Feed Input Losses

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Abstract

The connection between the Log-Periodic feed and the Low Noise Amplifier must be carried out with good efficiency in order for the overall system noise to be as small as possible. The plan for this connection is through a small microstrip circuit board at the tip of the inner pyramid which couples the balanced feed terminals to a balanced transmission line running down into the pyramid to the LNA. Losses are estimated for the various parts as follows. 1. 2-4 percent for the feed losses based on the feed simulations. 2.The impedance of each half line microstrip is 110 ohms for a match to the 220 Ohm antenna, and the total loss for each polarization is 1.0 $\sqrt(f/10GHz)$ percent. 3. An emission from that part of the transmission line over which the temperature drops from about 300K to the dewar temperature of 80K. This depends on the line length of this section and amounts to a radiation temperature of $0.50L^oK\sqrt(f/10GHz)$, where L is the length of the section in cm. 4. Radiation from the transmission line inside the dewar (at 80K) which is only $.086^oK\sqrt(f/10GHz)$ per cm of line.

1 Introduction

The connection between the Log-Periodic Feed and the low noise amplifier(LNA) consists of (a) a small printed circuit board which connects the feed elements to the transmission line which feeds the LNA, (b) a two wire line with a temperature gradient which connects between the circuit board and the input to the dewar, and (c) a run of two wire line in the dewar at constant low temperature which connects between the dewar input and the LNA. Since both linear polarizations will be received, there are two sets of input lines and LNAs. The antenna has a balanced output, and the LNA will have a balanced input to match it. The antenna has an input impedance of about 220 ohms. The ground or neutral structure of the antenna is the internal pyramid. The LNA input transmission line is coupled to the antenna through the apex circuit board. This board consists of four microstrip transmission lines with two lines for each polarization.

2 Feed Losses

The feed losses are not known precisely at the present writing but are expected to be between two and four percent at 10 Ghz based on the feed simulations. The feed losses should be nearly constant with frequency. That estimate is not based on the simulations. The estimate of the frequency dependence comes from the following argument. At any given frequency, radiation emanates from a point along the antenna that is about 1.5 wavelengths from the origin point in front of the tip. The antenna acts like a transmission line bringing the signal from the input at the tip to the radiation point. As a transmission line, the structure is an expanding line at constant characteristic impedance. It's incremental loss is proportional to the spacing, and the integrated loss is proportional to the log of the distance along the line, which is greater at the lower frequencies. The other effect is the copper loss which increases as the square root of frequency. These two dependences approximately cancel. Preliminary tests of the first prototype are consistent with the simulated loss of $2 - 4\%$

3 The feed Circuit Board

A top view of the feed circuit board is shown in Figure 1. The inputs for the two polarizations from the transmission lines connecting the two LNAs attach to the symmetrical antenna terminals through the curved microstrip lines. The bottom of the circuit board is metalized with vias for the parallel transmission lines. The bottom of the board is soldered to the end of the central pyramid. The circuit board dielectric is low loss CuFlon. It has relative permitivity $k_e = 2.1$ and loss tangent = .00045 at 10 GHz. The designed board thickness is 15 mils and the trace width is 10 mils. We evaluate the properties of the feed circuit board in two ways. One utilizes a simulation package, and the other uses a program from the Rogers WEB page (www.rogers-corp.com/mwu/mwiform.htm). The results agree. For each trace Z_O= 110 Ohms. Since this is half the line, the result is a balanced match to a 220 Ohm load, the impedance calculated for the feed antenna. The dielectric losses are .397 db/m, and the copper trace losses are 8.068 db/m, which are the major contribution (both at 10 Ghz). The trace lengths are 4.77mm, giving a loss of .0404 db for each trace. Since the signal from the parallel wire transmission line divides to go into the two microstrip lines, each half of the signal experiences the .040db loss, and the total loss is .040db. This amounts to 0.95 percent loss at 10 GHz, and it scales as the square root of frequency since the copper losses dominate.

4 The Transmission Line in the Dewar

The temperature in the dewar will be about 80K, and a substantial length of 220 ohm transmission line can be used in the dewar at that temperature with only a modest amount of loss. This will enable the LNA to be located at a large distance from the input end of the dewar which will be close to the tip of the antenna and therefore physically small. The impedance of a two wire line with line diameter d and separation s is

$$Z_o = 120cosh^{-1}(s/d) \tag{1}$$

For an impedance of 220 ohms, s/d = 3.2, and the line dimensions that fit the circuit board terminals are s=.081cm(32 mils) and d=0.025cm(10 mils). The power absorption coefficient along the line is

$$\alpha = \frac{2R_s}{\pi d Z_0}\frac{s/d}{\sqrt{((s/d)^2-1)}}cm^{-1} \tag{2}$$

R_s is the surface resistance

$$R_s = \sqrt{(\pi f \mu \rho)} = \sqrt{(\pi(4\pi \times 10^{-7})f\rho)} = .0020\sqrt{(f\rho)}Ohms \tag{3}$$

At T=273K, the resistivity of Copper is $\rho = 1.72 \times 10^{-8}$ Ohm-m, whereas at 80K $\rho = 0.2 \times 10^{-8}$ Ohm-m, nearly an order of magnitude lower. The transmission line losses are therefore substantially lower at the lower temperature. At 80K, $R_s = .0090\ \sqrt{(f/10GHz)}$ Ohms. Substituting this value and the other parameters into equation (2) gives $\alpha = .0011\sqrt{(f/10GHz)}cm^{-1}$, a small absorption.

For a transmission line with absorption α and physical temperature T_o, the brightness temperature emitted by a one centimeter length of line is (for $\alpha \ll 1$)

$$\Delta T_B = T_o \alpha \tag{4}$$

For the line at 80K, this amounts to only $0.086^o K\sqrt{(f/10GHz)}$. Thus a 12 cm length of input line in the dewar at 80K physical temperature would only add 1K to the system temperature at 10 GHz.

5 Contribution from the line with a temperature gradient

The section of line at the input to the dewar over which the temperature rises from the interior dewar temperature of 80K up to the circuit board temperature of about 300K will also contribute to the system temperature. We assume the temperature along this line has a constant gradient with position.

$$T(z) = 300 - (z/L)220 \tag{5}$$

L is the line length, and z is a position along the line, which starts at z=0. Because the temperature varies along the line, the absorption coefficient also varies along the line. A simple interpolation formula from the tabular data for the resistivity temperature dependence is

$$\rho = .75 \times 10^{-8}((T-20)/132)^{1.35} Ohm - m \tag{6}$$

Substituting this relation into equation (3) for R_s yields

$$R_s = 1.73 \times 10^{-7}((T-20)/132)^{.67}\sqrt{(f)} \tag{7}$$

The brightness temperature emission from the line in the optically thin limit is

$$T_B(L) = \int_0^L T(z)\alpha(z)dz \tag{8}$$

Substituting the expressions above into the integral leads to the final integral

$$T_B(L) = \int_0^L [300-(z/L)220](.0021)\sqrt(f/10Ghz)(\frac{[(300-(z/L)220)-20]}{132})^{0.67}dz \tag{9}$$

This integral has been evaluated for values of L from 1 to 10cm. The resulting dependence on L is very close to linear and is fit within one percent by the relation $T_B(L) = 0.50\sqrt(f/10GHz)L^oK$. Smaller lengths produce less noise but, of course, have more heat flow. The final choice for the length must take into account the heat losses and manufacturing constraints.

6 Summary

This is a summary of the losses in terms of system temperature contributions for a plausible choice of parameters. The summary is for 10 GHz.

Source	Emission	Noise Temperature
Feed Antenna	3% at 300^{o}K	9.0^{o}K
Circuit Board	1% at 300^{o}K	3.0^{o}K
Transition Line(5cm)	5×0.5^oK	2.5^{o}K
Cold Line(25cm)	25×0.086^oK	2.2^{o}K

The total is 16.7^{o}K. At lower frequencies, the losses should decrease as the square root of frequency, except for the antenna losses, which should not change much with frequency.

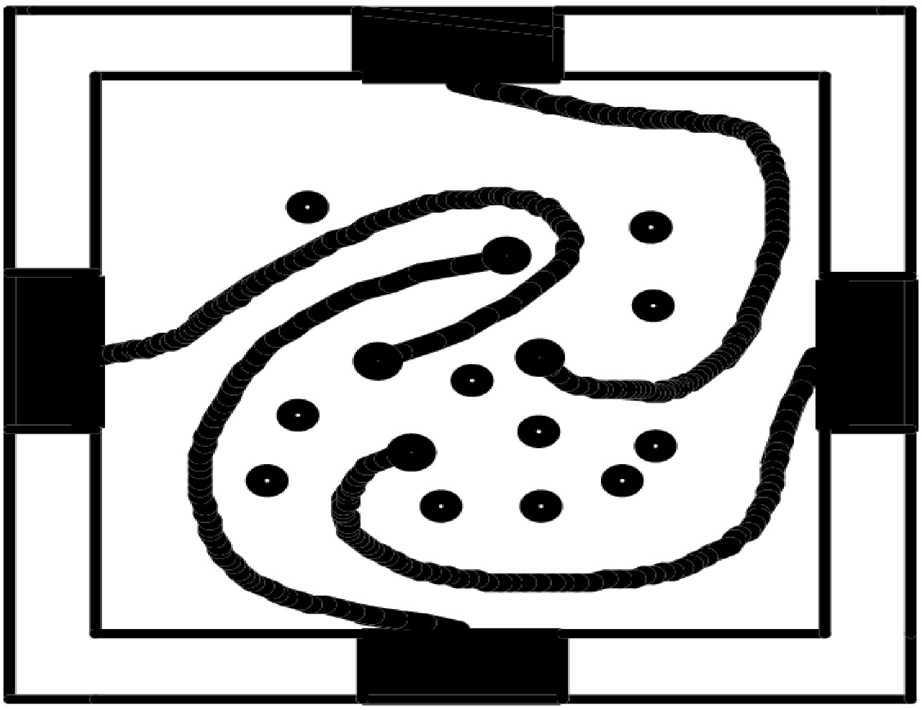

Figure 1: Top view of the feed circuit board showing the traces which connect the balanced antenna feed terminals to the balanced transmission lines leading to the Low Noise Amplifiers. The four square pads at the perimeter are the balanced inputs to the two linearly polarized feed antennas. Curved traces connect these four pads to the filled round pads to which the two pairs of balanced lines attach. Below these filled pads are circular holes (vias) in the base ground plane. The pads are drilled out to accept the transmission lines from the LNAs in the pyramid below. The isloated pads with central holes provide some electrical isolation between the traces and alignment guides for the diagonal membrane which separates the two transmission lines.