurements in Celsius.
- The terminator was heated to approximately 50 degrees Celsius using a hot air gun from a solder reflow station. The terminator was heated until the DC resistance and temperature were seen to stabilize.
- Heating was discontinued after the resistance stabilized and the terminator was allowed to cool to room temperature. Resistance and temperature readings were acquired manually and recorded to a lab notebook as the temperature cooled.

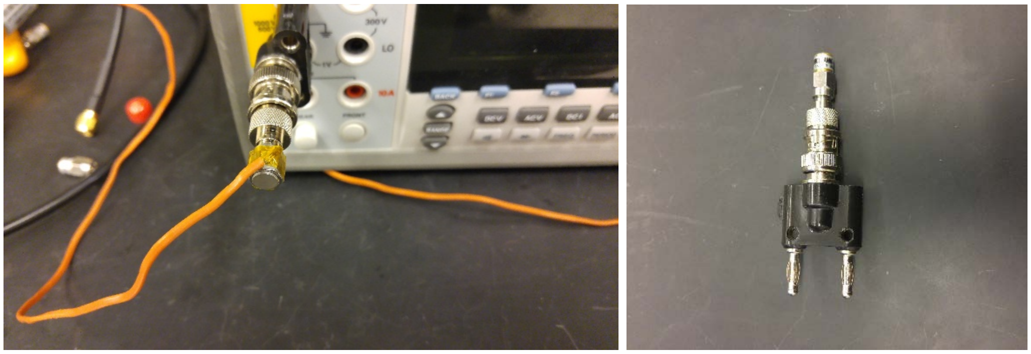
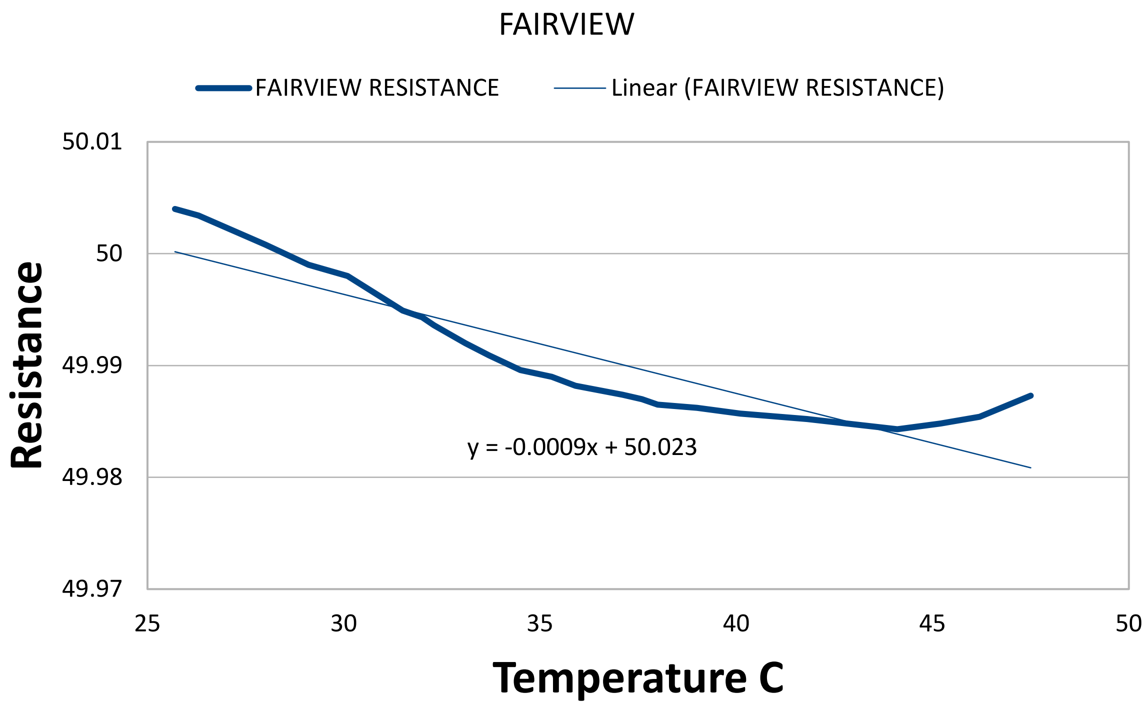


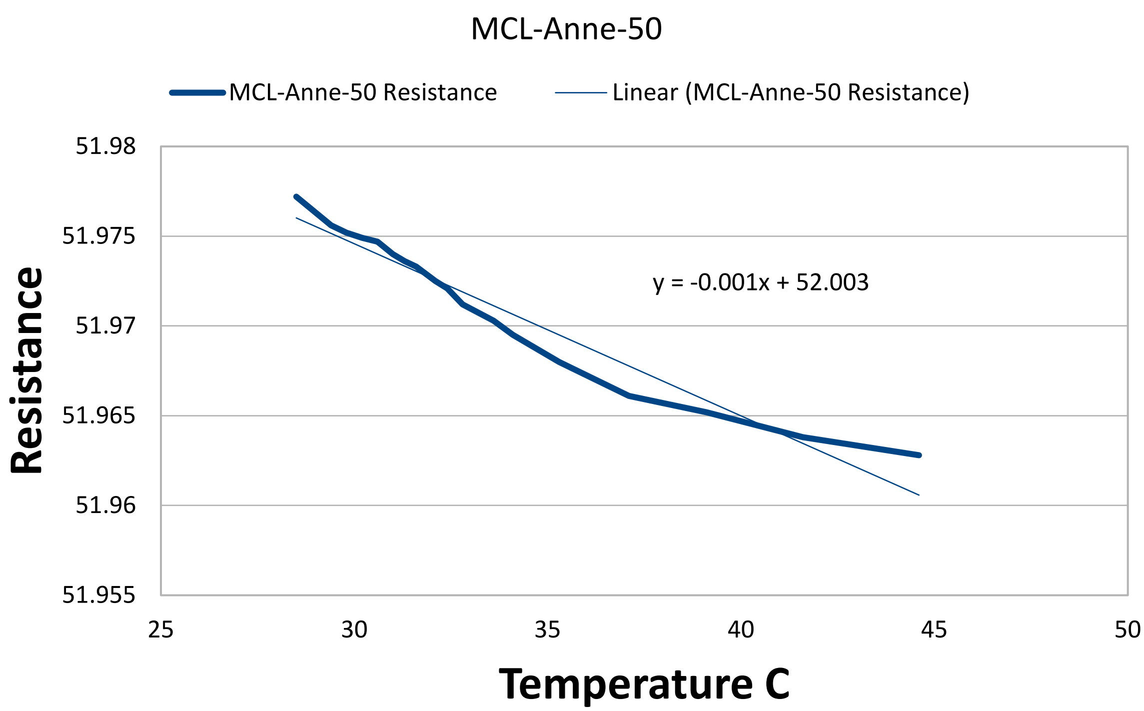
Figure 1. Measurement setup at ASU.

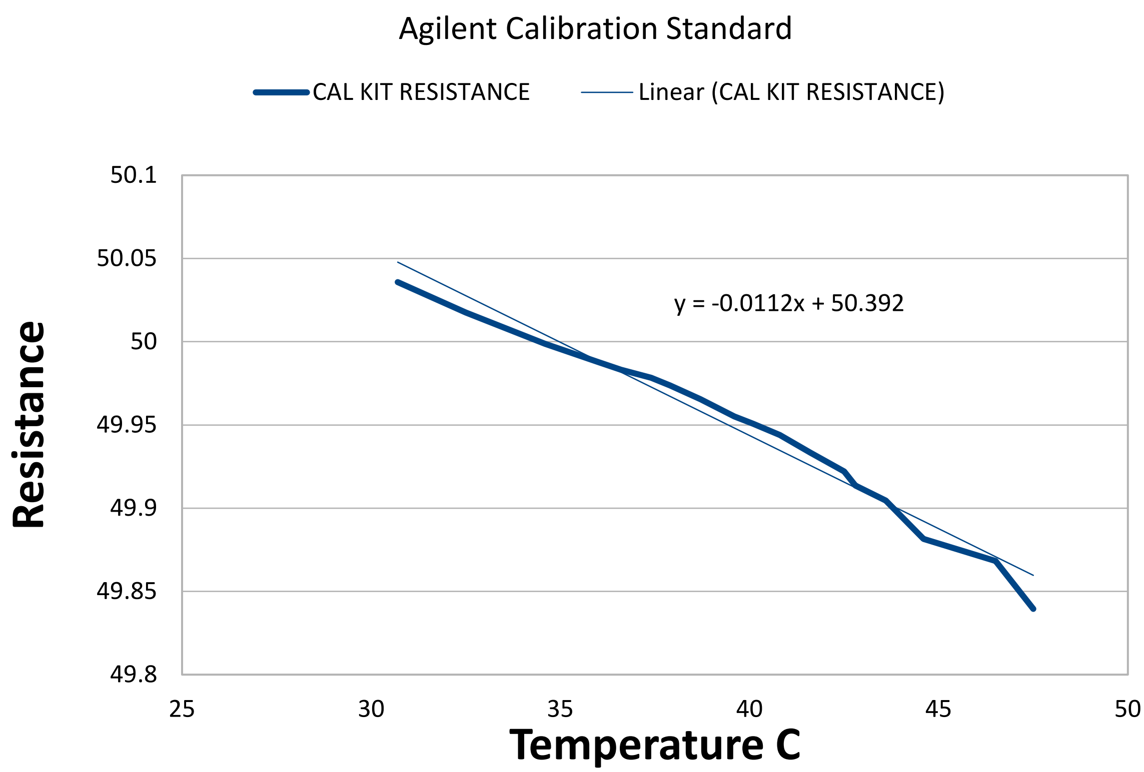
Table 1. DC resistance and temperature measurements for each terminator in the ASU sample.

MCL-ANNE TEMP c	MCL-ANNE RESISTANCE	CAL KIT TEMP c	CAL KIT RESISTANCE	FAIRVIEW TEMP C	FAIRVIEW RESISTANCE
44.6	51.9628	47.5	49.8395	47.5	49.9873
41.6	51.9638	46.5	49.8682	46.2	49.9854
39.1	51.9652	44.6	49.8815	45.2	49.9848
37.1	51.9661	43.6	49.9045	44.1	49.9843
35.3	51.968	42.8	49.9136	41.8	49.9852
34.1	51.9695	42.5	49.922	40.1	49.9857
33.6	51.9703	41.6	49.9334	39	49.9862
32.8	51.9712	40.8	49.9439	38	49.9865
32.4	51.9721	40.1	49.9506	37.6	49.987
32.1	51.9725	39.6	49.9551	37.1	49.9874
31.6	51.9733	38.7	49.9654	35.9	49.9882
31.3	51.9736	37.9	49.9738	35.3	49.989
31	51.974	37.4	49.9784	34.5	49.9896
30.6	51.9747	36.6	49.9832	33.7	49.9909
30.2	51.9749	36	49.9877	33.1	49.992
29.8	51.9752	34.6	49.9987	32.3	49.9936
29.4	51.9756	32.5	50.0176	32	49.9943
28.5	51.9772	30.7	50.0358	31.5	49.9949
				30.1	49.998
				29.1	49.999
				28	50.0008
				26.3	50.0034
				25.7	50.004

Below are plots of the ASU measurements, along with linear fits.







Below are the derived thermal dependence values for the ASU measurements, along with the values reported by Alan for the Haystack measurements.

S11 temperature coefficient is calculated from the definition of S11 = (Z-50)/(Z+50), giving dS11 = dZ/(100+dZ), assuming the terminators reference impedance is Z=50 Ohm.

ASU Measurements:

	Temperature dependence of DC resistance between ~25 and ~50 degC		S11 temperature coefficient	
Agilent calibration standard:	-0.0112	$degC^{-1}$	-112	PPM/degC
Fairview:	-0.0009	$degC^{-1}$	-9	PPM/degC
MCL-Anne-50:	-0.001	$degC^{-1}$	-10	PPM/degC

Haystack Measurements:

	Change in DC resistance when heated from 25 to 100 degC		S11 temperature coefficient	
MCL ANNE-50a:	+0.2	Ohm	+27	PPM/degC
MECA SMA:	-1.0	Ohm	+130	PPM/degC
Pasternack:	-0.2	Ohm	-27	PPM/degC
Unknown:	+0.6	Ohm	+60	PPM/degC

Conclusions

The magnitude of the ASU and Haystack measurements are in general agreement. In particular, the magnitude of the temperature dependence of the MCL terminator was similar in both cases, although the signs of the effect differed.

Some terminators are up to an order magnitude worse than the best-performing MCL, Fairview, and Pasternack parts. Surprisingly, the Agilent calibration standard appears to have high thermal dependence. The Aligent standard is used for absolute calibration of EDGES receivers and their VNA systems. Its relatively large thermal dependence suggests that the laboratory calibration procedure may need to be conducted under thermal control, which has not been a significant consideration in prior calibrations.

Although we were not interested in the closeness of a terminator's impedance to an ideal 50 Ohms in this analysis, we note that the MCL terminator measured at ASU performed relatively poorly in this regard compared to the Fairview and Agilent terminators.