

MWA memo
Beamformer contribution to total system power

Brian Corey
MIT Haystack Observatory
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Summary

The fraction of the total system power contributed by the beamformer (BF) has been calculated from measured tile spectra to be <10% over 80-300 MHz, and <2% over 80-200 MHz.

Introduction

The noise temperature of a well-designed RF receiving system should be dominated by the sum of external signals received by the antenna (sky, RFI, etc.) and noise generated in the first amplifier, with “2nd-stage noise” from electronics further downstream contributing a small fraction (<10%, say) to the total system power. Data were taken for a 32T tile during X13 in March 2010 to determine whether indeed the hardware complies with this dictum.

X13 data

The data are 3-second-integration burst-mode spectra for one polarization of a single tile: tile 4X connected to Rx 4 slot 2X. The tile 4X BF has a “high-gain” delayline board, which has an SGA-4563 amplifier (the same amplifier to be used in 512T) on each input. Rx 4 slot 2X was selected because it has the PSI anti-alias filter that cuts off above 300 MHz appropriately.

Data were taken on March 19 between 0720 and 0848 UTC, corresponding to 0254-0422 LST, when the Galactic Center was well below the horizon. During this same time range, the sun went from an az/el position of 294°/40° to 280°/21°.

Spectra were recorded for six different system configurations:

1. Full tile pointed at zenith
2. Full tile pointed at az/el = 90°/70°
3. Full tile pointed at az/el = 90°/50°
4. Dipole “A” (in northwest corner of tile) connected to BF; all 15 other dipoles disconnected, and their corresponding BF inputs “terminated” with 10-dB attenuators
5. All 16 dipoles disconnected from the BF, and all 16 inputs terminated
6. Same as #5, but all inputs left unterminated (nothing connected to SMA connectors)

Configurations 2 and 3 were included to test for possible solar contamination entering in strong sidelobes or grating lobes at the higher frequencies.

For each configuration, spectra were recorded for three or more different receiver attenuations spanning at least 10 dB, to test for saturation or low-power (too weak a signal to tickle the A/D bits) effects that could distort the spectra.

Furthermore, for each configuration and attenuation, multiple spectra (typically three) were recorded. A few individual spectra were observed to be anomalous by having, e.g., too much power below 60 MHz or excessive scatter from frequency to frequency. Such spectra were omitted from the analysis. Differences among “good” spectra for the same configuration and attenuation are typically < 0.1 dB rms over frequency. Each spectrum used in the analysis or displayed in this memo is the mean of the good spectra for that configuration and attenuation.

Spectra and effects of different receiver attenuations

Figure 1 shows spectra for configurations 1 and 5: (1) a full tile of 16 dipoles steered to zenith, for seven different receiver attenuations, and (5) all 16 BF inputs terminated with 10-dB pads, for three different attenuations. After adjustment for the attenuation differences, the spectra for a given configuration can be seen to agree to < 1 dB above 80 MHz except in regions of RFI and except above 280 MHz in a few cases. The latter exceptions become more pronounced with increasing attenuation and reflect added digital “noise” incurred after (or conceivably in) the ADC as the analog signal level approaches the noise floor observed in all spectra below 60 MHz. (If the spectra were plotted without correction for attenuation, this noise floor would be seen to be nearly independent of attenuation, except for the 5-dB full-tile spectrum.)

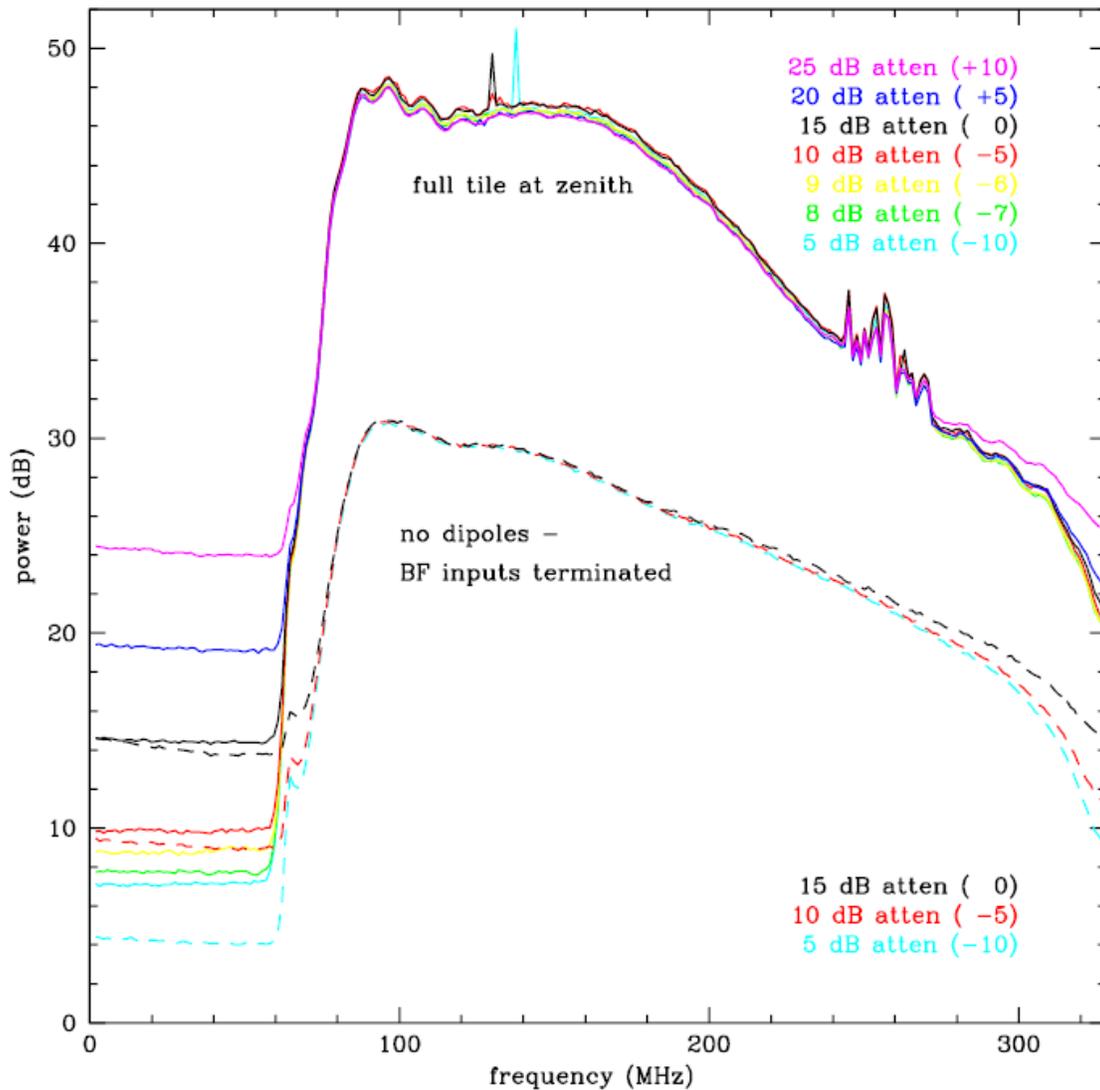


Figure 1. Burst-mode spectra for 16-dipole tile pointed at zenith (top 7 curves) and for BF with 16 inputs terminated (bottom 3 curves). The full-tile spectra were taken between 0720 and 0734 UTC. For each of the two configurations, spectra were recorded with different receiver attenuations, as noted in the legends. In order to simplify comparisons of the effects of different attenuations, the spectra were shifted vertically by the amount shown in parentheses, which is the difference in attenuation from 15 dB.

In figure 2, spectra are displayed for the first three configurations listed on page 1, including three different epochs of zenith spectra spanning the test period. The largest differences are ~ 2 dB and occur between the spectrum at 50° elevation and the zenith spectra. For the present purposes, the differences, and any potential solar contamination, are negligible.

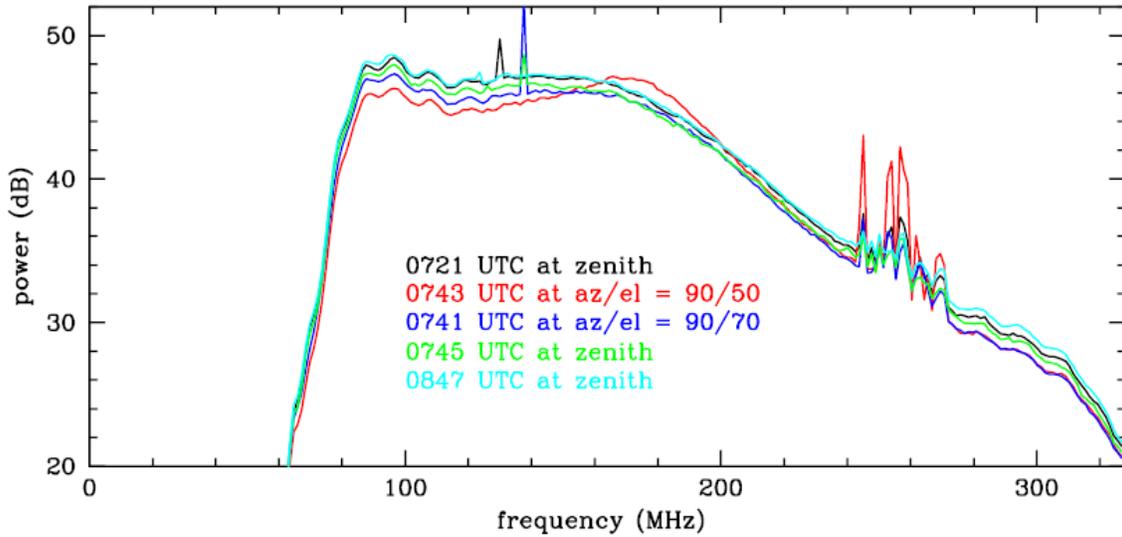


Figure 2. Full-tile spectra with receiver attenuation = 15 dB.

Figure 3 displays spectra for configurations 1, 4, 5, and 6 for a “reference” attenuation of 15 dB. For the three weaker spectra, the spectrum acquired with an attenuation of 5 dB is shown, as it avoids the added digital noise at the high-frequency end; each of the three is shifted down by 10 dB to compensate.

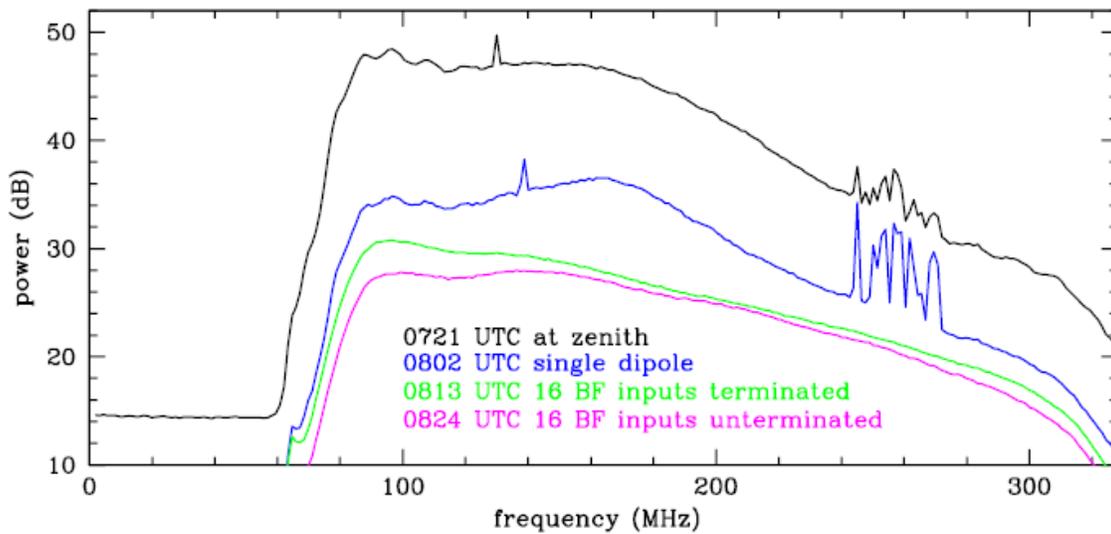


Figure 3. Spectra for four different configurations of dipole and BF hardware for a reference attenuation of 15 dB (see text).

Analysis and results

For the analysis, refer all powers and noise temperatures to the BF inputs. Let $P_{16\text{dip}}$ be the spectral density of the power received from all 16 dipoles. (Because the sky signals from two dipoles can be coherent, $P_{16\text{dip}}$ must be defined carefully. Strictly speaking, it is the portion of the BF output power that arose in the dipoles as sky or LNA noise, divided by the BF gain.) Let P_{bf} be the power spectral density of the noise arising in the BF for a *single* BF channel. Convert to temperature by dividing by Boltzmann's constant. The effective temperature for a full tile is then

$$T_{\text{tile}} = T_{16\text{dip}} + 16 T_{\text{bf}} .$$

With the dipoles disconnected and the inputs terminated, the effective temperature is

$$T_{\text{term}} = 16 T_{\text{amb}} + 16 T_{\text{bf}} ,$$

where T_{amb} is the ambient temperature of the terminations, whose impedance is assumed to match the BF input impedance. (A 10-dB pad is not a perfect match, but it's close enough!) Let R_{obs} be the ratio of the observed full-tile and input-terminated spectra, so that

$$R_{\text{obs}} = T_{\text{tile}} / T_{\text{term}} .$$

The desired quantity is the ratio between the dipole power and BF internal noise, or $T_{16\text{dip}} / 16 T_{\text{bf}}$. From the above equations and definitions, it is given by

$$T_{16\text{dip}} / 16 T_{\text{bf}} = R_{\text{obs}} (1 + T_{\text{amb}} / T_{\text{bf}}) - 1 \quad (1)$$

The noise temperature of a single BF channel has been measured to be between 160 and 180 K except near 80 MHz, where it is lower (see http://mwa-ldf.haystack.mit.edu/twiki/pub/Main/MWATECHNICALMEMOSERIES/MWAmemo_2ndStageNoise.pdf). This range agrees well with the typical noise temperature of 180 K quoted on the SGA-4563 data sheet. For $T_{\text{amb}} = 310$ K and $T_{\text{bf}} = 180$ K, equation (1) becomes simply

$$T_{16\text{dip}} / 16 T_{\text{bf}} = 2.72 R_{\text{obs}} - 1 .$$

For higher T_{bf} , the ratio decreases, but it never drops below $R_{\text{obs}} - 1$, which is the value for an infinite T_{bf} .

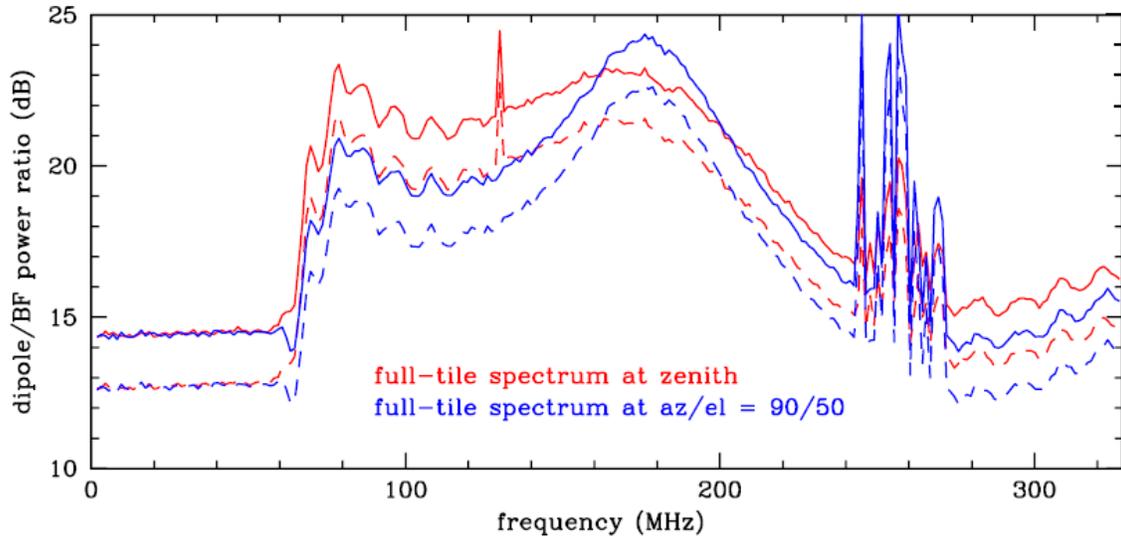


Figure 4. Estimates for the dipole/BF power ratio obtained from equation (1). For the red curves, the two spectra used are the full-tile zenith and terminated spectra in figure 3; for the blue curves, the zenith spectrum is replaced by the 50° elevation spectrum of figure 2. The solid curves are calculated from equation (1) with $T_{\text{amb}} = 310$ K and $T_{\text{bf}} = 180$ K; for the dashed curves, $T_{\text{bf}} = 360$ K.

Figure 4 presents the $T_{16\text{dip}} / 16 T_{\text{bf}}$ values calculated for two different full-tile spectra and for two different assumed values of T_{bf} . The lower T_{bf} value of 180 K, which gives the higher ratios, is more realistic; the (arbitrarily doubled) value of 360 K yields ratios ~ 2 dB lower.

During the time of observation, the zenith sky temperature was within 20-30% of the coldest temperatures anywhere on the sky, so the estimates in figure 4 should be within 1-2 dB of the worst case. A conservative upper bound of 10% can therefore be set on how much a BF contributes to the total system power over 80-300 MHz for any observing direction. Between 80 and 200 MHz the upper bound is more like 2%.

Comparison with earlier results

Similar BF spectra with 16, 8, 1, and no dipoles connected to a tile were recorded on a spectrum analyzer by Mark Waterson during X5 (see <http://mwa-lfd.haystack.mit.edu/twiki/bin/view/Main/X5EngBfNoise>). The dipole/BF power ratios calculated from those 16- and 0-dipole spectra with $T_{\text{bf}} = 180$ K agree with the solid red curve in figure 4 to 1-2 dB. On the other hand, X5 burst-mode spectra exhibited a much higher noise floor than either the X5 spectrum analyzer spectra or the present X13 burst-mode spectra (see http://mwa-lfd.haystack.mit.edu/twiki/pub/Main/X5EngBfNoise/beamformer_tests_amended.pdf). This high noise floor was traced after X5 to a PFB problem, which was subsequently fixed, as confirmed by these X13 data and other evidence.

Acknowledgements

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