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OPTIMIZAITON OF CONNECTOR POSITION OFFSET FOR BANDWIDTH ENHANCEMENT OF A MULTIMODE OPTICAL FIBER LINK

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ABSTRACT

The multimode fiber bandwidth enhancement techniques to meet the Gigabit Ethernet standards for local area networks (LAN) of the Kennedy Space Center and other NASA centers have been discussed. Connector with lateral offset coupling between single mode launch fiber cable and the multimode fiber cable has been thoroughly investigated. An optimization of connector position offset for 8 km long optical fiber link at 1300 nm with 9 μm diameter single mode fiber (SMF) and 50 μm diameter multimode fiber (MMF) coupling has been obtained. The optimization is done in terms of bandwidth, eye-pattern and bit pattern measurements. It is simpler, is a highly practical approach and is cheaper as no additional cost to manufacture the offset type of connectors is involved.

OPTIMIZATION OF CONNECTOR POSITION OFFSET FOR BANDWIDTH ENHANCEMENT OF A MULTIMODE OPTICAL FIBER LINK

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1. INTRODUCTION

Recently there has been a demand for increased data transmission rate of local area networks (LAN) in the form of new Gigabit Ethernet standards. These high-speed optical links are required for offices, buildings and campus backbones. One of the most important requirements of these high-speed links is low cost, which can not be achieved by replacing the existing narrow band MMF by large bandwidth single mode fiber links. Unfortunately the bandwidth – distance product of these multimode fiber links is limited due to modal dispersion. It has been observed that even at 1300 nm wavelength for low dispersion MMF, the maximum bandwidth capacity for 62.5 μm diameter multimode fiber is only 500 MHz.km for over-filled- launch (OFL) conditions which is far short of the required 1 GHz.km. The modal dispersion in the MMF is caused due to various propagation paths for different modes. The higher order modes travel farther away form the fiber axis thus taking longer time to travel the same distance as the lower order modes traveling close to the fiber axis. This time difference in traveling modes results into pulse broadening or dispersion, which reduces the fiber capacity. Haas and Santoro [1] in 1991 reported a method to overcome this problem in MMF by using single-mode launching to multimode to single –mode reception. The idea was to launch only fundamental mode into multimode fiber and filter out the fundamental mode on reception. This splicing provides larger bandwidth but results into heavy signal losses especially at the receiver splice due to energy losses in higher order modes. Later these authors proposed another scheme of selective excitation of higher-order modes by using single mode fiber launch into multimode fiber at an angle as shown in Fig. 1, [2]. This method provides fairly good improvement in the bandwidth but maintaining the angular offset under vibrations is not easy. In an another SMF to MMF launch technique, a small launching spot is radially offset from the MMF core, Fig. 2, [3]. In this technique the authors have experimented three methods of launching light from SMF into MMF. The first one uses two lenses, an initial collimating lens followed by a focusing lens so that the spot size at MMF can be varied. In the second method a fiber lens is placed close to the MMF end resulting in a very small spot. In the third method, the SMF end is placed against the MMF with an offset. These methods provide up to four times bandwidth enhancement even with large number of fiber modes being propagated. However, focusing the spot on MMF under vibrations and other ambient conditions may be difficult. The method under investigation at KSC uses the SMF to MMF launch using connector position offset rather than simple fiber offset. The connector position offset is simple, highly practical, sturdy, cheaper as no additional cost to manufacture the offset connector and is easy to fabricate and maintain even under adverse conditions. The main drawback of offset connector launch is the attenuation of the signal and introduction of noise. Therefore in order to maintain proper signal to noise ratio, the optimization of offset is very important. The main objective of this project is to do an experimental study of the optimization of connector position offset for bandwidth and attenuation of optical signal at higher bit rate.

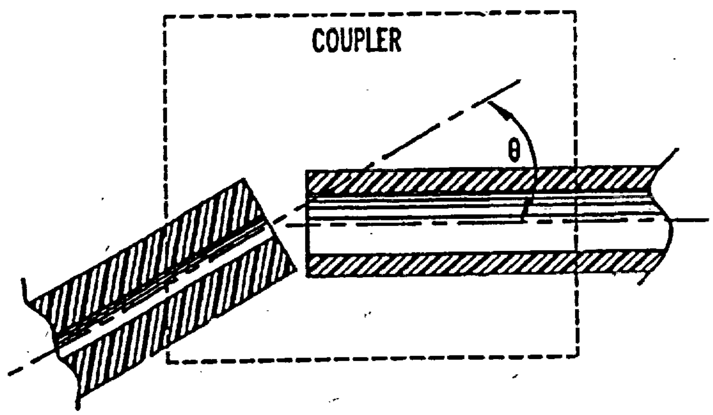
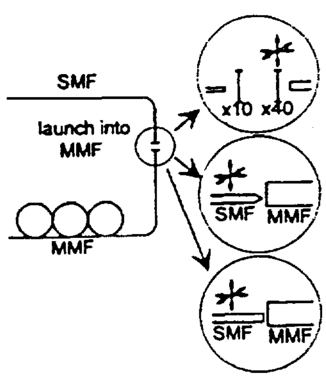
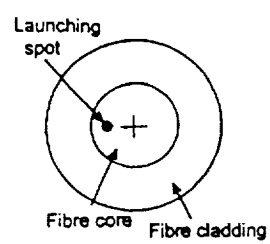


Fig.1. Angular offset coupler for SMF to MMF launch



(a) Three different launching schemes



(b) Realization of offset launch

Fig.2. SMF to MMF coupling using radially offset launching spot

2. BASIC CONCEPT AND ANALYSIS OF OFFSET CONNECTOR LAUNCH TECHNIQUE

The basic concept of offset launch is to excite only a group of all the modes of the MMF at the launch thus reducing the pulse broadening due to lower modal dispersion. This lower modal dispersion results into increase in bandwidth. It is observed that the relative propagation delay is dependent on the refractive index profile of MMF and mode group order in the fiber as shown in

Fig. 3. It is evident that the resulting pulse broadening can be reduced by considering a selective excitation of modes as the modal group delays change linearly with mode number [5]. Also the higher order mode groups contain more modes than the lower order ones. It means the selective mode excitation still propagates larger number of modes resulting into reduced modal noise along with reduced dispersion. However, the noise is certainly higher compared to OFL condition, therefore the optimization of connector position offset is necessary. The modal propagation constants and delays can be determined for MMF with a pure "power law" refractive index profile and through analytic solutions [4]. The effective number of excited fiber modes are given as

$$m = (\Sigma a_i)^2 / \Sigma a_i^2 \qquad (1)$$

where a_i is the power in the i^{th} mode. The mode dependent losses are obtained from loss coefficient of the type [3],

$$P_{v\mu} = \exp (x.R^{2y}_{v\mu}) \qquad (2)$$

for $LP_{v\mu}$ th mode with x and y as fitting constants and $R^2_{v\mu}$ as the relative propagation constant given as

$$R^2_{v\mu} = ½ . [n_{core} / (n_{core} - n_{clad})] [1 - \beta^2_{v\mu} / k^2_0 n^2_{core}] \qquad (3)$$

where n_{core} is the refractive index at core center, n_{clad} is the cladding refractive index, $\beta_{v\mu}$ is the propagation constant and k_0 is the free space wave number. The fitting constants x and y are obtained by fitting the function to the experimental data of the dependence of detected power on the launch position.

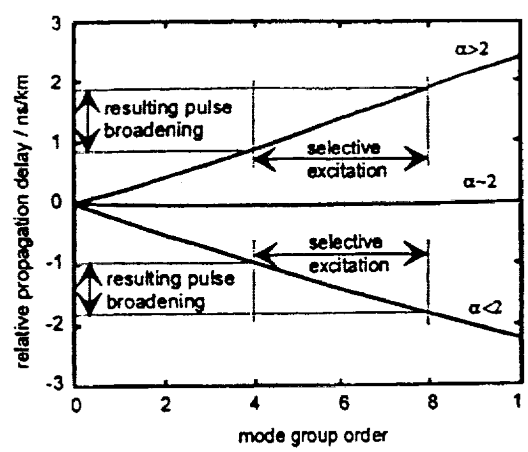


Fig.3. Relative propagation delay for various mode groups as a function of refractive index profile parameter α, with fiber diameter of 50 μm and 1300 nm wavelength (Ref. [3]).

If all the modes of a MMF are not excited perfectly, the bandwidth varies due to changes in the launch power distribution. The tuning or excitation of the modes in the fiber is determined in terms of differential mode delay (DMD) measurement [5]. The DMD measurement is important for determining and improving the performance of MMF as any variation in the refractive index profile from the optimal refractive-index profile is easily determined by measuring DMD compared to measuring refractive–index profile. At the same time the noise for offset connector condition increases due to reduced number of modes. Under OFL condition, the noise is reduced due to noise phase cancellation of various modes while for offset condition this cancellation does not take place due to reduced number of modes.

3. EXPERIMENTAL STUDY OF OFFSET CONNECTOR UNDER INVESTIGATION AT KSC

The offset connector under study at KSC consists of a standard FC type connector at the end of input SMF coupled to a standard ST type connector at the end of output MMF. This connector assembly is housed in a 12.4-cm long cylindrical metallic container. The input SMF (yellow color) in the form of a cable has a diameter of 9 μm and is about 10 m long while the output MMF (orange color) also as a cable has a diameter of 50 μm and length of 8 km. The complete offset connector assembly on a positioning system is shown in Fig. 4. The input power from the source is kept at about – 0.35 dBm and the output power at the end of 8 km long cable for no-offset condition is about – 8.3 dBm i.e. a loss of 7.95 dB in the fiber. For offset conditions the power at the end of 8 km long MMF cable depends on the size of offset. The measurements of bandwidth, bit- pattern and eye- pattern were conducted using offset connector coupler. For comparison purpose all the measurements were conducted for 500 and 700 Mbps signals at 1300 nm wavelength. It is to be noted that the measurements in the Gbps range could not be conducted as the signal generator in this range was not available in the KSC- Optical Fiber Laboratory at the time of these experiments. The block diagrams of attenuation, bandwidth and data-rate/eye-pattern measuring systems are shown in Figs. 5 (a), 5 (b) and 5 (c).

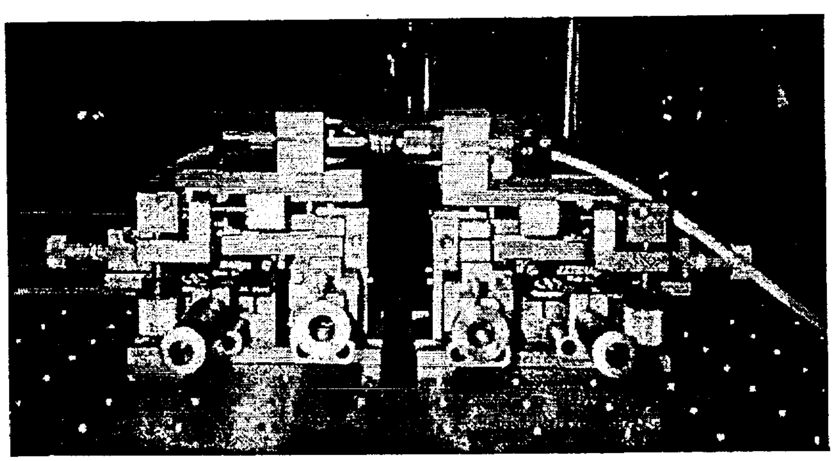
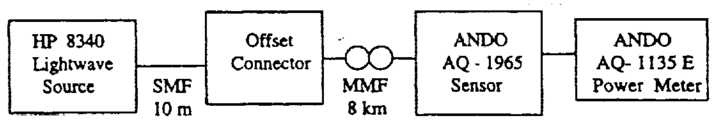
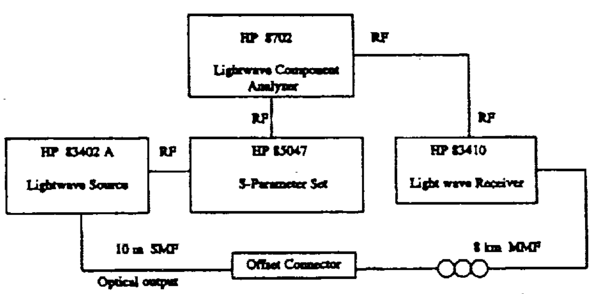


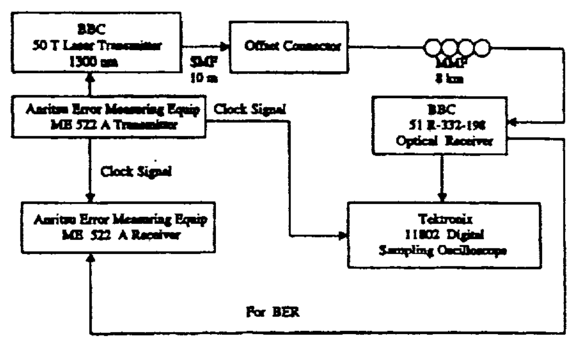
Fig.4. Offset connector assembly on positioning system

As shown in Fig. 5 (a), the attenuation was measured with the help of HP 8340 lightwave source, ANDO AQ-1965 optical detector or sensor and ANDO AQ-1135 E power meter. The bandwidth measurement system as shown in Fig. 5 (b), consists of HP 8340 A lightwave source, HP 83410 lightwave receiver, HP 8702 lightwave component analyzer and HP 85047 S-parameter set. The lightwave source is modulated with RF signal coming from lightwave receiver through component analyzer and S-parameter set. The offset connector under investigation is connected to 10 m long SMF at the input side and to 8 km long MMF at the output. The optical output at the end of 8 km long MMF is automatically measured for various frequencies. The main components of the data rate and eye-pattern measuring system shown in Fig. 5 (c) are: BBC-50 T, 1300 nm laser transmitter, BBC-51 R-332-198 optical receiver, Anritsu error measuring equipment with ME 522 A optical digital transmitter/receiver and Tektronix 11802 digital sampling oscilloscope.



(a) Attenuation measurement



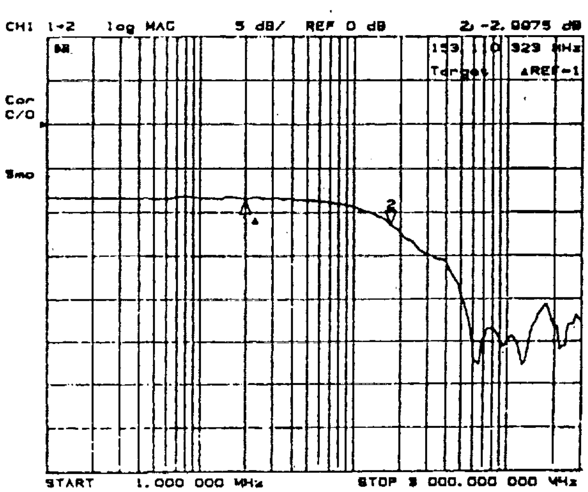


(b) Bandwidth measurement (c) Eye-pattern and data rate measurement

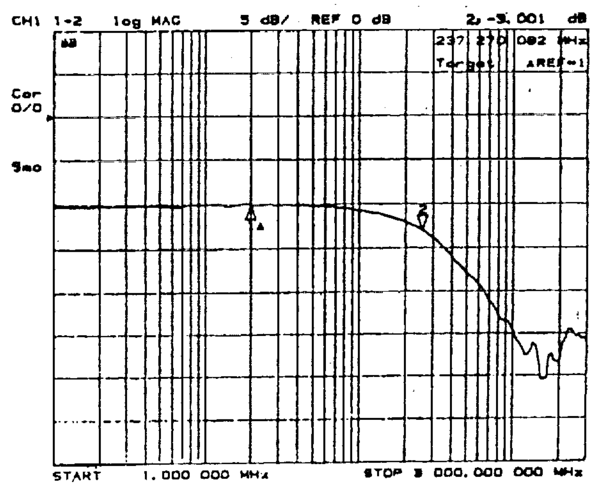
Fig.5. Block schematics of measurement set-ups

4. RESULTS AND DISCUSSION

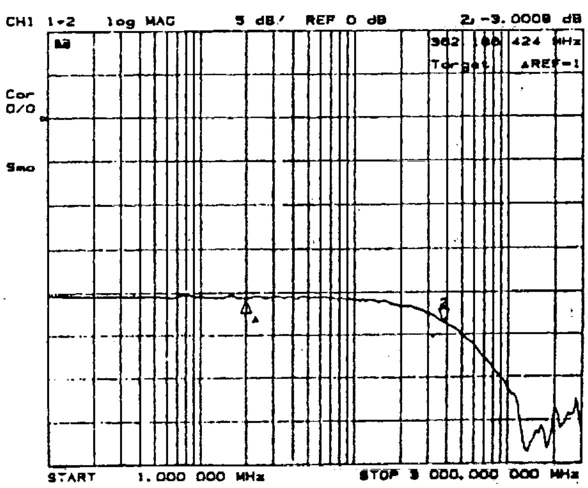
The 3-dB bandwidth of the signal and received power for 10, 20 and 30 μm offset positions are shown in Fig. 6 while Table 1 represents these values for all the measured offset positions as well as percentage increase in bandwidth and the fiber capacity. Due to page limitations only a few representative experimental figures are being provided. As expected the bandwidth increases when the offset is increased but at the expense of received power. It is observed that in comparison to the bandwidth at 0 μm offset the percentage increase in the bandwidth for 20 μm offset is 136.56 which is slightly less than the maximum value of 139.53 for 25 µm offset. But the received power at 20 µm offset is 6.3 dB higher than the 25 µm offset. For higher offset values not only the power decrease but the bandwidth also decreases. Thus the 20 µm offset can be considered as an optimization point where the received power of –20.4 dBm is also within acceptable limit.



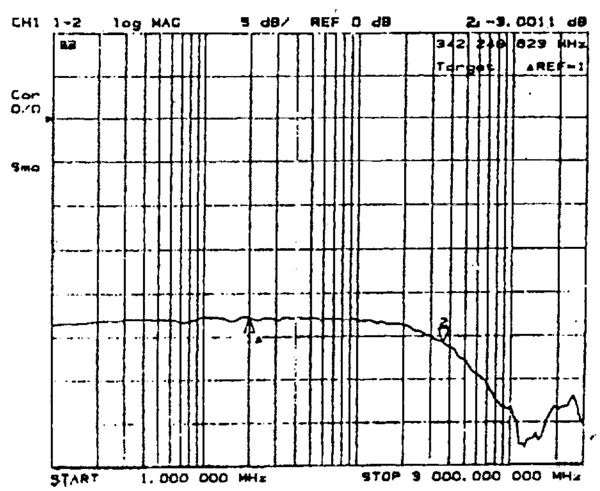
(a) 0 µm offset



(b) 10 µm offset



(c) 20 µm offset



(d) 30 µm offset

Fig. 6. 3-dB Bandwidth and received power for different offset positions

The improvement on bandwidth due to connector offset position can also be visualized from digital perspective of the signal transmission. This has been experimentally obtained in the form of eye-pattern and bit-pattern as shown in Fig.7 for some selected offset positions. Table 2 summarizes the effect of offset on eye-opening and percentage noise jitter for 500 Mbps and 700 Mbps signal transmissions for all offset positions.

Table 1- 3-dB Bandwidth and received power for various offset positions

Offset μm	3-dB Bandwidth MHz	% Increase in BW	Received Power dBm
0	153.11	-----	-8.3
5	187.13	22.22	-10.0
10	237.27	54.96	-10.3
15	272.47	77.96	-11.8
20	362.19	136.56	-20.4
25	366.75	139.53	-26.7
30	342.25	123.53	-28.3

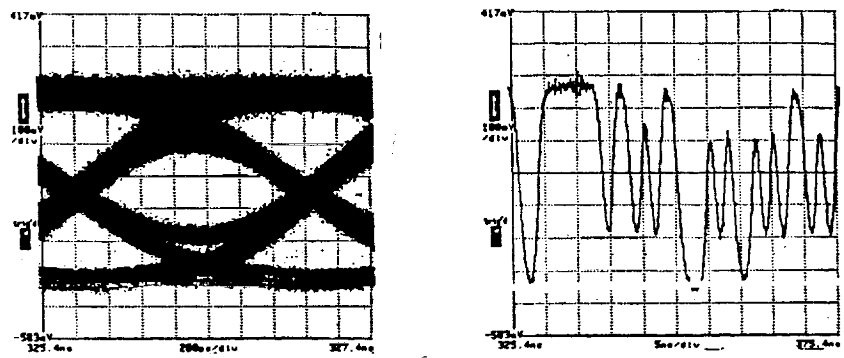
Table 2- Eye pattern size, pulse rise time and noise jitter for various offset positions

Offset	For 500 Mbps				For 700 Mbps			
	Eye pattern size		Rise time	Jitter	Eye pattern size		Rise Time	Jitter
μm	Hor ns	Ver mV	ns	%	Hor ns	Ver mV	ns	%
0	1.375	143.75	2.4688	31.25	----	----	2.1875	---
5	1.656	325.00	2.8125	18.19	0.850	162.50	1.7525	40.50
10	1.750	325.10	0.9575	12.50	1.150	237.50	1.0938	19.50
15	1.688	350.00	1.4375	16.63	1.126	262.50	1.0655	21.22
20	1.719	337.50	0.5313	14.06	1.175	487.50	0.9375	17.75
25	1.698	305.50	0.5527	15.13	1.061	275.50	0.9885	25.77
30	1.688	287.50	0.5625	15.63	0.913	181.25	1.1250	36.16

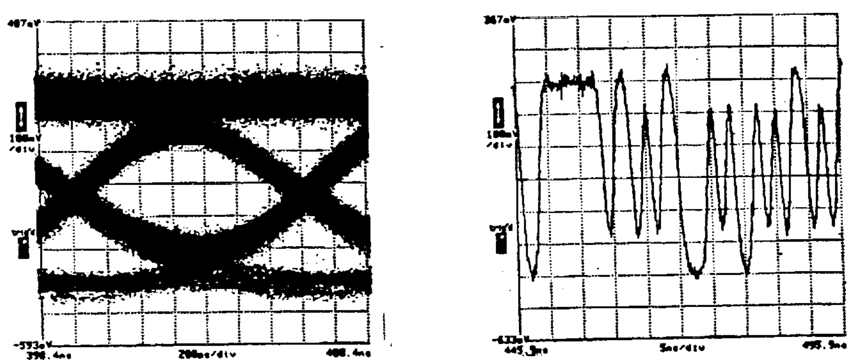
From Fig. 7 and Table 2, it is evident that the eye-pattern opening is maximum for 20 μm offset resulting into higher bit rate performance of the fiber. For higher values of the offset the noise level goes up, thus reducing the eye opening. This is also indicated by the lowest value of noise jitter in the Table. For zero offset condition the noise level becomes very high as large number of modes propagate in the fiber resulting into very high dispersion and noise. At the same time it is also observed that the pulse rise time for 20 μm offset is only 0.9375 ns and the noise jitter is

17.75%, which are the lowest of all the values indicating lower dispersion and noise. After comparing the signal transmissions at 500 Mbps and 700 Mbps it is noticed that the offset does not make much improvement on 500 Mbps transmission.

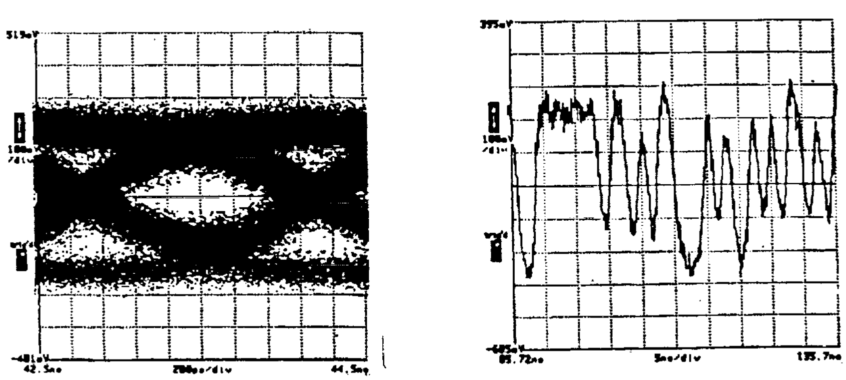
Eye-pattern Bit-pattern



(a) 10 μm offset



(b) 20 μm offset



(b) 30 μm offset

Fig. 7. Eye- and bit- patterns for different offset positions

5. CONCLUSION

Basic concept and analysis of an offset connector launch technique has been thoroughly investigated. The connector position offset has been experimentally optimized at an offset of 20 μm where noise and received signal levels seem to be within acceptable limits. It is important to note that the positioning system used in the experimental study was not very precision one and also the experiments have been conducted for 700 Mbps signal transmission rather than 1 Gbps or greater as required by the Gigabit Ethernet standards. It is recommended that before implementing this technique for KSC and other NASA centers further investigations regarding noise, differential mode delay and vibration effects with utmost precision should be conducted.

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