Chapter 21

GMRT Receivers

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21.1 Introduction

This chapter discusses the GMRT receiver system chain. This chain starts from the Multi-frequency RF Front-Ends and ends at the Baseband system. The major blocks in this chain along with their various possible configurations are described.

A detailed analysis of the noise contributed by the various components of this chain is presented. The length of the fiber optic cables linking the antennas to the CEB varies from about 600m for the nearest antennas to about 21km for the most distant ones. Since the transmission loss increases with increasing fiber length, different antenna systems will have different signal to noise ratios at the CEB. However by optimally adjusting the operating power levels at different points of the receiver chain one can ensure that the maximum degradation of the system noise temperature is less than 1% for all antennas.

21.2 Overview of the GMRT Receiver Chain

The GMRT receiver chain is shown schematically in Figure 21.1. The first block is the multi-frequency front end. This is located in a rotating turret at the prime focus. All the feeds and low noise RF front-ends have been configured to receive dual polarization signals. Lower frequency bands (from 50 to 610 MHz) have dual circular polarization channels, i.e. left hand circular and right hand circular polarizations which have been labelled as CH1 and CH2 respectively. The L-band (1000-1450 MHz) system has dual linear polarization channels, i.e. vertical and horizontal polarizations (also labelled CH1 and CH2 respectively).

The first local oscillator (I LO, situated at the base of the antenna, inside a shielded room) converts the RF band to an IF band centered at 70 MHz. After passing the signal through a bandpass filter of selectable bandwidth, the IF at 70 MHz is then translated (using II LO) to a second IF at 130 MHz and 175 MHz for CH1 and CH2, respectively. The maximum bandwidth available at this stage is 32 MHz for each channel. This frequency translation is done so that signals for both polarizations can be frequency division multiplexed onto the same fiber for transmission to the CEB.

At the CEB, these signals are received by the Fiber-Optic Receiver and the 130 and 175 MHz signals are then separated out and sent for base band conversion. The baseband converter section converts the 130 and 175 MHz IF signals first to 70 MHz IF (using III

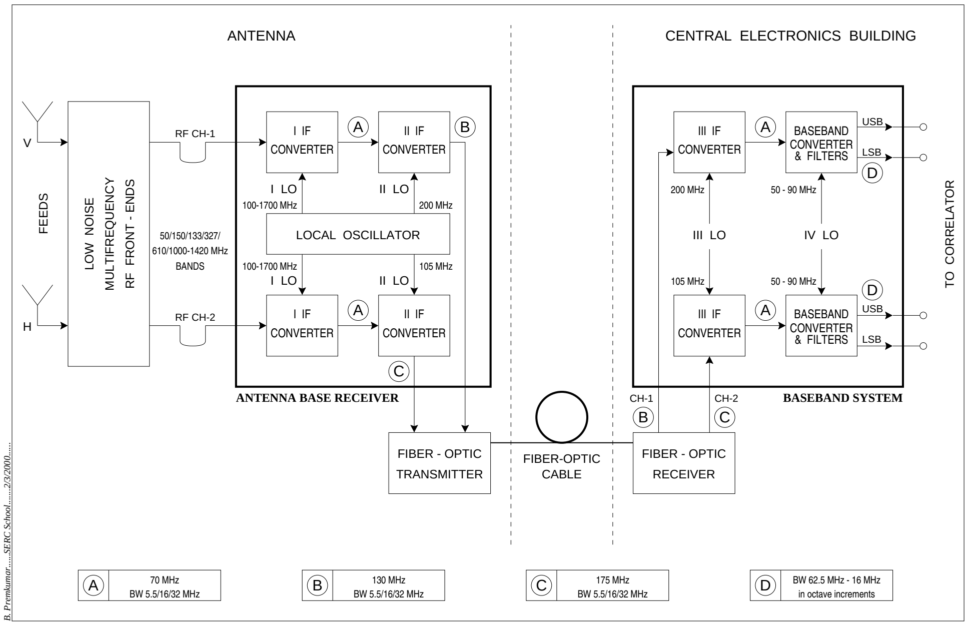


Figure 21.1: Schematic block diagram of the GMRT receiver. See the text for more information.

LO), these are then converted to upper and lower side bands (each at most 16 MHz wide) at 0 MHz using a tunable IV LO. The various local oscillators and baseband system are discussed in more detail in Chapter 23. There are also two Automatic Level Controllers (ALCs) in the receiver chain (not shown in Figure 21.1 but discussed in more detail below). The first is just before the Fiber Optic transmitter and the second is at the output of the baseband unit.

21.3 Receiver Design Considerations

Each of the various blocks in the receiver chain has some gain (or loss) associated with it. The receiver chain hence has distributed gain. There are several considerations involved in determining exactly how to distribute the gain across the RF, IF and BB electronics, viz.

1. The response of the entire system must remain linear over a wide range of noise temperatures from cold sky to the high antenna temperatures anticipated when observing strong sources like the Sun.
2. The entire receiver system should remain linear even in the presence of strong interference signals. In particular the inter-modulation distortion (IMD) products should be below a critical threshold[1]. Also the receiver should have a high desensitization

[1]Basically one needs receiver with high enough Compression and Spurious Free Dynamic Range (CDR and SFDR) to handle the range of astronomical signals and interference signals present. In communications receiver

dynamic range[2] so that a single dominant out of band interfering signal does not reduce the receiver SNR by saturating the subsystems in the receiver.

3. The RF Front End gain should be such that no more than 1 K noise is added to the Low Noise Amplifier (LNA) input noise temperature by the rest of the receiver chain.

4. The gain should be so distributed that no more than 1% gain compression should occur at any stage of the receiver chain.

5. The level of signals at the input of the cables that run from antenna turret to the base of antenna should be sufficiently high compared to any extraneous interference signals that might be picked by these cables.

6. Components whose contribution to the signal phase needs to be kept constant should preferably be located at the antenna base room where the temperatures are relatively stable compared to that at the prime focus.

7. Internally-generated spurious products (if any) in the receiver, must be very low compared to the receiver noise floor.

8. The Antenna Base Receiver (ABR) input (which receives the the RF signals from the front end through long lengths (about 100 m of cable) should be well matched for the full RF band i.e. 10 MHz to 1600 MHz. A poor match would result in passband ripples.

9. The receiver should have a good image rejection (at least 25 dB). Further since the RF pass band in the common box electronics (see below) has 10 MHz - 2000 MHz coverage, a 70 MHz signal may find a path past the amplifiers and mixer and be coupled into the 70 MHz IF circuitry. The units have to be optimally configured such that a good IF rejection[3] is achieved.

10. The ALCs should be active over a large signal amplitude range.

21.4 The Multi Frequency Front Ends

A block diagram of the Multi Frequency Front Ends is given in Figure 21.2. There are six possible observing bands centered at 50 MHz[4], 150 MHz, 233 MHz, 327 MHz, 610 MHz and an L-band extending from 1000 to 1450 MHz[5]. The L-band is split into four sub bands centered at 1060 MHz, 1170 MHz, 1280 MHz and 1390 MHz, each with a bandwidth of 120 MHz. The L-band receiver also has a bypass mode in which the entire RF band can be brought down to the ABR.[6] The 150 MHz, 233 MHz, 327 MHz and 610 MHz

parlance, the SFDR is defined as the power ratio between the receiver thermal noise floor and the two tone signal level that will produce third order IMD products equal to the noise floor level. The CDR is defined as the power ratio between the receiver thermal noise floor and the 1 dB compression point. However, for radio astronomical receivers it is customary to define the upper limit for the CDR as the signal level where 1% gain compression occurs and in the case of SFDR, the upper limit as the two tone signal levels which produce IMD products 20 dB below the noise floor.

[2]The desensitization dynamic range is defined as the power ratio between the level of the strong undesired signal which reduces the SNR by 1 dB and the receiver noise floor.

[3]IF rejection is a measure of attenuation between the receiver input and the IF circuit.

[4]The 50 MHz feed is as of yet not commissioned.

[5]Some of the L-band feeds have coverage up to 1750 MHz to allow observations of the OH molecular lines.

[6]This mode is useful in for example making observations at frequencies below 1000 MHz the nominal bottom of the L band.

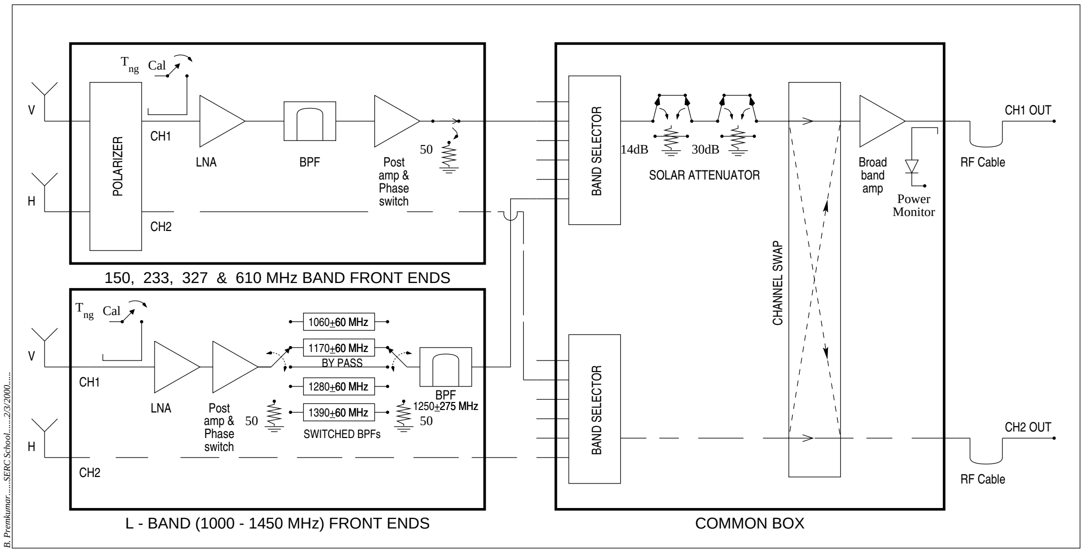


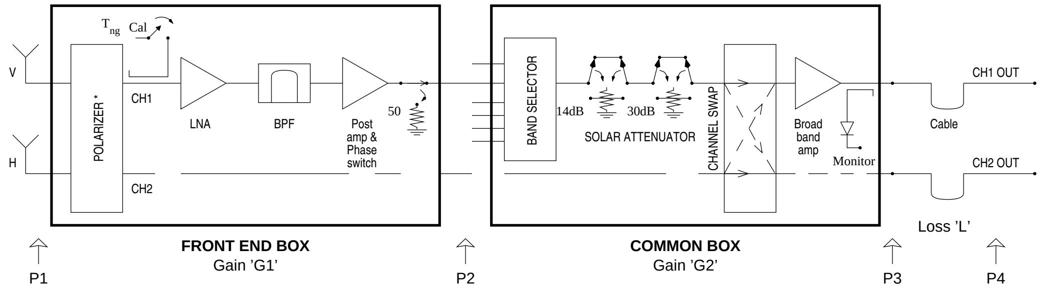
Figure 21.2: Block diagram of the GMRT multi-frequency front end. For illustrative purposes, the upper left side block has been shown as any of the 50 MHz to 610 MHz RF receivers, the lower block is an L band RF receiver. See the text for more information.

bands have a nominal bandwidth of 40 MHz[7]. Table 21.1 gives a break up of the contribution from various sources to the system noise temperatures at the different frequency bands. Figure 21.3 gives the expected RF power (for a 32 MHz bandwidth) at different stages of the multi-frequency front end.

At the lower frequencies (50 MHz to 610 MHz) there is a polarizer before the LNA which converts the received linear polarization to circular. At L band, in order to keep the system temperature low, this element is not inserted into the signal path, and the linear polarized signals are fed directly to the LNA. To calibrate the gain of the receiver chain, it is possible to inject an additional noise signal (of known strength) into the input of the LNA. It is possible to inject noise at any one of four levels. These are called Low cal, Medium cal, High cal and Extra high cal and are of monotonically increasing strength. To minimize crosstalk between different signals a phase switching facility using separate Walsh functions for each signal path is available at the RF section of the receiver. It is also possible to connect a 50 ohm resistor instead of the LNA to the output of the RF receiver. This is primarily of use in debugging.

At all bands the signals go through one additional stage of amplification in the 'Common Box'. The common box has a broad band amplifier which covers the entire frequency range of the GMRT. The band selector in the common box can be configured to take signals from any one of the six RF amplifiers. The common box (and the entire receiver system) has the flexibility to be configured for receiving either both polarizations at a single frequency band or a single polarization at each of two different frequency bands. It is also possible to swap the polarization channels (i.e. to make LCP come on CH2 instead of CH1 and RCP on CH1 instead of CH2), this is primarily for debugging use. For observing strong radio sources like Sun, solar attenuators of 14 dB, 30 dB or 44 dB are available in the common box. In addition there is a power monitor whose output can be continuously monitored to verify the health of the subsystems upstream of the common box.

[7]But the usable bandwidth is often somewhat larger.



FREQ. BAND (MHz)	T_{sys} (K)	P1 (dBm)	G1 (dB)	P2 (dBm)	G2 (dB)	P3 (dBm)	L (dB)	P4 (dBm)
150	580	- 96	34	- 62	28	- 34	8	- 42
233	234	- 100	37	- 63	27	- 36	9	- 45
327	108	- 103	38	- 65	27	- 38	11	- 49
610	101	- 104	35	- 69	26	- 43	15	- 58
1060	83	- 104	50	- 54	25	- 29	22	- 51
1170	77	- 105	49	- 56	24	- 32	23	- 55
1280	74	- 105	49	- 56	23	- 33	24	- 57
1390	72	- 105	47	- 58	23	- 35	26	- 61

Note : Power levels are over 32 MHz BW; with 0dB solar attenuator - * The L-Band (1000 - 1400 MHz) FE does not have the polarizer

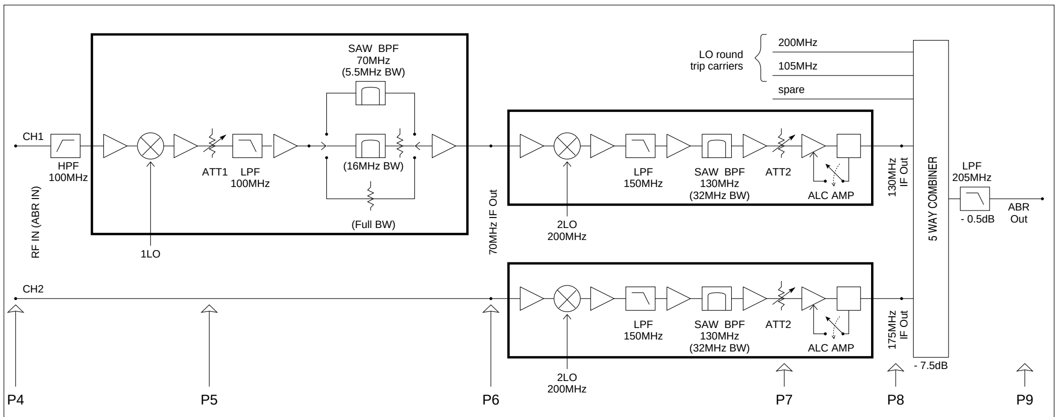
Figure 21.3: The RF power levels for a 32 MHz bandwidth at various locations in the RF receiver chain for the different GMRT frequency bands and sub bands. It is assumed that the solar attenuator has been bypassed and that the noise diode is off.

Table 21.1: Contributions from different sources to the system temperature at the various GMRT bands.

Band (MHz)	BW (MHz)	Cable Loss (dB)	Pol Loss (dB)	LNA (K)	Receiver (K)	Ground (K)	Sky (K)	Sys (K)
50	40	1.33	0.80	895	1651	19	6500	8170
150	40	0.2	0.75	150	260	12	308	580
235	40	0.55	0.25	35	103	32	99	234
327	40	0.13	0.18	30	55	13	40	108
610	40	0.22	0.15	30	59	32	10	101
1060	120	0.22	-	35	53	25	5	83
1170	120	0.22	-	32	49	24	4	77
1280	120	0.22	-	30	47	23	5	74
1390	120	0.22	-	28	45	23	5	72

21.5 The Antenna Base Receiver

From the Common Box, the signal is brought down via a coaxial cable[8] to the Antenna Based Receiver (ABR), which is housed in a shielded room inside the antenna shell[9] Figure 21.4 shows a schematic block diagram (and also gives the expected signal levels for a 32 MHz bandwidth) at different stages of the ABR, and the nominal values to be set for the pre and post attenuators (see below).



FREQ. BAND (MHz)	P4 (dBm/32MHz)	P5 (dBm/32MHz)	ATT1 (dB)	P6 (dBm)	P7 (dBm)	ATT2 * (dB)	P8 (dBm)	P9 (dBm)
150	- 42	- 17	18	- 34	- 17	16	- 12	- 20 in each channel or - 17 total power
233	- 45	- 20	16	- 35	- 18	16	- 12	
327	- 49	- 24	12	- 35	- 18	16	- 12	
610	- 58	- 34	10	- 43	- 26	8	- 12	
1060	- 51	- 28	10	- 37	- 20	14	- 12	
1170	- 55	- 33	10	- 42	- 25	8	- 12	
1280	- 57	- 35	10	- 44	- 27	6	- 12	
1390	- 61	- 40	8	- 47	- 30	4	- 12	

Note 1. Atenuation for ALC mode: (For Non-ALC mode operation add 6dB more attenuator to get - 12dBm a P8)
2. Channels 16 & 20 of MCM #9 should read 131 **(± 5)** counts, to indicate proper ALC setting. For quick check, adding 4dB more attn. in the above setting will cause the MCM channels (16 & 20) counts to read **215 (± 5)** showing that operating point is just under for AGC.

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Figure 21.4: Schematic block diagram of the antenna base receiver. The nominal values that the attenuators should be set to, as well as the expected power levels at different stages are also shown. See the text for more information.

The High pass filter (HPF) at the input of the ABR has a rejection of about 40 dB at 70 MHz and provides the IF rejection[10]. After mixing the signal power level can be adjusted using a variable attenuator[11] (which can be set from 0 to 30 dB in steps of 2 dB). After this the the signal passes through a SAW filter where one of three bandwidths (32 MHz, 16 MHz and 5.5 MHz) can be chosen. The net gain of the filter is independent of the chosen bandwidth due to the incorporation of bandwidth compensating gain circuitry. The signal is then up-converted to either 130 or 175 MHz (depending on which polarization it is), passed through further gain and an attenuation[12] and then an Auto-

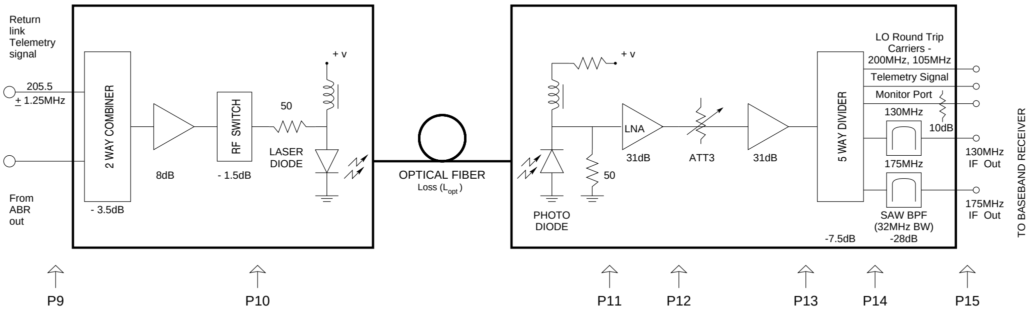
[8]The loss in this cable is a strong function of frequency. This fact can be used to advantage in the bypass mode for image rejection. In the bypass mode if one places the I LO above the RF of interest, the image frequency is suppressed due to the greater attenuation at higher frequencies.

[9]The concrete structure on which the dish rests is called in local parlance the “antenna shell”.

[10]i.e. prevents passage of a 70 MHz signal from the RF directly through to the 70 MHz IF stages.

[11]Which in local parlance is called the “pre-attenuator”.

[12]Also settable from 0 to 30 dB in steps of 2 dB, and called the “post-attenuator”.



P9 (dBm)	P10 (dBm)	L_{opt} (dBm)	P11 (dBm)	P12 (dBm)	ATT3 (dBm)	P13 (dBm)	P14 (dBm)	P15 (dBm)
- 17 (- 20 per ch.)	- 14 (- 17 per ch.)	0	- 50	- 19	22	- 10	- 17.5 (- 20.5 per ch.)	~ - 49 @ 130MHz & 175MHz Outputs
		5	- 60	- 29	12			
		10	- 70	- 39	2			
		11	- 72	- 41	0			

Note : 0dB Nett gain in the optical fiber link means P9 to P14 GAIN is 0dB

Figure 21.5: Schematic block diagram of the Fiber Optic Link. See the text for more information on each block.

matic Level Controller, (ALC). The ALC ensures that the even if the RF signal level varies (for eg. because you point at a bright source) the signal level at the IF remains at the optimum level for transmission through the optical fiber[13] The IF powers are continuously monitored and the monitoring data is sent to the CEB. The recommended IF power level is -20 dBm per polarization.

At the final stage of the ABR, the LO round trip carriers, the monitoring data as well as the astronomical signal are combined in a 5 way combiner and sent to the CEB via the optical fiber link.

21.6 The Fiber-Optic Link

Figure 21.5 shows the schematic block diagram and the nominal powers at different stages of the the fiber-optic return link[14]. The link consists of a laser diode (which converts the input electrical signal into an optical signal), the optical fiber itself, a photo diode (which converts the optical signal back into an electrical signal) followed by an amplifier and a 5 way divider which separates out the monitoring data as well as the two polarizations of the astronomical signal.

The Fiber optic link is designed to provide a net gain of 0 dB from the input (P9 in Figure 21.4) to the output (P14 in Figure 21.5) which is also the input to the baseband system discussed in Chapter 23. The link is meant to have 0 dB gain irrespective of the length of the fiber optic cable linking the antenna to the CEB. The attenuator (ATT3 in the Figure 21.5) can be varied in accordance with link optical loss to provide this no loss/gain configuration. The level diagram shows the attenuator settings for 0, 5, 10 and 11 dB of

[13] The ALC has a time constant of the order of 0.1 seconds. This can produce artifacts in signals (eg. pulsars) whose short timescale structure is of interest. For such observations there is a provision to switch the ALC off.

[14] As discussed in Chapter 22 each antenna has two fibers connecting it to the CEB. One fiber is used to send control signals to the antenna, and is referred to as the forward link, while the other fiber is used to bring back the astronomical signal and monitoring data to the CEB and is called the return link.

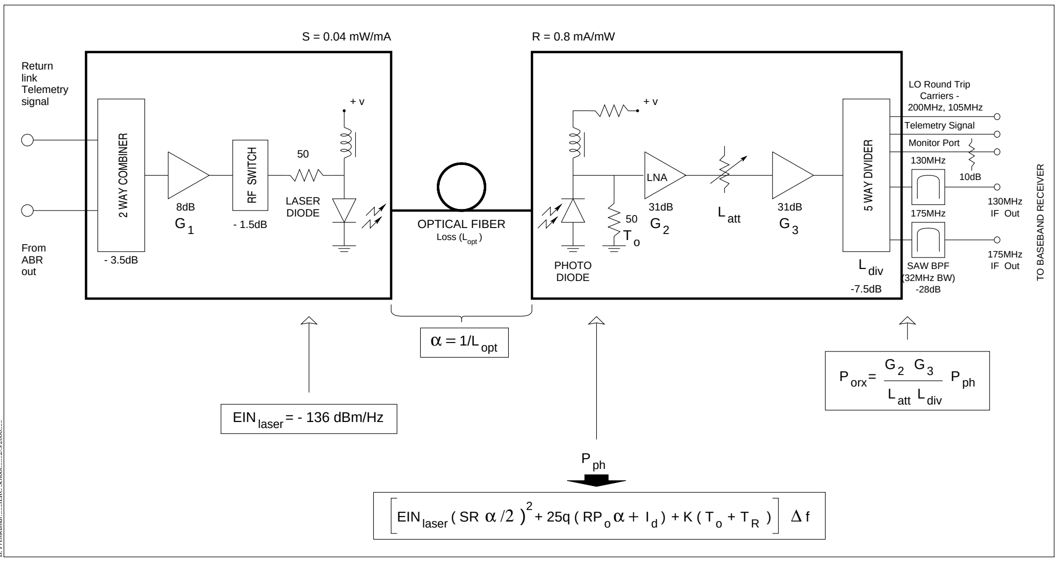


Figure 21.6: Values or expressions for the gain/loss at in the various stages of the fiber optic link. See also Figure 21.7.

optical loss (L_{opt}).

The fiber-optic receiver also contains 32 MHz SAW filters centered at 130 and 175 MHz to separate out the 130 and the 175 MHz IF signals for routing to the base band converter subsystem. The level of the signal at this point (P15) is nominally -49 dBm[15]

An ideal communications link would transfer signals unaltered from the input to the output. Any real link however introduces both additional noise as well as distortions into the signal it transports. In the GMRT fiber-optic link, these non idealities include the laser intensity noise, shot noise and thermal noise of the laser diode, loss and reflections in the optical fiber, as well as shot noise and thermal noise in the photo-diode. Figure 21.6 gives expressions for these various noise terms, and Figure 21.7 and Table 21.7 give the expected values for the various noise terms for the GMRT fiber optical link. The largest loss is for the most distant antennas, and turns out to be ~ 11 dB. From Table 21.2 (or Fig 21.8) the corresponding equivalent input noise (EIN) is ~ -41 dBm. The nominal input power level (P9) of -20 dBm would hence give a signal to noise ratio of ~ 20 dB, i.e. 100. In this case, the system temperature is degraded by 1% due to noise added by the link.

[15]The fiber-optic receiver has a monitor point at the front panel in order to allow measurements of the IF signals and other carriers using a Spectrum Analyzer.

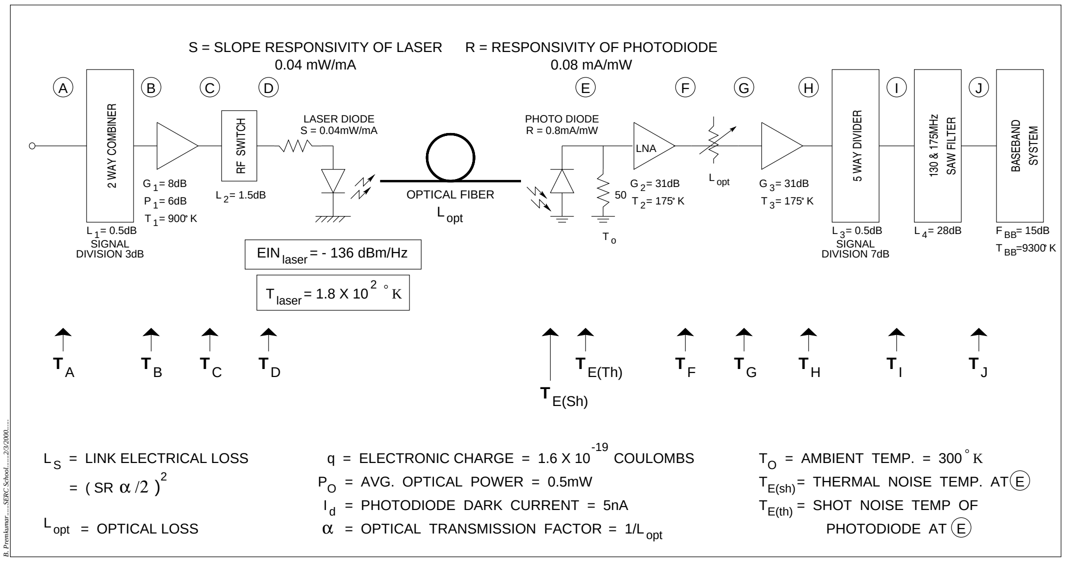


Figure 21.7: Equivalent system noise temperatures at various stages of the GMRT fiber optic link. The link has been designed to have a net gain of 0 dB and to increase the system temperature by less than 1%.

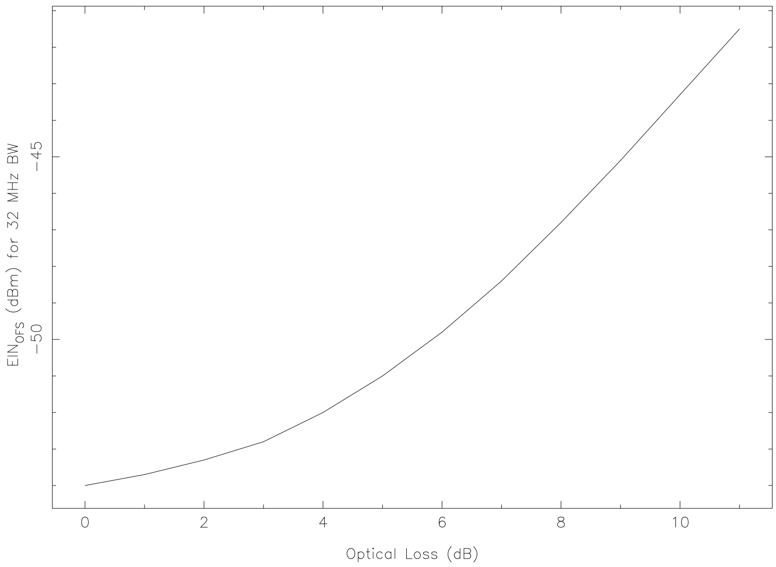


Figure 21.8: Equivalent input noise as a function of optical loss for the GMRT fiber optic link. The maximum optical loss (which occurs for the most distant antennas) is ~ 11 dB.

Table 21.2: Equivalent system noise temperatures as a function of link loss at various stages of the GMRT fiber optic link. See also Figure 21.7.

EIN_{OFS} (dBm)	T_A 10^6K	T_B 10^6K	T_C 10^6K	T_D 10^6K	L_S dB	L_{opt} dB	T_{ORX} K	$T_{E(sh)}$ K	$T_{E(th)}$ K	T_F 10^4 K	L_{att} dB	T_G 10^2 K	T_H 10^6 K	T_I 10^6K	T_J 10^2 K
-54.0	9.00	4.02	25.38	17.97	-36	0	4062	116	3946	437	22	271.82	34	6.06	93
-53.7	9.61	4.29	27.06	19.16	-38	1	2751	92	2659	275	20	271.82	34	6.06	93
-53.3	10.55	4.71	29.69	21.02	-40	2	1922	73	1849	173	18	271.82	34	6.06	93
-52.8	12.07	5.39	34.04	24.10	-42	3	1407	58	1349	110	16	271.82	34	6.06	93
-52.0	14.36	6.41	40.47	28.65	-44	4	1069	46	1023	69	14	271.82	34	6.06	93
-51.0	18.10	8.08	50.96	36.08	-46	5	861	37	824	44	12	271.82	34	6.06	93
-49.8	23.74	10.60	66.90	47.36	-48	6	722	29	693	28	10	271.82	34	6.06	93
-48.4	32.44	14.48	91.39	64.70	-50	7	629	23	606	17	8	271.82	34	6.06	93
-46.8	46.99	20.98	132.38	93.72	-52	8	580	18	562	11	6	271.82	34	6.06	93
-45.1	70.76	31.59	199.32	141.11	-54	9	555	15	540	8	4	271.82	34	6.06	93
-43.3	106.74	47.65	300.62	212.82	-56	10	530	12	518	6	2	271.82	34	6.06	93
-41.5	160.94	71.85	453.34	320.94	-58	11	506	9	497	3	0	271.82	34	6.06	93

$T_A = T_{OFS} = 2.24T_B + (L_1 - 1)T_0$ $\quad T_B = T_C/G_1 + T_1 \simeq T_C/G_1$ $\quad T_C = L_2 T_D + (L_2 - 1)T_0 \simeq L_2 T_D$

$T_D = L_S T_{ORX} + T_{laser}$ $\quad T_{ORX} = T_{E(th)} + T_{E(sh)}$ $\quad T_{E(th)} = T_0 + T_2 + T_F/G_2$

$T_{E(sh)} = \frac{25a(RP_0\alpha + T_0)}{K}$ $\quad T_F = L_{att}T_G + (L_{att} - 1)T_0$ $\quad T_G = T_H/G_3 + T_3$

$T_H = 5.6T_1 + (L_3 - 1)T_0$ $\quad T_I = L_4 T_{BB} + (L_4 - 1)T_0$ $\quad T_J = T_{BB}$; $L_S = 1/2(SR\alpha)^2$