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Phase stability of GMRT Fiber Optic System

By : S.SureshKumar

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Abstract

The report explains the origin of the the phase variation found in the GMRT fiber optic system. The GMRT fiber optic system show short and long periodic phase variations, experiments were carried to identify the component which introduces the phase variation. The periodic behaviour indicates it is due to temperature dependence of the system. This report identifies the temperature dependent component of the fiber optic system to be the Optical Transmitter consisting of a Fabry Perot laser diode. The phase variation due to the thermal expansion of the burried fiber optic cable is also evaluated separately.

1. Introduction:

The Phase stability of the GMRT system is found to be poor and the phase difference between the antennas seem to vary with time. This certainly puts a limitation to the system usage. The over all phase variation is a response of the over all GMRT system. Here we consider only the phase variation contributed by the fiber optic system. Many measurements were done at GMRT project site and lab in pune. The fiber optic system showed almost no phase change when connected back to back i.e optical transmitter connected directly to the optical receiver with only 20 meter fiber link. But the same system showed good phase variation when connected with a link of say 4 km distance.

The report explains the phase variation at the GMRT Project site and also suggests some methods to improve the phase stability of the system.

2. Temperature dependence of the Fiber Optic System:

The fiber optic transmitter uses a Fabry Perot Laser diode with built in Thermister, Peltier cooler and a monitoring photodiode. The Laser diode characteristic shift in and out with temperature as shown in figure1. From the figure it is clear that at higher temperature the laser diode bias has to be increased to bring back the set biased optical power of 0.5 mW (- 3 dBm) and at low temperature the bias current is to be reduced to decrease the increasing optical power.

The Thermister monitors the temperature of the Laserdiode and controls the current to the Peltier cooler which cools the Laserdiode. The control circuit is set at 25 °C and it pumps current to the Peltier cooler to cool the Laserdiode when the Laserdiode exceeds the 25 °C . But the when the room temperature is less than 25 °C the Peltier cooler do not heat the Laserdiode to bring the opterating 25 °C.

In GMRT Project the CEB (Central electronics Building) is kept between 15 and 20 °C. Thus the Laserdiode operates between 15 and 20 °C and not at 25 °C the Optical power is adjusted by the monitoring photodiode and hence we see less of signal power variation when the transmitter is operated between 15 and 20 °C.

It is to be noted that only the optical power is adjusted to the set value but the Laserdiode keep operating at lower temperature and Peltier cooler takes no effect to keep the temperature of the Laser diode constant. This is clear from figure 2 showing temperature vs laser bias and temperature vs cooler voltage. We see the cooler has no effect at temperature less than 21 °C and the laser bais is to be varied to keep the optical power constant.

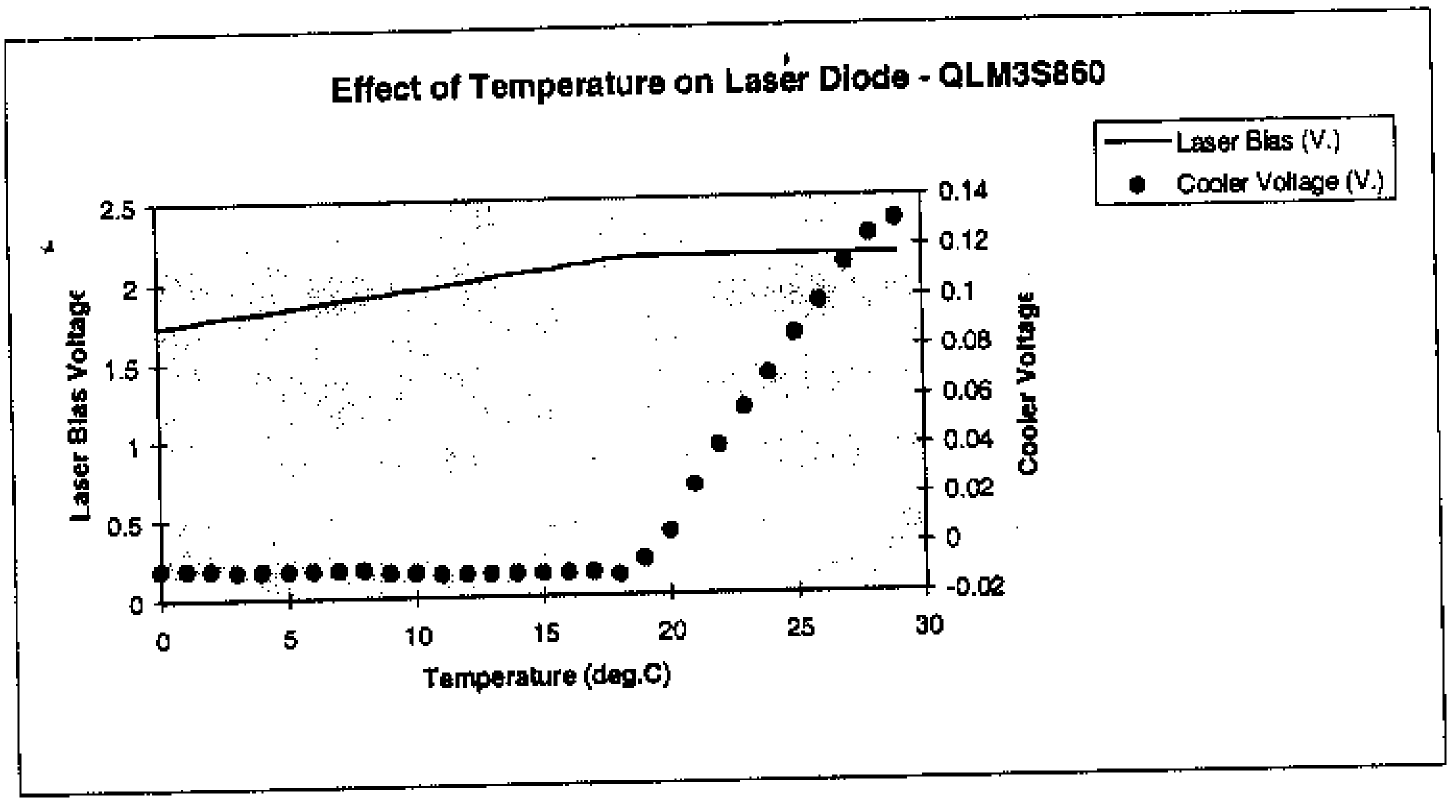

Figure 2. Effect of temperature variation on Laser Diode - QLM3S860
(measurement done at NCRA- TIFR, Pune, using environmental chamber).

3. Operating Wavelength and its temperature dependence.

The Laserdiode used at GMRT project works at 1300 nm wavelength at 25 °C. The wavelength do not change at higher temperature since the Peltier cooler cools the Laserdiode to bring back to the same wavelength. But at lower temperature the Peltier cooler has no control over the wavelength drifting. The manufacturer specifies 0.5 nm drift per degree change in temperature. Since the laser is operated between 15 and 20 °C the wavelength changes by 2.5 nm. The Air condition unit at CEB switches between 15 and 20 °C over a period of time. Thus the wavelength of the Laser source will also change over the same period of time.

4. Phase change and its Wavelength dependence:

The fiber dispersion value show less of a change for a change in wavelength of 2.5 nm only. But when the distance of the fiber is more the small change in wavelength gives a reasonable delay at the output end.

$$\delta\tau = D \cdot L \cdot \delta\lambda \quad \text{seconds}$$

$$\delta\phi = 360^\circ \cdot f \cdot \delta\tau \quad \text{degrees}$$

Where

$\delta\tau$	-	Increase in time delay (s)
D	-	Fiber dispersion (ps/nm.km)
L	-	Fiber Length (km)
$\delta\lambda$	-	Change in Wavelength (nm)
$\delta\phi$	-	Change in phase (°)

f - Frequency of the RF signal (Hz)

From the above expression we find the following phase change at the receiver end due to a periodic variation of the temperature at CEB from 15 to 20 °C.,

$D = 3.5$ ps / nm. km
$L = 1$ km
$\delta\lambda = 2.5$ nm for 5 °C change in temperature
$f = 200$ MHz

Then the change in delay $\delta\tau = 8.75$ ps

and the corresponding phase change $\delta\phi' = 0.63° /$ Km

If the distance $L = 20$ Km (the longest link of GMRT)

then $\delta\phi = 12.6°$

Since the temperature increases and decreases over a time interval say 1 hour the increase and decrease in phase of the link will also show a period of 1 hour. This further confirms that the phase change is due to the temperature variation of the system.

5. Phase variation under loop back conditions:

The loop back can be done either optically by removing the optical transmitter and receive at the shell and connecting the forward and return link fiber using an optical coupler or just RF looping back by connecting the RF output of forward link to return link RF input at antenna base. When optical loop back is done we are by passing the optical transmitter and receiver at the antenna shell and effectively we are increasing only the fiber length and the system see only one temperature variation at CEB. Thus we will see periodic phase variation with respect to the temperation variation at CEB alone. Thus a 1 hour temperature cycle will see a 1 hour phase variation cycle but larger phase change due to increased fiber length.

But if RF loop backing is done then the temperature effect at CEB and Antenna shell is to be considered. Say is the CEB temperature varies from 15 to 20 degrees in 1 hour and the antenna at 20 Km distance vary same 15 to 20 °C in 10 hours we see the forward link sees 1 hour periodic phase variation and the return link shows same phase variation in 10 hours period. Thus when RF loop back is done we see the effect of both forward and backward links. Thus when measured we see a short periodic phase variation along with a longer periodic phase variation. This can be verified by studying the difference in the temperature cycle at CEB and Antenna shell.

6. Effect of Ground temperature variation on the system phase stability.

The optical fiber cable is burried under 1 to 1.5 meter depth in ground to have less of phase variation with change in temperature. The temperature at the above depth vary not greater than 0.5 °C and the cycle of this variation is of longer period. Let us estimate the phase variation due to this 0.5 °C temperature change on a 20 Km fiber optic link.

From D.S. Sivaraj's thesis "*Optical Fiber Communication System for the GMRT*"

$$\frac{\delta\phi}{\phi} = 0.78 \cdot \alpha \cdot \delta T$$

$$\phi = \frac{2 \cdot \pi \cdot f \cdot n \cdot L}{c}$$

where

$\delta\phi$	=	change in phase
ϕ	=	path length in degrees
α	=	thermal expansion coefficient of bare silica fiber (5.5×10^{-7} meters / °C)
δT	=	change in temperature
L	=	Fiber length
n	=	Group refractive index at 1300 nm (1.467)
f	=	Frequency of the RF signal (200 MHz)
c	=	Velocity of of light in free space (3×10^{8} m/s)

For 20 Km distance

Path length in degrees (P) = 122899.1046 degree
Change in Path length in degrees (d P)
for a temperature change (dt = 0.5 °C) = 0.026361857 degrees
i.e 0.052 degree / °C for 20 km fiber.

It is to be noted that the thermal expansion coefficient of bare silica fiber is taken in the above example. The thermal expansion coefficient of optical fiber enclosed in a cable structure packed with various jackets and gel surrounding the fiber will see still less of temperature change or have less of thermal expansion coefficient. Thus fiber expansion contribute less of phase change to the GMRT fiber optic system.

7. Methods to improve the Phase stability of the Fiber Optic system.

The fiber optic transmitter show more of temperature dependence than the receiver or the optical fiber. Thus it will be better to follow any one of the following solutions to improve the system phase stability.

a. The CEB and antenna can be operated above 20 say 21 to 26 degree celcius since wavelength drifting is not observed with the transmitter in the above temperature range and it may also not affect the other system requirements.

b. The transmitter can be operated at the present temperature range 15 to 20 degree celcius. The system is getting modified for the above operating range with minor modification in the existing transmitter range. But a fail in Air condition unit may over load the peltier cooler and may lead to failure of the device. The range at which the above scheme can work is presently being studied.

c. Temperature controller modules are available with heat and cool arrangements which provides a wide operating range. These devices can be installed to have less effect on the fiber optic system phase stability.

8. Conclusion:

Thus it is concluded that the **major phase variation** seen with the fiber optic system installed at GMRT project is due to the temperature dependence of the fiber optic transmitter and not due to thermal expansion of the buried fiber optic cable. Also suggestions are given to over come the above phase variation of the system.

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