Parabolic Antenna Noise Characteristic with Dual-Mode Feed

by Rastislav Galuscak – OM6AA(1), Pavel Hazdra(1) ,Milos Mazanek(1)

(1)CTU Prague, FEE, Dept. of Electromagnetic Field, Technicka 2, 166 27, Prague, Czech Republic E-mail: om6aa@yahoo.com ,hazdrap@fel.cvut.cz, mazanekm@fel.cvut.cz

Abstract. *Extraterrestrial RF communication employing "moon bounce" (Earth-Moon-Earth or EME), and satellite transmission techniques has presently become very popular among UHF radio amateur operators. These technically demanding applications require specialized knowledge to properly design and optimize parabolic dish antenna configurations for their associated "low-noise" communication stations. In this paper we provide a novel approach to antenna selection for extraterrestrial RF communication based on reception parameters of a parabolic dish antenna configured with a dual-mode prime focus feed.*

Introduction

Parabolic dish antennas are often used for reception of weak microwave signals due to their high efficiency and relative ease of fabrication. A good figure of merit frequently used to quantify the reception performance of these antennas is ratio *G/Ta*, where *G* is antenna gain and *Ta* is antenna noise temperature. The higher the ratio is, the better would be the reception. That is why we will use hereafter the ratio *G/Ta* to assess the noise behavior of a dual-mode microwave antenna feed (designed for 23cm band by W2IMU [1]) in prime focus and offset dish antenna configurations. Furthermore we will use "directivity" modeled by the computer as a substitute for the actual antenna gain in the *G/Ta* ratio calculations since the radiation patterns modeled by modern computer methods are very accurate, conveniently supplying statistically small difference between directivity and real antenna gain. So, to avoid confusion, we will use the standard term "gain" which is usually associated with the *G/Ta* ratio regardless actually using directivity.

1. Parabolic dish reflector illumination, side lobes and noise temperature

Significant factors affecting parabolic antenna noise temperature are the main beam width, side lobe magnitude and dish spillover. While the main beam affects antenna noise primarily at low elevation angles, side lobe magnitude and dish spillover affect antenna noise temperature at higher elevation angles. For analyzing larger dish antennas, the radiation patterns of their feeds are often simplified by using defined field distributions above the reflector surface i.e. Gaussian, $cos^{2N}(\theta)$ or quadratic functions. Further information regarding this practice has been addressed by others [2].

As an illustration, the behavior of side lobe magnitude for a prime focus antenna feed configuration with quadratic electromagnetic field distribution is shown in Fig. 1. We see that with lower edge illumination (taper), antenna side lobe magnitude decreases. Simultaneously, lower edge illumination results in a corresponding decrease of gain. Maximum gain is achieved with an edge taper of about -10 dB. Thus, dish reflector illumination from a standard real feed leads to relatively high spillover which, in turn, causes an increase in antenna noise temperature since spillover and side lobes are directed toward the Earth and obtain relatively high noise temperatures from the Earth's surface.

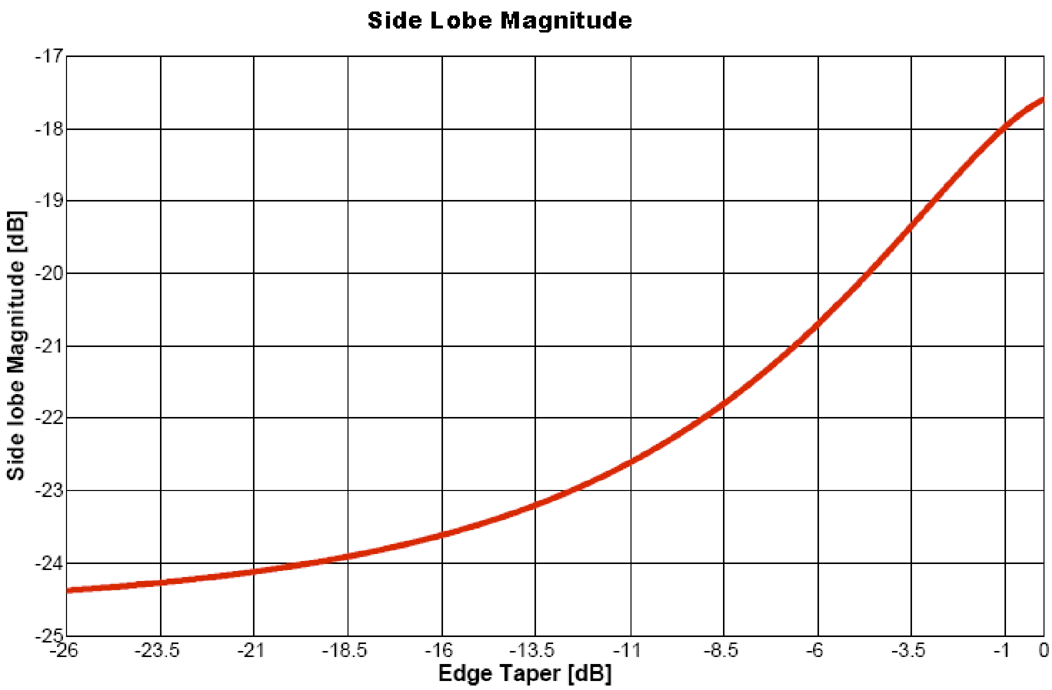

Fig. 1 – The level of the first sidelobe as a function of the edge taper for quadratic distribution.

2. System noise temperature

We consider the system noise temperature calculation [3] of a typical system as depicted in Fig. 2. The overall temperature T_s is sum of antenna temperature T_a and receiver chain temperature T_{RX} :

$$T_s = T_a + T_{RX} , \tag{1}$$

where

$$T_{RX} = L_{c1}\left\{L_r\left[T_{LNA} + \frac{L_{c2}T_{DRX} + T_{c2}}{G_{LNA}}\right] + T_r\right\} + T_{c1} \tag{2}$$

In the above equation, L represents insertion losses of relevant components and T represents their noise temperatures. See Fig. 2.

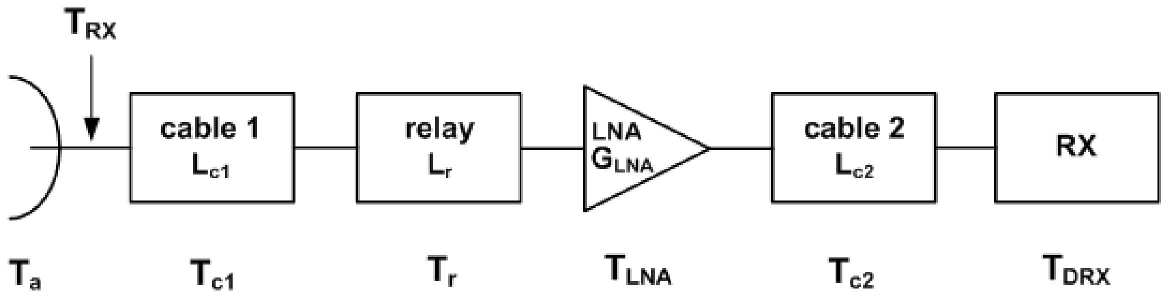

Fig. 2 - Block diagram for noise temperature calculation of a typical system

3. Dual-mode feed horn (Potter horn)

The dual-mode feed horn utilizes two modes, TE_{11} and TM_{11}, mixed together near its aperture [4]. See Figs. 3a and 3b. The feed's "A" section is usually fabricated with a waveguide-to-coaxial transition and septum polarizer to achieve circular polarization. The tapered section, "B", allows excitation of a higher TM_{11} mode and the horn section, "C", combines both modes together and forms the output radiation.

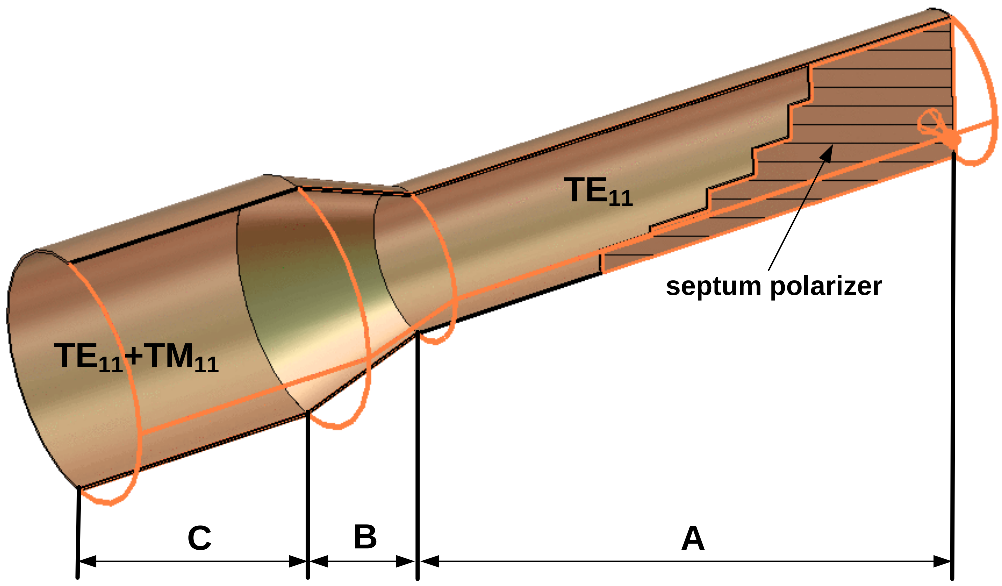

Fig. 3a - Dual-mode feed, CST MWS model

Fig. 3b - Real dual-mode feed, front view

Dual-mode feeds provide both very good radiation characteristics and exceptional suppression of side-lobe and backward radiation [1], [4], [5]. The co-polarization pattern is shown in Fig. 4. Note that the cross-polar pattern is suppressed by more than 30 dB.

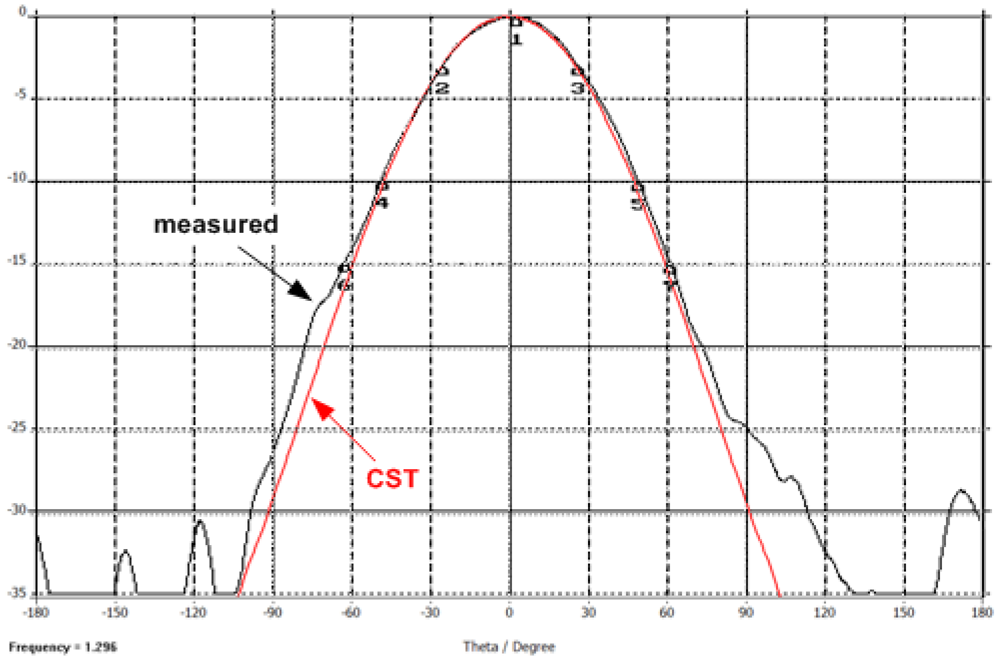

Fig. 4 - Measured and simulated (CST) radiation pattern of the dual mode feed

Now consider a 15λ diameter dish antenna having a prime focus feed configuration. A parabolic dish of this size is frequently used on the 23cm band by the EME community. Unfortunately, this dish size delivers relatively poor EME performance because reception of weak signals is very sensitive to its *G/Ts* ratio. Due to this handicap, this antenna system consisting of the feed and dish needs to be fully optimized for low-noise operation. To accomplish this, an antenna system consisting of a dual-mode feed and dish with variable f/D parameters was modeled and calculated using CST MWS. A typical antenna configuration with prime focus feed is depicted in Fig. 5. The dependence of antenna gain on f/D ratio with calculated efficiency is shown in Fig. 6.

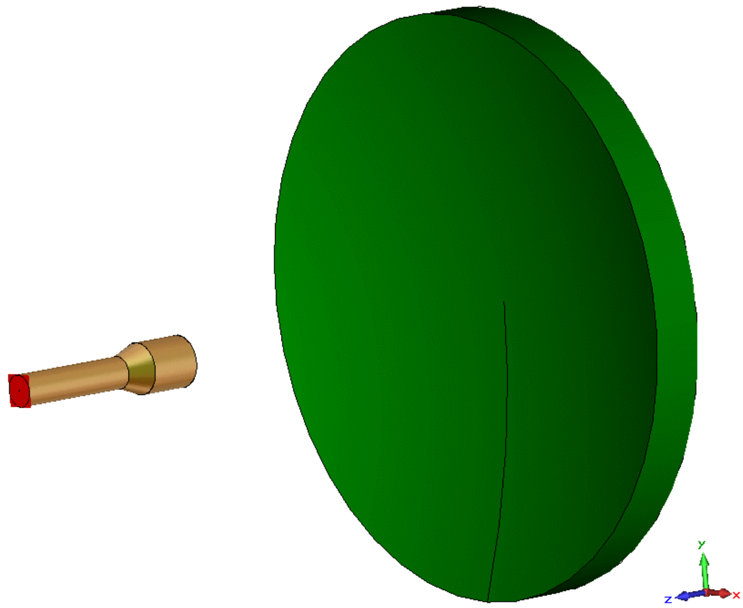

Fig. 5 – Prime focus dish antenna configuration

Fig. 6 shows that maximum antenna gain for a prime focus antenna configuration employing the W2IMU dual-mode feed is attained with a dish having an *f/D* ratio of 0.6. Such antenna configurations are best used for transmitting and will be referred to as TX optimum.

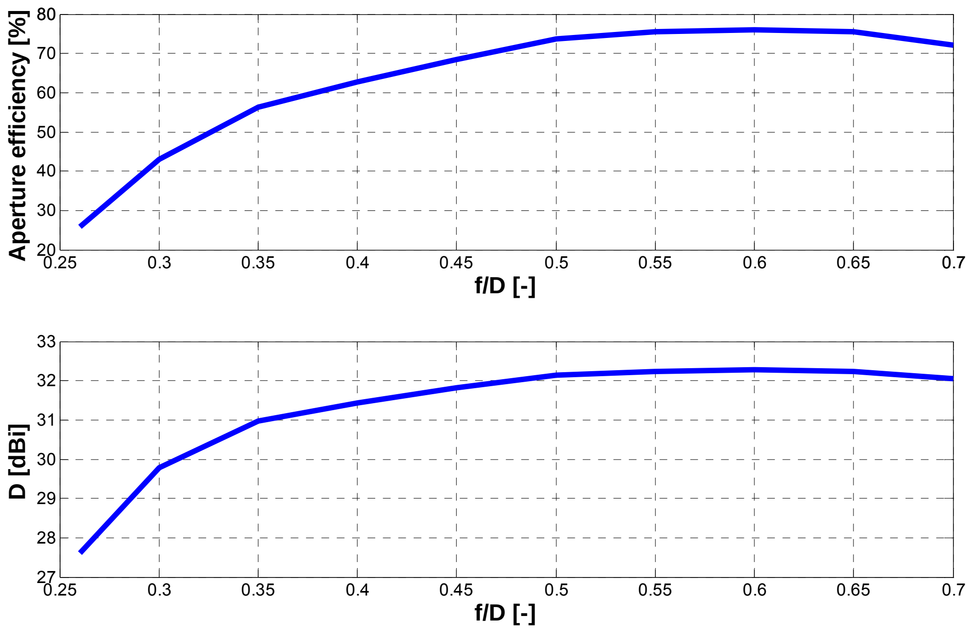

Fig. 6 - Antenna efficiency and directivity

4. Antenna noise temperature and system noise temperature

To calculate antenna and system temperatures Antenna Noise Temperature Calculator (ANTC) software [6] was used. The antenna noise temperature was calculated as an average value for the elevation angle interval α of 0 to 90 degrees. See Fig. 7. Details on the ambient noise temperature used can be found in [7]. For system temperature, receivers with noise figures of 0.2 dB, 0.4 and 0.6 dB were considered. The dependence of antenna and system temperatures on f/D dish antenna ratio is plotted in Fig. 8.

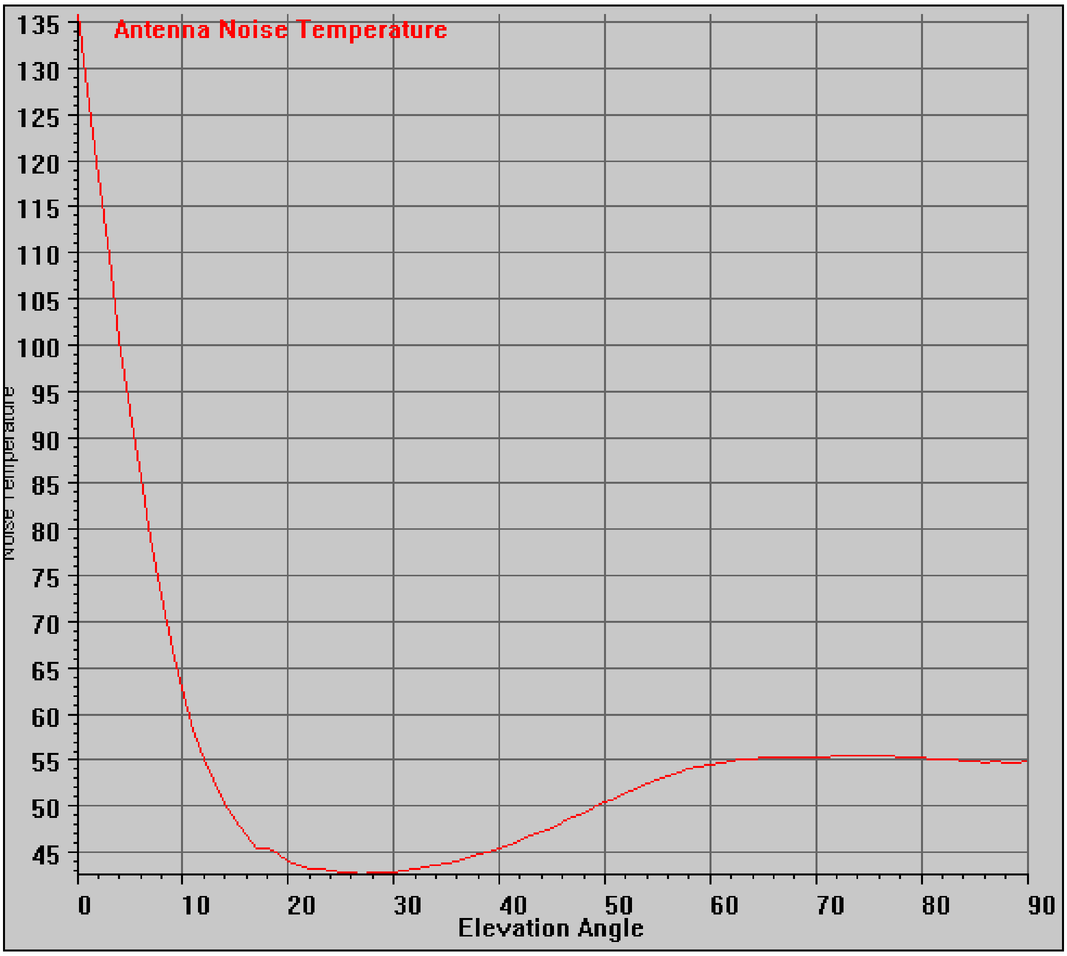

Fig. 7 - Dependence of antenna noise temperature on elevation angle for a dish with f/D ratio 0.65. Note accrual of antenna noise temperature for higher elevation angles, above 50 degrees, due to antenna spillover.

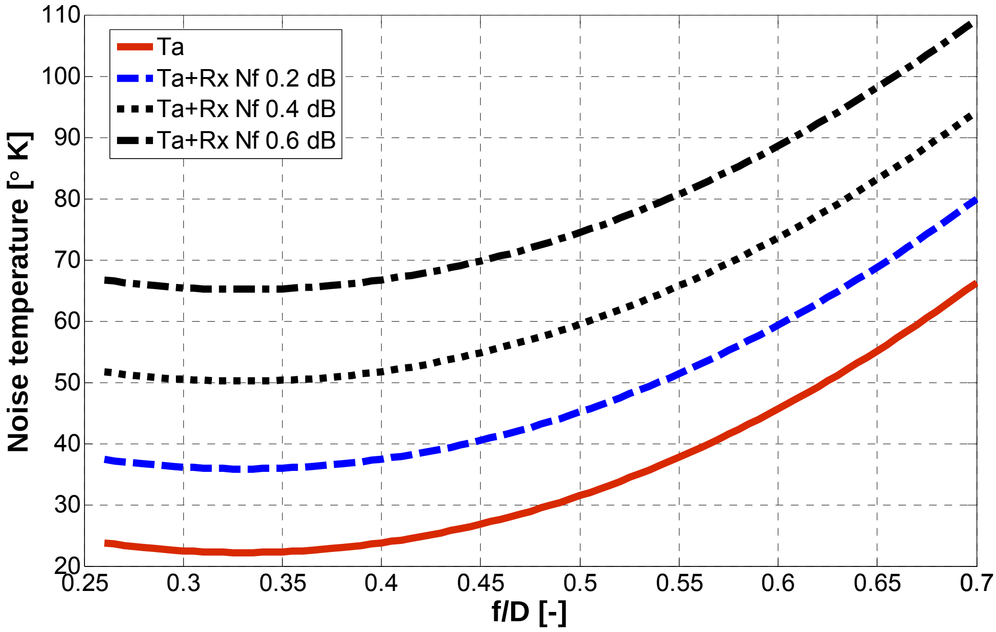

Fig. 8 - Average antenna and system noise temperature

5. Optimal receiving (RX) performance, G/Ts ratio

The computed G/Ts curves from the above results (Figs. 6 and 8) are shown in Fig. 9.

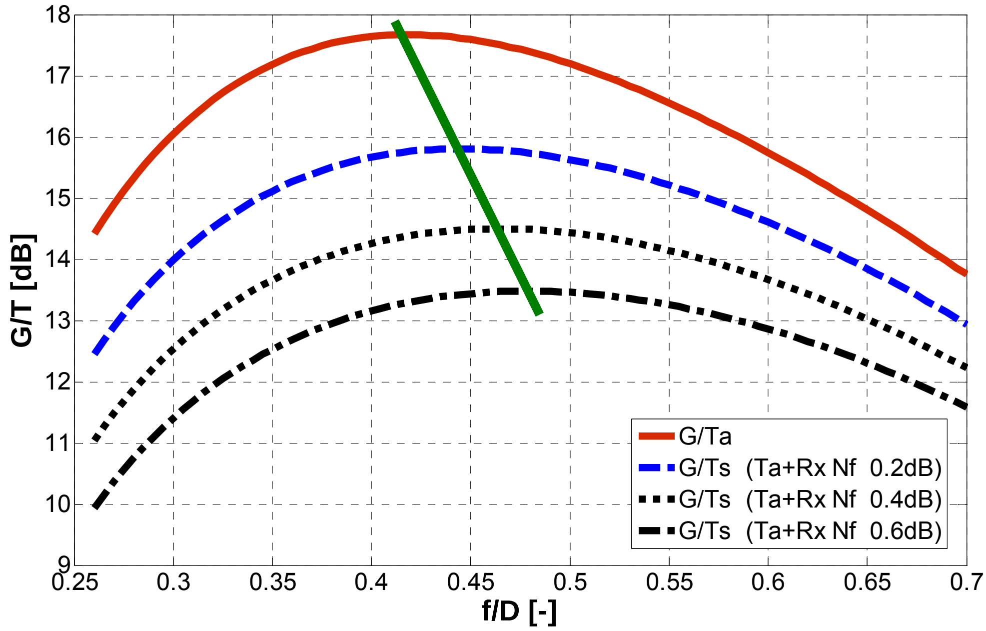

Fig. 9 - Antenna and System G/T ratio

Inspection of Fig. 9 reveals that the best (highest) *G/Ta* ratio for RX operation is obtained at a different *f/D* ratio than the *f/D* ratio that delivers maximum antenna gain-efficiency for TX operation. Also note that the best *G/Ts* ratio is affected by the receiver noise figure, i.e. one has to optimize the entire receiving chain. Any subsequent increase in system noise temperature leads not only to a corresponding decrease in *G/Ts* ratio but to an increase in the optimum *f/D* ratio as well (see Fig. 9, green line). When a receiver with high noise temperature T_{RX} dominates over moderate antenna noise temperature, T_a, there is essentially little or nothing to be gained from optimization and the "reception optimum" antenna configuration *f/D* ratio equals the *f/D* ratio for maximum dish gain and/or dish efficiency.

6. Practical experience

We had the opportunity to test antenna reception performance in designing feeds for the antennas of Christoph Joos (call-sign HB9HAL) and CAMRAS [8]. See Fig. 10 and 11. These antennas are 10 m and 25 m in diameter with *f/D* ratios of 0.43 and 0.45 respectively. We were able to calculate radiation patterns of both physically and electrically large antennas; however we were not able to calculate absolute values of antenna noise temperature due to current algorithm-limitations in the ANTC software. This issue is currently being addressed by employing adaptive integration. The interaction between the shape of the antenna (*f/D* ratio) and dual-mode feed was studied using models with scaled reflector dimensions. The measured G/T_a ratio of CAMRAS antenna is 35.6 dB at 1420 MHz. Unfortunately actual G/T_a ratio measurements of Christoph Joos antenna are not available to date. Despite that, excellent reception performance of both antennas was reported. The CAMRAS antenna is therefore used not only for EME tests but also for reception on the 1420 MHz band for radio astronomy purposes. The measured antenna main lobe patterns utilizing sky point noise sources are shown in Fig. 12.

Fig. 10 - D=10 m Joos (HB9HAL), equipped with dual-mode feed

Fig. 11 - D=25 m CAMRAS station antenna

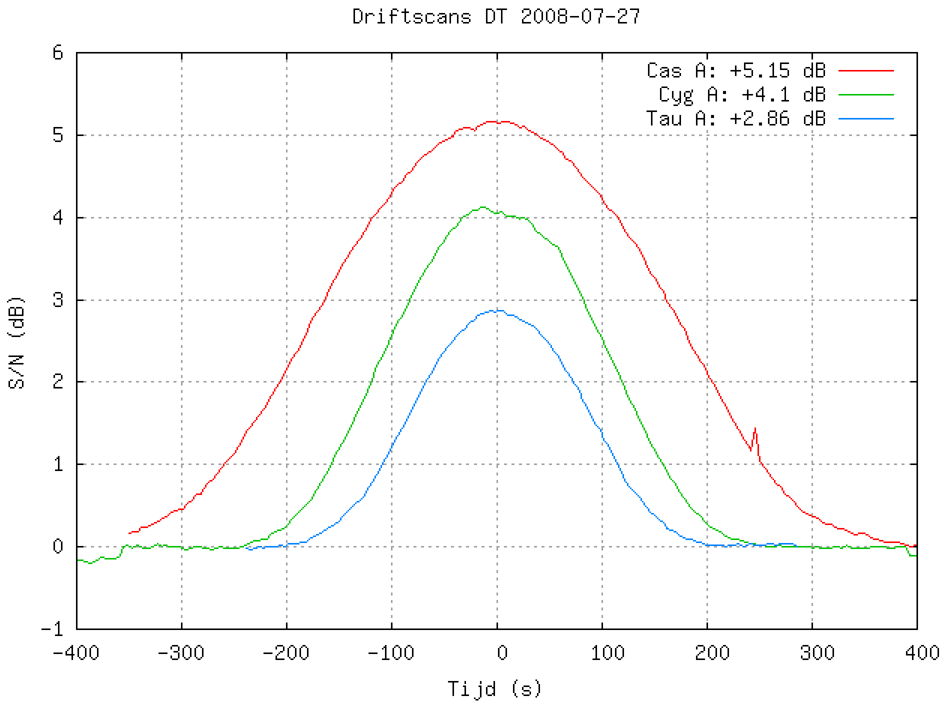

Fig. 12 - Envelope of main pattern utilizing sky source reception: Cassiopea A-upper trace, Cygnus A- mid trace, Taurus A- lower trace.

Summary and conclusion

Our analysis of dish antenna systems with dual-mode feeds finds that two performance maximums occur over the range of commonly used dish *f/D* ratios. The first represents the best TX performance and is associated with maximum available dish gain (aperture efficiency). The second, corresponding to a maximum G/T_a ratio, provides the best RX performance. While the antenna configuration (*f/D* ratio) for the best TX performance is fixed, the *f/D* ratio for the best RX performance varies with the overall system temperature, *Ts*, which consists of inherent antenna noise temperature and the overall receiver noise temperature, T_{RX}. Dual-mode feeds exhibit very low antenna noise temperature, especially when in the offset dish configuration; therefore the influence of system noise temperature becomes significant. It was also shown that as lower RX temperature is achieved, the optimum *f/D* ratio for maximizing the G/T_a ratio becomes lower.

For EME and other space communication applications it is most important to achieve the best reception performance, particularly when the available dish size is limited. In this case it would be prudent to use a dual-mode feed and dish with an *f/D* ratio selected for the best G/T_a ratio and tolerate the slightly lower TX performance. The TX penalty is less than 1 dB which can be quite easily compensated by increasing ERP (Effective Radiated Power) either by boosting transmitter power to the license limit or by using a low-loss feeder cable. So, for noise-limited space communications we recommend using dual-mode feeds with deep dish reflectors having *f/D* ratios between 0.4 and 0.45. This conclusion contradicts the typical common sense choice of using dual-mode feeds with shallow dishes having *f/D* ratios of about 0.6.

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