Faster Antenna Noise Temperature Calculations using a Novel Approximation Technique

William A. Imbriale
Jet Propulsion Laboratory, California Institute of Technology
Pasadena, CA 91109, USA
E-mail: Imbriale@jpl.nasa.gov

Introduction

In order to properly tradeoff the various antenna and feed configurations for the Square Kilometre Array (SKA) optical design it is necessary to evaluate the gain and noise temperature of each configuration over a wide range of frequencies. German Cortes [1] describes the standard technique for computing antenna noise temperature. However, since the total antenna pattern needs to be calculated over the entire 4 pi steradians at a fine enough resolution to accurately include the main beam, the computer time required is enormous. Even at modest frequencies and reflector sizes (~5 to 10 GHz for a 12 meter main reflector) the technique can take days on a single node of a supercomputer. Utilizing the standard technique to compute the noise temperature for all the cases required to properly characterize the SKA design is clearly not feasible. At least a 100 to 1000 speedup in the computation time is required. This paper describes an approximation technique that can accomplish this improvement with extremely small errors in noise temperature calculation of a few tenths of Kelvin.

Antenna Noise Temperature

Consider a lossless antenna pointing in the direction $\mathbf{r}_0$, as shown in Figure 1, then, the radiometric noise temperature, for a single mode at the i^{th} port, at a given frequency ν, is given by [1] where $Pn(\nu,\theta,\varphi|r_0)$ is the *total* radiation pattern for that particular polarization port when the antenna is pointing in the direction $\mathbf{r}_0$. $T_b(\nu,\theta,\varphi)$ is the apparent radiometric temperature distribution, also known as the brightness temperature distribution, from the "scene" surrounding the antenna at that particular frequency.

$$T_A(\nu|\hat{\mathbf{r}}_o) = \frac{\iint\limits_{4\pi} T_b(\nu,\theta,\phi)\, P_n(\nu,\theta,\phi\,|\hat{\mathbf{r}}_o)\, \sin\theta\, d\theta\, d\phi}{\iint\limits_{4\pi} P_n(\nu,\theta,\phi)\, \sin\theta\, d\theta\, d\phi}$$

The different source contributions from the brightness temperature distribution surrounding the antenna are detailed in [1]. As is well known the major noise contribution comes from the energy in the backside of the antenna that hits the ground (θ > 90 degrees).

Noise Temperature Contributors

The geometry under consideration is offset dual shaped Gregorian reflector system fed with a Lindgren the wide band frequency feed described in [2]. To understand the noise temperature it is necessary to understand the various scattering field components. Figure 2 shows the main diffraction components of the full radiation pattern. Most of the energy goes to the main beam wherein it adds the brightness temperature of that pointing direction to the antenna noise temperature. There are two diffraction cones, one produced by feed spillover past the subreflector and the other from the field radiated from the subreflector spilling past the main reflector. The full 4 pi steradians pattern using all field components at 1.4 GHz is shown in fig. 3a.

Approximate Technique

As stated previously, the noise temperature contribution from the main beam is primarily given by the brightness temperature in its pointing direction and the spillover from the sub and feed contributes the remainder of the noise temperature. However, computing the main beam over the 4 pi steradians is the major time consuming element since it is the larger of the two reflectors and thus requires a finer integration grid as well as more computed points to capture the pattern variations. However, as seen in fig. 3b, only using the feed and subreflector pattern does not suppress the radiation behind the main reflector. Both patterns are shown over a 50 dB dynamic range referenced to the peak gain. Figure 3c shows the shadow generated by the rays radiated from the feed that are blocked by the main reflector. Applying the mask of Figure 3a to the feed plus subreflector pattern of Figure 3b produces the radiation pattern in fig. 3d. This pattern contains the energy from the main and subreflector diffraction cones but not the main beam itself. Using the radiation pattern from fig. 3d in equation (1) and adding the brightness temperature in the direction of the main beam provides an excellent approximation of the noise temperature without having to calculate the radiation pattern of the main reflector. The computer time is reduced by a factor of 100 to 1000 with the larger savings at the higher frequencies. To demonstrate the accuracy of the approximate technique fig. 4 compares the approximate technique to an exact noise temperature over a wide frequency range.

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References

[1] German Cortes, “Antenna Noise Temperature Calculations”, *SKA Memo 95*, July, 2007.
[2] W. A. Imbriale. S. Weinreb and H. Mani, Design of a wideband radio telescope. In Proc. IEEE Aerospace Conference, pages 1-2, March 3 -10, 2007.

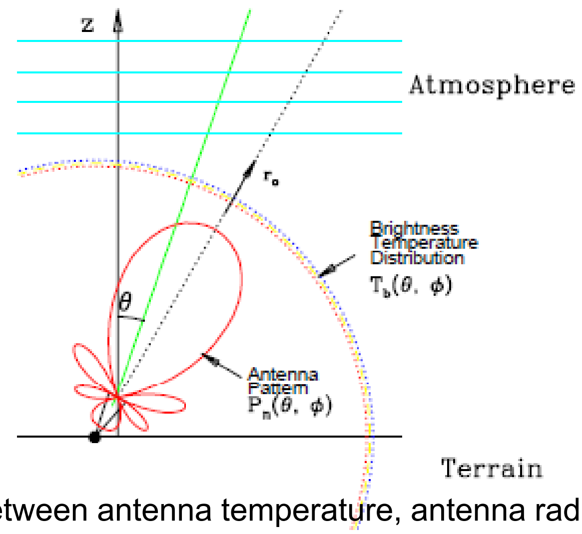


Figure 1: Relation between antenna temperature, antenna radiation pattern and the brightness temperature of the observed scene (From German Cortes [1])

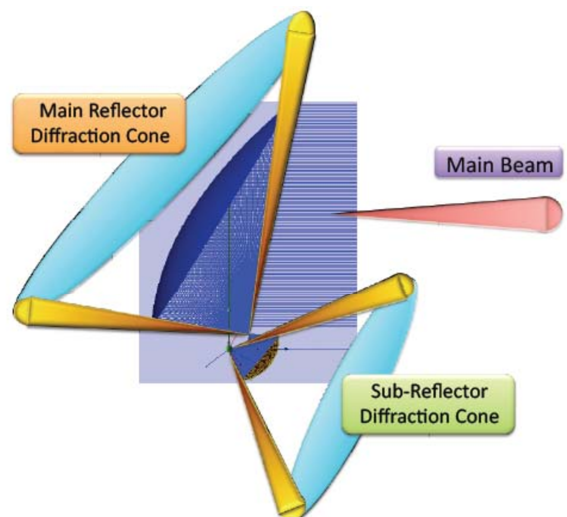


Figure 2. Main diffraction components of a full radiation pattern in an Offset Gregorian Optics (Figure provided by German Cortes)

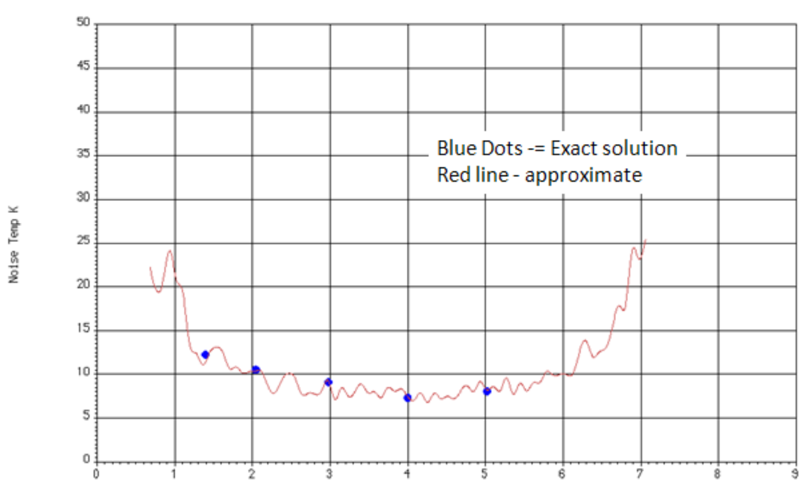
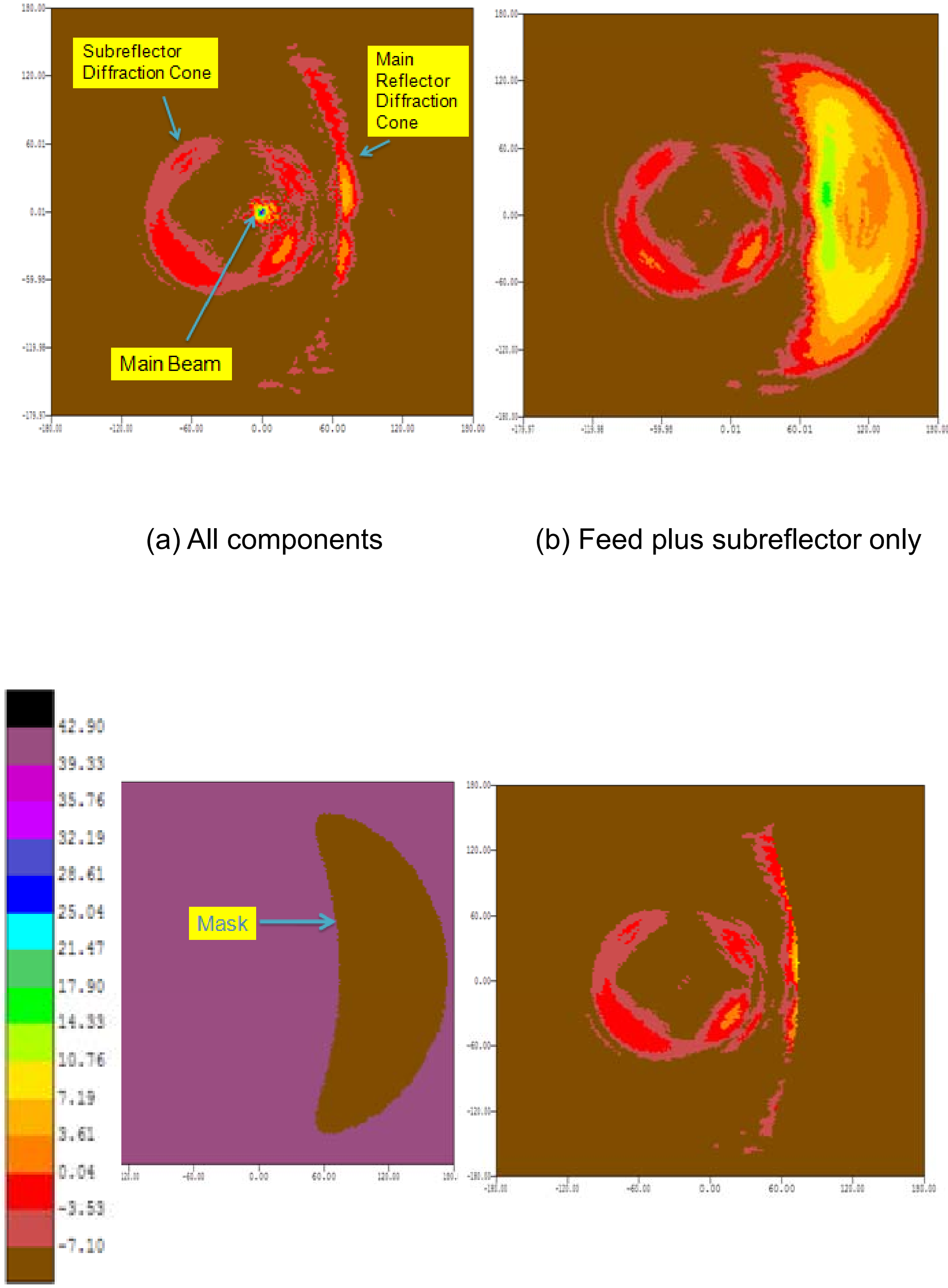


Figure 4. Comparison of approximate and exact computations



(a) All components

(b) Feed plus subreflector only

(c) Main reflector Mask

(d) Feed plus subreflector with Mask

Figure 3. Full 4 pi steradian radiation patterns at 1.4 GHz with 50 dB range