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Updated July 16, 2012

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To: EDGES Group
From: Alan E.E. Rogers and Delani Cele
Subject: Spectral flatness of HP346C noise source

The HP346C noise source is marked with calibration data at 10,100 and 1000 MHz with traceability to a thermal calibration at NIST. The values given are as follows:

Freq MHz	ENR dB
10	12.70
100	12.82
1000	12.73

and indicates that there is a variation in the flatness at a level of about 0.1 dB. To measure the flatness at a level better than 0.01 dB we constructed a hot noise source which operates at about 380 K. Figure 1 shows the circuit of the hot noise source. A high temperature 50 ohm resistor is attached to the end of about 3" of stainless steel 0.141 semi-rigid coax. The coax is heated by a 75 ohm resistor attached to the coax via a copper strap. Figure 2 shows a photo of the testing of the heater during construction of the hot noise source. The resistors and coax are packed in fiber glass insulation and enclosed in a 4"×2.5"×1.5" aluminum box. Following approximate calculations of the heat loss via conduction along the coax to the SMA feed-thru attached to the box it was found, by experiment, that 15 volts was sufficient to raise the temperature of the coax more than 100 C above ambient with sufficient heat loss to keep the rise below 200 C. The flatness of the hot noise source limited by the variation of the attenuation of the coax which is estimated to produce a slope of about 0.005 dB/50 MHz between 50 and 100 MHz. The advantage of the thermal noise source is that the flatness is not affected by the problems of $1/f$ noise and the influence of components in the bias injection which limit the flatness of diode noise sources especially in the frequency range below 1 GHz.

Initially it was found that the reflection coefficient was only -30 dB. The 50 ohm resistor which was mounted in a coaxial manner at the end of the coax had its end wire connection looped back to the coax has an excess inductance due to this wire. The problem was fixed by using a tubular section of copper tape wrapped around the resistor and soldered to the outer conductor of the coax on one end and soldered to the far end of the resistor on the other end. Then the copper tape tube was squeezed a little closer to the resistor to minimize the reflection coefficient. A reflection coefficient of about -50 dB was obtained from 50 to 200 MHz.

The hot noise source and the HP346C (with 10 dB attenuation) were measured using the EDGES P×14400 3-position switched spectrometer. Following correction of the internal noise source in

EDGES using a correction for the slope and curvature the spectra of the hot noise source was flattened.

Using the data from the hot source the internal calibration temperature was corrected by a slope and $1/f$ term to

$$10 \log_{10} \left[\frac{(P_{cal} - P_{load})}{(P_{hot} - P_{load})} \right]$$

Where P_{cal} = power on internal cal

P_{load} = power on internal load

P_{hot} = power on internal hot load

The internal calibration corrections were

Slope -0.202 dB/100 MHz

$1/f$ 0.605 dB 100 MHz

Using this 2 parameter correction the hot noise source is flattened to a constant 378.5 K from 50 to 200 MHz with rms deviation under 100 mK. Using this calibration the spectrum of the HP346C through a 10 dB attenuator from 50 to 200 MHz is shown in Figure 3. The variation of the spectrum in Figure 2 is about 0.1 dB peak to peak and consequently is consistent with the variation of ENR in the data at 10,100 and 100 MHz. This memo illustrates that noise sources like the HP346C are not sufficiently flat for an accurate calibration of EDGES. While it is possible to obtain a noise source with more calibration points from NIST these data would need to reach the 0.0005 dB level to accurately represent the level of flatness down to 100 mK.

Added note:

In June 2012 the Caddock resistor was replaced with a minicircuits ANNE-50 50 ohm termination connected to the stainless steel semi-rigid using a OSM-202-1A female connector. The temperature of the termination was measured with a Fluke 80BK-A. With these changes the hot load becomes an absolute standard with accuracy under 2% and flatness better than 20 ppm/MHz. The measured temperature coefficient of resistance from 25 to 100 C was 25 ppm/K and the reflection coefficient was better than -50 dB from 50 to 200 MHz. The expected slope in excess temperature due to the frequency dependence of the loss (~ 0.5 dB/m) of the 0.141 stainless semi-rigid is about 50 ppm/MHz at 100 MHz. Given the fundamental nature of this “hot” load it may no longer be necessary to obtain the absolute scale from a comparison with the HP346 C standard. In principle this hot noise source could be built into the EDGES but given the relatively high power consumption it may still be better to only use it to calibrate the internal noise diode. A photo of the hot load with cover removed is shown in Figure 4.

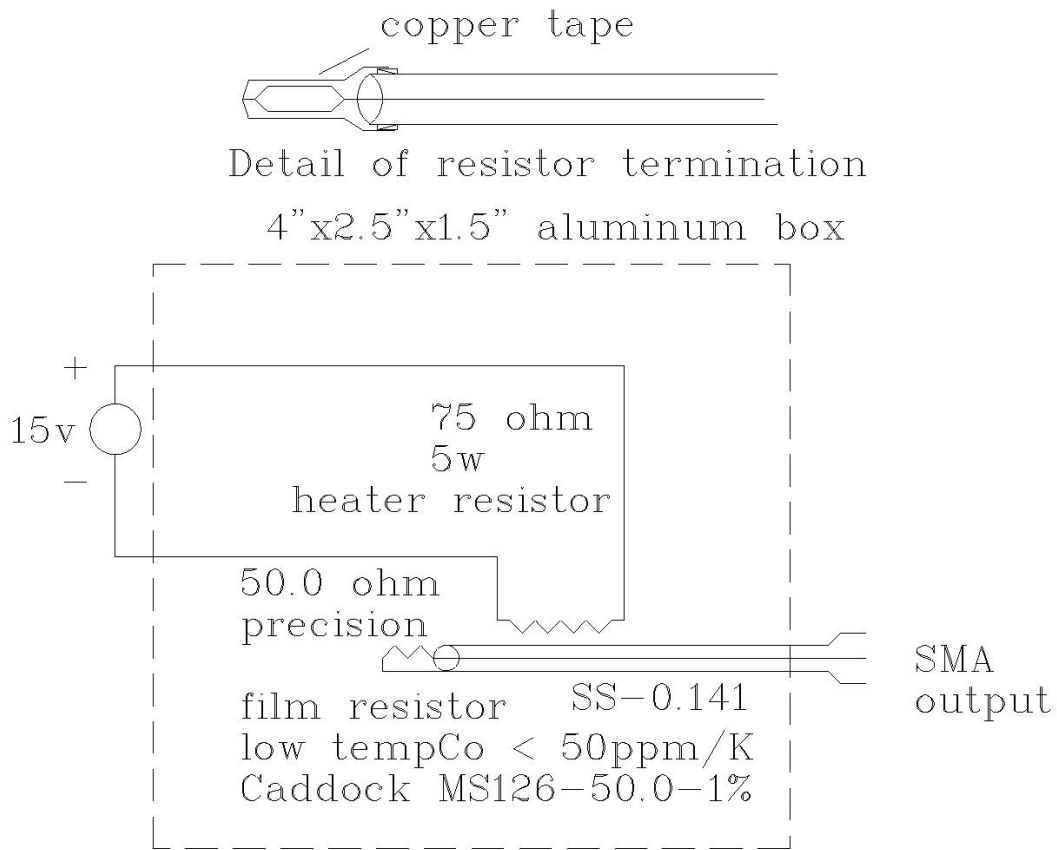


Figure 1. Heated resistor noise source

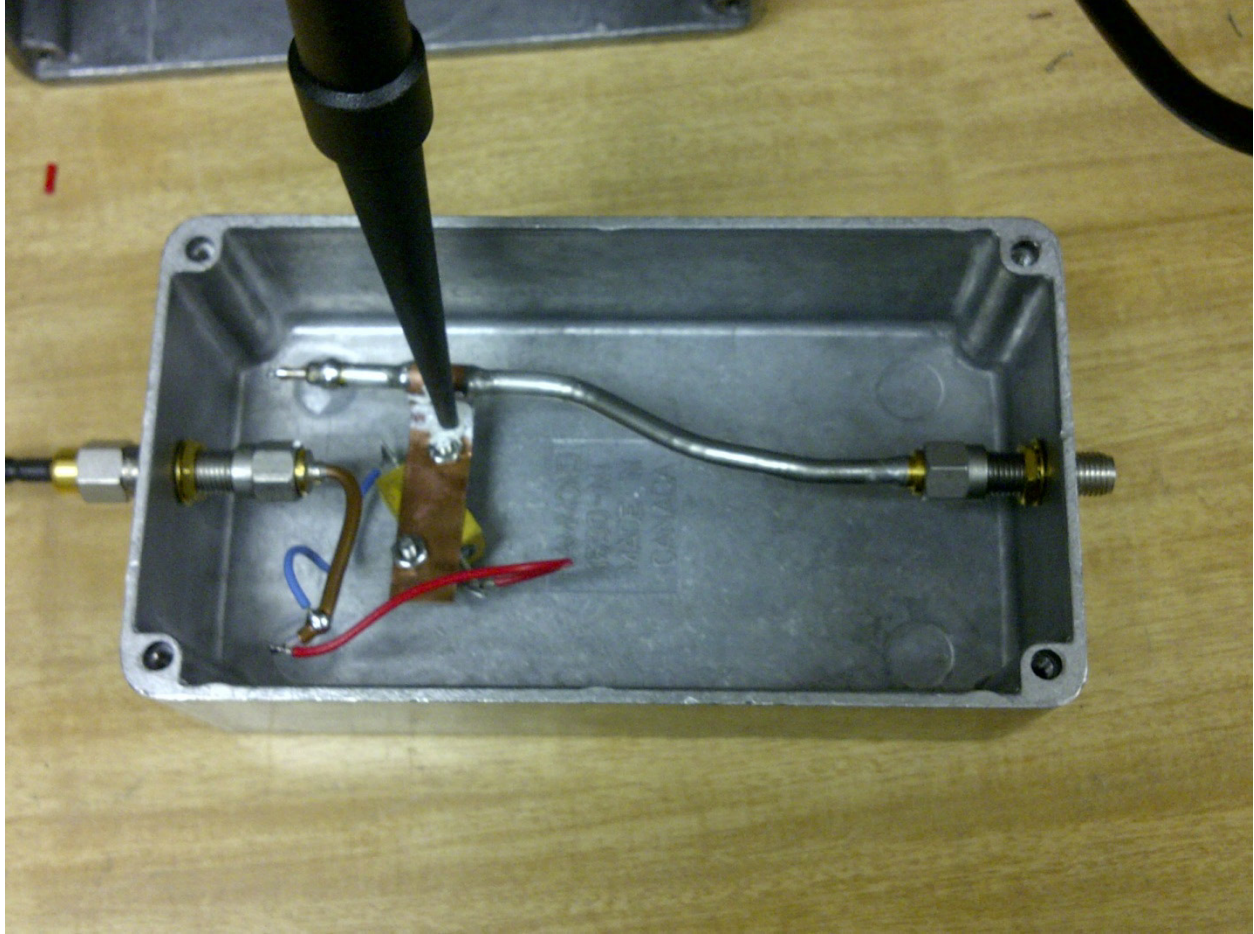


Figure 2. Photo of tests of heater on hot load during construction (black probe is measuring temperature).

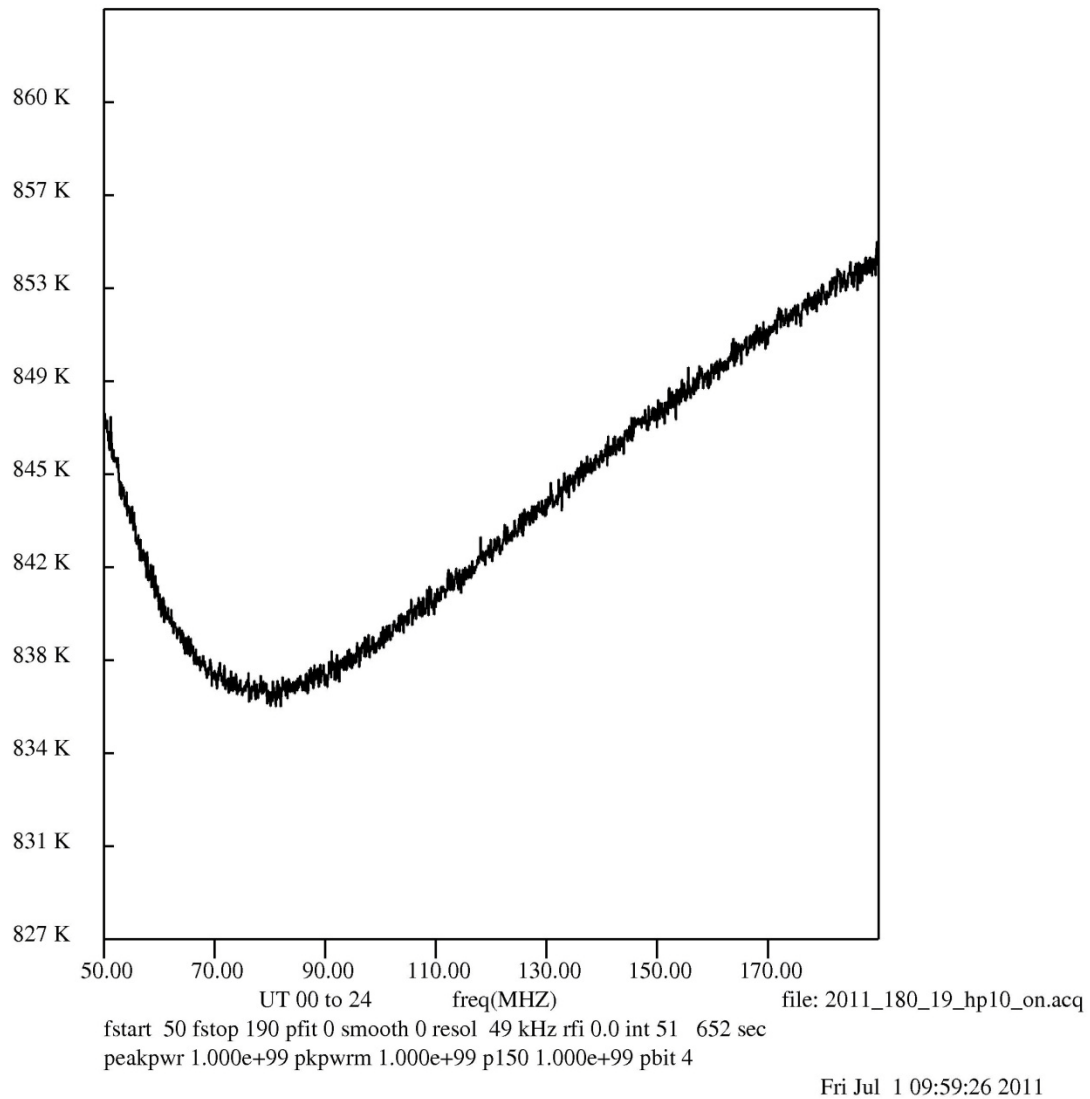


Figure 3. Spectrum of HP346C measured internal noise source corrected by hot noise source.

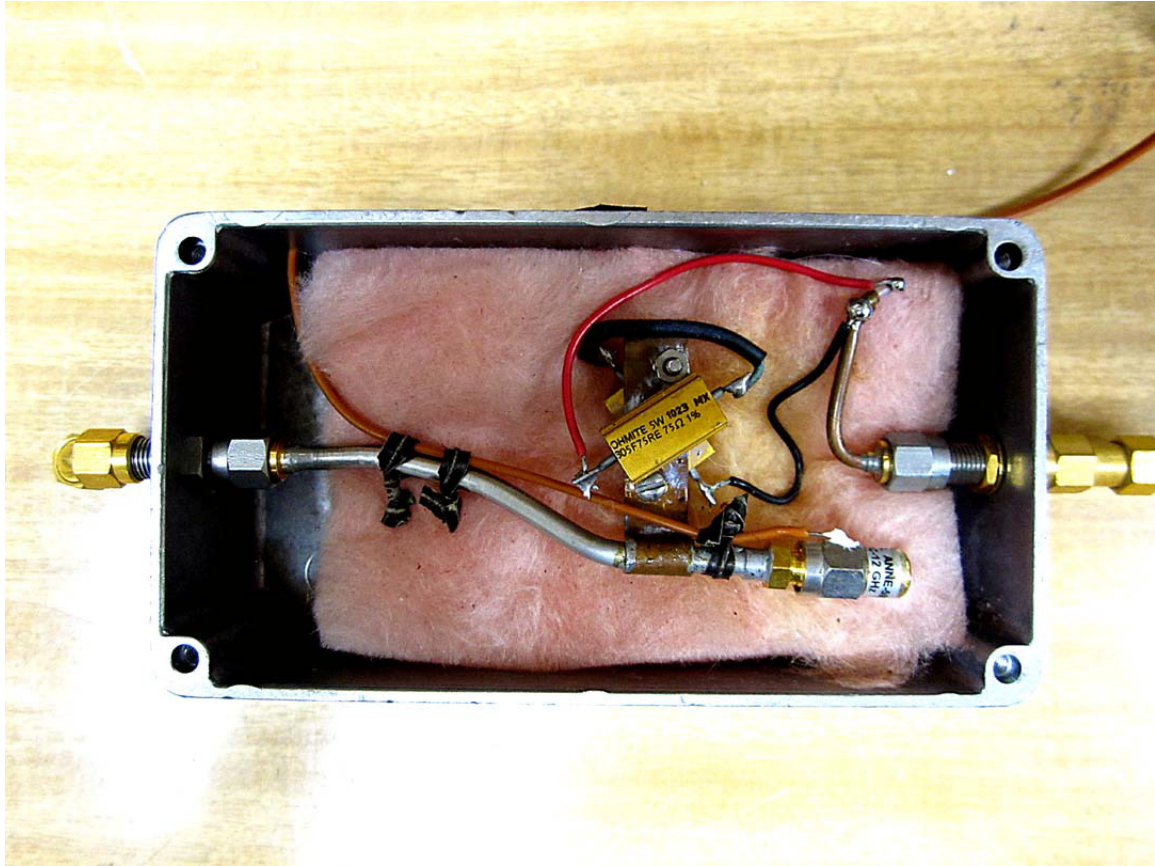


Figure 4. Hot load using minicircuits ANNE-50 load (specified to 100°C) and Fluke 80 BK-A temperature probe.