MEASUREMENT OF DOMESTIC PAY TV SATELLITE DISHES

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ABSTRACT

A number of Australian satellite pay-television companies have engaged CSIRO to measure the performance of their domestic reception antennas. These reflector antennas have their feed integrated with a low-noise block-down-converter (LNB), which converts 12.25-12.75 GHz to 0.95-1.450 GHz. We calculate the LNB noise temperature and gain by using a hot/cold-load Y-factor technique and a known noise source. For the cold load, we use absorber soaked in liquid nitrogen and ambient-temperature absorber for the hot load. The system noise temperature is calculated from another Y-factor measurement where the antenna is pointed at the sky for the cold load and ambient temperature absorber placed in front of the feed for the hot load. The gain is measured on an antenna range and we use a Fresnel-zone gain correction, as the range is too short for far-field measurements. We have identified the major sources of uncertainty and estimated the overall uncertainty.

Keywords: antenna measurements; commercial products; G/T; noise measurement; noise temperature; satellite broadcasting.

1. Introduction

This paper describes a measurement process for domestic satellite reception antennas performed for a number of companies in the Australian pay-television industry. The antennas are offset paraboloids ranging from 0.6 to 1.2 m in diameter (see Figure 1). They have ring slot feeds that are integral with low-noise block-down-converters (LNBs). The reflectors are made from pressed steel and have arms to support the LNB.

The LNBs have an 11.3 GHz local oscillator (LO), converting 12.25-12.75 GHz to 0.95-1.450 GHz and they amplify the signal by about 65 dB (see Figure 2). They use 75 Ω F-type connectors and require 12 to 18 V DC to power them.

The parameters we report on are:

- Antenna gain
- LNB Noise Temperature
- LNB Gain
- System Temperature
- Antenna/LNB combined G/T

Figure 1 - 0.6 m Antenna

Figure 2 – Typical LNBs

2. Measurement Process

The effective noise temperature of the LNBs is measured using a hot/cold load Y-factor method [1]. The "electronic" gain, as opposed to feed directivity, is measured by comparing the noise power of the LNB when presented with a hot load with the power from a known noise source. The gain of the antenna/LNB combination is measured using a standard gain horn as the range illuminator and system noise is measured using a Y-factor technique where the hot load is ambient temperature absorber and the cold load is the sky.

An alternative technique would be to use a satellite signal as described in [2] or [3]. These methods require a satellite signal with a known flux density and have not been tried for this application to date.

2.1 LNB Noise Temperature and Gain

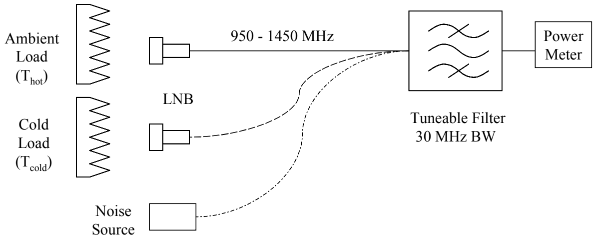

Figure 3 – Hot and Cold Radiated Loads Schematic

Figure 4 – Cold Load

As the feed is integral to the LNB, we cannot measure the "electronic" gain directly. Figure 3 shows a simplified diagram of the hot/cold-load measurement configuration. The filter is tuned to the down-converted frequency of interest, eg. 1.2 GHz for a radiated frequency of 12.5 GHz. The hot load is absorber at room temperature and the cold load is absorber dipped in liquid nitrogen.

Considerable experimentation went into the method of presenting the cold load to the LNB feed. A shield is placed over the absorber because small percentages of the radiation pattern presented with "hot" (ambient) surfaces have a significant effect on the result. This shield will be "hot" but the radiation from the shield is expected to be insignificant because it is a good conductor (see Figure 4). The absorber is dipped into the liquid nitrogen and we wait until the boiling slows, indicating that it has reached the liquid nitrogen temperature. It is then lifted just above the level of the liquid nitrogen and the LNB is inserted into the hole in the shield to make the measurement. The absorber is mounted on a perforated metal plate, allowing the liquid nitrogen to drain. The perforations are sufficiently small to ensure any energy from the ground below the bath is reflected and does not interfere with the measurement. Timing is important because, if the absorber is in the air too long, ice forms on it and its temperature increases. We have noted that the power level measured is stable for 10 to 20 seconds after the absorber is lifted above the liquid level, and this gives us confidence that we are seeing a temperature close to the boiling point of nitrogen.

The calculations are based on power radiated from a black body at a specific temperature [4]: $P = kTBG$ where P is the power in watts, k is Boltzman's constant, T is the temperature in Kelvin, B is the bandwidth in hertz and G is the amplifier gain.

The power ratio for the hot and cold loads is:

$$Y = \frac{P_{hot}}{P_{cold}} = \frac{k(T_{LNB} + T_{hot})BG_{LNB}}{k(T_{LNB} + T_{cold})BG_{LNB}}$$

where
T_{LNB} is the effective noise temperature of the LNB,
T_{hot} is the temperature of the ambient absorber,
T_{cold} is the temperature of the liquid nitrogen load and
G_{LNB} is the gain of the LNB.

Rearranging gives:

$$T_{LNB} = \frac{T_{hot} - YT_{cold}}{Y - 1}$$

The gain of the LNB is determined by replacing the LNB with a known noise source. The ratio of the power measured with the LNB looking at the hot load to that with the noise source is:

$$\frac{P_{hot}}{P_{noise\_source}} = \frac{k(T_{LNB} + T_{hot})BG_{LNB}}{kT_{noise\_source}B}$$

where T_{noise_source} is the effective temperature of the noise reference used.

Rearranging this equation gives:

$$G_{LNB} = \frac{P_{hot}T_{noise\_source}}{P_{noise\_source}(T_{LNB} + T_{hot})}$$

2.2 Antenna Gain

The Rayleigh distance ($2D^2/\lambda$) for these antennas ranges from 35 to 120 m and our longest facility has a 38 m working length and so we used a Fresnel-zone correction [5] to compensate. The correction assumes a constant phase and parabolic amplitude taper for the aperture distribution, giving sidelobes 25 dB below the main beam. Our antennas under test will differ from this in both amplitude and phase to some degree, but comparisons with far-field measurements on smaller reflectors indicate the correction is sufficiently accurate.

The reduction in power, in decibels, from the $1/R^2$ far-field relationship is [5]:

$$-10\log\left[\left(\frac{16\Delta}{\pi}\right)^2\left(1-\frac{16\Delta}{\pi}\sin\frac{\pi}{8\Delta}+\frac{128\Delta^2}{\pi^2}\left(1-\cos\frac{\pi}{8\Delta}\right)\right)\right]$$

where $\Delta=\dfrac{R}{2D^2/\lambda}$, R is the range length, D is the aperture diameter, in this case the projected aperture diameter of the elliptical offset reflector, and λ is the wavelength. Figure 5 shows plots of the power densities for the far-field and Fresnel-zone calculations and the correction, equal to their difference. Because of the uncertainties in it, the correction factor is kept to a minimum by using the largest range length possible.

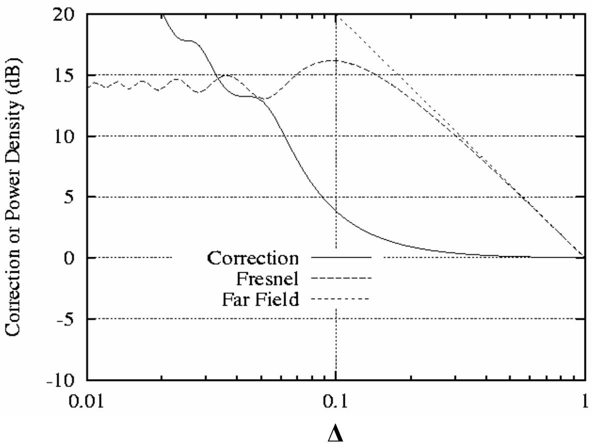

Figure 5 – Fresnel-Zone Correction

The AUT is illuminated with a standard gain horn (SGH) and the power density is calculated from the power fed to the SGH and the range length. The power level at the AUT end is measured after the LNB through a coupling network. A broadband power meter is used to measure the levels of these signals because they are at different frequencies. It was found that some LNBs leaked their LO signals sufficiently to interfere with the power level measurement at the transmit end and so we turn off the LNB when measuring the transmit power. Care is also taken to filter extraneous signals at the LNB end.

2.3 System Temperature

The system temperature is determined by measuring the ratio of the powers with the feed covered with absorber, P_{hot}, and with the antenna pointing at the sky, P_{sky}:

$$\frac{P_{hot}}{P_{sky}}=\frac{k(T_{LNB}+T_{hot})BG_{LNB}}{kT_{sys}BG_{LNB}}$$

where T_{sys} is the antenna-feed system temperature and T_{hot} is the absorber temperature.

Rearranging this equation gives:

$$T_{sys}=\frac{P_{sky}(T_{LNB}+T_{hot})}{P_{hot}}$$

and the spillover contribution can be calculated by:

$$T_{spill}=T_{sys}-T_{brightness}-T_{LNB}$$

where $T_{brightness}$ is the effective noise temperature the antenna sees looking at the sky. It includes the attenuation of the atmosphere and the cosmic background:

$$T_{brightness}=AT_{cosmic}+(1-A)T_{atmosphere}$$

where A is the fractional attenuation in the atmosphere, $T_{atmosphere}$ is the mean temperature of the atmosphere and T_{cosmic} is the cosmic background radiation, 2.7 K.

The attenuation in the atmosphere is calculated from [6] and is typically 0.07 dB. $T_{atmosphere}$ is calculated from an estimate given by [7] and is typically 0°C. $T_{brightness}$ is calculated to be 6 to 12 K for the conditions under which we have been making these measurements.

3. Typical Results

Typical performance figures for these antennas follow:

- Gain: 70 to 80% efficiency. These figures have been a little higher than expected but they are reasonable within the overall uncertainty.
- LNB Noise Temperature: 65 to 80K. This is usually slightly higher than the manufacturer's quoted values but we expect they measure the electronics only and do not take into account losses in the feed or any mismatch.
- LNB Gain: 60 to 70dB. The values we obtain are similar to the manufacturer's specifications.
- System Temperature: 80 to 110K.

The worst case Fresnel-zone correction is for a 1.2 m reflector at 38 m range length, the full extent of our outdoor facility, and comes to 0.4 dB.

4. Uncertainties

This measurement process comprises a large number of sources of uncertainty in both the instrument readings and the models used. The analysis done to date is by no means exhaustive and a number of factors have not been fully investigated. The major contributors identified are:

LNB gain stability: The gain of the LNB is measured at a different time to the gain of the antenna/LNB combination and any drift in gain due to temperature differences will contribute directly to an error in the G/T. We use 0.3 dB for the gain uncertainty.

Reference noise source: We estimate this contributes 0.25 dB to the overall uncertainty.

Range Reflections: We estimate these contribute 0.2 dB to the overall uncertainty.

Fresnel-zone correction: The AUT may differ significantly from the model used for this correction. A particular case is where the feed may not be correctly positioned at the focus, yielding either an over estimate or under estimate of the correction. We estimate the uncertainty to be 0.1 dB.

There are a large number of smaller contributors resulting in a root sum of squares estimate of about 0.6 dB for the final G/T value.

5. Future Work

Several improvements to our procedures are being considered:

- Using the sky as cold load rather than liquid nitrogen for the LNB measurements. We have done some preliminary work on this and it looks promising. The potential advantages are in avoiding the use of liquid nitrogen (with its hazards and inconvenience) and the benefit of a much lower cold load temperature (~10K as opposed to 80K).
- Developing a better brightness temperature model for the conditions under which we do our tests. More attention can be given to both the atmosphere and checking we are clear of any strong celestial radio sources.
- Developing a better knowledge of the liquid nitrogen load. We are investigating measuring the temperature of the absorber using thermocouples. We could also check the reflectivity of the absorber as the liquid nitrogen evaporates from it.
- Comparing the results with a system on which the LNB can be separated from the feed. This would allow characterisation of the gain of the LNB and the feed separately.
- Measuring LNB gain stability and perhaps doing the LNB gain measurements immediately before or after the range measurements to reduce effect of drift on the result.

6. Conclusion

We have taken a number of standard techniques and combined them to give a procedure for measuring G/T for small satellite reception antennas. The techniques can be applied to other active receiving antennas, yielding the "electronic" gain and a noise temperature that includes not only the amplifier noise but also the losses in the antenna itself. The method has proven to be repeatable and the results match expected values within the uncertainties.

7. References

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8. Acknowledgments

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