Conceptual Representation of RxCAL - A tool for GMRT Receiver Calibration

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1 Introduction

The giant radio astronomical receiver like GMRT requires a continuous performance study of the individual antennas through controlled monitoring of gain and phase. If this monitoring can be done during a GTAC observations(especially of weak sources), then it becomes a very powerful online facility for data flagging by the astronomer and fault correction by the engineer, as the data can help to identify any in-band amplitude instability or phase related problems.

Broadcasting of a CW signal from a signal generator on the forward link to all antennas is the main building block toward the Receiver Calibration(RxCAL) scheme. The frequency of this CW signal would corresponds to the user specified RF band of operation and could be automatically set to the middle of a specified(say 125) spectral channel in the correlator. Due to the CW nature, its coherence time(reciprocal of bandwidth) is always greater than the maximum path delay (200μs for C02 - S06). So we can expect a non-zero correlation in that spectral channel for all baselines.

At each antenna, the signal is combined with FE signal at the ABR input point and processed in ABR, BB and correlator like astronomical signal. A scope of the RxCAL scheme can be explored at OFM output or at correlator. For the, the former, the broadcast signal has to be converted to one of the second IF frequency at CEB using another locked Signal Generator, whose frequency is set to an arithmetical combination of the first LO and second LO(105 or 200MHz) frequency, depending on the configuration of the observation.This converted signal is given to the reference channel A of Vector Voltmeter(VVM). The 30-to-1 output is given to channel B of VVM. The VVM readout shows the combined effect on phase and gain introduce by forward link, antenna-shell dependent variations and by return link. The data could be also seen at correlator output by standard tools like “xtract”.

2 System Upgradations

To realize the scope of sending RF tone and loop-back at ABR input requires to upgrade and add additional accessories in the forward link and in antenna base electronics as has been worked out in figure 6. Response curve(figure 3) of optical fibre and associate electronics in the forward link(through the experiment set-ups like figure 1) is indicating that the main bottleneck is coming from the old MCL make 4way and 12way divider(DC to 200MHz). These are now replaced by the new wide-band counterparts(0 to 2GHz), manufacturing by Pulsar Microwave. The new upgraded forward links for three antennas have been characterized as per the coupling loss of directional coupler(for injecting RF tone), the insertion loss of wide-band divider and optical fibre loss at tone frequency. The figure 4 shows the upgraded optical fibre response with wide band dividers. The new forward link frequency response is uniform upto the frequency of ~800MHz.

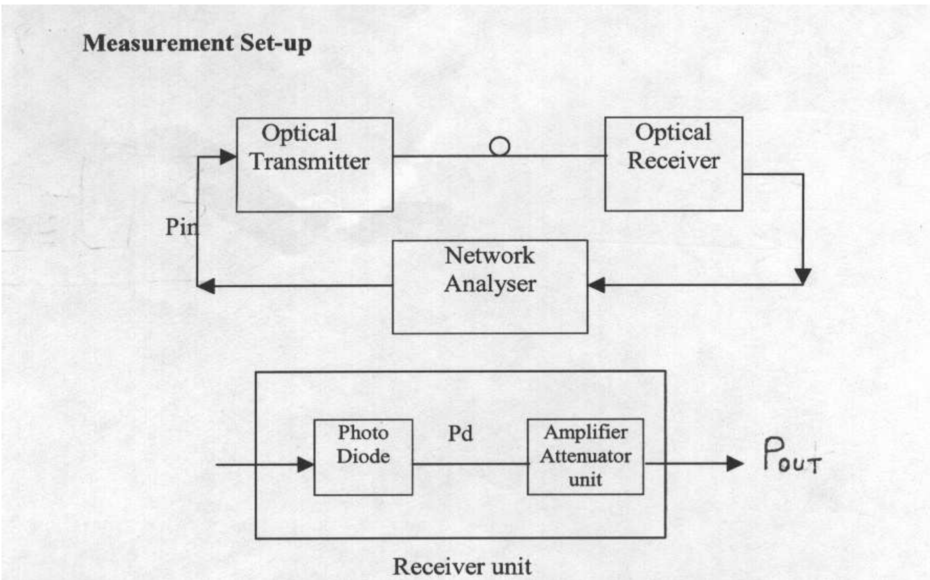

Figure 1: Frequency response measurement set-up for optical transmitter-receiver link

This carrier tone is coupled with the broad band RF at the ABR input, through a directional coupler. Now to extract this carrier and to attenuate all other forward link signals(like 18MHz telemetry, 97.5MHz, 106MHz, 201MHz reference LO) the input of directional coupler contains a HPF(figure 5). The directional coupler is combined with the 100MHz HPF in the same PCB as shown in figure 6. The "RF in" port is used to connect the RF cable running from front-end to the antenna base shell. The "CPL in" port is used to fed

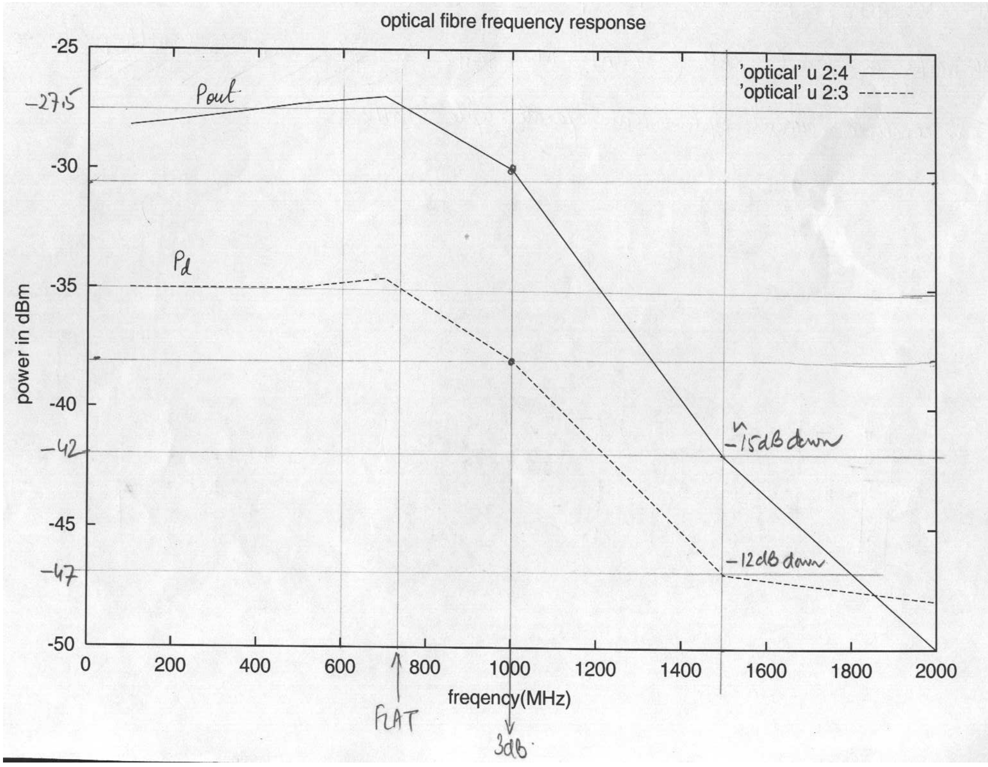

Figure 2: Optical fibre frequency response of C02 antenna along with transmitter-receiver. Here input power was -20dBm.

the RxCAL signal, after filtering out from the previous mentioned HPF. The "RF out" port contains all the combined signal, i.e. RF spectrum and the cw RxCAL signal.

3 Overall Experimental Block Diagram

The implementation of RxCAL contains the upgradations of forward link frequency response and the addition of associated electronics circuit at the antenna base receiver. At the same time to make the provision of amplitude and phase monitoring at the optical fibre output in the receiver room, one stage of frequency conversion is required. This will shift the RF tone to the appropriate position on 130MHz or 175MHz IF bands. For phase coherence all the signal generators are locked to the derived 1MHz frequency reference of the observatory's. The phase comparison has done through Vector Voltmeter(VVM) at the shifted RF tone frequency.

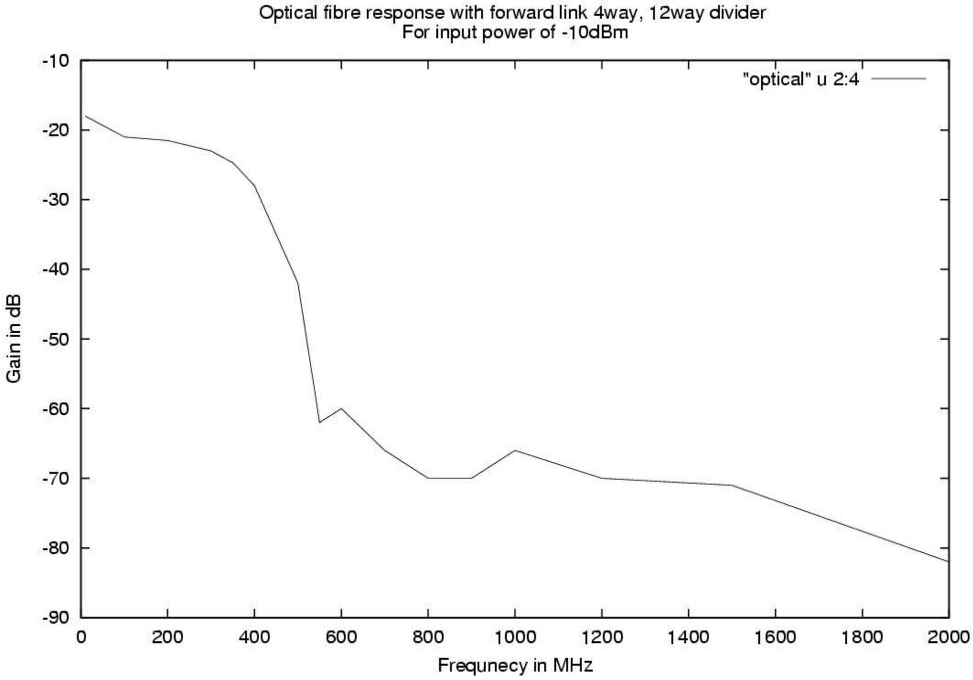

Figure 3: Optical fibre frequency response of C02 antenna along with narrow-band 4way 12way divider

4 Data acquisition and analysis

The RxCAL data consists of self amplitude of any antenna(with RF carrier) or the cross amplitude and phase of any baseline. The data can be acquired as "LTA" or "LTB" file(may be with 2secs integration) or as unnormalized raw data of 128msecs integration. Due to the cw nature of the injected RF carrier we can select any channel for putting the tone. We can select 125 spectral channel for that purpose, which normally not used for final mapping procedures. Then this facility can run on a 24X7 basis with the option to make it turn off anytime as user want. The "showbase_new" program in corracqa PC is for acquiring all selfs and crosses of all possible baselines among the selected antennas. The channel selection options can be used to select any number of spectral channels. The data can be acquired with online integration over 128msecs raw data rate. The normalized cross correlation coefficient can be calculated offline using the require selfs and cross counts.

Simultaneously with the data acquisition at correlator output, there is a provision of monitoring data at the output of optical fibre, before baseband system, using the conventional 30-to-1 data acquisition arrangement. This scope may require for diagnosis of the system problems by breaking the whole signal chain into different sub-sections.

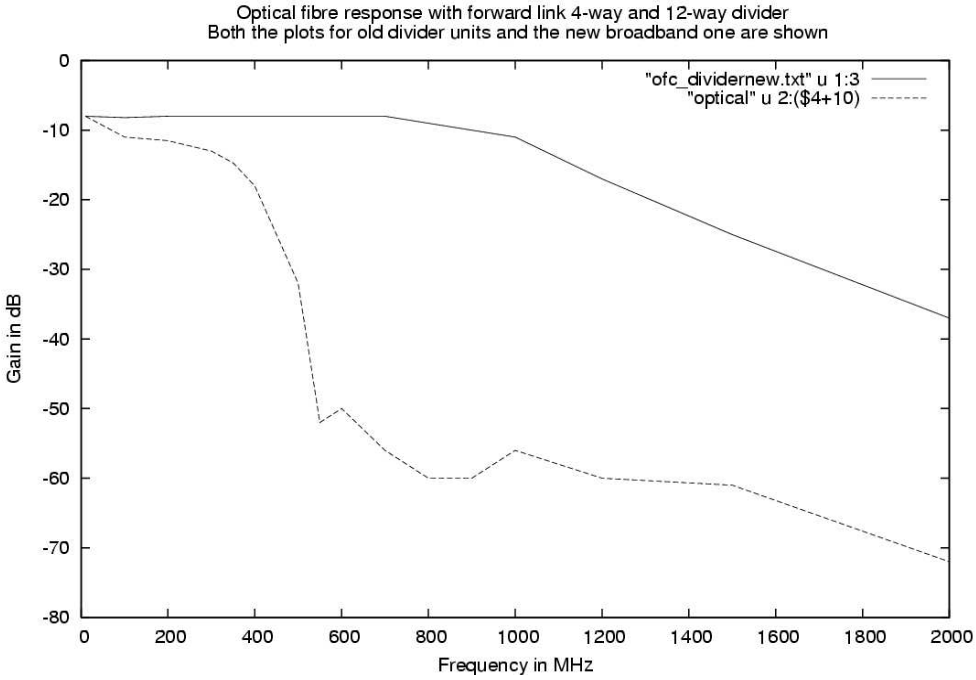

Figure 4: Optical fibre frequency response of C02 antenna along with old and new 4way 12way divider

The scope of the RxCAL has explored in different RF bands with different parameters settings. The analysis of acquire data is aimed to answer some of the obvious questions about this scheme. The results are explained below as it has come out.

1. The presence of RF tone with suitable power($\sim$5dB above the base-band band floor) is not affecting the adjacent spectral channel of the desired one. This has shown in the figure8 and 9. The RF tone at 96 channel(for 610MHz RF) of the correlator is giving more than 80% of correlation, where the adjacent channels are showing $\sim$5% of it. This value is actually supporting the flux density of 3C286.

2. The self power variation on the adjacent channel is giving the same theoretical mean-rms ratio($\sim$500) as for 610MHz frequency band(shown in figure 10). The mean variation on the line channel self count can be explained from the fact that there is a vector addition of constant phase carrier and source with rotating phaser($\pm$180deg) along the circumference of a circle.

3. When fringe correction and delay updating are disabled for locally generated RxCAL signal we should expect stable cross phase behavior in

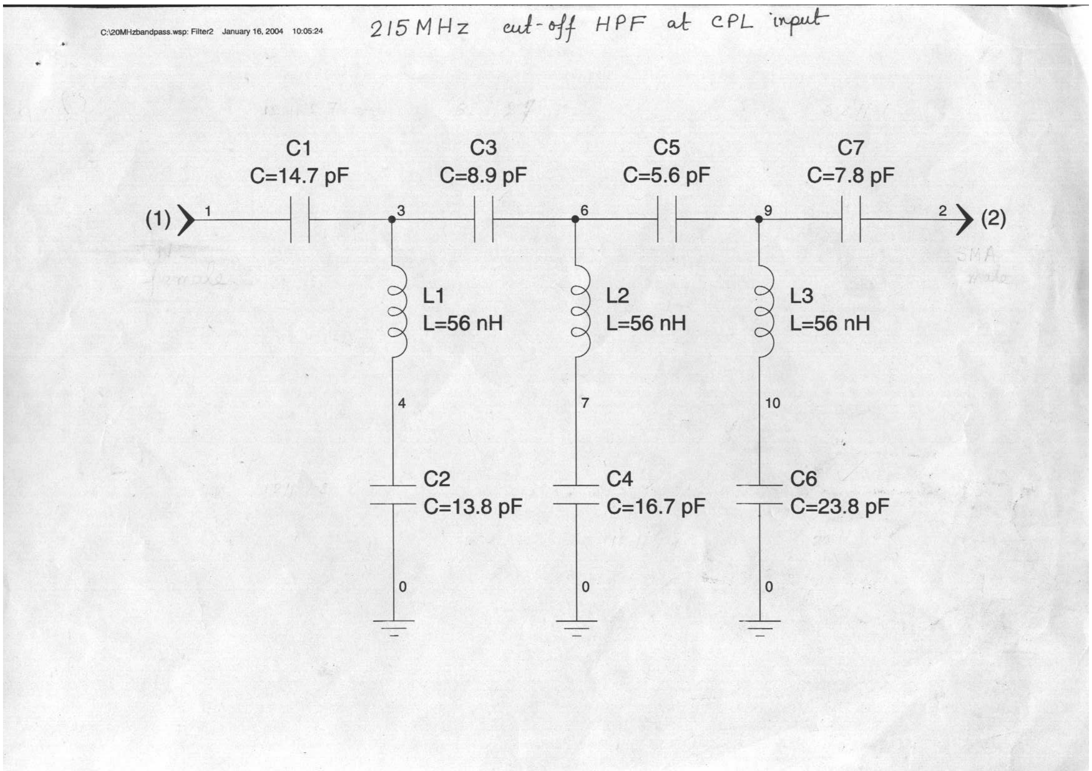

Figure 5: High pass filter to filter out the telemetry and reference LO signal

the line channel and all the other channel will show ±180deg phase winding. The cross phase in line channel of the C11-C12 baseline is showing ±3deg variation (figure 11). In this case with the slowly varying sinusoidal pattern, there is a fast varying component sitting, as clearly visible in figure 12. As shown in this figure these fast fringes are vanished as we move 5deg off the source. The slowly varying pattern of ~15min one cycle may be due to the ambient condition(temperature) at the antenna base. The other channel except the line one are showing the phase winding with the rate of fringe frequency. After offline fringe correction the source channel phase also starts showing stable phase behavior(shown in figure 13). The "offstop" program is used to correct the fringe. The large rms in this phase compare to tone phase is due to the weak 3C286 source(21Jy only). But the overall phase is showing the ±15deg variation over the period of ~2hrs.

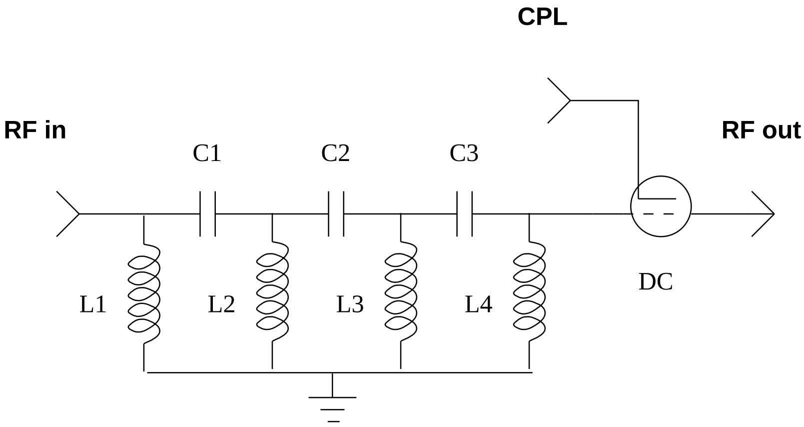

Figure 6: RxCAL circuit schematic for combining the cw tone with RF spectrum. Here C1=C2=C3=18pf and L1=L4=51.8nH, L2=L3=29.5nH

5 Case Study

The experimental procedures of RxCAL have been verified in the realistic field to study C02 antenna phase jump problem. The problem definition was : "C02 antenna is showing phase jumps for 1405RF and 1335LO settings. In the following RxCAL experiment three antennas(C02, C11, C12) sub-array configuration was used with all were in FE terminated conditions. The tone frequency was adjusted according to the LO frequency, such that it would be always at the 32nd spectral channel of the correlator. For 1335MHz LO the phase jump were noted in the C02-C11 cross phase 4-5 times for 20-25 minutes of the scan(figure 14). Later LO was changed to 990MHz and a major phase jump was noted(50 deg) over the 45 minutes scan excluding the other smaller jumps(figure 15). But when the LO was set to 540MHz, for 2.5hrs of scan the jump was not noted(figure 16). This experimental results points to the associates LO electronics for L-band(synthesizer and YIG oscillator).

6 Conclusions

The presence of RxCAL is not affecting the adjacent channel when use as a "monitoring" tool(with observation), so the tone can co-exist with the normal observing mode provided the feeding power is not to large. If the spectral channel selected for the tone is 125, then upto 124 channel user can use. This scheme can be applied as "diagnosis" tool also. In this mode there are several ways of doing the experiments, depending upon the requirements, like

FE terminated condition.

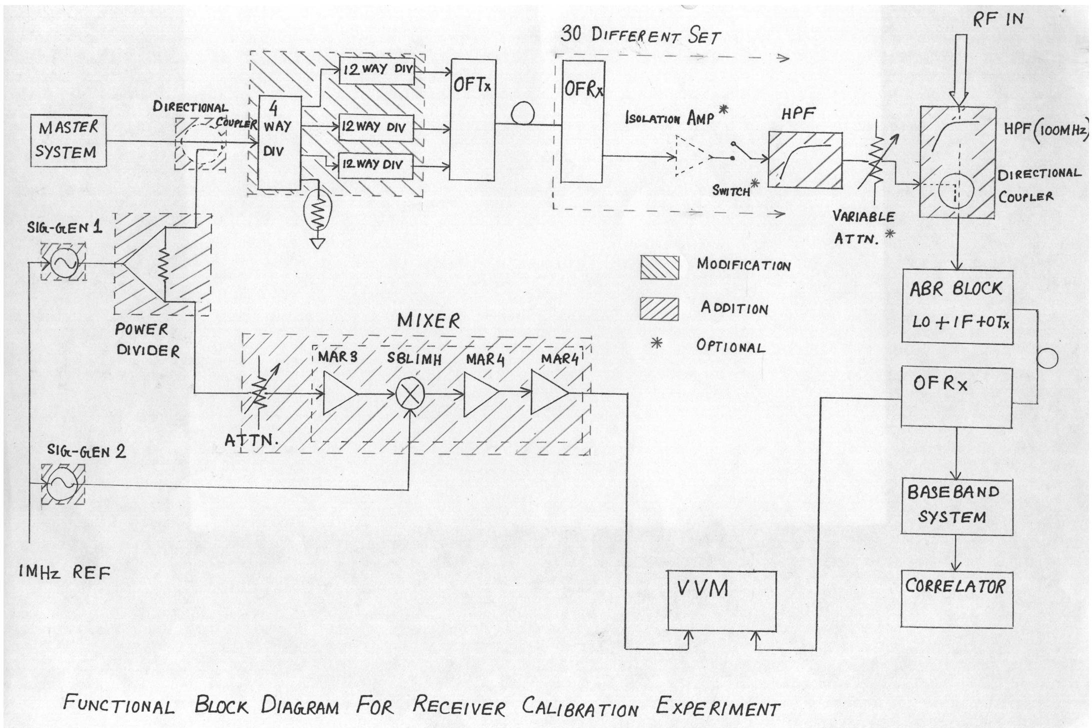

Figure 7: Block diagrammatic representation of RxCAL experimental set-up

Tracking source with fringestp and dlytrack like normal observation.
Tracking source without fringestp and dly correction.

As the scheme is working as diagnosis tool the last one is preferable. Then we will get cross phase behavior in the line channel which will reflect the health of the antenna.

7 Future scopes

The current scope of RxCAL is limited upto ABR input, it can be extended to include the feeds and front-ends. There will be a dual polarized RxCAL transmitter feed(150MHz to 1500MHz) located at the apex of the GMRT dish. The CW transmission from this broadband feed can be picked up by the prime-focus feed. Then the tone signal will follow the whole receiver as like astronomical signal. This technique of injecting RF tone at feed also support the noise calibration aspect to keep track on the system temperature(Tsys) variation. At low frequency the galactic background has significant effect on Tsys, as its strength varies with the location of the sky. So system temperature for the target source may not agree with that for the

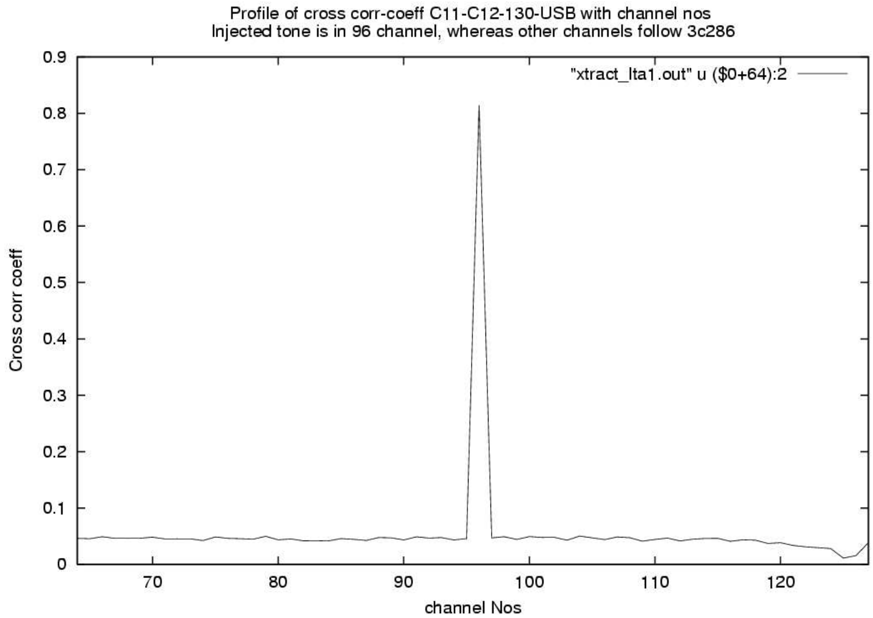

Figure 8: Cross-correlation coefficient as a function of channel number, where RF tone is at 96 channel and the antenna is tracking the 3C286

calibrator source. In that this online receiver calibration scheme can be used to estimate this variation.

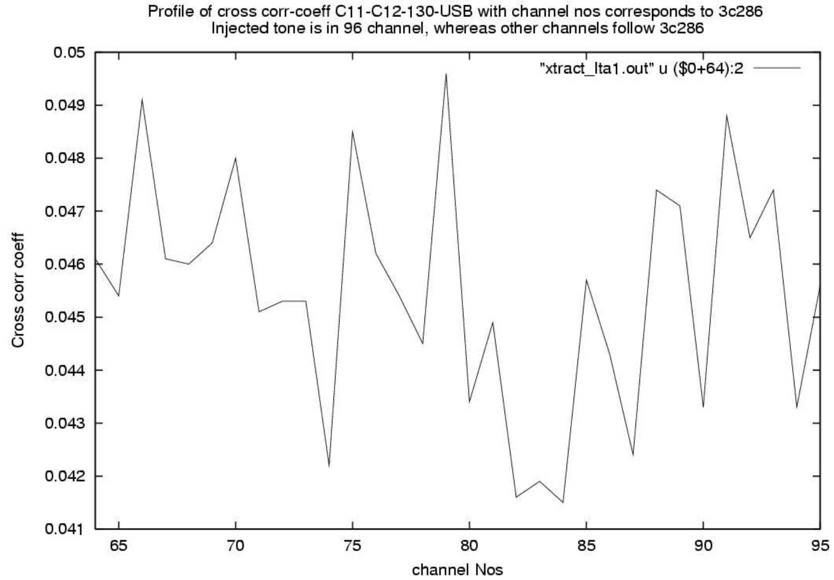

Figure 9: Cross-correlation coefficients factors at the adjacent channels of the line one

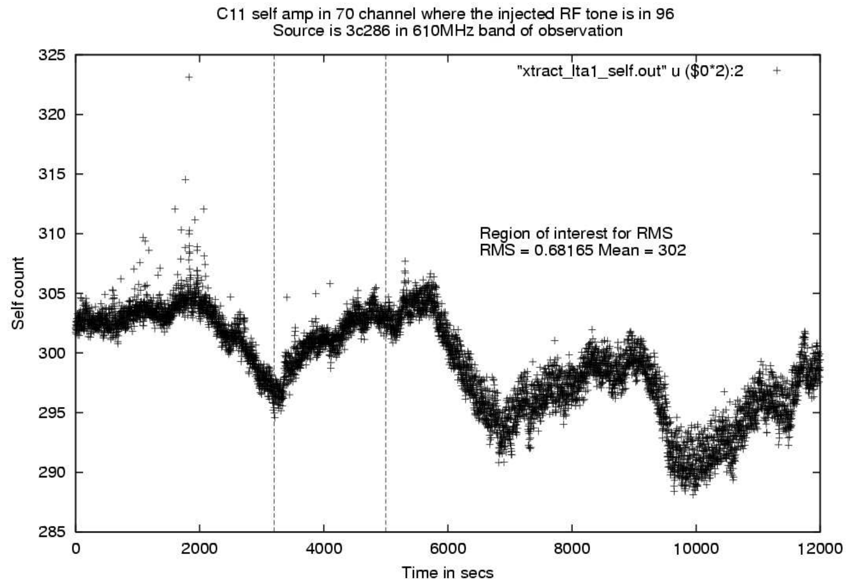

Figure 10: C11 self amplitude in 70 channel for 3C286, where RF tone is sitting in 96 channel

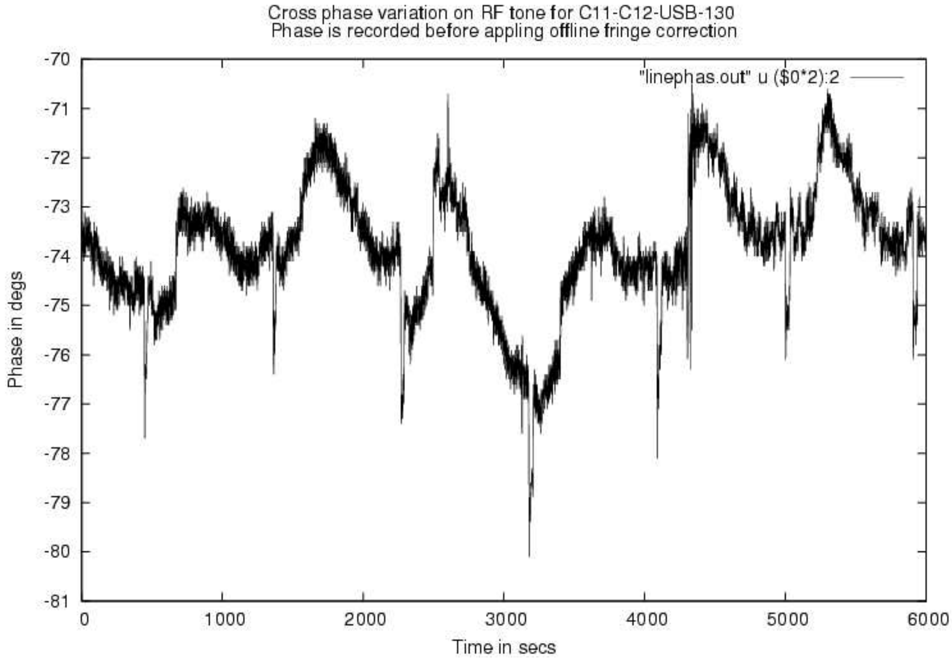

Figure 11: C11-C12 cross phase variation on the line channel

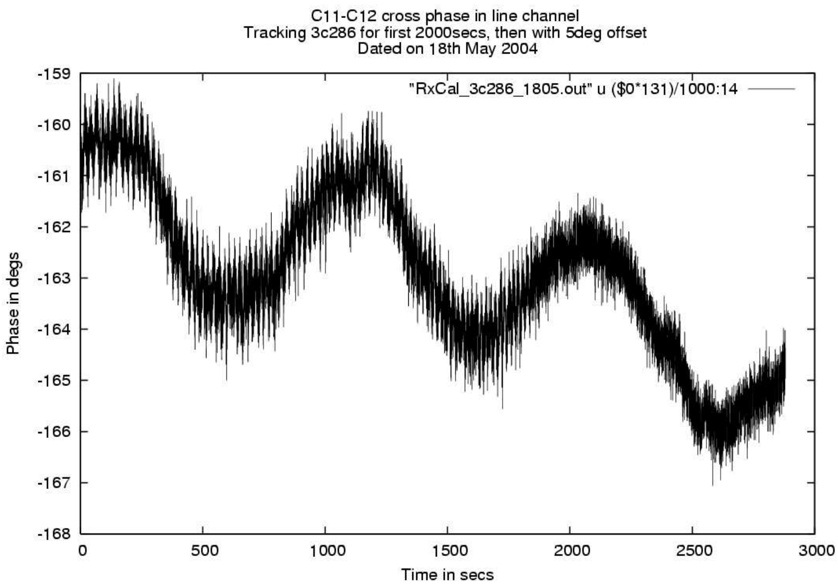

Figure 12: C11-C12 cross phase variation on the line channel with the off-source behavior

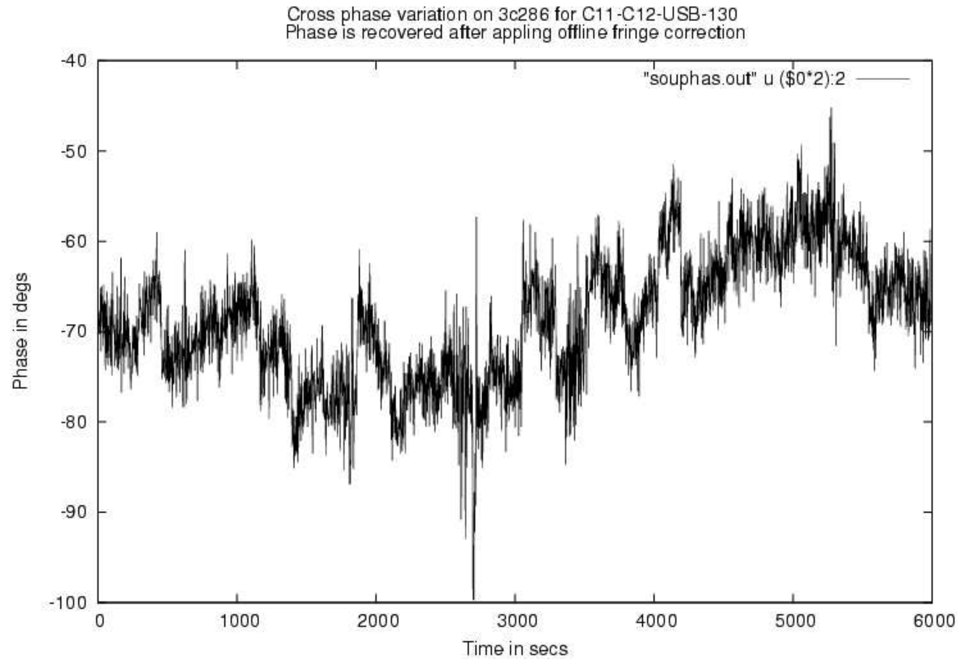

Figure 13: C11-C12 cross phase variation on-source after offline fringe correction

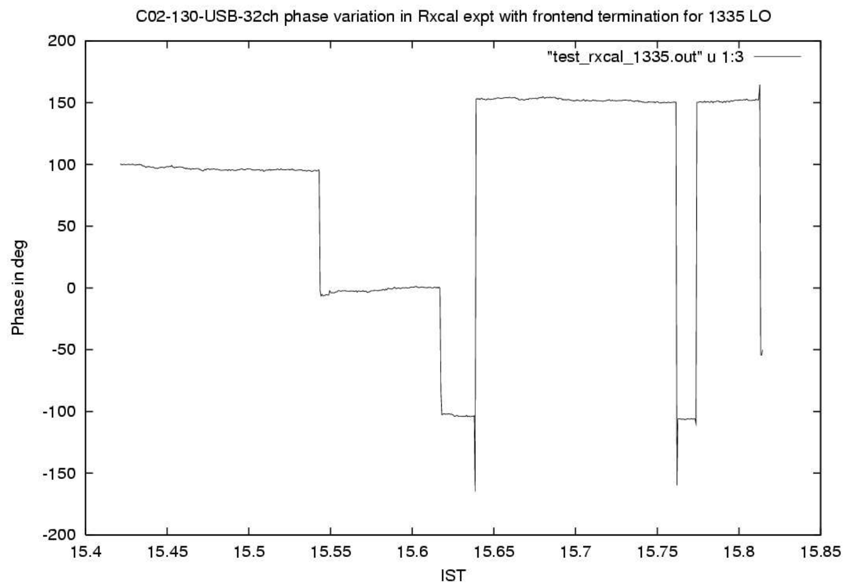

Figure 14: C11-C02 cross phase variation with FE termination

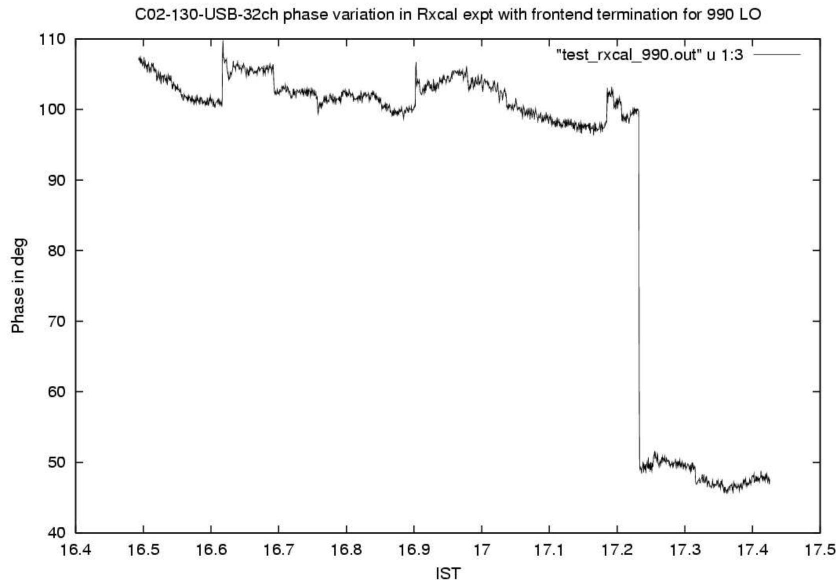

Figure 15: C11-C02 cross phase variation with FE termination

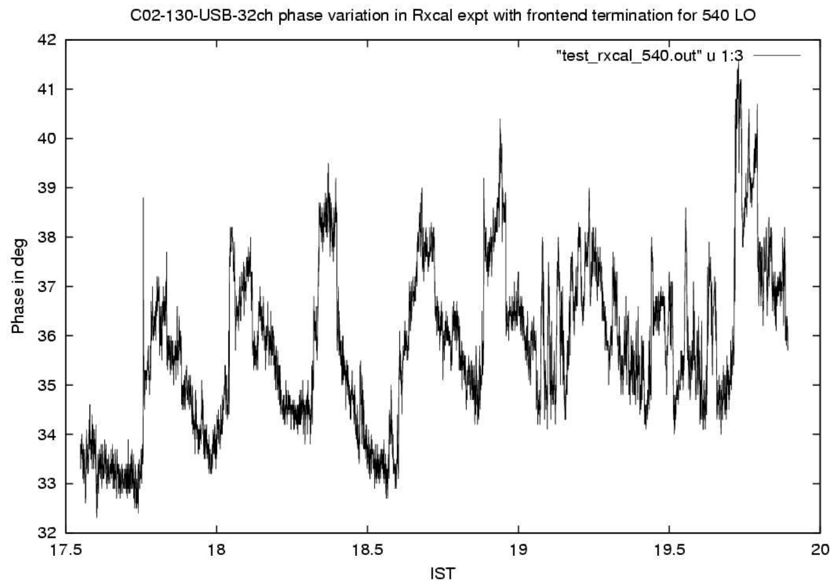

Figure 16: C11-C02 cross phase variation with FE termination