Planned Upgrade of the ATA Feed

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I Introduction

The overall goal is to widen the bandwidth and lower the system temperature of the existing ATA feed. Figure 1 shows two images of the current feed, one a photograph of the feed, and the other a depiction with the inner pyramid removed showing the vacuum dewar and the cryocooler. The two Low Noise Amplifiers (LNAs) which detect the orthogonal linear polarizations are cooled to 65K for low noise temperatures. They connect to the antenna input terminals via two wire balanced transmission lines through a microstrip circuit board at the tip of the antenna. The transmission lines pass through a glass wall at the end of the dewar and are at room temperature from that point to the antenna terminals. Figure 2 shows measurements of T_{sys} for one of the receivers based on Y-factor observations of the moon and Cass A compared with two theoretical curves (Welch et al, 2009). For these measurements, the antenna effective area was taken to be a constant 60% of the aperture area. However, accurate measurements of the feed gain, shown in Figure 3, indicate that its gain varies by ±1 dB across the band. The gain follows a log-periodic pattern, as expected. Most of the apparent T_{sys} variations follow the feed gain variations.

The model for the theoretical curves is shown in equation (1). f is in GHz. The first term is diffraction losses. The second is expected Ohmic losses in the input transmission lines and in the feed. $(10 + 0.8f)$K is the LNA noise temperature (Weinreb, private communication). 2.7K is the CMB. 7K is the combination of geometric optics spillover and emission from the mean atmospheric absorption, the combination nearly independent of antenna elevation. The last term is the synchrotron emission from the galaxy and is evidently only important at low frequencies.

$$Tsys = 4/\sqrt{f} + 6.3\sqrt{f} + 10 + 0.8f + 7 + 2.7 + 3/f^{2.7} \qquad (1)$$

The red curve in Figure 2 is for equation(1). For the dotted curve, the Ohmic losses were raised by a factor of 1.5 to allow for more than the theoretical losses. On the average, the dotted curve seems to give a better fit. It is the second term in (1) that we hope to eliminate in the new design. The red curve contribution is 14K at 5 GHz and about 20 K at 10 GHz. Without it, T_{sys} would be less than 40K over the frequency range in the figure and at higher frequencies as well.

II. The Overall Plan

The strategy is to put the entire feed into a transparent glass dewar. For this development, only half the length of the feed will be used, the part that works above 1 GHz. Figure 4 shows a model of the feed within a glass dewar. The goal is to bring the physical temperature of both the feed input lines and the high frequency part of the feed down to 65 K, the refrigerator temperature. At 65 K the electrical conductivity of sliver is increased by an order of magnitude over its room temperature value. There is also an additional reduction by a factor of four in the thermal electrical emissivity of the lines with this temperature change. Altogether the noise radiation contribution of the Ohmic losses should be smaller by more than an order of magnitude.

Although the entire feed will be in the dewar, only the high frequency portion will be cooled. To cool the whole feed would create an unmanageable infrared heat load. There will be a place in the pyramid about three inches back from the feed tip where there will be a large thermal resistance (but low electrical resistance) where the temperature will drop from ambient to 65K. The LNA will remain in close contact with the refrigerator, and there will be heat transfer lines from the refrigerator to the tip part of the feed pyramid. From the tip of the pyramid, thermal connections required to cool the high frequency feed sections will be made through the feed electrical connections.

Except for the cooled tip, most of the feed will be at room temperature. Because all of the feed will be in the vacuum, heat can pass from the room temperature part to the cooled tip part only by thermal conduction along the pyramid and feed. There will be no air to transfer heat by convection. Also, there will be little infrared heat transfer, because the feed sections will occupy solid angles too small for significant radiative coupling.

III. Thermal Issues

A. Radiative Loads: estimating the infrared heat transfer. Calculating the infrared heat transfer accurately is complicated because of the complex structures. We simplify the calculations by assuming that the radiation field is just that of a 300K blackbody everywhere. For example, inside the present dewar there is a refrigerator cooled structure within the outside dewar walls which are at about 300K. Because there is a small bit of surface at 65K, the overall field should be a little less than that of a 300K black body. The radiative transfer calculation to work this out would be difficult, and the assumption of a 300K blackbody field everywhere should provide an upper limit to the field intensity and hence an upper limit to the absorbed radiative energy on the cold surfaces within. The incident flux is therefore $F=\sigma T^4$, where $\sigma=5.7\times10^{-12}$ Watts/cm^2/K^4. At 300K, that's .0462 Watts/cm^2. All of the surfaces are either shiny copper or shiny silver, which have IR absorption coefficients, ε, of about 4%. Thus the absorbed energy, $\varepsilon\sigma T^4$ = (.04)(.0462)= 1.8 mWatts/cm^2. We assume that this is correct everywhere, and it is just a matter of adding up the total area to find an upper limit to the total radiative heat loads.

The surface area of the structure that supports the LNAs is 125 cm^2. The surface area of the pyramid from its tip to a point that is 9cm (3.5 in) along the pyramid is 29 cm^2. The area of the feed arms in this region, including both sides and the vane is about the same, 29 cm^2. The sum of these three surfaces is 183 cm^2. All are bathed in 300K radiation and will absorb a total of 330 mWatts.

B. Heat flow along the surface of the pyramid and the feed arms. In order to have a small region of the pyramid surface with a substantial thermal resistance but maintain its low electrical resistance, we use silver plated stainless steel for an axial distance of one cm.

The silver plating thickness is 3 micron, 1.5 skin depth at the lowest operating frequency of 1 GHz. Because silver has a thermal conductivity that is 2600 times that of stainless, the 3 micron layer will carry all of the heat. On the rest of the pyramid the plating will be much thicker, at least 10 micron, so that the nearly all of the thermal resistance will occur over the one cm patch and the temperature drop from 280K to 65K will be confined to that region. The heat flow is readily calculated across the one cm patch.

$$H = K(\Delta T/\Delta x)\text{Area} = (400\text{Watts/mK})(280 - 65)\text{K}/(.01\text{m})4\text{x}(.016\text{m})(3\text{x}10^{-6}) = 1.7 \text{ Watts}$$

A similar calculation for the feed arms yields a power flow of 1.0 watts. The LNA dissipation is 84 mWatts each, and the heat loss through the output cables is 24 mWatts. The total is 3.12 Watts. The refrigerator is capable of lifting 6 watts from 70K, and so we have a factor of two margin.

IV. Connection between feed and LNAs. In the present model, the LNAs connect to the feed through two wire lines and a microstrip board at the tip of the feed. In the new design, it will be possible to use coaxial cables for the connection because the coax will be at low temperature where the cable losses will be small. It will be a simpler mechanical arrangement and should improve the match. We also combine the input electrical connection and the thermal connection needed to transfer heat from the feed arms to the metal pyramid.

Figure 5 is a drawing of the planned layout with just one of the two polarizations shown. The coaxial cable ends are shown. The four grey blocks to which the lines to the feed are connected are ceramic capacitors which serve a dual purpose. They are heat conductors, and for the electrical connection the capacitor is the middle element of a T-circuit low pass filter between the input coax and the feed. It's capacitance is .059 pf. The lead up to the feed is a .48 nH inductor, and the extended center conductor of the coaxial line is a .48 nH inductor. Because of the length of the capacitor, we have allowed for about .15 nH of inductance over it's length. These components are very small compared to wavelength, so that using a lumped circuit analysis should be reasonably accurate. The antenna impedance is about 200 Ohms which gives 100 Ohms on each side of the circuit. We use 95 Ohm coaxial cable, which is a commercial standard. The cable is 30 mils in diameter with a silver plated stainless steel center conductor. Figures 6 and 7 show the overall layout including the positions of the balanced LNAs. Figure 8 is the electrical circuit, and Figure 9 is the power frequency response of the T filter, showing good response up to 24 GHz. We have found that the thin wire that we are planning for the connection to the feed should provide good excitation of the transmission line mode of the antenna.

The thermal connection which must carry about 250 mWatts of heat from the feed down to the aluminum pyramid is also managed by the input connection. The ceramic capacitor is made of AlN, a material with very low electrical conductivity and very high thermal conductivity. Its thermal conductivity peaks at 60K at 2000 Watts/mK, about three times greater than that of copper at the same temperature. The heat from the feed arm is brought down by a copper lead that is 10(mils)x30(mils)x40(mils long). It can carry 250 mWatts of heat with a 2K temperature drop. The ceramic will carry the heat the rest of the way to the aluminum pyramid with only a 0.2 K temperature drop.

V The Glass Dewar. The thickness of glass that is used for ordinary light bulbs is 0.46mm. To get an idea of what a dewar of this thickness might be like, we display the normal reflection coefficient of a piece of glass of this thickness in Figure 10. We also show what one possible antireflection coating could do for this piece of glass. Up to about 10 GHz, the Teflon does not help much, nor is it really needed. For operation to as high a frequency as 24 GHz, the anti-reflection coating does help. At the moment, we are studying the possibility of using glass of this thickness with an actual Teflon coating.

Acknowledgement: It is a pleasure to acknowledge that it was Jill Tarter's idea to use the coaxial input lines in this application.

Reference: The Allen Telescope: The First Widefield, Panchromatic, Snapshot Radio Camera for Radio Astronomy and SETI, Jack Welch et al, 2009, IEEE, in press.

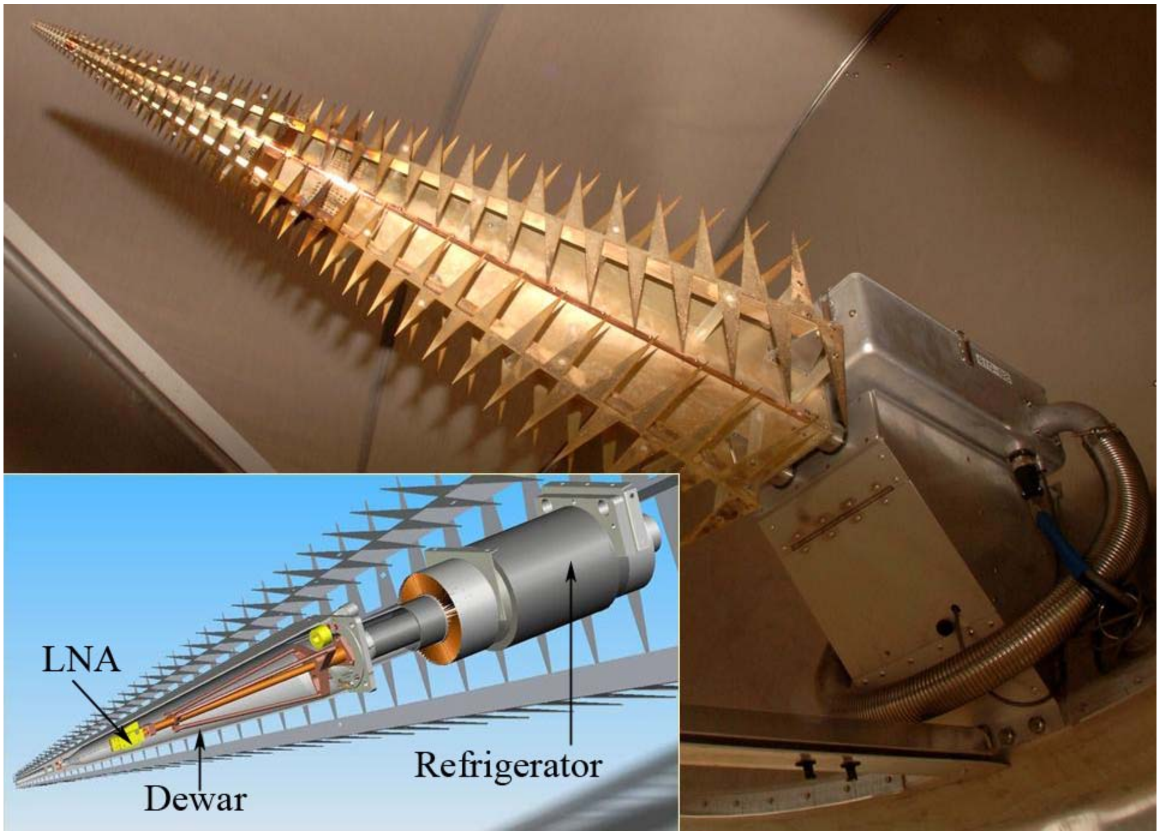


Figure 1: above: A photograph of the ATA feed mounted in an antenna. below: a drawing with the pyramid removed, showing the LNA, dewar, and refrigerator.

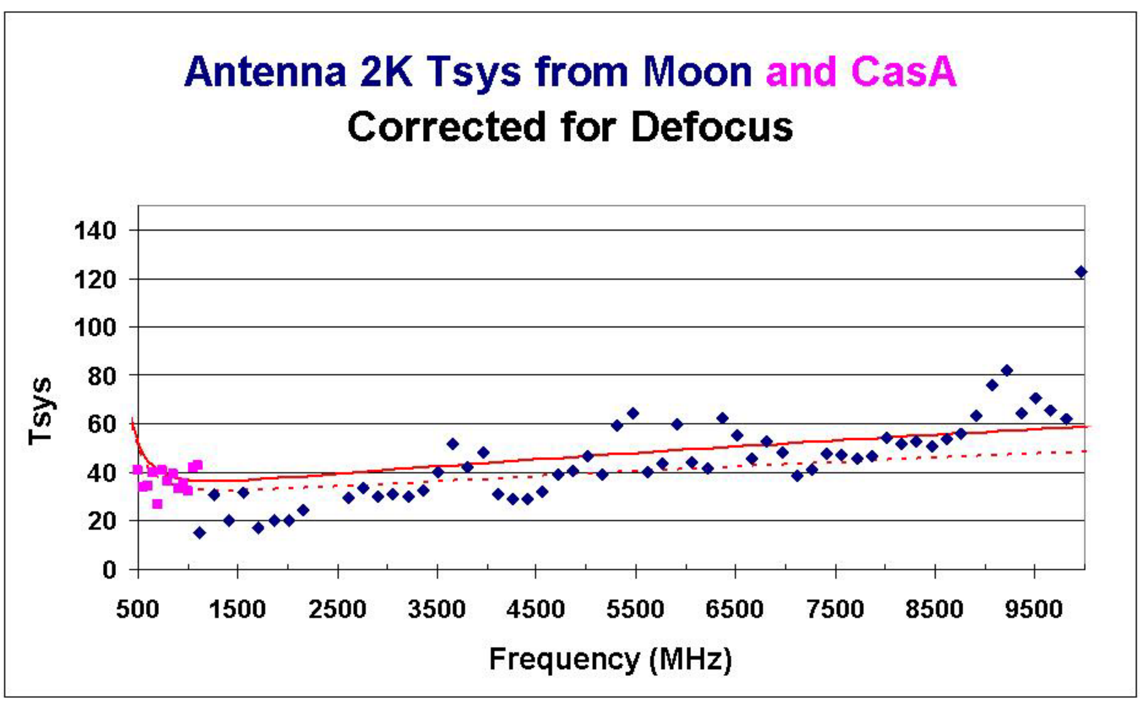


Figure 2: Tsys measurements corrected for defocus but not for the variation in feed gain.

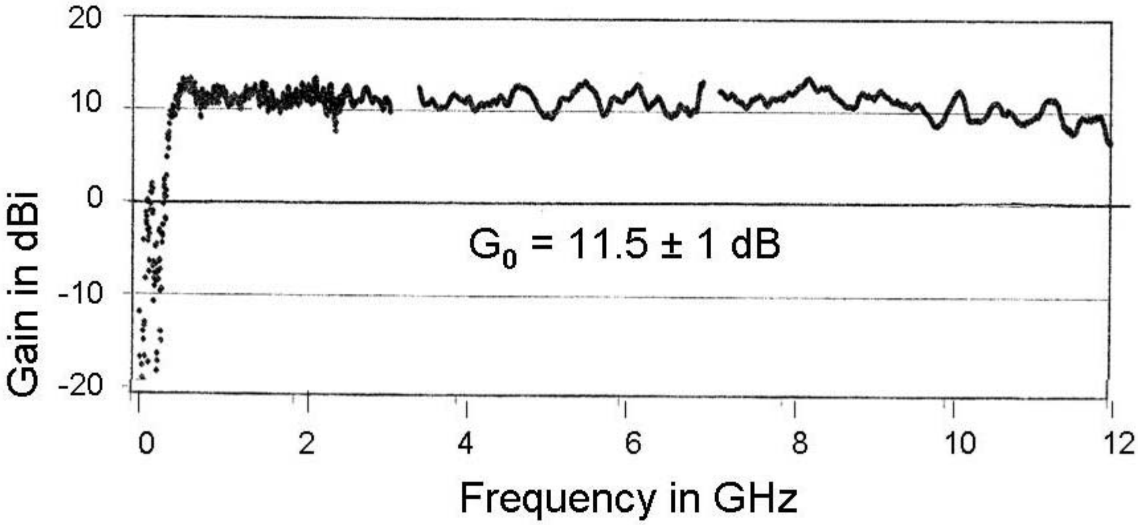


Figure 3: Accurate (~1%) log-periodic feed gain measurements.

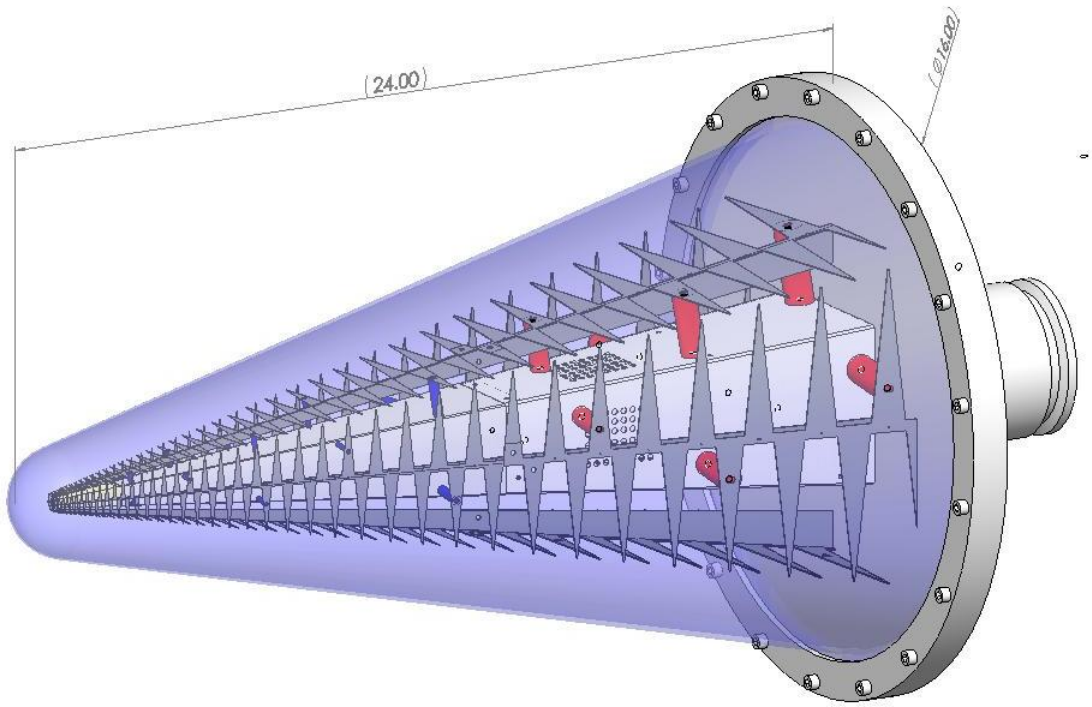


Figure 4: General conception of the feed in a glass dewar.

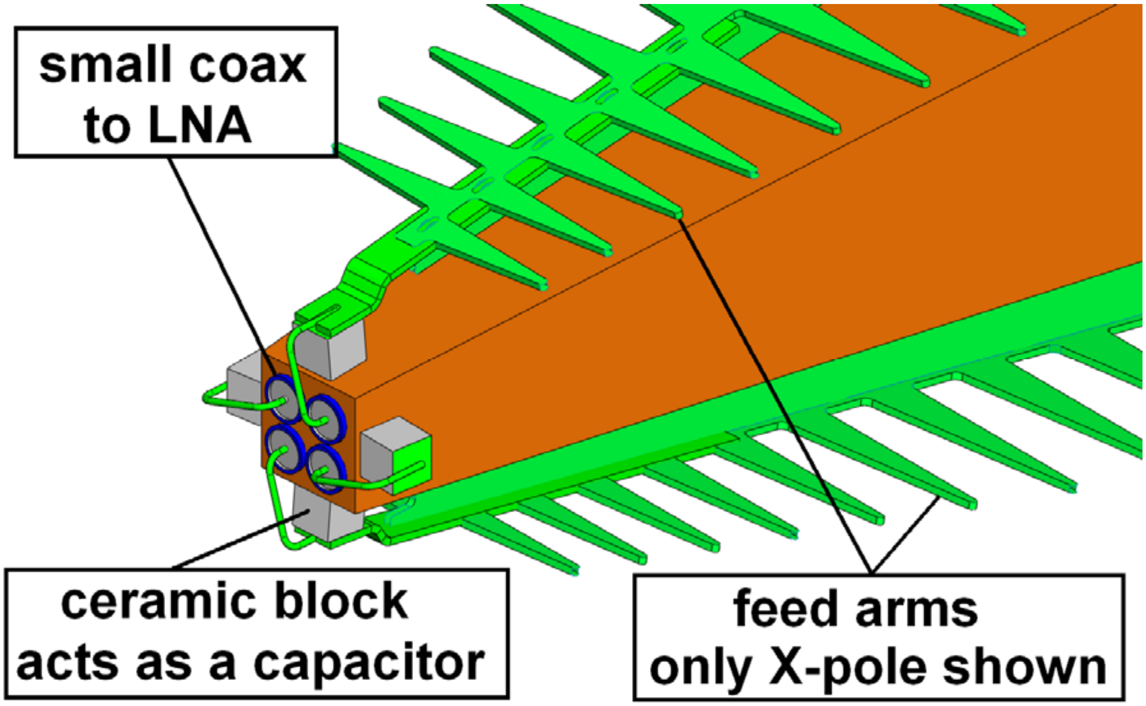


Figure 5: New feed conception; Coax lines are .03 inch diameter; Caps are .03 inch cubes

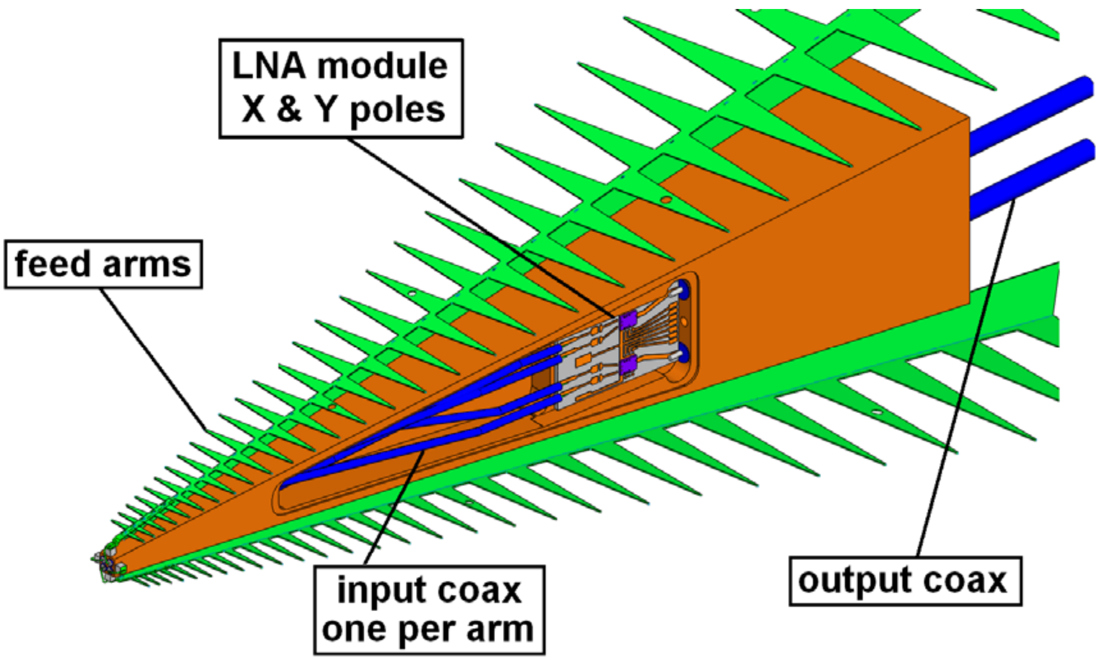


Figure 6: Planned feed showing location of coax cables and LNA module.

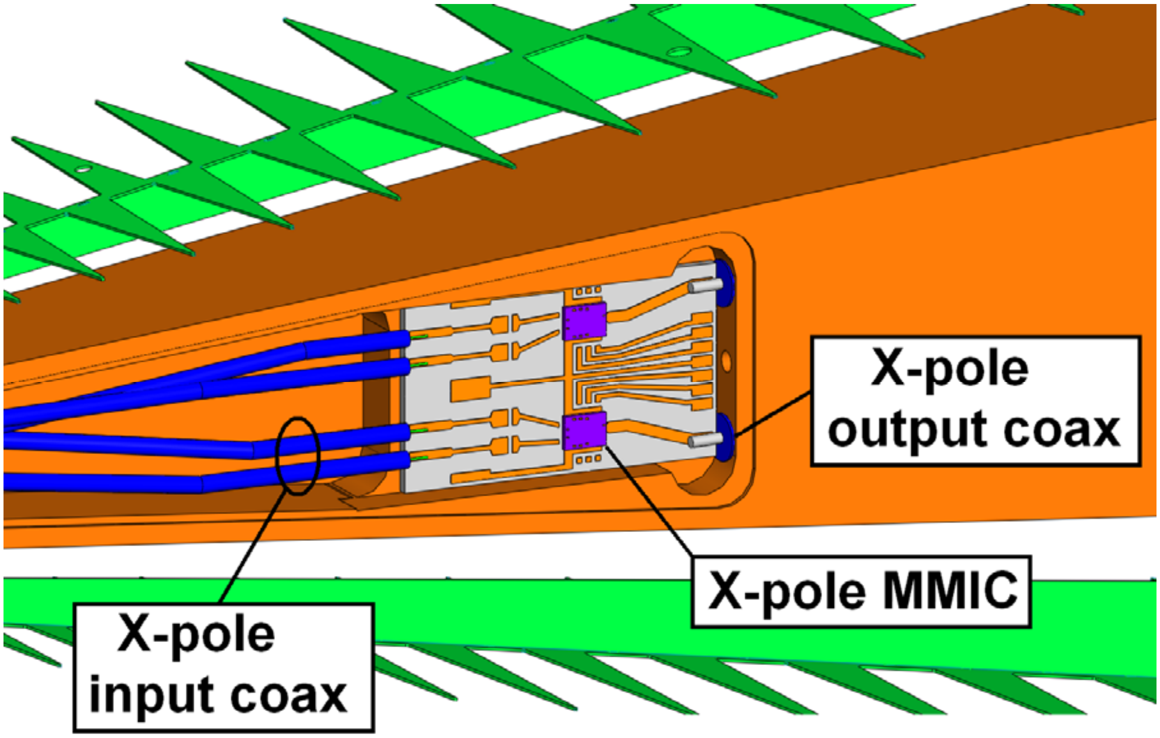


Figure 7: Detail of the mimic chip location and input cables.

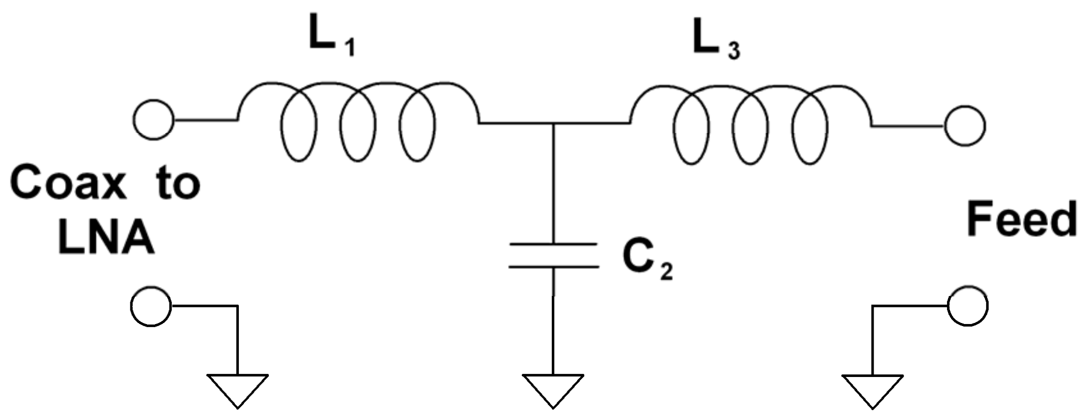


Figure 8: The low pass filter joining coax to feed.

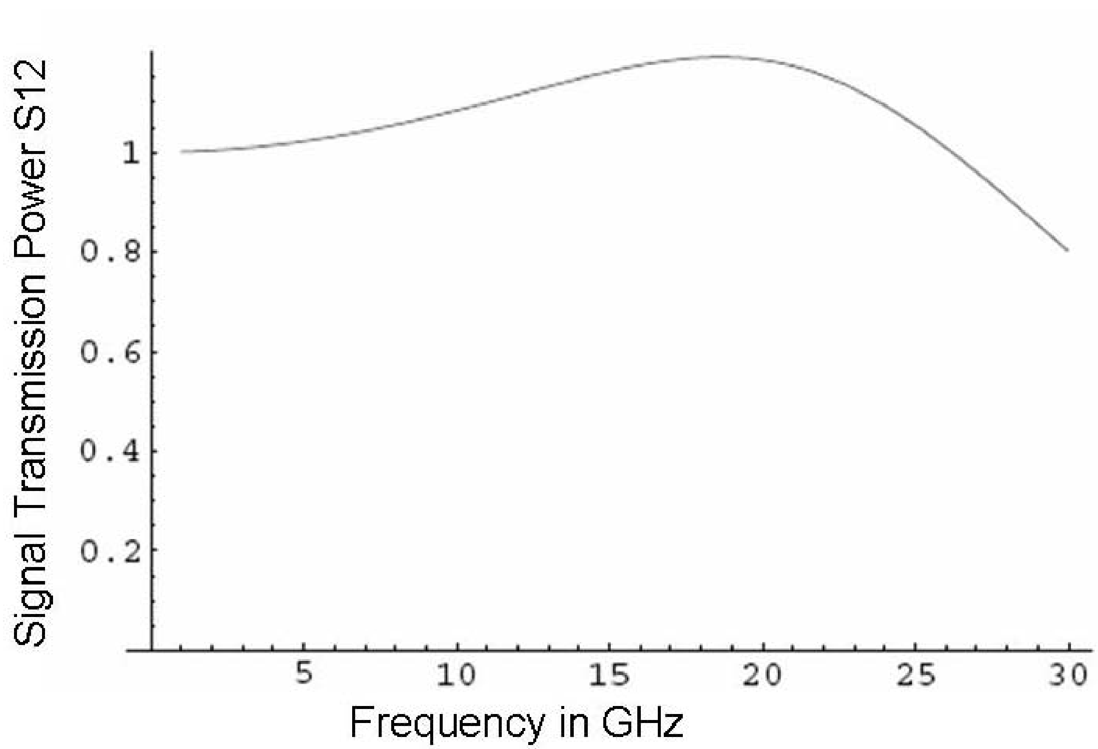
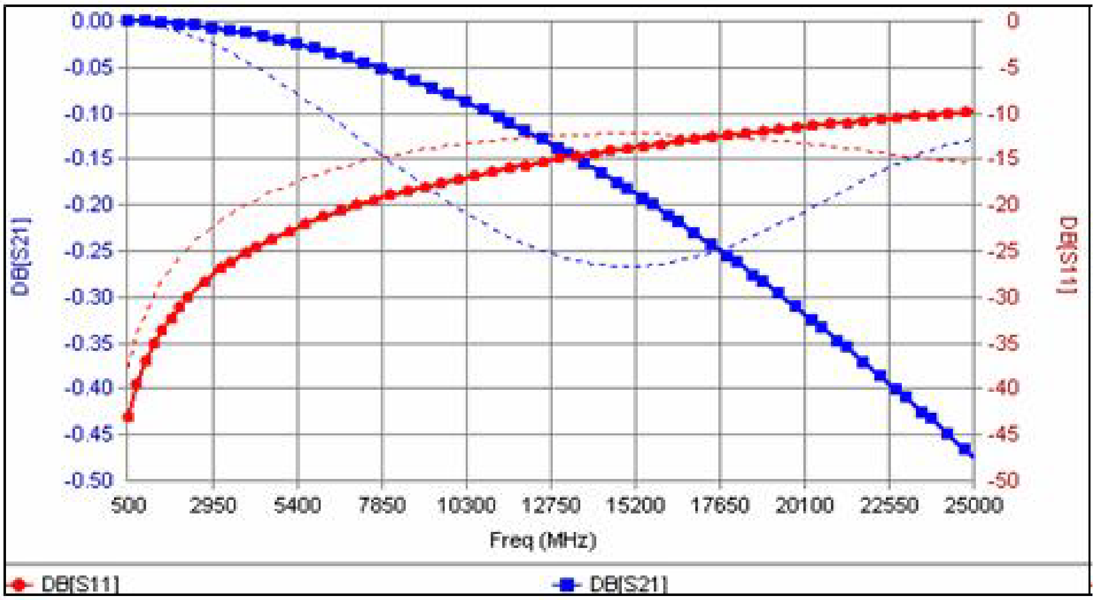
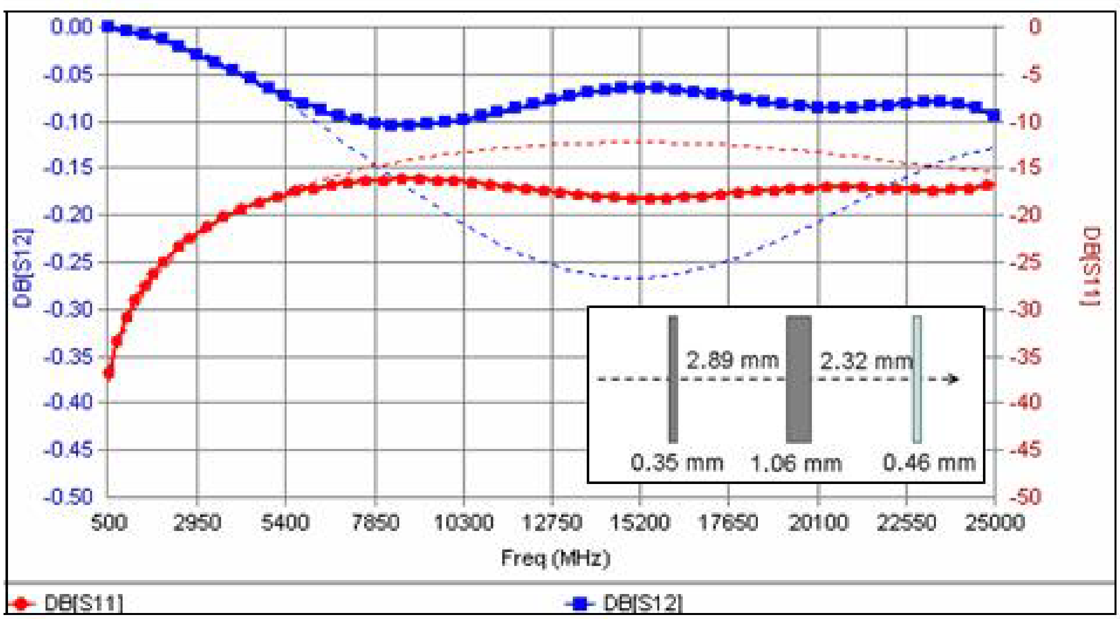


Figure 9: Frequency response of the low pass filter connecting coax and LNA to feed antenna.

Reflection of plane wave from flat glass of thickness 0.46 mm



Without coating



With 2 layers of Teflon anti-reflection coating

Figure 10: above: Reflection of plane wave from glass plate. below: Reflection from glass and indicated layers of Teflon.