Impedance Matching Issue with the CALLISTO Solar Radio Spectrometer

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One of the main components of a CALLISTO (**C**ompound **A**stronomical **L**ow frequency **L**ow cost **S**pectrometer and **T**ransportable **O**bservatory [1]) is the commercially available Philips TV-tuner CD-1316, which has an antenna input impedance of 75 Ω according to the datasheet [2]. This impedance does not fit to the remaining components of a radio telescope like connectors, cables, low noise amplifier, and antenna, which usually are designed as 50 Ω components. Ideally, all components in an RF-system have the same wave impedance to avoid standing waves and minimize unwanted gain or loss in the receiver chain. Questions arose many times whether this mismatch is a serious issue or whether we can ignore it. The only way to get an answer is to measure the input reflection coefficient s11 [3] of the tuner with a vector network analyzer (VNA) as shown in figure 1.

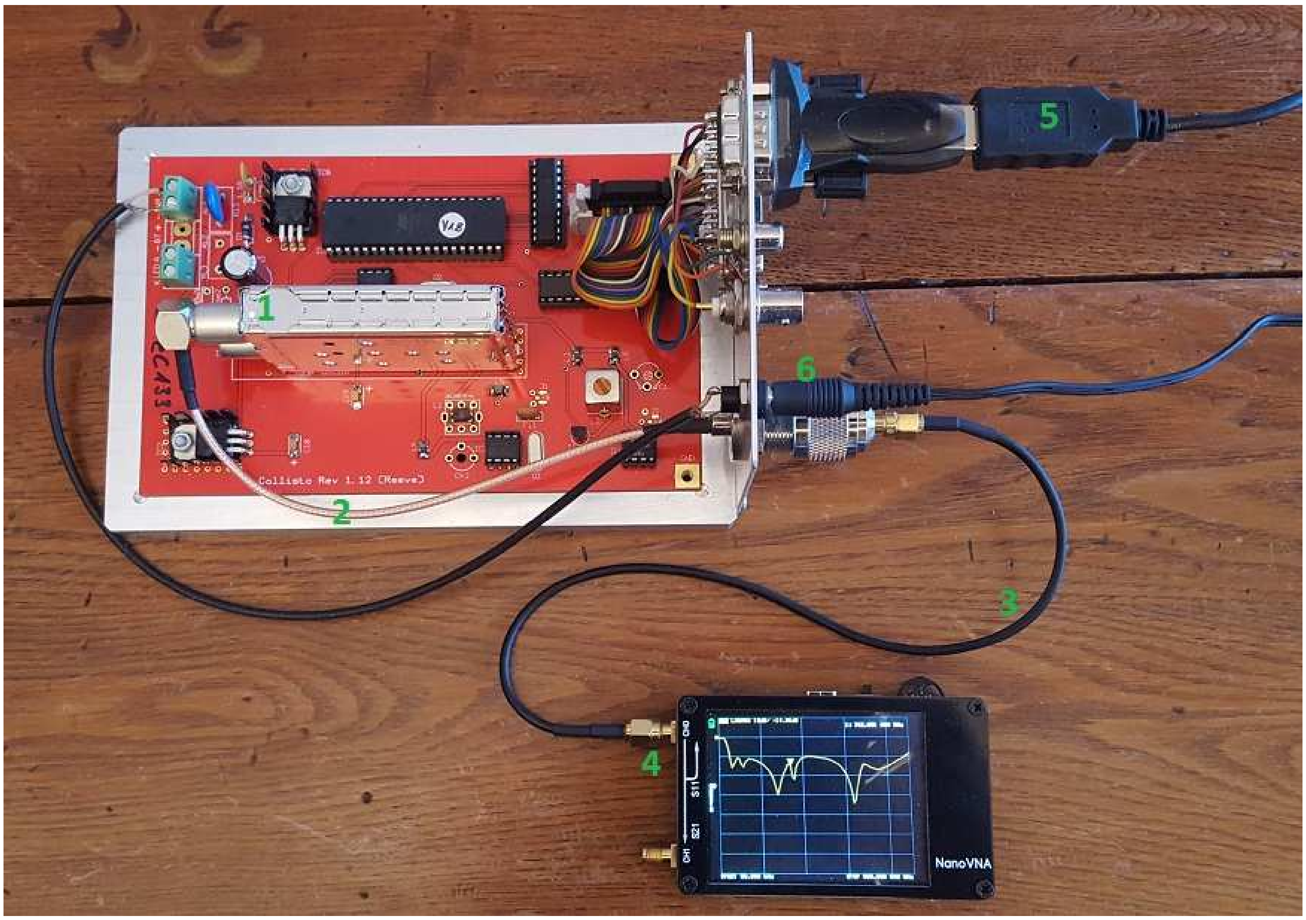


Fig. 1: Measurement setup with CALLISTO s/n eC133 printed circuit board mounted on a test frame. Key (green): 1 = Tuner antenna input 75 Ω; 2 = SMA cable from tuner to antenna input 50 Ω; 3 = Short SMA cable to connect NanoVNA 50 Ω; 4 = s11 port of NanoVNA; 5 = Serial connection to the Windows 7 notebook for programming CALLISTO; 6 = 12 volts power cord. The current s11 measurement point on the VNA at 342 MHz indicates –14.79 dB.

Fortunately, there are very cheap VNAs available on the market, e.g. the NanoVNA which can cover 50 KHz up to 900 MHz for less than 100$ [4]. Measurement of s11 is not trivial because CALLISTO is not a single frequency receiver, it is a frequency agile spectrometer and each frequency shows a different input reflection coefficient s11. Therefore, we need to measure s11 for many frequencies.

The measurement setup is shown in figure 1 and is composed of the NanoVNA, CALLISTO and a notebook PC. The notebook controls the CALLISTO by commanding the instrument via a terminal program such as PUTTY. While the NanoVNA measures a set of frequencies in the range 50 KHz – 900 MHz, the CALLISTO tuner is manually changed from one frequency to the next, in this case from 45 MHz up to 870 MHz in steps of 9 MHz. The frequency step size of 9 MHz was chosen because the NanoVNA can measure 100 points, giving a frequency resolution of exactly 9 MHz for the 900 MHz measurement range.

The selection of the CALLISTO frequency is through its serial interface. For example, 342 MHz is commanded as the text entry F0342<ENTER>. After setting the frequency, the cursor of the NanoVNA was scrolled to the same frequency and s11 was read out and entered into an ASCII text file. Once the full frequency range was covered, the text-file was fed into a Python script which read the data and produced a plot as shown in figure 2.

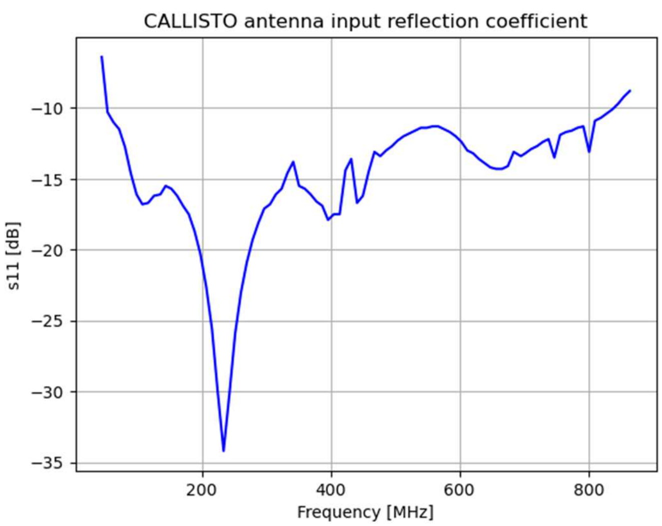


Fig. 2: Measurement results for CD1316LS/IV-3 tuner input reflection coefficient s11 between 45 MHz and 870 MHz in steps of 9 MHz. Values of s11 below –10 dB are acceptable in terms of mismatch.

We recognize that every individually programmed frequency appears with its own reflection coefficient and it varies by several dB. Neighboring frequencies (aside of the programmed one) sometime show a better s11, sometimes worse. We can state that s11 is mostly below –12 dB between 50 MHz and 750 MHz. Only at the edges of the frequency range does s11 get worse, but it still is around –8 dB. In other words, most of the frequencies have a mismatch on the order of 6% which we can neglect.

Impedance matching in RF equipment is sometimes improved by inserting a 50:75 ohm impedance matching pad or a 50:75 ohm impedance matching transformer. However, a minimum loss impedance matching pad introduces at least 5.7 dB loss to the RF circuit so it would significantly reduce system gain and drastically increase receiver noise figure, both by at least 5.7 dB. An example of a minimum loss matching pad is the Mini-Circuits (MCL) SFQFM-5075. This device would help to improve the reflection coefficient, is cheap at less than 50$ and shows good VSWR at the input as well as on the output (see data sheet [5]).

Alternatively, one could use a matching transformer, for example the MCL SFMP-5075 for less than 100$. It introduces only 0.4 dB attenuation (see data sheet [6]). Another example, described more below, is the MCL TC1.5-1X+ 1.5:1 transformer (see data sheet [7]). However, the CALLISTO tuner is not a perfect 75 ohms across its frequency band, as indicated by the s11 measurements above, so the transformation will not always be to a perfect 50 ohms. Thus, a potential disadvantage of the transformer would be a bad input/output VSWR in additional to a small amount of loss, which would degrade the noise figure.

In late 2013 we experimented with the TC1.5-1X+ transformer to determine how it would affect the CALLISTO's noise figure. The transformer was mounted in a special test fixture as seen in figure 3. Measurements were made with and without the transformer in the input circuit. The measurements show that, with the transformer, the CALLISTO noise figure is generally higher and is increasing with frequency, see figure 4. We concluded that, with respect to the noise figure, the added cost of the transformer does not make much sense.

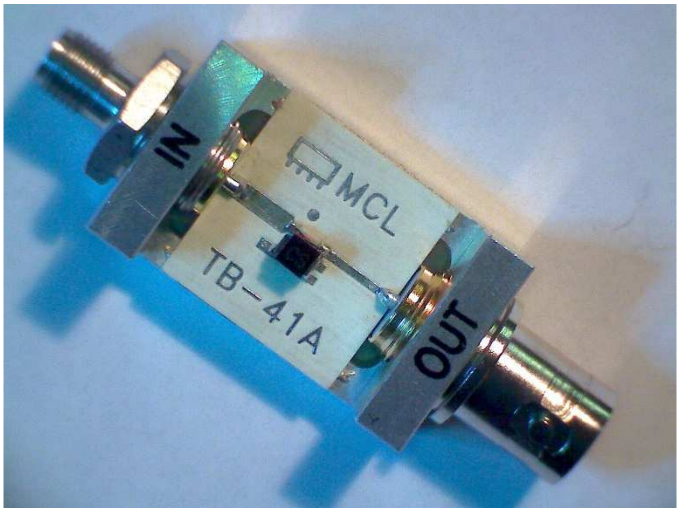
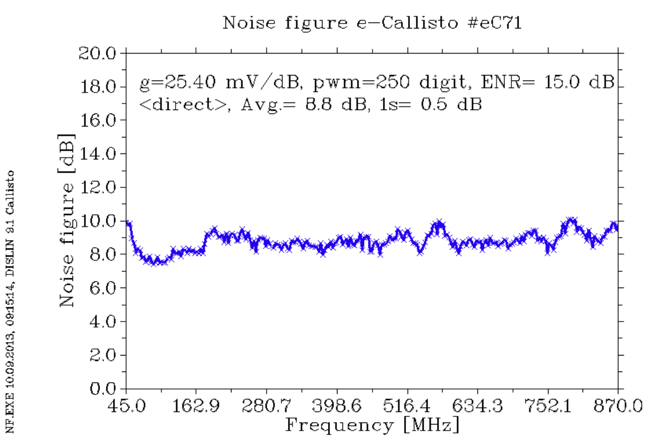


Fig. 3: Mini-Circuits TC1.5-1X+ impedance matching transformer in test fixture. The SMA-F connector on upper-left is the 50 ohm side and the BNC-F connector on the lower-right is the 75 ohm side. Two units were evaluated. The transformer itself is quite inexpensive at less than 3$ but it is a surface mounted device that would have to be integrated into the CALLISTO at added cost.



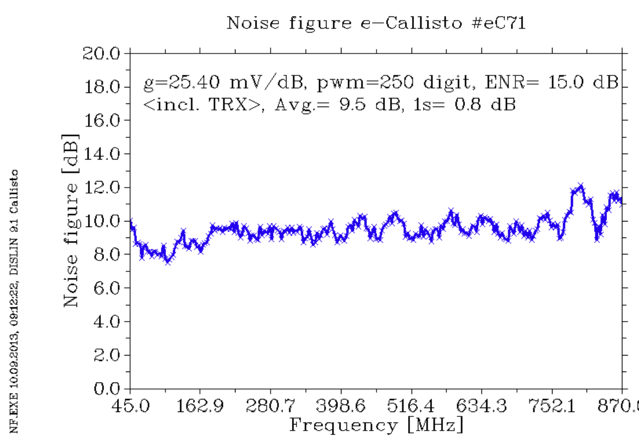


Fig. 4: Noise figure measurements with CALLISTO s/n EC71 without (on left marked <direct>) and with (on right marked <incl.>) the TC1.5-1X+ impedance matching transformer. The noise figure with the transformer is generally higher; the average noise figure increased by 0.7 dB and standard deviation of the individual noise figure measurements by 0.3 dB.

Links and references:

[1] CALLISTO: http://e-callisto.org/
[2] Tuner specifications Philips:
CD1316L/IV: http://e-callisto.org/Hardware/CD1300L_03.pdf
CD1316LS/IHP-3: http://e-callisto.org/Hardware/CD%28M%291300L_MK3%2005-09-01.pdf
[3] Reflection coefficient s11:
https://resources.altium.com/p/s11-vs-return-loss-vs-reflection-coefficient-when-are-they-same
[4] Nano VNA: https://nanovna.com/

[5] SFQFM-5075: https://www.minicircuits.com/pdfs/SFQFM-5075+.pdf
[6] SFMP-5075: https://www.minicircuits.com/pdfs/SFMP-5075+.pdf
[7] TC1.5-1X : https://www.minicircuits.com/pdfs/TC1.5-1X+.pdf

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