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DC-2GHz DWDM Based Analog FO system Characterization

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Introduction:

The GMRT receiver system is being upgraded to achieve seamless coverage from 50 to 1600 MHz. The upgraded broadband analog fiber optic link to bring in the RF signals directly from the frontend system to central electronics building without down converting it to IF signals. With the new advancement in DWDM technologies, we could combine signals from four LASER transmitters operating at different wavelength on to one single mode fiber using optical multiplexer at antenna base and it is separated into individual channels using optical de-multiplexer at central electronics building. Two optical transmitters are used to carry two polarizations of frontend signal and the third one is used for supporting the existing GMRT fiber optic system to carry the two IF signals, return LO and telemetry signals. The block diagram below explains the detail channel allocation in DWDM multiplexed system.

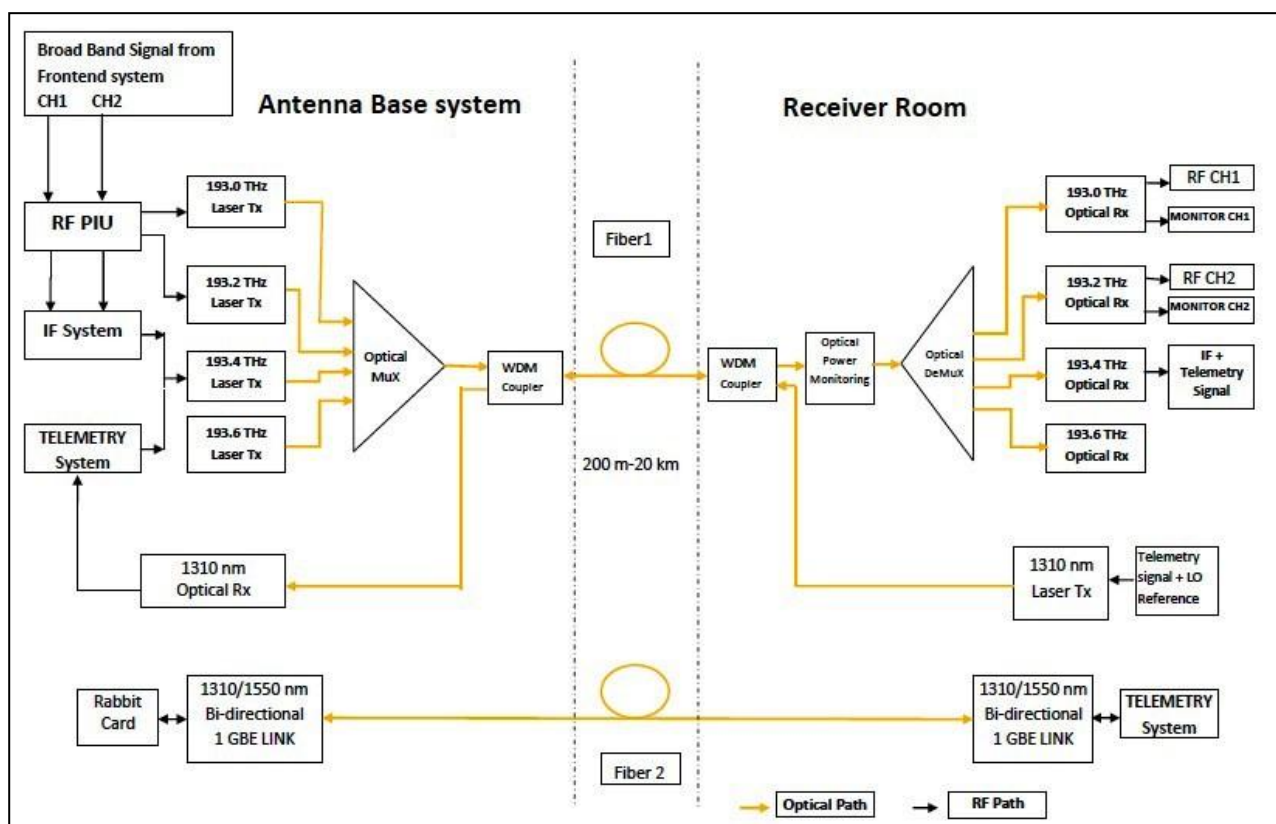


Figure 1. Upgraded fiber optics system

The forward link between CEB and antenna operates at 1310 nm and it is travelling in the opposite direction to the DWDM link from antenna to the central electronics building. This is done using bi-directional communication scheme by using WDM couplers with DWDM optical multiplexed system. The new upgraded system co-exists with the old fiber optic system of GMRT on one single fiber.

A variable attenuator is placed in the RF gain block unit which is the interface unit between the frontend and optical fiber system. The attenuator is adjusted to ensure linear operation of the new broadband analog fiber optic like at all RF bands. The total power received from the

frontend system vary with frequency band and to provide constant input power to the fiber optic system a variable attenuator is included in the RF gain block unit. The RF PIU at remote antenna base has two independent receiver chain carrying both the polarizations from frontend system. The signal from RF PIU is fed to laser transmitter which converts RF signal into optical signal and the optical signal is multiplexed and transmitted on to the single mode fiber from antenna base to CEB.

Bi-directional RF over fiber optic link

Following figure shows the 3 experimental setup for Bi-directional optical fiber link

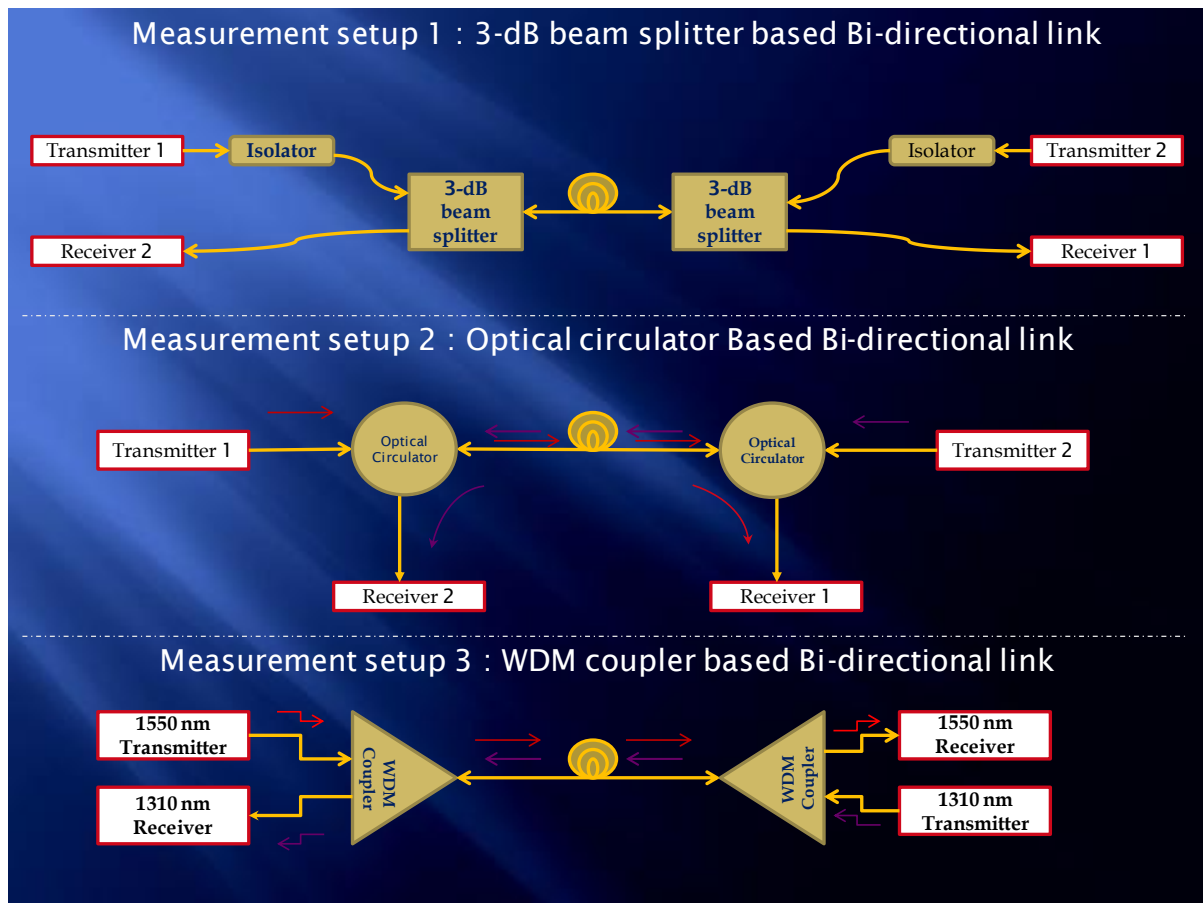


Figure 2. Experimental set-up for Bi-directional fiber optic link

The Isolator, Circulator and WDM coupler based Bi-directional link provides the isolation of 53, 57 and 80 dB. Isolator based set-up has low Isolation compare to others, and back reflected optical power can cause laser transmitter to oscillate and produce ripples in the band. Two opposite travelling wavelength sometimes cause inter-modulation between them and results in intensity noise at the output. The Circulator based Bi-directional provides better isolation but they are very costly. We have used WDM coupler based bi-Directional link for upgraded GMRT.

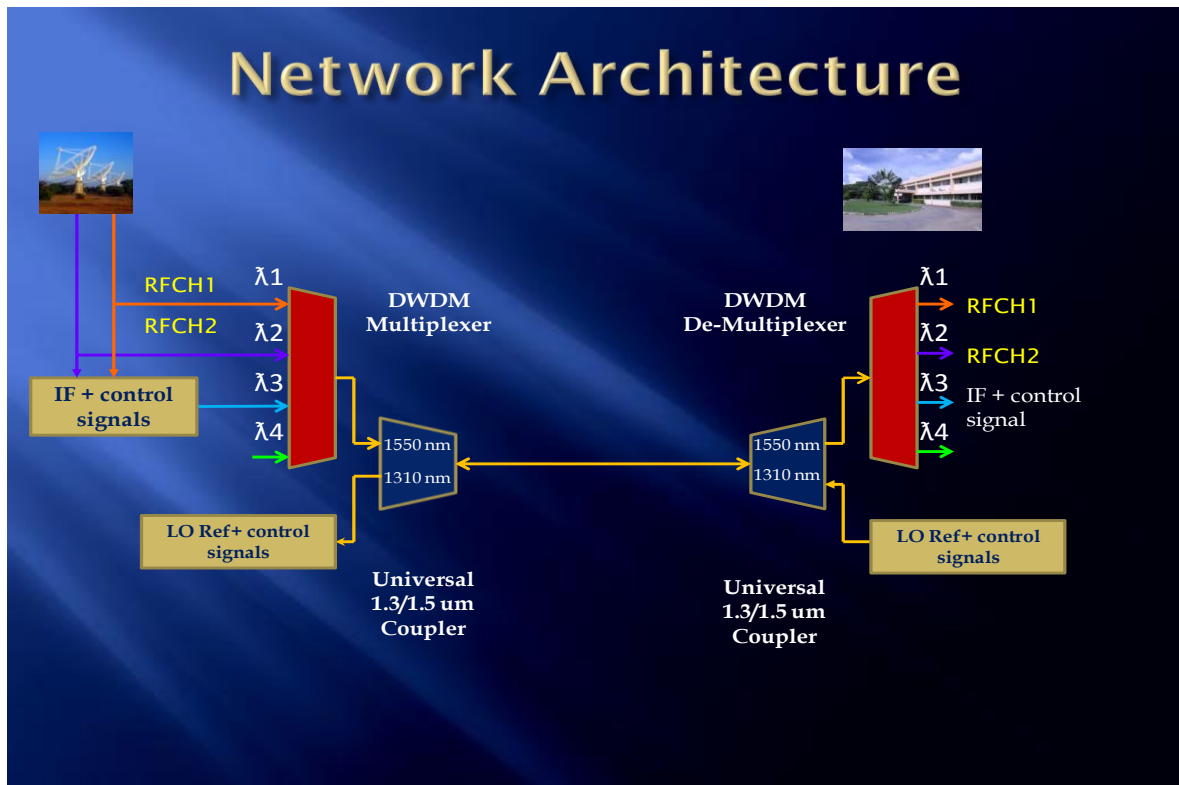


Figure 3. Network architecture of Bi-directional fiber optic link

Optical Multiplexer and Demultiplexer :

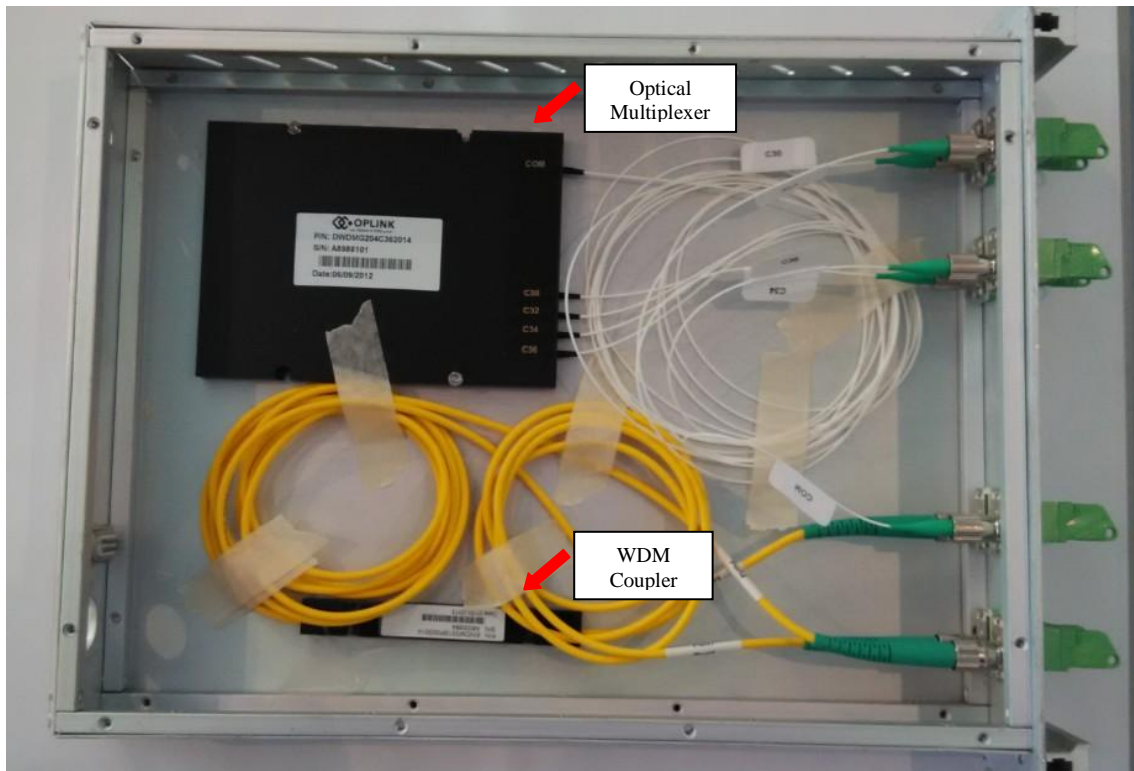


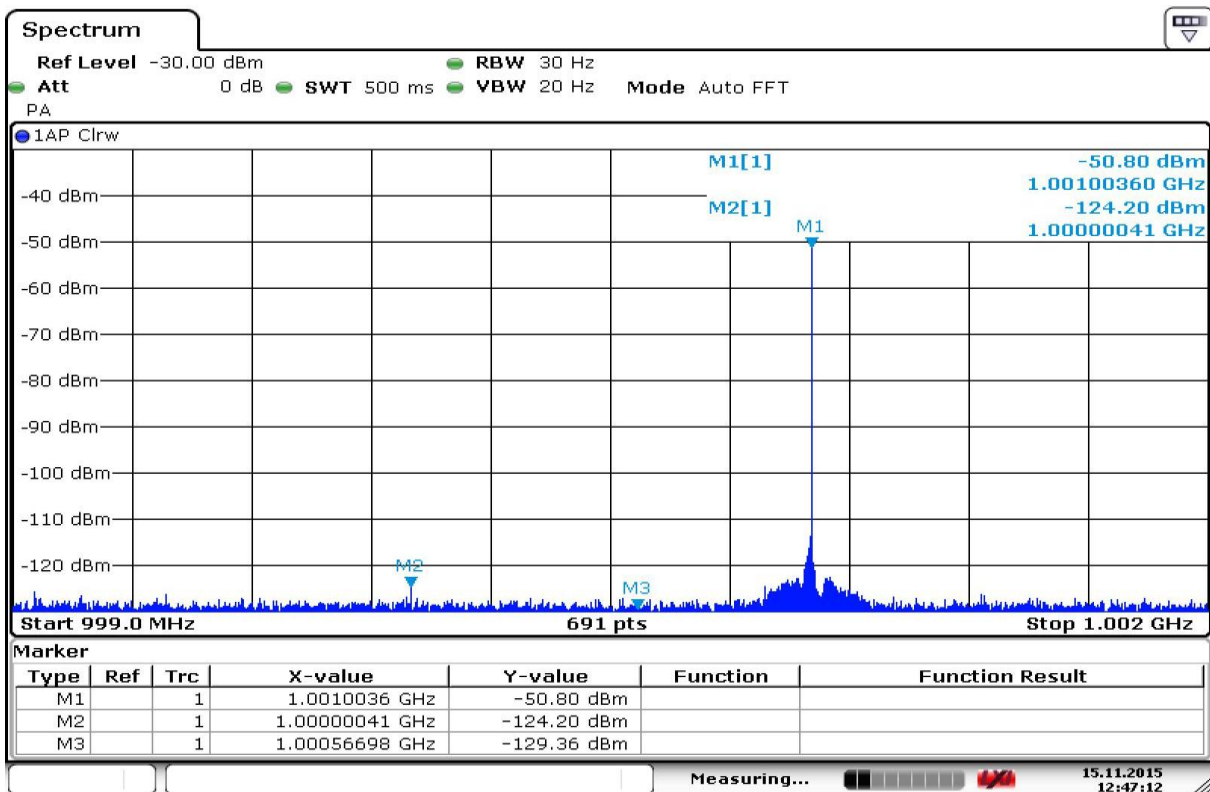
Figure 4. PIU containing WDM coupler and Optical Multiplexer

New Mux - Demux specification

Channels	I/P Optical power (dBm)	MUX Insertion loss (dB)	Demux insertion loss (dB)	Adjacent Channel Isolation (dB)
193.0 THz	9.3	1.3	1.2	48
193.2 THz	9	1.9	0.7	53
193.4 THz	8.2	0.6	0.7	49.2
193.6 THz	8.2	0.4	2.7	-----

Total Channel power at Mux O/P = 13.8 dBm

Isolation between the two opposite travelling 1310nm and 1550nm wavelength



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Figure 5. Isolation between the two opposite travelling 1310nm and 1550nm wavelength

The WDM coupler based bi-direction link provides a RF isolation of around 75 dB between the two opposite travelling 1310nm and 1550nm wavelengths.

Optical power measurement at various stages:

Laser Transmitter	Optical Output (dBm)	Multiplexer output (dBm)	WDM Coupler Output (dBm)	De-multiplexer input (dBm)	Optical Receiver I/P (dBm)
193.0 THz	8.9	11.7	10.9	9.9	6.0
193.2 THz	7.7				4.6
193.4 THz	8.3				4.1

Fiber Optics Transmitter System:

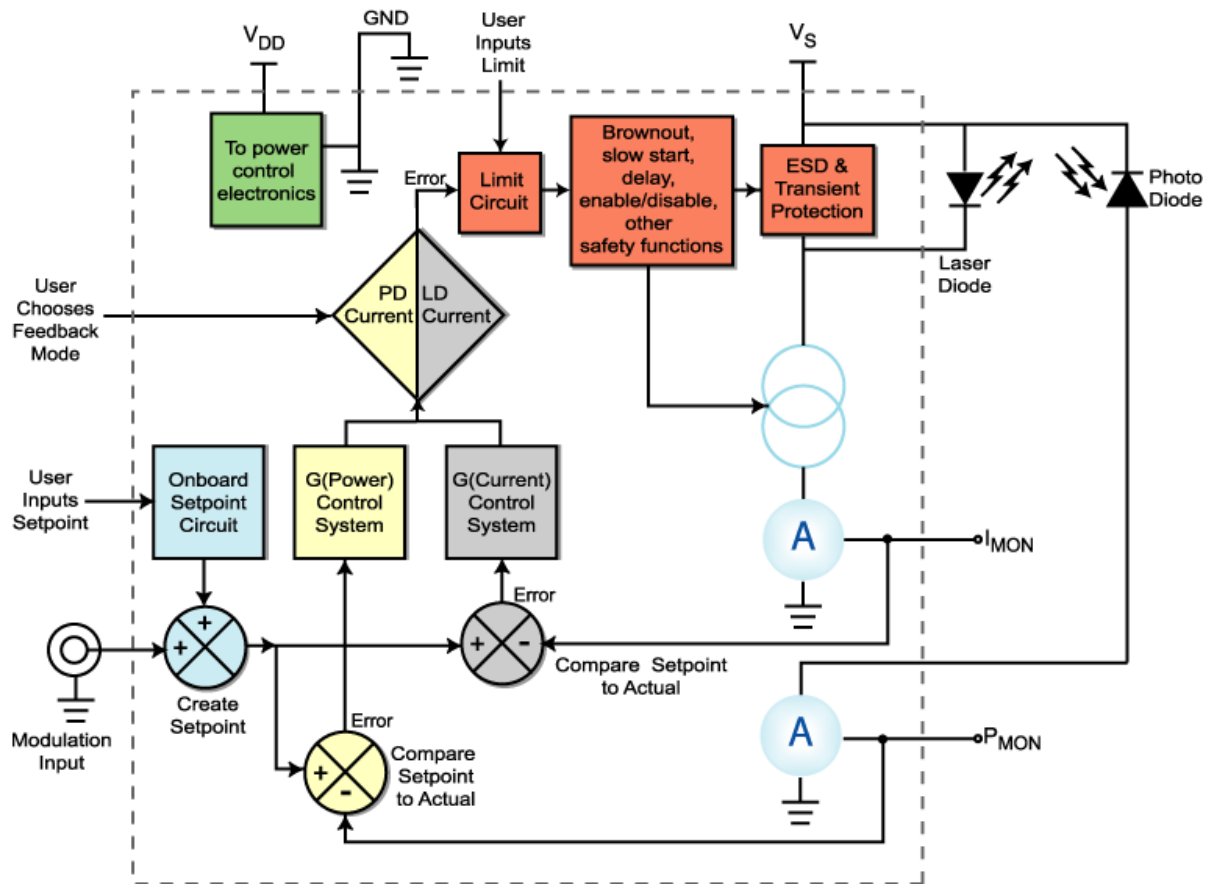
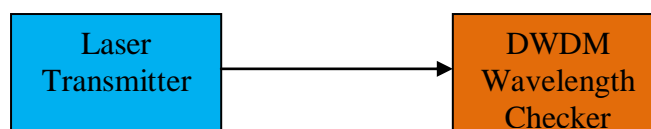


Figure 6. Laser diode driver

The Above figure shows the block diagram of Laser diode driver, it is a constant current source, noiseless and accurate, that delivers exactly the current to the laser diode that it needs to operate for a particular application. The user chooses whether to keep laser diode or photodiode current constant and at what level. Then the control system drives current to the laser diode safely and at the appropriate level.

Testing procedure for Laser Transmitter:

1. After integration of laser diode transmitter, we power up the circuit and measure the optical power level, it should be at least 8 dBm (Ideal is 10 dBm). With the help of DWDM wavelength checker, we check its operating wavelength and respective power level. If it is less we tune the circuit and change the set bias point. All the measurement are done at 22 Degree, which is the antenna base shell temperature.



2. Next procedure is to determine the Optical power stability of the Laser transmitter.



Figure 7. Test setup in Environmental Chamber

This is the test setup for laser transmitter in environmental chamber. we vary the temperature of chamber from 10 to 35 degree Celsius, the temperature variation is made very slow i.e. 0.25°C/minute. The output of all three laser transmitters is fed to optical multiplexer at their respective ports and combined output is given to optical De-multiplexer and a set up is made to continuously record the optical power and bias voltage from individual transmitter. The combination of Optical multiplexer and demultiplexer acts as wavelength filter, If we not get the constant optical power at demultiplexer output during thermal cycling, it means that there is wavelength shift in the laser output and thermal electric cooler is not working efficiently, which has to be corrected.

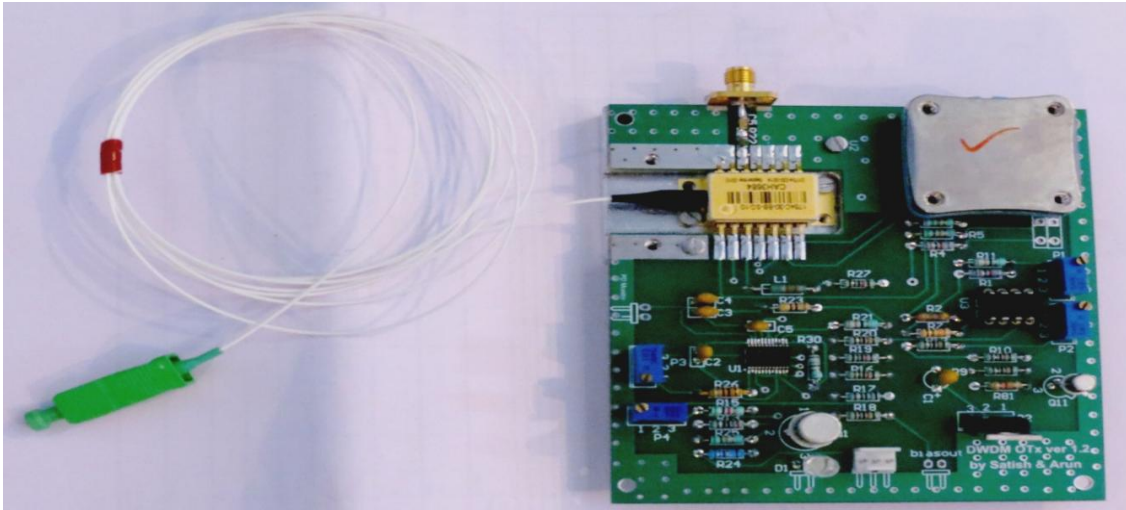


Figure 8. Populated Optical Transmitter Board

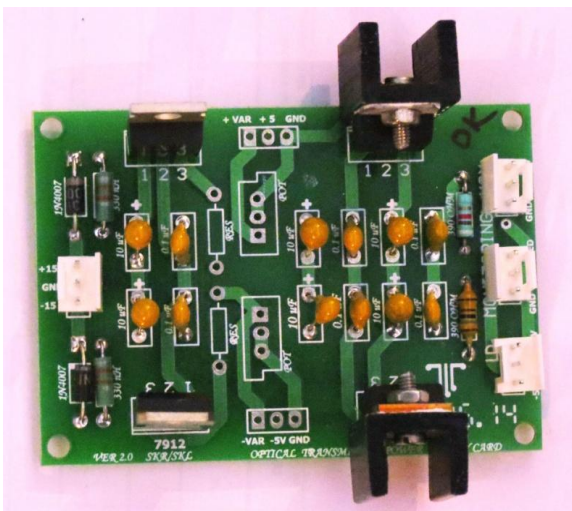


Figure 9. OTx power supply and Optical Transmitter PIU

The forward bias threshold current for lasing action of laser diode is 20mA, the maximum forward bias current is 120mA, the Q-point of laser diode is fixed at 60mA. The optical transmitter has a pre-amplifier (20dB Sirenza) whose biasing current is 70 mA.

Electrical Specification of Laser Transmitter:

Sr. No	Supply Voltage (V)	Current (mA)
1.	+15	130
2.	-15	110

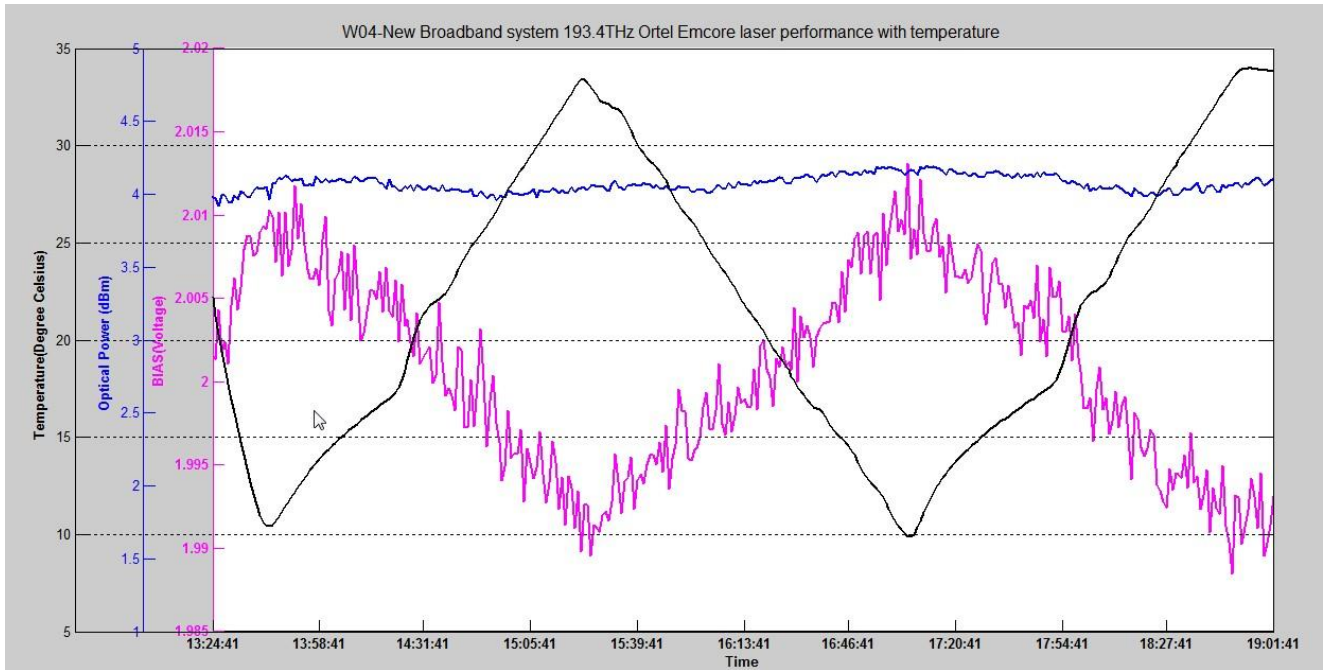


figure 10. Performance of Optical Transmitter with temperature.

Above figure shows the results of laser transmitter test in environmental chamber. The black color shows the temperature variation in environmental chamber, the magenta shows the bias voltage (which is the voltage drop across 33 ohm resistor due to laser forward bias current) and blue one shows the optical power at the output of demultiplexer measured by Eigenlight optical power meter. Transmitter is equipped with the control circuitry which tries to maintain the constant optical power and laser temperature so that it generates optical power in proper window. Laser is having inbuilt thermistor which senses the internal temperature of laser. Its output is given to TEC controller as input which will generate appropriate current, which will drive the laser thermoelectric cooler and tries to maintain the laser set temperature.

Fiber Optics Receiver System:

Photo detection is the process of conversion of signal from optical to electrical domain. The optical signal brought from the antenna base receiver is converted back again to RF signal.

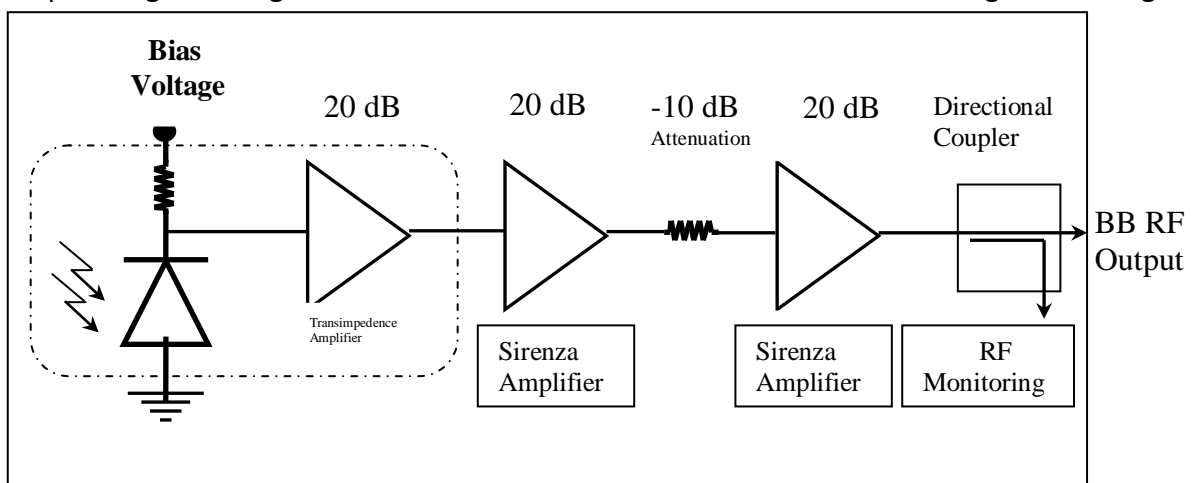


figure 11. Block diagram of the Upgraded GMRT optical receiver

The photodiode used by us is Discovery semiconductor make model DSC-R402, which is a linear and versatile PIN + Transimpedance (TIA) amplifier suited for a variety of digital and analog applications and has a dark current of 5 nA and responsivity of 0.8 mA/mW.

The electrical to Optical conversion at Antenna base and again optical to electrical conversion in receiver room, cause a RF loss of around 40 dB, which is compensated by using pre-amplifier in laser transmitter and post amplifier in optical receiver unit. To provide the large linear operating range we have set the optical power level at -5 dBm.

The link gain of optical transmitter and receiver without any pre and post amplifier (conversion loss)

$$\begin{aligned} &= 20\log(\eta \times R) - 2(\text{optical loss}) \\ &= 20\log(0.2 \times 0.8) - 2(12) \\ &\approx -40 \text{ dB} \end{aligned}$$

Where,

η = Laser diode slope efficiency.

R = Photodiode responsivity.

The photodiode in receiver is having inbuilt Transimpedance amplifier having high input impedance and gain of 20 dB. The post amplifier is MMIC based Sirenza amplifier having broad frequency operating range from 50 MHz to 6 GHz and gain of 20 dB, to simultaneously monitor the system without disturbing main port 20 dB direction Coupler is used.

Broadband Fiber Optics system characterization:

1. RF PIU Characterization:

This block is interface between frontend and fiber optics system, this consist of 20 dB amplifier, 3-dB power splitter and a variable attenuator. During characterization we found out the gain of each RF path at different attenuation values. The splitter creates the copy of frontend signal, which goes to existing IF system.

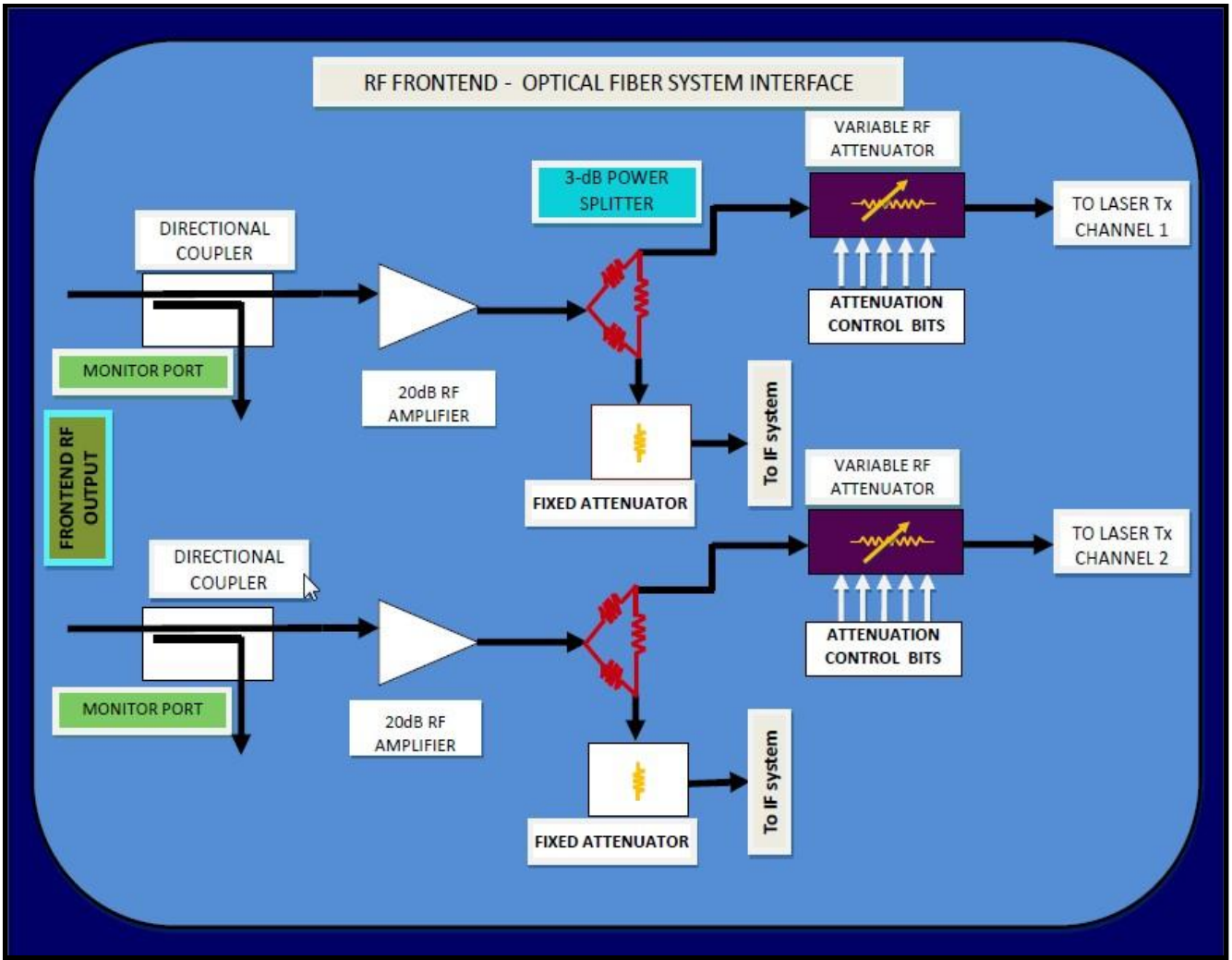


figure 12. RF PIU Block diagram



Figure 13. Response of RFPIU Broadband Channel



Figure 14. Response of RFPIU IF Channel

2. Optical transmitter and optical receiver characterization

In second phase of testing we are characterizing the optical transmitter, multiplexer, Demultiplexer and optical receiver. Each Set for both channels are characterized with the network analyzer with recommended optical input power of -5 dBm.

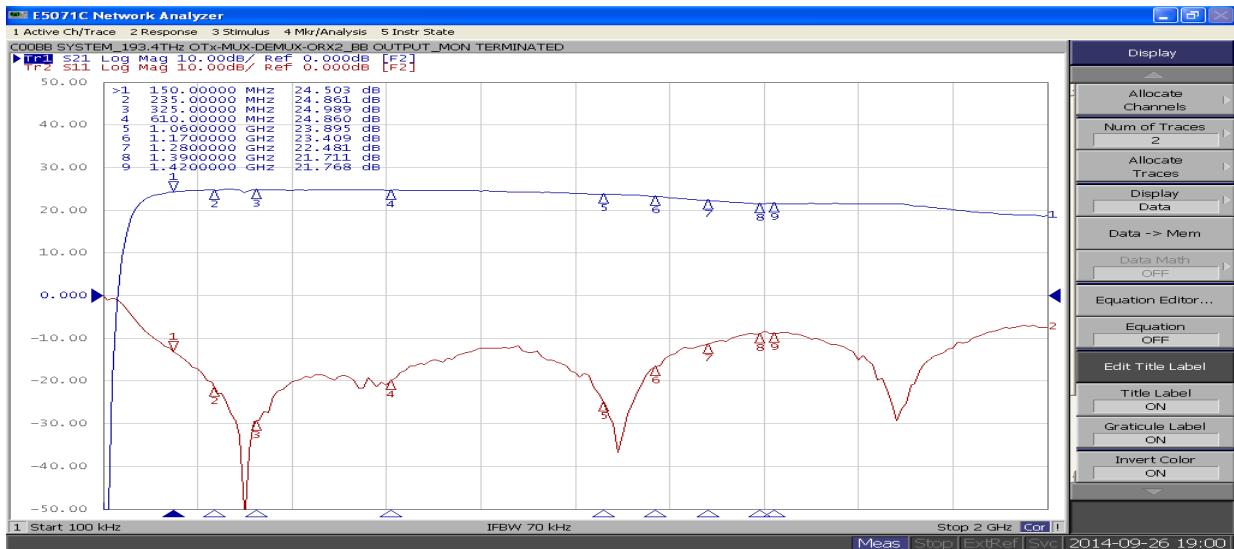


Figure 15. Response of OTx-Mux-Demux-ORx

3. Cascaded Broadband fiber optics system characterization

In the last stage of characterization we are cascading the RF PIU and optical system, and then we characterize this with network analyzer at different RF attenuation values (present in RF PIU). This gives the overall performance of fiber optics chain.



Figure 16. Response of cascaded Broadband fiber optics system



Figure 17. Response of cascaded Broadband fiber optics system monitor port

Phase response of fiber optics system

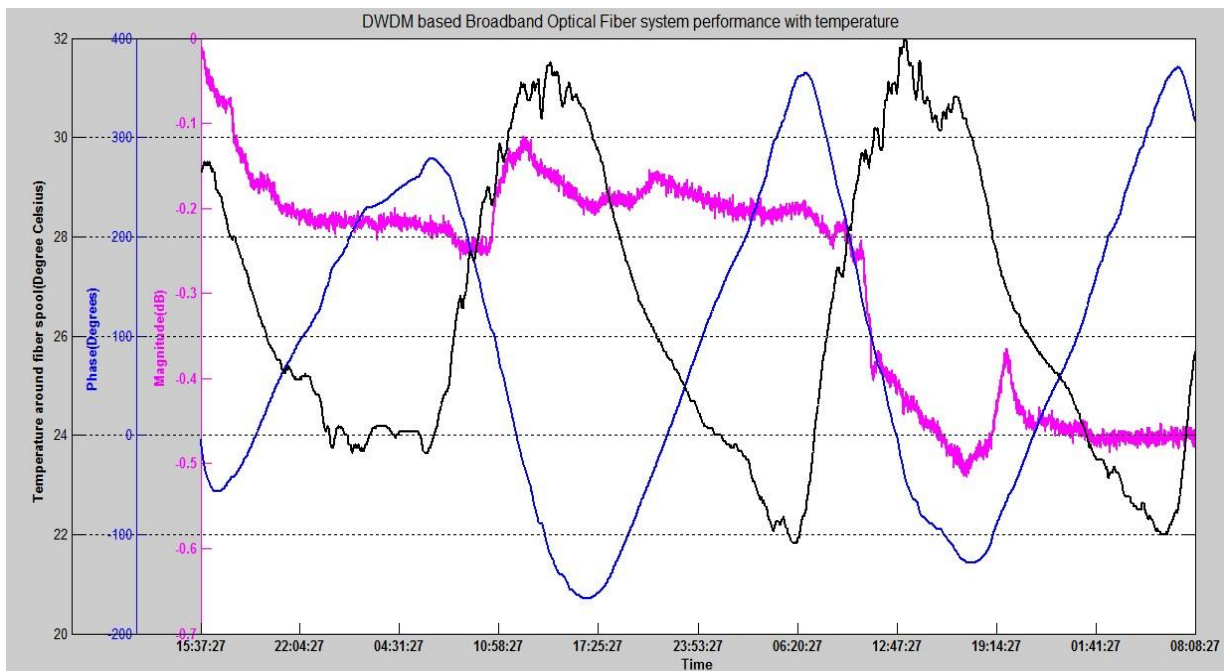


Figure 18. Phase response of single mode 8km Broadband fiber optic link with fiber cable kept in open environment

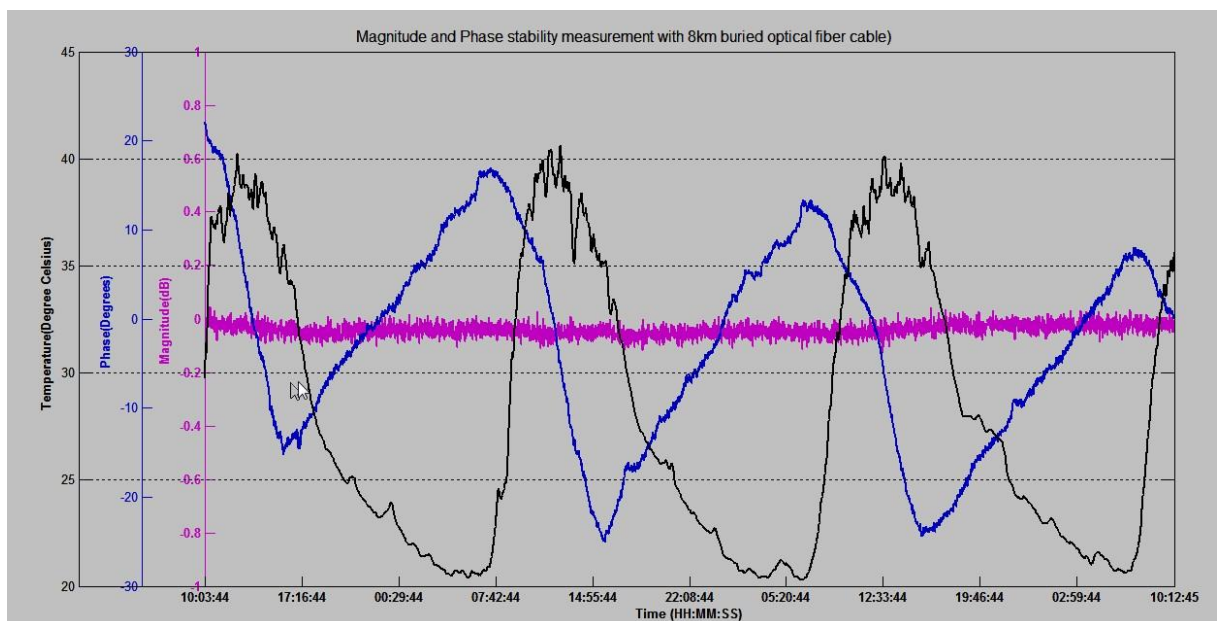


Figure 19. Phase response of single mode 8km Broadband fiber optic link with fiber cable buried in ground at 2m depth

Above figure shows the magnitude and phase response of broadband fiber optic link with two conditions

1. Fiber cable kept in open environment (Directly in contact with ambient temperature)
2. Fiber cable buried in ground at 2m depth (Indirectly in contact with ambient temperature)

In above experiment, fiber in open environment shows a large phase variation of around 360 degrees and for buried fiber the phase variation was around ± 20 degrees. In both cases magnitude is relatively constant with 0.5 dB variation for fiber kept in open environment and less than ± 0.1 dB for buried fiber.

Parameters of Broadband Fiber optics system:

Parameters	Value
Input optical power to ORx	-5 dBm
Current (ORx)	300 mA
Gain Of RF PIU	12 dB
Gain of OFC Broadband system	38 dB
1-dB compression point (P1 dB)	-15 dBm
TOI (IP3)	-6 dBm
Compression Dynamic Range	58 dB for 400 MHz bandwidth
Spurious free Dynamic range	105 dB/Hz

Conclusion:

The Broadband optical fiber system is suitable for analog application. The system works for 3 GHz bandwidth, the gain of the system is 38 dB at 1dB RF attenuation in RF interface card. The TEC Cooler and its control circuitry is highly efficient which makes the laser to operate at single wavelength with constant output power.

Future Scope:

In future we are trying to study the phase and magnitude characteristics of the broadband fiber optics system having different length of fiber like 2km,4km, 8km and 16km with temperature.