National Centre for Radio Astrophysics

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Characterisation of Solar Atteunators at GMRT

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Objective: To characterise the spectral response and temporal stability of the GMRT solar attenuators.

Revision	Date	Modification/ Change
Ver. 1	12 January 2016	Initial Version

Motivation: The solar attenuators are used to bring down the signal level when observing very strong sources. The original attenuators installed will continue to be used for the uGMRT system. They are used infrequently and to the best of our information, information about their detailed characterisation is not available. Being simple passive devices, they are not expected to show significant ageing and are also expected to have a flat spectral response and be stable in time.

Usually, these attenuators are used when observing the Sun, and are switched out when observing the flux calibrator (and also other calibrator) sources. Therefore, in order to do a reliable flux transfer from the calibrator to the Sun, one needs to know the response of these attenuators. As a part of preparing to observe the Sun with the uGMRT, we have characterised the performance of some of these attenuators.

These attenuators are located in the common box of the antennas and hence are common to all observing frequencies. Their performance will be tested on available antennas with common box boadband power monitor setup in the frequency band of interest.

Measurement Setup: Here we use the 250-500 MHz uGMRT band to test the performance of the attenuators. Based on the availability of broadband power monitoring capability, and the general availability of antennas, we used the following seven antennas – C10, C11, C13, E2, S1, S2 and S4. Of these C10 attenuators were studied in much greater detail as described below.

Experiment 1: ***Testing C10 attenuators at a few specific frequencies***

Experimental Setup: C10 has an ARONIA LPD (Log Periodic Dipole) radiator which is designed to radiate in the 380 MHz – 4 GHz frequency band. The LPD was fed by a signal generator (Anapico 109 kHz - 6.1 GHz) at the antenna base and the output of the common box was fed to a spectrum analyser (Agilent CXAN9000A 9kHz-3GHz). Even though a part of the band of interest to us was outside the specified range for the LPD, in practice it only implies a loss in transmission efficiency, which is not important in the present context. This setup provides a good test bed to evaluate the frequency response of the attenuator in the band of interest.

The LPD was set up using the signal generator to radiate a power of -30dBm at 300 and 500 MHz. The power level chosen was high enough that the signal would still be detectable above the noise floor even at the highest attenuation, while not being high enough to saturate the front end. The power detected at the spectrum analyser without any attenuation was noted down. Similarly, power detected with attenuations of -14dB , -30dB and -44dB (= -30-14 dB) were also noted down.

Measurements: This experiment was done for polarisation channel 1 alone. Table 1 shows the power recorded by the spectrum analyser at the 2 chosen frequencies with and without attenuators being switched in. The actual measured value and the noted value are reported.

Frequency	300 MHz				500 MHz			
Attenuator (dB)	0	-14	-30	-44	0	-14	-30	-44
Peak Value (dBm)	-28.4	-42.1	-57.0	-70.6	-27.8	-41.2	-54.4	-67.9
Noise Floor (dBm)	-67.1	-80.2	-88.9	-89.6	-75.4	-87.1	-90.1	-90.5
Measured attenuation	0	-13.7	-28.6	-42.2	0	-13.4	-26.6	-40.1

(dB)				**-42.3***				**-40.0***

Table 1: LPD radiated power readings from C10 antenna with and without attenuators being switched on (expected value of attenuation assuming the system to be in linear regime).*

Analysis and Conclusions: From Table 1 it is clear that actual attenuation achieved by switching in different attenuators is close to but not exactly the same as the nominal values. For the -14 dB attenuator, the deviation from the nominal value is quiet small (+0.3 and +0.6 dB). Additionally, the actual attenuation achieved at two frequencies 200 MHz apart differ only by 0.3 dB, implying that the spectral response is quite flat. However, the -30 dB attenuator shows a deviation of +1.4 dB and +3.4 dB at 300 MHz and 500 MHz, respectively, from its nominal value, implying a spectral slope of ~-1 dB/100 MHz. The -44 dB attenuation is achieved by switching in both -14 dB and -30 dB attenuators and the measurements corresponding to it differ from the expectations based on linearity of the system by only 0.1 dB, which is about the limit of accuracy of this experiment.

While it was not explicitly recorded and no quantitative estimates were made, it was observed that the power levels remained very steady over time scales of a few minutes, with the variations being of order 0.01 dB.

Sources of error: As the measurements of the power with and without attenuation are not simultaneous, one is inherently assuming that the radiated power incident on the feed is constant in time. In presence of time variable RFI this assumption is violated and introduces a potential source of error. In this particular instance, given that the value measured are quite consistent across the four different measurements, we do not expect this to be a significant source of error.

Experiment 2: ***Testing C10 attenuators across the 250-500 MHz band***

Motivation: To go beyond the spot spectral sampling achieved in Experiment 1 and get a complete sampling of the 250-500 MHz spectral band.

Experimental Setup: The hardware setup was the same as for Experiment 1. The only difference were that

1. The frequency generator was set up to sweep across 250-600 MHz in 2000 steps, spending 10 ms at each step.
2. The spectrum analyser was set up in the 'max hold' mode, where it measures the maximum power received at any frequency. It was set up the scan the 250-600 MHz band in 4.67 ms.

The arrangement ensures that as the signal generator sweeps through the band, the spectrum analyser will measure the power corresponding to the frequency which is being radiated at any time and hold its value, thus allowing us to measure spectral characteristics of the attenuators across the entire band. Plots of the max hold values against frequency were made for 0 dB, -14 dB, -30 dB and – 44 dB attenuations switched in. These data was gathered for both the polarisations.

Measurements: The plots showing the measured max hold values (dBm) as a function of frequency for both the polarisations are presented in Figs 1 and 2, respectively, for all the different values of attenuation used.

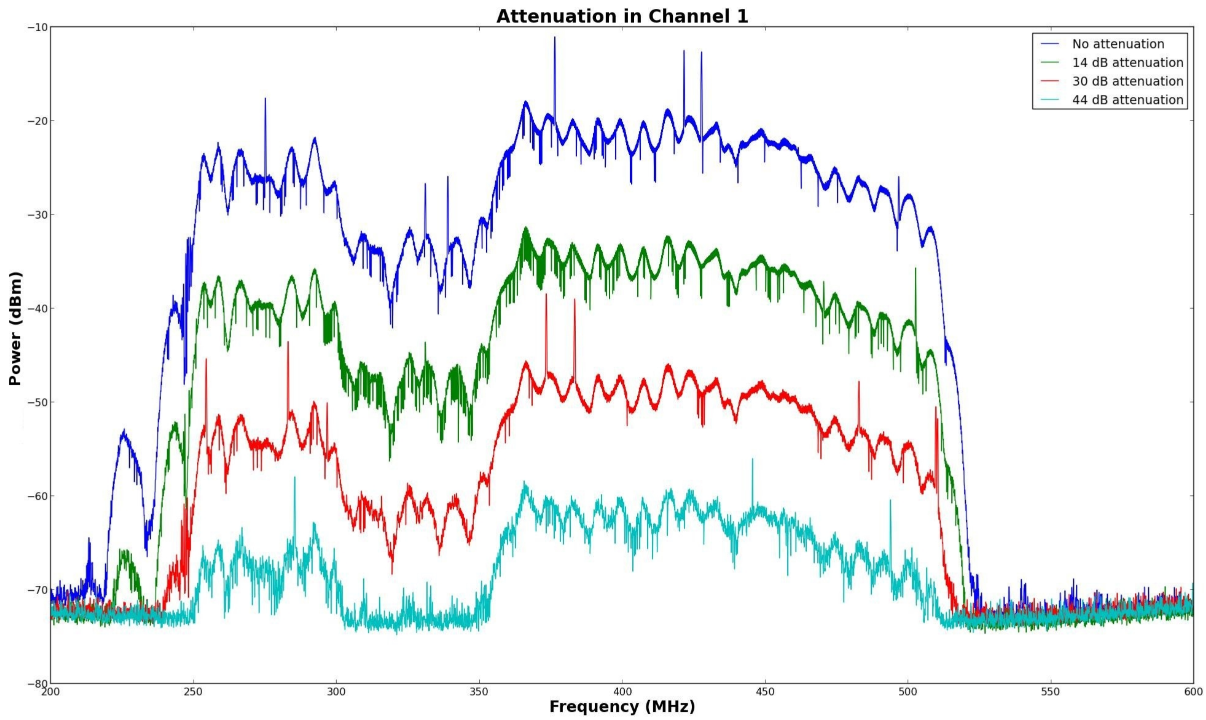

Figure 1: Polarisation channel 1 data with and without attenuations.

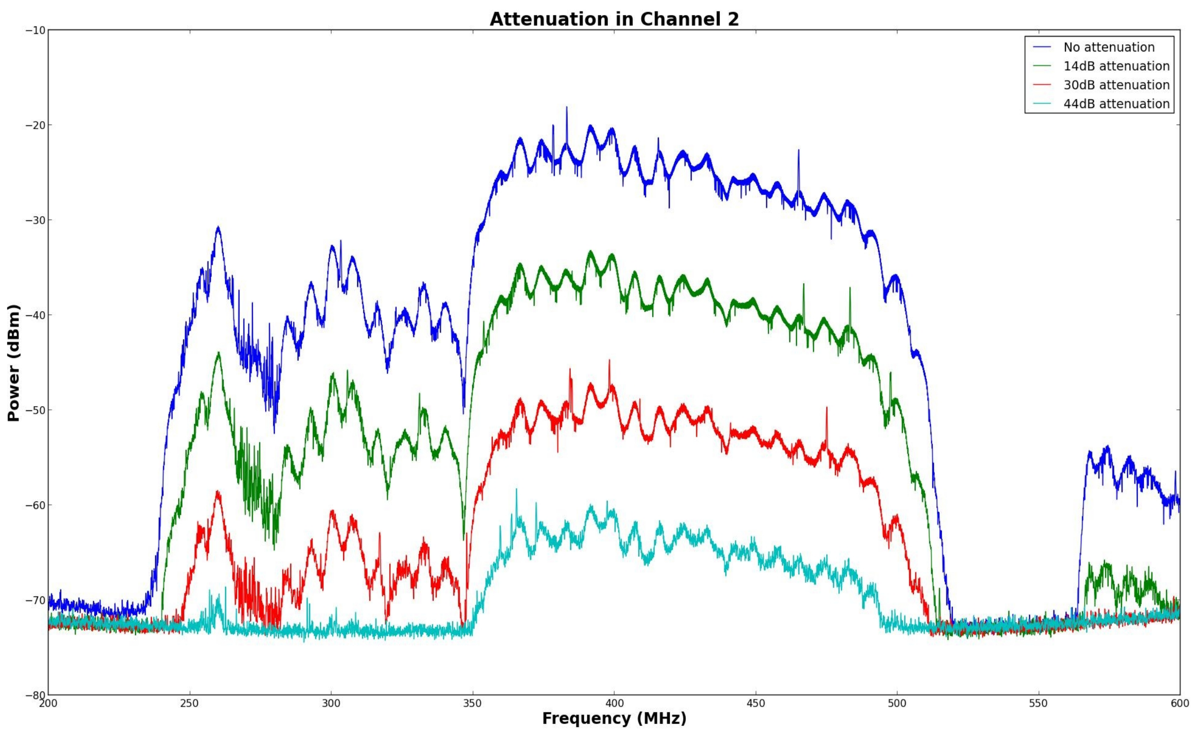

Figure 2: Polarisation channel 2 data with and without attenuations. We had taken 2 sets of data for this channel. The mean spectrum is shown here. Median deviation between the 2 data is only 0.12dB.

The sharp fall off in the band close to 350 MHz is because of the loss in efficiency of the ARONIA LPD which is rated for a nominal bandwidth of 380 MHz to 4 GHz. The fall offs at 250 and 510 MHz reflect the pass band of the 250-500 MHz feed. The sharp spikes seen on the traces are due to RFI.

Analysis: The difference in the power levels measured corresponds to the effective attenuation at that specific frequency. To determine the effective attenuation as a function of frequency we only need to difference the bandshapes power levels (measured in dBm) with different levels of attenuation from the one without any attenuation. These differences for each of the attenuation settings for each of the polarisations are shows in Figs 3 and 4. The measurements are cleanest in the **360-500** MHz band and were used for fitting a straight line to the data. The RFI affected channels were not used for the fits. Table 2 lists the coefficients obtained for each attenuator.

Channel	Parameters	14 dB	30 dB	44 dB
1	Slope (dB/MHz)	1.45E-5 ± 2.58E-11	-0.009 ± 6.2E-11	-0.012 ± 1.1E-09
	Intercept (dB)	13.41 ± 5.19E-09	30.78 ± 1.36E-03	45.32 ± 2.14E-02
	RMS error	0.1 dB	0.2 dB	0.9 dB
	Error interval on best fit	0.4 dB	0.4 dB	1 dB
2	Slope (dB/MHz)	-E-03 ± 2.06E-11	-0.01 ± 2.97E-10	-0.02 ± 8.63E-10
	Intercept (dB)	13.64 ± 3.39E-04	31.63 ± 6.25E-03	47.09 ± 1.88E-02
	RMS error	0.1 dB	0.4 dB	0.7 dB
	Error interval on best fit	0.2 dB	0.4 dB	0.8 dB

Table2 : All parameters of the attenuator fits are reported here. RMS error is found using the formula $Dy=\sqrt{(y_{fit}-y_{obs})^2}$ *. Error interval is defined in such a way that the y' =y ± dy curves enclose the* y_{obs} *points. This was done by rough inspection. The error interval is shown in every attenuator characterisation plots.*

Conclusions: The conclusions are consistent with those from Experiment 1, and provide a more robust characterisation. The attenuator values for the two polarisations are not identical, as is expected. While the -14 dB attenuator has a nearly flat spectral response, the -30 dB one has a spectral slope of about -1 dB/ 100 MHz. While the impact slope of this magnitude can be ignored, when compared to other sources of uncertainty, over the usual GMRT bandwidth of 30 MHz (0.3 dB = ~7%), over uGMRT bandwidth ranging from 200 to 400 MHz (2 dB = ~60%), they become large enough that they will need to be calibrated out. In Channel 1 -14 dB attenuator hardly shows a slope across frequency band 360-500 Mhz (BW= 140 MHz). It causes negligible attenuation variation across the 140 Mhz bandwidth. Also note that the slopes for -30 dB and -44 dB attenuations are comparable.

Sources of Error: The presence of RFI is one of the key reasons for uncertainty, for the same reasons as mentioned in Experiment 1.

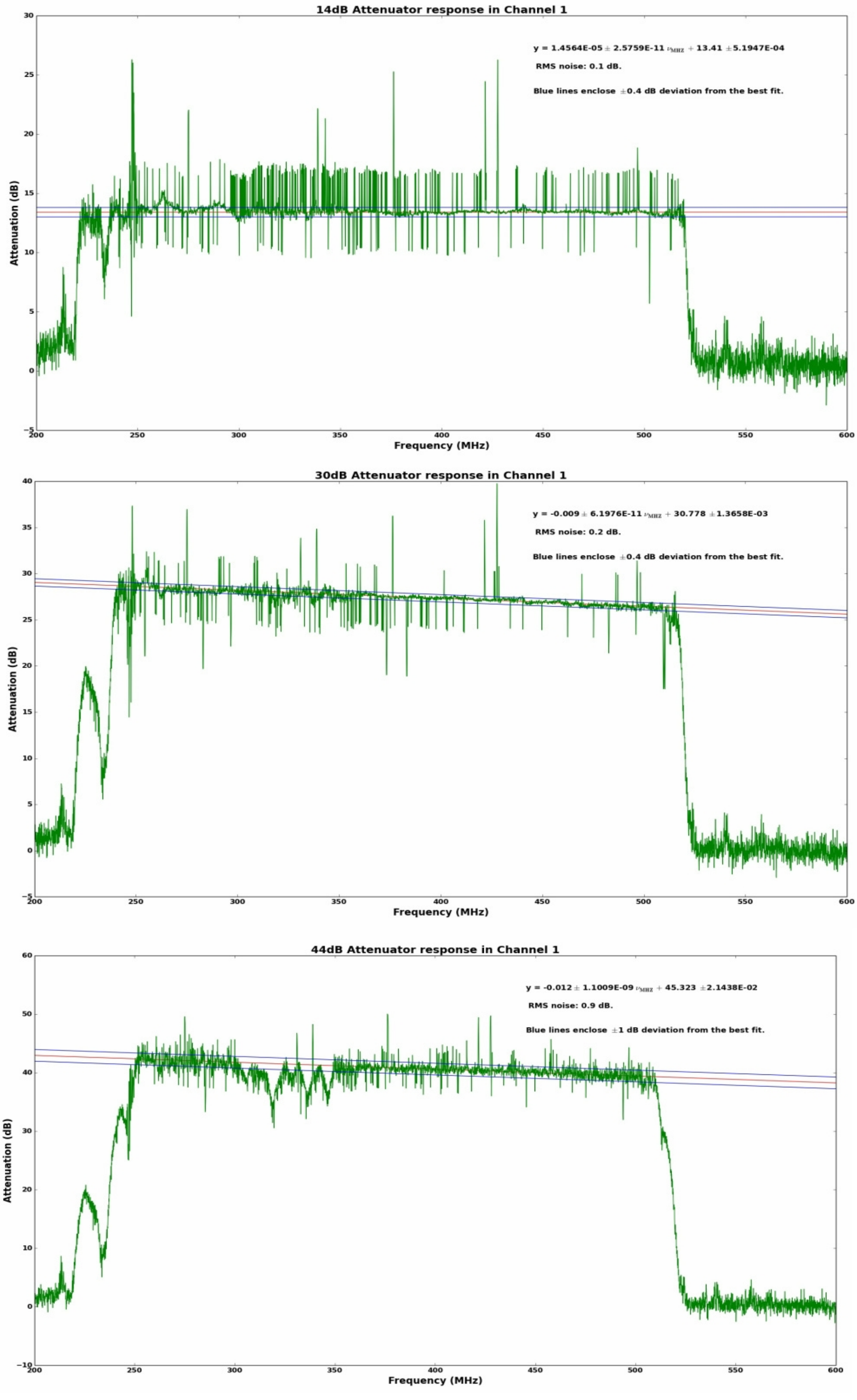

Figure 3: Polarisation channel 1 attenuator frequency response for attenuation values of -14 dB (top panel), -30 dB (middle panel) and -44 dB (bottom panel).

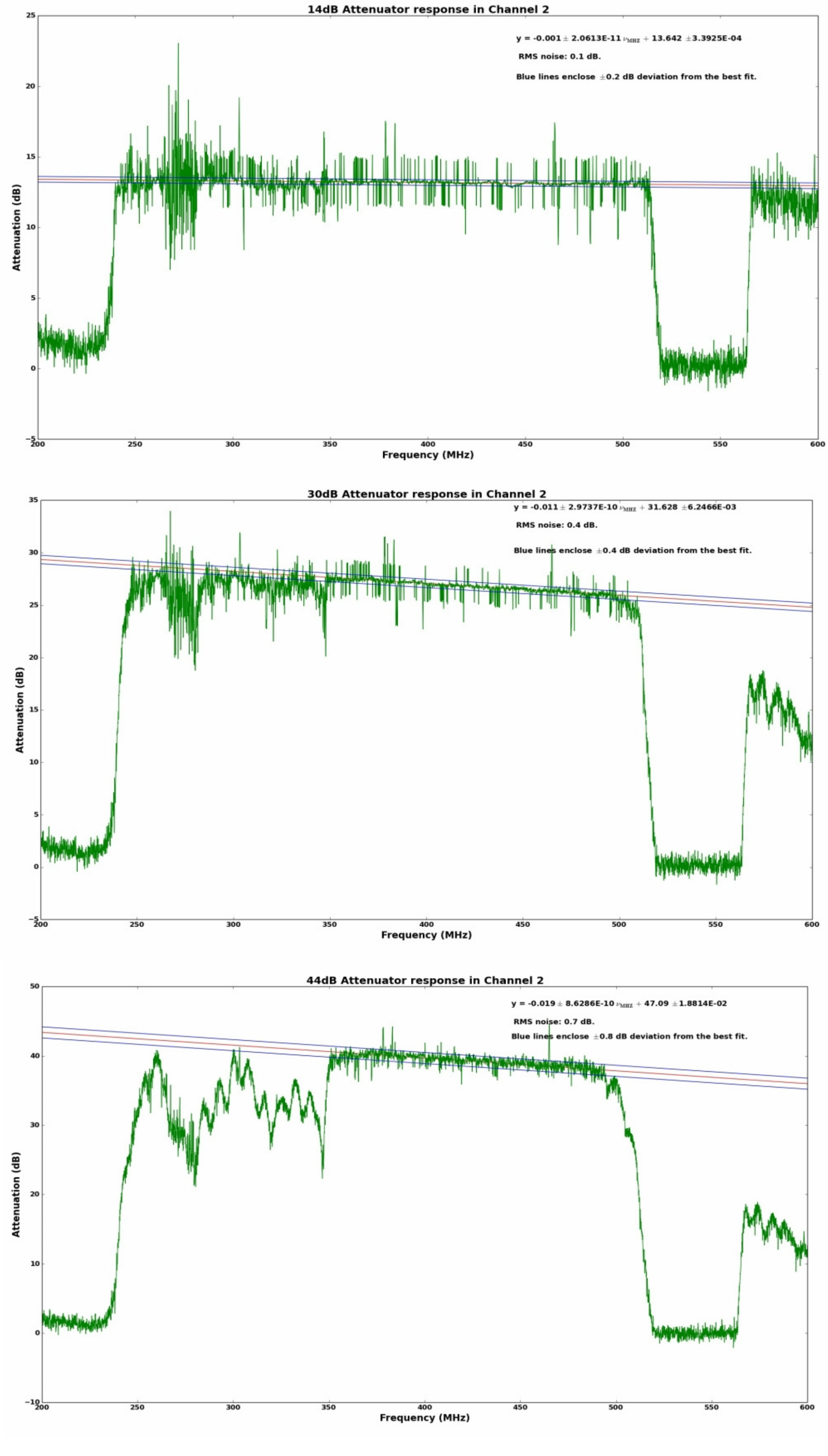

Figure 4: Polarisation channel 2 attenuator frequency response forattenuation values of -14 dB (top panel), -30 dB (middle panel) and -44 dB (bottom panel).

Experiment 3: Estimating attenuator characteristics using total power monitoring in the common box

Motivation: While the measurements made at C10 antenna base, described in Experiments 1 and 2, are more accurate they cannot be done at all antennas. Very few antennas (2) have the LPD radiator set up, besides it is much more effort intensive and time consuming to make measurements at the base of individual antennas one at a time. There is, therefore, a strong need for being able to make similar measurements remotely from the GMRT Control Room. The uGMRT monitor and control system provides the capability to monitor the total power at a monitor point at the output of the common box. We wanted to use this system and evaluate its usefulness for this project.

Experimental Setup: We used this system, while it was in the process of being commissioned to monitor the total power at common box output for the following antennas: C11, C13, E2, S1, S2 and S4. As this monitoring point can only provide total (integrated) power in the band, we decided to use the 4 sub-bands filters (260-340, 300-400, 360-460 and 420-500 MHz) to get a coarse but quantitative estimate for spectral characteristics of these attenuators.

Observations: Observations were made on the Sun and CygA. E2 and S4 antennas only had broadband power monitors installed (no sub-bands). So we were able to use only broadband power monitoring for them. In the time available, we were able to record the net power variation with and without attenuation for the Sun only in two of the four sub-bands, 260-340 and 300-400 MHz. The 300-400 MHz band observation was repeated for CygA. Multiple measurements were recorded for attenuation values of 0, -14 dB -30 dB and -44 dB for each of the runs. For each of the attenuation setting we recorded the power every 10 sec for a period of 10min. The counts were very stable across mutiple reading and rarely fluctuated by ±1 count. Table 2 presents the mean values of the measurements made. The raw counts were converted to dBm units using a mapping function which had determined earlier from lab tests. This is described in detail in ITR-XXX (reference to the technical report by Gaurav where this is described).

Antenna		Sun (260 – 340 Mhz)				Sun (300 – 400 Mhz)				Cyg A (300 – 400 Mhz)			
		No attenuation	14dB	30dB	44dB	No attenuation	14dB	30dB	44dB	No attenuation	14dB	30dB	44dB
C11	Chn2	218	202.5	186	178	217	201	186	178	195.75	182	177.6	177
	Chn1	210	194	180	176	206	190	179	176	185	177	176	176
C13	Chn2	216	201	185	178	216	201	186	179	194	182	178.5	178
	Chn1	207	191.5	179	174	216	200	186	178	194	181	177	176.4
E2	Chn2	200.5	200	201	187	200	200	200	188	200	200	185.1	181
	Chn1	199	198.5	197	183	198	198	197	183	198	199.7	186.4	179
S1	Chn2	218.5	203	187	179	217	202	187	179	194.5	182	178	177.1
	Chn1	172	172	172	172	172	172	172	172	172	179.5	172	172
S2	Chn2	130	130	42	42	130	130	42	42	129.5	129.4	42	42
	Chn1	129	129	44	44	129	129	44	44	129	129	44	44
S4	Chn2	227.5	213	196	183	229	213	197	183	209.5	193.6	181.1	177.75
	Chn1	227.5	213	197	183	228	213	197	183	209.25	196	186	179
Values in Voltage													
C11	Chn2	3.52	2.91	2.27	1.95	3.48	2.85	2.27	1.95	2.65	2.11	1.94	1.91
	Chn1	3.20	2.58	2.03	1.88	3.05	2.42	1.99	1.88	2.23	1.91	1.88	1.88
C13	Chn2	3.44	2.85	2.23	1.95	3.44	2.85	2.27	1.99	2.58	2.11	1.97	1.95
	Chn1	3.09	2.48	1.99	1.80	3.44	2.81	2.27	1.95	2.58	2.07	1.91	1.89
E2	Chn2	2.83	2.81	2.85	2.30	2.81	2.81	2.81	2.34	2.81	2.81	2.23	2.07
	Chn1	2.77	2.75	2.70	2.15	2.73	2.73	2.70	2.15	2.73	2.80	2.28	1.99
S1	Chn2	3.54	2.93	2.30	1.99	3.48	2.89	2.30	1.99	2.60	2.11	1.95	1.92
	Chn1	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	2.01	1.72	1.72
S2	Chn2	0.08	0.08	-3.36	-3.36	0.08	0.08	-3.36	-3.36	0.06	0.05	-3.36	-3.36
	Chn1	0.04	0.04	-3.28	-3.28	0.04	0.04	-3.28	-3.28	0.04	0.04	-3.28	-3.28
S4	Chn2	3.89	3.32	2.66	2.15	3.95	3.32	2.70	2.15	3.18	2.56	2.07	1.94
	Chn1	3.89	3.32	2.70	2.15	3.91	3.32	2.70	2.15	3.17	2.66	2.27	1.99
Power in Decibels													
C11	Chn2	-13.066	-27.185	-39.43	-55.143	-13.988	-28.438	-39.43	-55.143	-32.486	-44.317	-56.86	-59.75
	Chn1	-20.483	-33.717	-48.559	-65.559	-24.129	-36.413	-51.481	-65.559	-40.378	-59.75	-65.559	-65.559
C13	Chn2	-14.913	-28.438	-40.378	-55.143	-14.913	-28.438	-39.43	-51.481	-33.717	-44.317	-53.208	-55.143
	Chn1	-23.229	-35.406	-51.481	-82.143	-14.913	-29.252	-39.43	-55.143	-33.717	-46.214	-59.75	-63.072
E2	Chn2	-28.847	-29.252	-28.438	-38.588	-29.252	-29.252	-29.252	-37.82	-29.252	-29.252	-40.277	-46.214
	Chn1	-30.045	-30.435	-31.573	-42.763	-30.819	-30.819	-31.573	-42.763	-30.819	-29.492	-39.082	-51.481
S1	Chn2	-12.607	-26.759	-38.588	-51.481	-13.988	-27.607	-38.588	-51.481	-33.371	-44.317	-55.143	-59.24
	Chn1	-108.552	-108.552	-108.552	-108.552	-108.552	-108.552	-108.552	-108.552	-108.552	-49.939	-108.552	-108.552
S2	Chn2	-576547.57	-576547.57	-651826670672	-6.518E+011	-576547.57	-576547.57	-651826670672	1826670672	-635772.644	-648312.078	-651826670672	-651826670672
	Chn1	-700932.721	-700932.721	-510854977761	-5.109E+011	-700932.721	-700932.721	-510854977761	0854977761	-700932.721	-700932.721	-510854977761	-510854977761
S4	Chn2	-4.504	-17.699	-32.306	-42.763	-3.173	-17.699	-31.573	-42.763	-20.944	-33.992	-46.006	-56.197
	Chn1	-4.504	-17.699	-31.573	-42.763	-4.06	-17.699	-31.573	-42.763	-21.174	-32.306	-39.43	-51.481

Table 2 : Common box Power monitor readings with and without various attenuators in line. The readings are the net power in repective frequency bands.

Analysis: The counts measured were found to be very stable, varying only by ±1, which is just the quantisation error. Of the 6 available antennas, only the measurements from C11, C13, S1 (only channel 2) and S4 provided meaningful data. Other measurements seem to have gone wrong due to some technical problems. Power recorded by the different channels of the same antenna were found to be differing by a few dBm. Table 3 provides the values of attenuation arrived at for each of the observing runs.

			Attenuators				Attenuators				Attenuators		
Antenna			**14dB**	**30dB**	**44dB**		**14dB**	**30dB**	**44dB**		**14dB**	**30dB**	**44dB**
C5 Chn1			14.119	26.364	42.077		14.45	25.442	41.155		11.831	24.374	27.264
Chn2			13.234	28.076	45.076		12.284	27.352	41.43		19.372	25.181	25.181
C14 Chn1			13.525	25.465	40.23		13.525	24.517	36.568		10.6	19.491	21.426
Chn2			12.177	28.252	58.914		14.339	24.517	40.23		12.497	26.033	29.355
E2 Chn1	**Broadband**	**Sun (260 -340 Mhz)**	0.405	-0.409	9.741	**Sun 350 Mhz Band**	0	0	8.568	**Cyg A (350MHz band)**	0	11.025	16.962
Chn2			0.39	1.528	12.718		0	0.754	11.944		-1.327	8.263	20.662
S1 Chn1			14.152	25.981	38.874		13.619	24.6	37.493		10.946	21.772	25.869
Chn2			0	0	0		0	0	0		-58.613	0	0
S2 Chn1			0	011	6.5183E+011		0	011	6.518E+011		12539.434	011	6.52E+011
Chn2			0	011	5.1085E+011		0	011	5.109E+011		0	011	5.11E+011
S4 Chn1	**Broadband**		13.195	27.802	38.259		14.526	28.4	39.59		13.048	25.062	35.253
Chn2			13.195	27.069	38.259		13.639	27.513	38.703		11.132	18.256	30.307

Table 3: Attenuation measured in dB for various antennas. S2 antenna is clearly showing junk values. E2 atenna broadband power readings were also junk unlike S4.

Conclusions: From this experiment we can conclude that:

1. The true attenuation values tend to differ by few to many dB from the nominal expected value.
2. We note that the observed attenuations for -14 dB and -30 dB attenuators do not add up to the observed attenuation when both of them are switched in (-44 dB), they differ by a few dB. There is no definite trend in the difference, sometimes it is positive and at other times it is negative. Possible explanations include:
   1. the system is in a non-linear regime
   2. the least count of the system is too coarse for this measurement
   3. RFI related problems
   4. some other issue with the conversion of raw counts to dB units.

      We examined the least count issue in the Appendix and determined that can explain the observed differences.
3. The total power monitoring system can be used for characterising the -14 dB and -30 dB attenuators individually but is not suitable for characterisation of -44 dB attenuator. In view of the fact that the -44 dB attenuation is arrived simply by switching in both the -14 dB and -30 dB attenuator in, this is not a major drawback.

Sources of Error:

1. As usual, the uncertainty regarding RFI is an important source of error, as with the earlier experiments.
2. We have used the same mapping function to go from counts to dBm for all the antennas and polarisations used. Later work has shown that the mapping functions do indeed differ from one power monitor to another and this needs to be taken into account. This work will be presented in an independent ITR.

Overall Conclusions: Key conclusions from this exercise are the following:

1. The measured attenuations provided by the attenuators can be substantially different from their nominal values. For the -30 dB attenuator the difference from the nominal value can approach 5 dB. So a characterisation of these attenuators is required for a reasonable flux calibration.

2. Using a braodband radiator at the antenna base is an effective way to do a detailed characterisation of the attenuators, as demonstrated in Experiments 1 and 2 .
3. The detailed spectral characterisation of the attenuators on C10 shows that the -30 dB attenuator does have a spectral slope of about -1 dB/100 MHz. This slope is large enough that it will need to be corrected for over bandwidths of 200-400 MHz provided by uGMRT.
4. Total power monitoring from the GMRT Control Room provided by the new Monitor and Control system can provide an efficient way to do a coarser characterisation of the attenuators. While it can be used to characterise the -14 dB or the -30 dB attenuators individually, the present implementation of power detector does not offer sufficient dynamic range to characterise the -44 dB attenuation.

Future Work: Here are some of the things which need to be followed up on:

1. Using a broad band source will make Experiment 2 more effective. Rather than the 'max hold' mode, one than then average over the spectra and obtain more reliable measurements. A suitable broad band source is believed to be available already in the front-end lab. We wil coordinate with the FE group to make these measurements.
2. Repeat experiment 2 with a broad band source on the other antenna on which an apex radiator is available.
3. Repeat experiment 3 with all available antennas, and this time record the total power both at the output of the FE box and the output of the Common box. These simultaneous measurements will be better suited for attenuator characterisation and will be relatively immune from RFI issues.
4. Develop an SOP for determining the attenuations provided by the -14 dB and -30 dB attenuators for all available antennas using the total power monitoring tool used in Experiment 3. These measurements can then be take periodically by the control room staff and one can assess the time stability of these attenuators.

Acknowledgements: We acknowledge with gratitude the generous help and guidance received from S. Suresh Kumar and Pravin Raybole, along with other members of the front-end group.

Appendix: A look at the least count of the common box total power monitoring tool.

The power monitor tool provides a short int as its output. Using the function provided to map from counts to power in dBm we computed the dBm range associated with a step of unity in the measured output of the power monitor tool. The output values range from 170 to 225 and the mapping function covers 60+ dBm in this range and is very non-linear at the lower end. The power changes by 24 dBm as one steps from 170 to 171 counts. The linear regime of the mapping function starts beyond about 185, after which each count corresponds to close to a dBm. Table A lists the change in power in dBm units for a change by unity in the measured counts at representative count values. To be able to use the power monitoring tool effectively, we should operate in the range where the counts do not fall below ~185, where the mapping function becomes rapidly non-linear. However, as seen in Table 2, our measurements go down to values as low as 172. The non-linearity at such low counts is quite sufficient to account for the observed deviations.

Counts variation	**Power (dBm)**
170 - 171	23.95
175 - 176	7.3
180 - 181	2.41
185 - 186	0.96
190 - 191	0.68
195 - 196	0.73
200 - 201	0.83
205 - 206	0.91
210 - 211	0.95
215 - 216	0.95
220 - 221	0.93
225 - 226	0.91

Table A : Table shows what a unit count variation correspond to in dBm units at variation counts. Count to decibel conversion function isn't linear and this is why $\frac{d\,Counts}{d\,dBm} \neq Constant$