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Characterisation of Power Monitoring Units in the GMRT Common Box

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Objective: The two objectives of this work were:

1. To arrive at a simpler functional form for the mapping function to go from the measured voltages to RF power in dBm units
2. To check if a single mapping function is sufficient for all the different power monitoring units or will one need to characterise them individually.

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

Motivation: As a part of uGMRT effort a new fine grained power monitoring capability has been provided in the common-box. The expectation is that it will provide a measurement of RF power with an accuracy of about a 1 dBm. A mapping function to go from the measured voltage to the RF power in dBm units, spanning a range of about 70 dBm, was determined using a Gussian fitting MATLAB tool. This work is described in detail in the ITR GMRT/FES/002-April 2015 by Gaurav Parikh and Anil Raut. It was realised during the course of the effort of characterising solar attenuators (ITR-XXX), that the useful range of this mapping function is essentially the linear regime of the power monitor, leading to a much simpler form for this mapping function. We also wanted to determine if an accuracy of measurement to ~1 dBm can be maintained by using a single mapping function for all the devices.

Measurements: As a part of the testing of the power monitoring units, lab measurements of input RF power and the counts reported by the monitor and control units, spanning the linear range of the power detectors, were done for 32 units by Gaurav Parekh and these data were made available to us. The counts, C, were converted to a voltage, V, using the following linear relation:

$$V = -5 + 0.001 \times 39.0625 C \qquad \textbf{(1)}$$

The data set made available had five (voltage, RF power in dBm) ordered pairs for all 32 units spanning the linear range of counts, which had been determined to roughly lie in the range 185-225 counts. In our analysis we assume that the above expression for conversion from counts to voltage is valid for all the units tested here. So we restrict our consideration only to the voltage to dBm conversion.

Analysis: The linear regime of the power monitor (~185 – 225 counts) corresponds to a voltage range of 2.3-4.0 V (Eq. 1). In this regime the change in power corresponding to the least count in the voltage scale (40 mV) is < 1 dBm of RF power. We chose this range to do a linear fit. Figure 1 shows some typical examples of the fits obtained, and also the worst one (bottom right panel). Table 1 lists the best fit values of the fit parameters (slope and intercept) along with the errors on each of these quantities and the reduced chisq for the fit. In general, the linear model is a good fit to the data, though both the slopes and the intercepts show significant variations. The reduced chisq exceeds 1 for only one of the fits, the device with serial no. 11 for which it is 2.629. All the other fits have a reduced chisq value < 0.607 which supports the respective linear model with > **63%** confidence.

To provide a quantiative sense for the errors incurred by using a single common mapping function, we compute the true values of RF power in dBm units corresponding to a given voltage close to the centre of the linear range (3.0 V). A histogram of these values is shown in Fig. 2. Clearly this isn't a Gaussian distribution around a mean power value. This shows that the monitored power values are from inherently different distributions. They are not random numbers distributed around a single mean value. Maximum power recorded was -5.2 dBm (Sr. No. 18 monitor) and minimum was -7.454 dBm (Sr. No. 2 monitor). This means using a different fit function can introduce a systematic error of up to 2.25 dB error at 3.0 V. This significantly exceeds the target uncertainty of 1 dBm which has been targeted for common-box RF power monitoring.

A histogram of the best fit slopes for each of the units is shown in Fig. 3. Except for the unit bearing serial number 11, all others have a very low value of redcued chisq, signifying a good fit. The standard deviation of the intercept taking all monitors together is found to be $\sim$2.15 dBm. Standard deviation in the slope of all the systems together is 0.597 dBm/V.

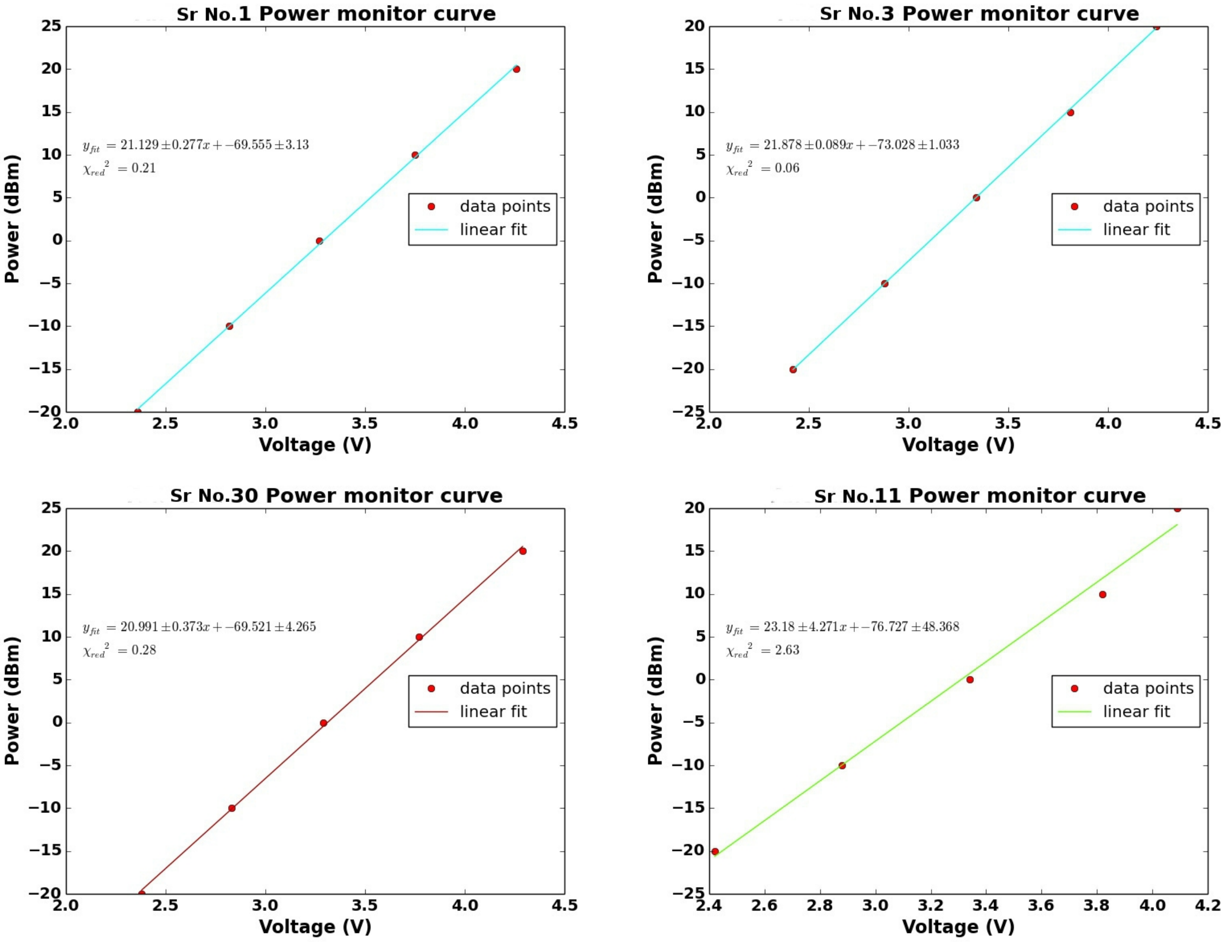

Figure 1 : Best fits for 4 different antenna Power monitors in the linear regime. The worst fit obtained was the one for power monitor Sr. No 11 shown in the bottom right subplot. The chisq of all the other plots assures that the fits are good models for the respective data with ***>90%*** *confidence.*

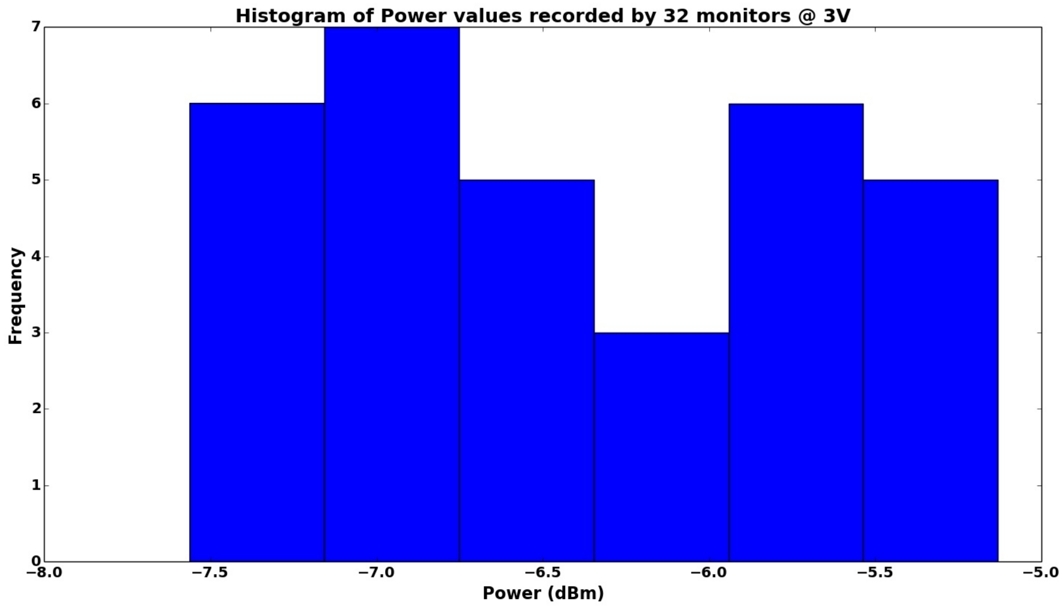

Figure 2: The distribution of power in dBm corresponding to a voltage of 3.0 V, using the linear fits for the different power monitoring units. Clearly this isn't a Gaussian distribution around a mean power value. This implies that the monitored power values do not come from a single underlying Gaussian distribution. Maximum power recorded was -5.2 dBm (Sr. No 18) and minimum -7.454 dBm (Sr. No 2).

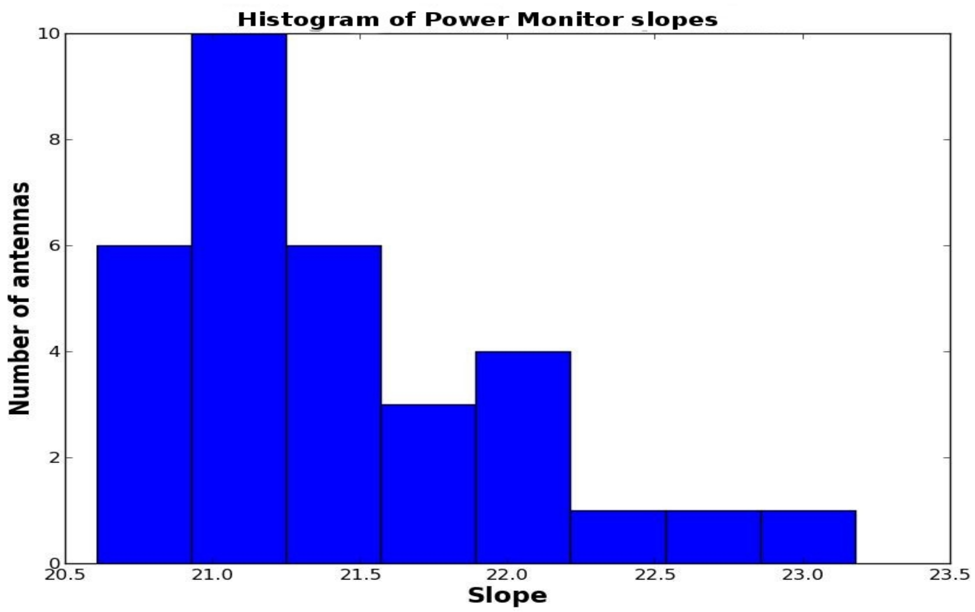

Figure 3: The histogram of best fit slopes for all power monitor units.

Antenna	Slope	Intercept	χ^2 value
1	21.129 +- 0.277	-69.555 +- 3.13	0.207
2	21.544 +- 0.164	-72.087 +- 1.905	0.118
3	21.878 +- 0.089	-73.028 +- 1.033	0.062
4	22.163 +- 0.22	-72.384 +- 2.434	0.149
5	21.363 +- 0.1	-71.651 +- 1.169	0.073
6	20.906 +- 0.298	-69.827 +- 3.465	0.227
7	21.003 +- 0.109	-68.765 +- 1.218	0.082
8	20.606 +- 0.265	-68.328 +- 3.043	0.208
9	22.562 +- 0.267	-74.318 +- 3.004	0.175
10	20.688 +- 0.328	-67.195 +- 3.618	0.256
11	23.18 +- 4.271	-76.727 +- 48.368	2.629
12	22.233 +- 0.851	-71.992 +- 9.264	0.573
13	21.215 +- 0.347	-70.943 +- 4.034	0.257
14	22.133 +- 0.893	-73.17 +- 10.13	0.607
15	21.133 +- 0.182	-69.316 +- 2.036	0.136
16	20.937 +- 0.576	-68.505 +- 6.43	0.437
17	21.363 +- 0.1	-70.156 +- 1.122	0.073
18	21.138 +- 0.086	-68.613 +- 0.943	0.064
19	20.822 +- 0.241	-67.837 +- 2.668	0.185
20	21.821 +- 0.291	-71.048 +- 3.202	0.203
21	21.225 +- 0.136	-70.722 +- 1.571	0.101
22	21.411 +- 0.04	-71.257 +- 0.46	0.029
23	21.458 +- 0.025	-70.339 +- 0.284	0.018
24	20.684 +- 0.409	-67.761 +- 4.58	0.318
25	21.961 +- 0.38	-72.734 +- 4.323	0.262
26	21.785 +- 0.025	-72.632 +- 0.286	0.017
27	20.775 +- 0.319	-67.601 +- 3.525	0.246
28	21.352 +- 0.325	-70.89 +- 3.722	0.237
29	22.108 +- 0.345	-73.134 +- 3.911	0.235
30	20.991 +- 0.373	-69.521 +- 4.265	0.282
31	21.039 +- 0.288	-69.765 +- 3.301	0.217
32	21.031 +- 0.461	-69.612 +- 5.255	0.347

Table 1: Slopes, intercepts and their uncertainties, along with the reduced chisq of the fit for linear model fits to the different power monitor units. The uncertainty in the slopes is typically at 1% level and that in the intercepts is usually < 10%.

Conclusions: This work has met its objectives and has lead to the following conclusions:

1. A linear model is quite adequate for the power monitors in the linear range. Such a model was derived for all the 32 units for which measurements were available.
2. Use of a common mapping function for all the power monitors can compromise the accuracy of power monitoring to ~2.25 dBm (representative value in the middle of the linear range), significantly worse than the 1 dBm design specification for the power monitoring system.

Future Work/Recommendations: Here are some of the future work and recommendations arising from this work:

1. Only five measurements are usually available in the 2.5 – 4 V range, which corresponds to the linear range of the power detector. Even with the simplest (linear) model having only two free parameters, this is only just enough. It is desirable to have a larger number of points in this range, to better constraints the fit parameters, and gain more confidence in the linear model.
2. One of these units (Sr. No. 11) shows a poor fit and 2 others (Sr. Nos. 12 and 14) show reduced chisq values significantly larger than the average values for reduced chisq. The measurements need to be repeated for these units to check if the large reduced chisq values come from measurement errors or these units do indeed behave differently. If any hardware issues are found, they will need to be fixed.
3. We worked on data from only 32 of the common box power monitors. The unit-to-unit variations have now been determined to be large eough that all of these units should be charaterised individually. So an organised effort to make the relevant measurements for all of the power monitoring units will need to be undertaken.
4. In addition, to be able to use the correct mapping function for each of the power monitoring units, the engineering teams involved will need to keep track of which unit is installed for which polarisation of which antenna and maintain a database with this information, along with the best fit parameters for that unit.

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