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Precise Timing Signal Transmission by a New Optical Fiber Cable

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Abstract

For the precise timing signal transmission, a new optical fiber cable system was developed and installed between the 2.5GeV LINAC gun room and the TRISTAN control room. This fiber cable showed the reduced thermal transmission delay change less than 10psec/km in the temperature range from -20 to 30 °C(average 0.04ppm/°C), which is 100 times smaller than that of any other existing coaxial cables and conventional optical fiber cables. The developed optical to electrical(O/E) and electrical to optical(E/O) converters also achieved the timing accuracy within 11psec over the temperature range from 10 to 35 °C.

The installed cable system in KEK eliminated the necessity of adjusting the phase drift of the TRISTAN Accumulation Ring(AR) RF signal(508MHz), which was required with the former coaxial cable due to the temperature change in a year. Measured full width of jitter over the installed 1600m fiber link was 18.8psec.

Keywords: timing, jitter, optical, fiber, O/E, E/O

1. Introduction

Optical fiber transmission system has advantages of low attenuation (0.35dB/km), wide bandwidth(more than 1GHz over dozens of kilometer) and immunity to electro-magnetic interference. In order to exploit these benefits of optical fiber cable in the precise timing transmission over a long distance, a special optical fiber cable, which features the highly stabilized transmission delay time against temperature change as low as 0.1ppm/°C and high resistance against irradiation, was developed in combination with corresponding analog electrical to optical(E/O) and optical to electrical(O/E) converters. This new system was installed between the TRISTAN AR and the 2.5GeV LINAC, and their performance in transmitting the AR RF signal(508MHz) has been evaluated. So far the new system eliminated the necessity of adjusting the RF phase drift in a year which had been frequently required with the former coaxial cable.[1],[2]

In this report, together with the field test results, we describe the performances of the developed optical fiber cable with minimum transmission delay drift, and E/O, O/E converters. The confirmed high stability suggests that the use of this cable system will effectively simplify and improve the "main drive lines" in the acceleration systems, where large diameter coaxial cables are used in the special conduit with sophisticated temperature control.

2. Phase stabilized optical fiber cable

Generally the transmission delay time drift in the cable is caused by the thermal elongation of the cable. The value is more than 10ppm/°C with the coaxial cables, which sometimes leads to a difficulty in transmitting a precise timing signal. For the conventional optical fiber cables, thermal coefficient of delay time(TCD) is still 6ppm/°C(30ps/km/°C) or more. The origin of TCD in optical fiber and the strategy to overcome it are as follows.

Transmission delay time τ for a fiber with length L is given by

$$\tau = \frac{L \cdot N}{c} \qquad (1)$$

,where N is the refractive index of the fiber glass and c light velocity in vacuum. TCD in the optical fiber is obtained by differentiating the above equation.

$$\frac{1}{\tau}\frac{d\tau}{dT} = \frac{1}{L}\frac{dL}{dT} + \frac{1}{N}\frac{dN}{dT} \qquad (2)$$

The first term indicates the thermal elongation of the cable, which is usually of positive value. The second term corresponds to the thermal change of the refractive index, which is 6ppm/°C for the silica glass. Totally the TCD of the conventional optical fiber becomes 6ppm/°C or more. Since the second term is intrinsic as far as silica is used for the optical fiber, the residual strategy is to make the thermal elongation of the fiber negative by tightly coating the fiber with a negative thermal expansion material so that both terms in the right-hand side of the above equation cancel each other. Based on this approach, a new coating material was developed.

Figure 1 shows the measured transmission delay time change against temperature for the fiber cable installed in KEK. For the comparison, typical data for the conventional fiber is also shown in Figure 1. It is shown that TCD of the new cable becomes zero around 10°C. Even in the whole expected operation range -20 to +30°C, the transmission delay change is only within 10ps/km. These values are far better than any other existing cables.

3. E/O,O/E converters

The block diagrams of the developed E/O and O/E converters are shown in Figure 2 and Figure 3. The E/O converter consists of a wide bandwidth laser diode module, a driver circuit, and an auto-power control(APC) circuit in order to stabilize the emitted power. The timing signal is fed to the driver circuit with 50ohm impedance and equalized to achieve the flat frequency response.

The O/E converter consists of a PIN-AMP module and a commercially available low noise amplifier. For the following reasons, the PIN-AMP module was specially designed for the timing signal transmission system:

(1) In order to assure a wide bandwidth and high gain, a PIN-PD should be mounted very nearly to a pre-amplifier IC on the same substrate.

(2) The SMA connector interface is preferable as an electrical interface to the pin interface such as DIP or Butterfly.

The pre-amplifier IC is also developed specially for the timing signal transmission system by using GaAs process. Table 1 shows the experimental results. Figure 4 shows the total frequency response in transmitting the signal from the E/O converter to the O/E converter.

Also the phase drift of 600MHz signal transmission for each E/O and O/E converter was measured over the temperature range from 10 to 35 °C with the other converter holding at a constant temperature of 20 °C, respectively. The results are shown in Figure 5. The obtained over-all phase drift corresponds to only 11psec. Another investigation about the timing jitter width clarified that the origin of the phase jitter is derived from the thermal noise in the optical receiver circuit. Hence, an appropriate bandpass filter should be used to improve the signal to noise ratio.

4. Field Test Results

As shown in Figures 6 and 7, the new cable was installed from the gun room of LINAC to the main control room of the TRISTAN AR in April 1989. The cable has 800m length and contains 6 fibers in it. 300 meter of the total cable was layed even in the underground Positron Beam Transfer(BT) Line(Figure 7) where the cable was subjected to the irradiation. Since the core material of this fiber is pure silica, this fiber cable is much resistant to irradiation than conventional fiber cables.

One of the six fibers in the cable was connected to the E/O and O/E converters at both ends to replace the existing coaxial system of transmitting 508MHz RF timing signal. This coaxial cable, although it had been designed to have a thermally stabilized electrical length, required phase adjusting several times a year. On the contrary, the new optical fiber cable system has been operating without any phase delay adjusting to March 1990. The superiority of the new system is demonstrated.

For the further characterization of the system, the following experiments were conducted. Two other fibers in the cable were connected together at the gun room so that they made a 1600m link with both input and output ends locating at the control room. Using this 1600m link with measuring setup shown in Figure 8, jitter and drift of the 508MHz signal were evaluated under the following conditions. Here, except for the condition (d), a bandpass filter of $500 \pm 10MHz$ was inserted in front of the RF amplifier.

(a) Direct monitoring of Signal Generator(SG)

(b) Direct connection of E/O and O/E with short fiber

(c) 1600m link transmission

(d) 1600m link transmission without bandpass filter

Phase jitter was measured by a Tektronix 11802 Oscilloscope, and recorded every 40 seconds for 24 hours to evaluate the long-term drift. As the stabilization indexes, three parameters shown in Figure 9 were extracted. From the full width of the jitter w in every measurement, the average value M and the standard deviation σ_w were calculated. Also the standard deviation σ_c for the center position C of the jitter width was calculated. The measured and calculated results for the above conditions are shown in Figures 10 to 11, and Table 2.

The full width of the jitter for the SG, represented by the average value M shown in Figure 9, was measured as small as 4.4psec, which indicates the stability limit of the employed electrical set-up(Figure 10(a)). The full width of the jitter becomes larger when the E/O and O/E converters are inserted in the circuit, but the value is still as small as 29.1psec(Figure 10(b)). After incorporating a 1600m fiber link, the jitter full width rather decreased to 18.8psec(Figure 10(c)), which is considered that the decrease in input power to O/E converter improved the S/N of the electrical output signal. Anyway it was comfirmed that the jitter in the optical link is evoked only by the E/O and O/E converters and the stability of the timing signal does not degrade even when the transmission length is increased. The long-term drift over the 1600m link transmission is almost negligiblly small(Figure 11), which again demonstrates the advantage of the developed phase stabilized fiber cable. The importance of the bandpass filter is shown in Figure 10(d). Without the bandpass filter of ±10MHz bandwidth, jitter full width increased from 18.8psec to 171.5psec, due to the thermal noise of the O/E converter. Aiming at the further improvement, a narrower bandpass filter of $\pm 2MHz$ bandwidth is being prepared.

5. Conclusion

A new optical fiber cable with highly stabilized transmission delay time and improved resistivity against irradiation was installed in KEK for the transmission of 508MHz timing signal between LINAC gun room and TRISTAN AR. The new optical system eliminated the frequent phase adjusting in the former coaxial transmission system required from the temperature change in a year. Another experiment demonstrated that the jitter over the 1600m fiber link is only 18.8psec and the long-term drift is negligible. The use of this phase stabilized optical fiber system will be effective in the precise transmission of timing signals in the acceleration systems.

Acknowledgements

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References

[1] J.Urakawa, K.Ishii, E.Kadokura, T.Kawamoto, M.Kikuchi and E.Kikutani, To be published in Nucl. Instr. and Meth., A, 1990

[2] J.Urakawa, Submitted to Int. Conf. on High Energy Accelerators, Tsukuba, Japan, Aug 22-26, 1989

Table 1 Characteristics of fabricated E/O and O/E converters

(at 25 ± 5 °C and 600MHz)

Item	Performance	Note
Phase fluctuation	3.3 psec	in 10 minutes
E/O optical output power	+ 1.25 dBm	average value
E/O electrical input level	0 ~ −30 dBm	
O/E electrical output level	−9.7 ~ −39.8 dBm	optical input level is −10 dBm

Table 2 Measured parameters of jitter stabilization

Experiment	BPF	jitter full width		drift
		M	σ_w	σ_c
(a) SG	inserted	4.4 psec	1.4 psec	2.9 psec
(b) E/O and O/E	inserted	29.1	6.2	3.9
(c) 1600 m link	inserted	18.8	4.5	3.0
(d) 1600 m link	none	171.5	32.7	16.3

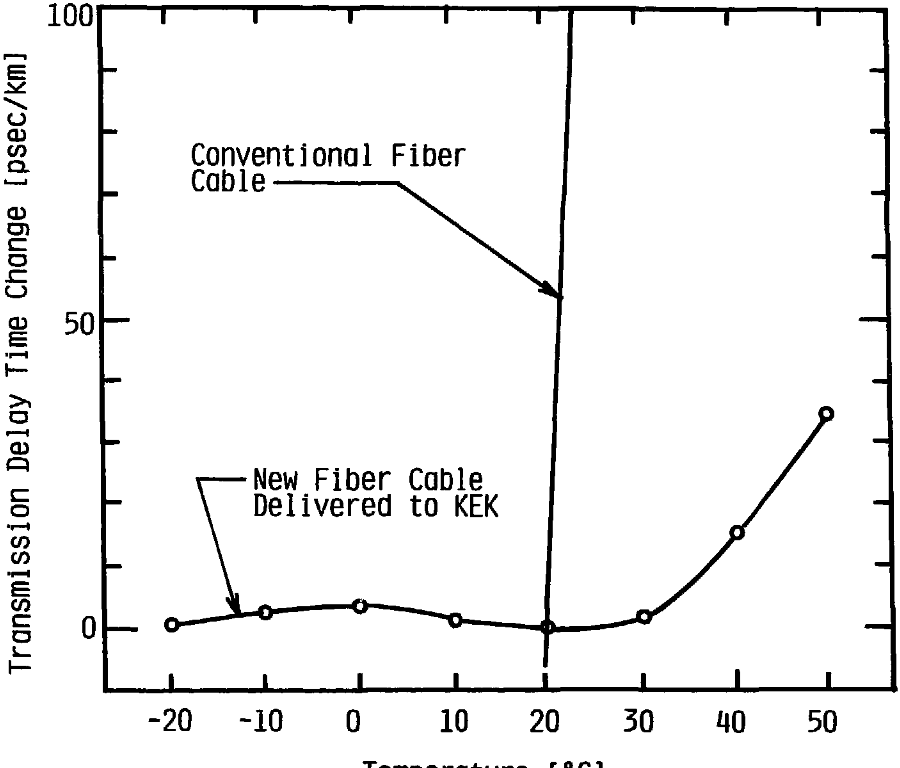

Fig.1 Measured transmission delay time change against temperature for the new cable delivered to KEK

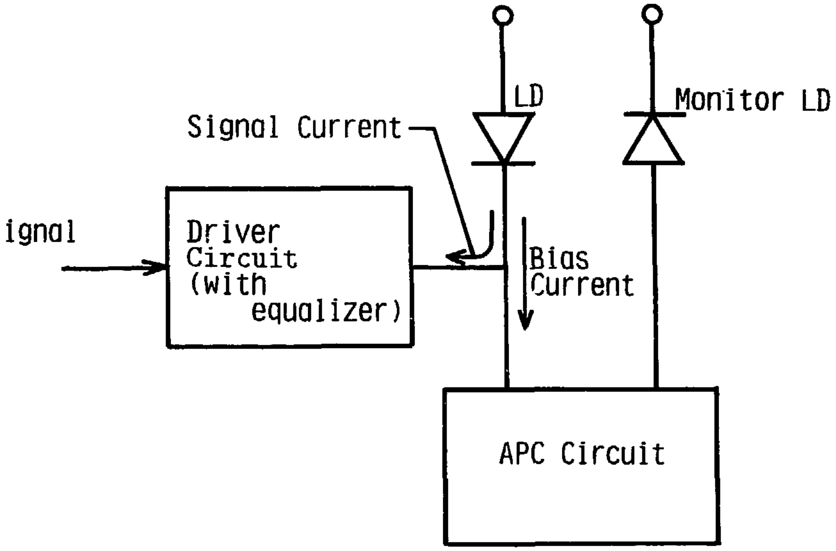

Fig.2 Block diagram of E/O converter

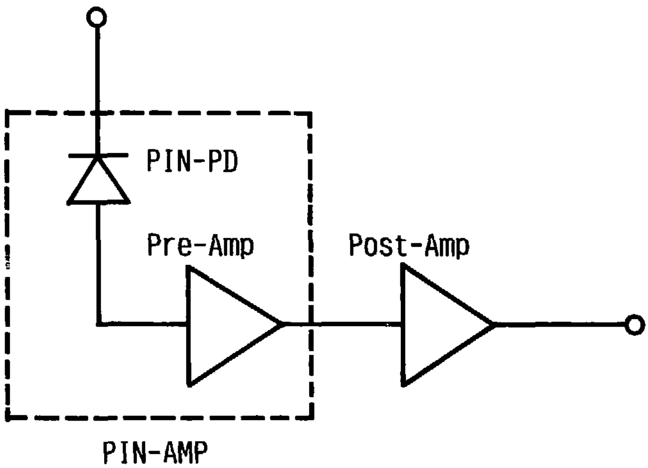

Fig.3 Block diagram of O/E converter

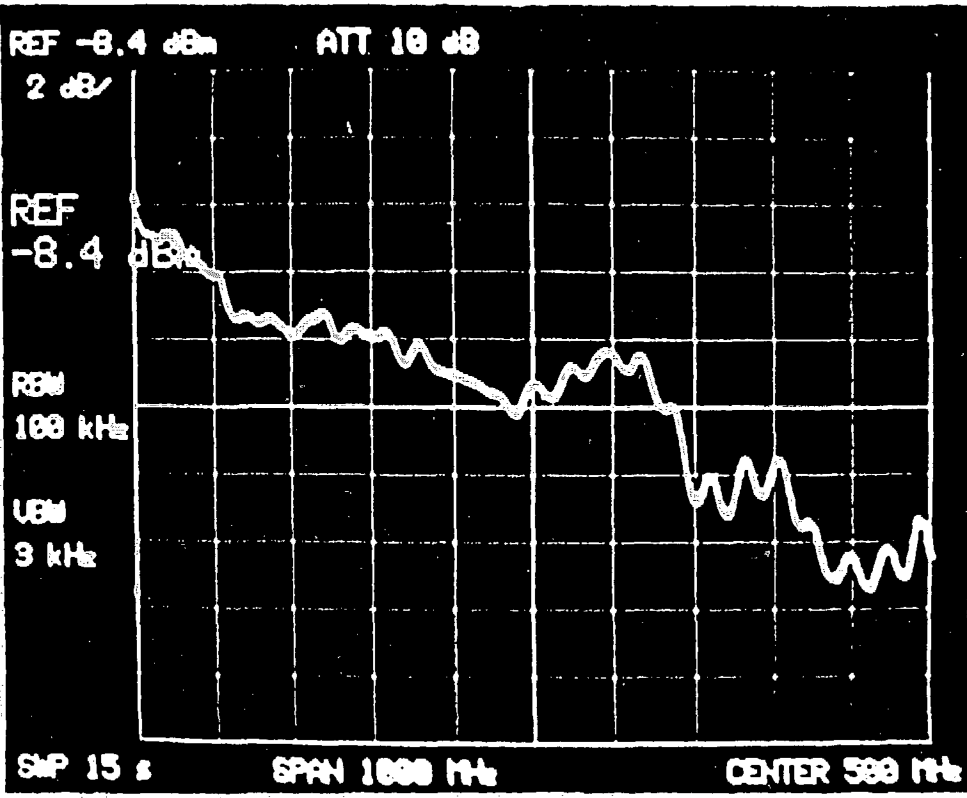

Fig.4 Frequency response of E/O and O/E
(100MHz/div, 2dB/div)

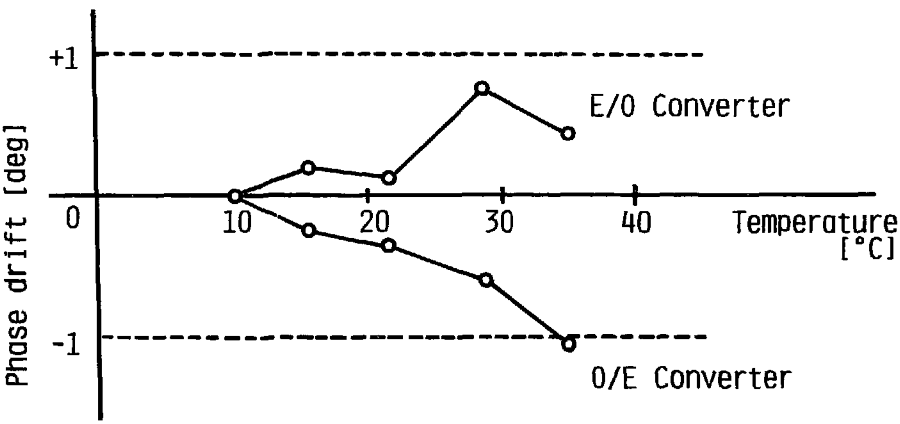

Fig.5 Thermal phase drift of E/O and O/E converters
(at 600 MHz)

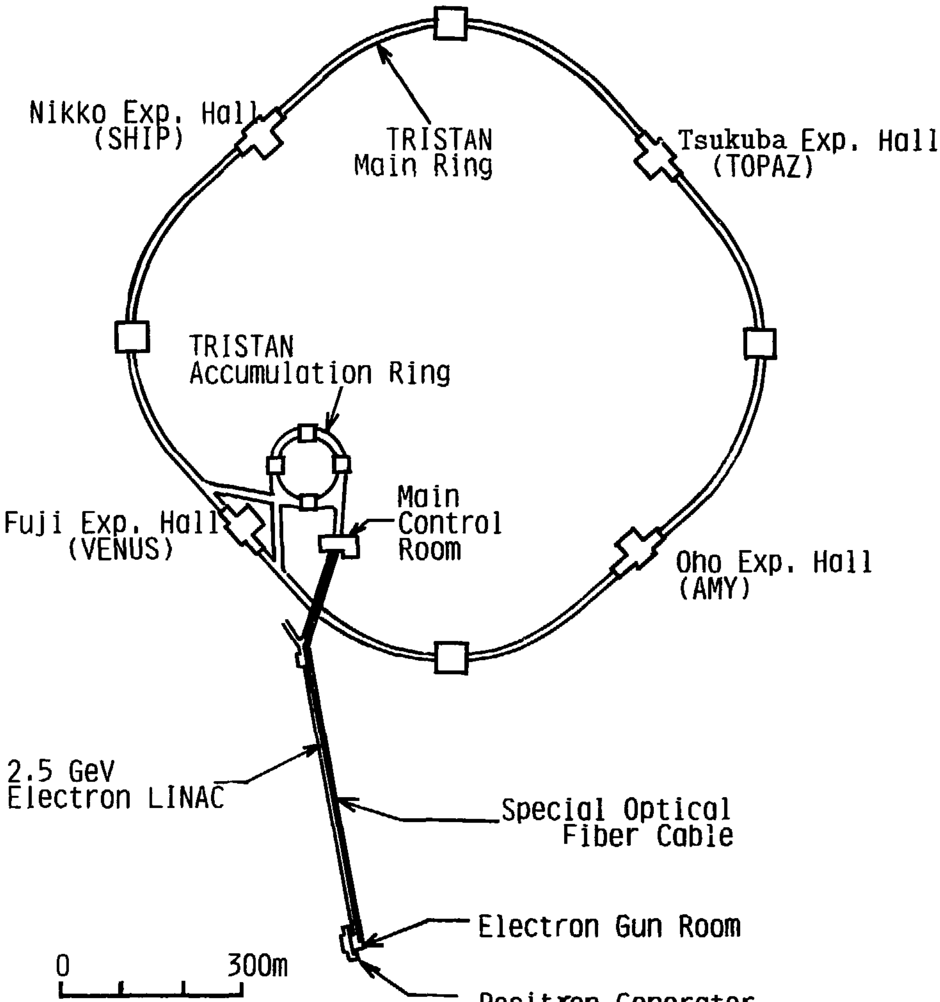

Fig.6 Layout of TRISTAN

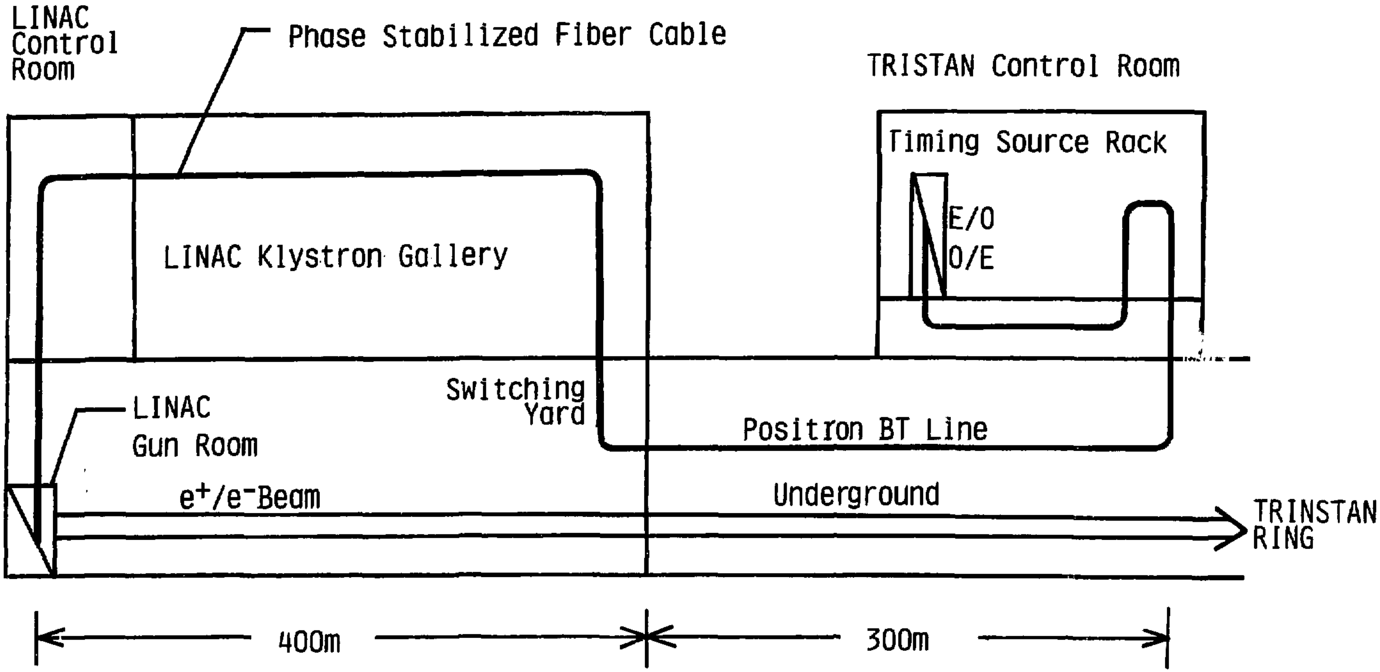

Fig.7 Route figure of optical fiber cable transmission system

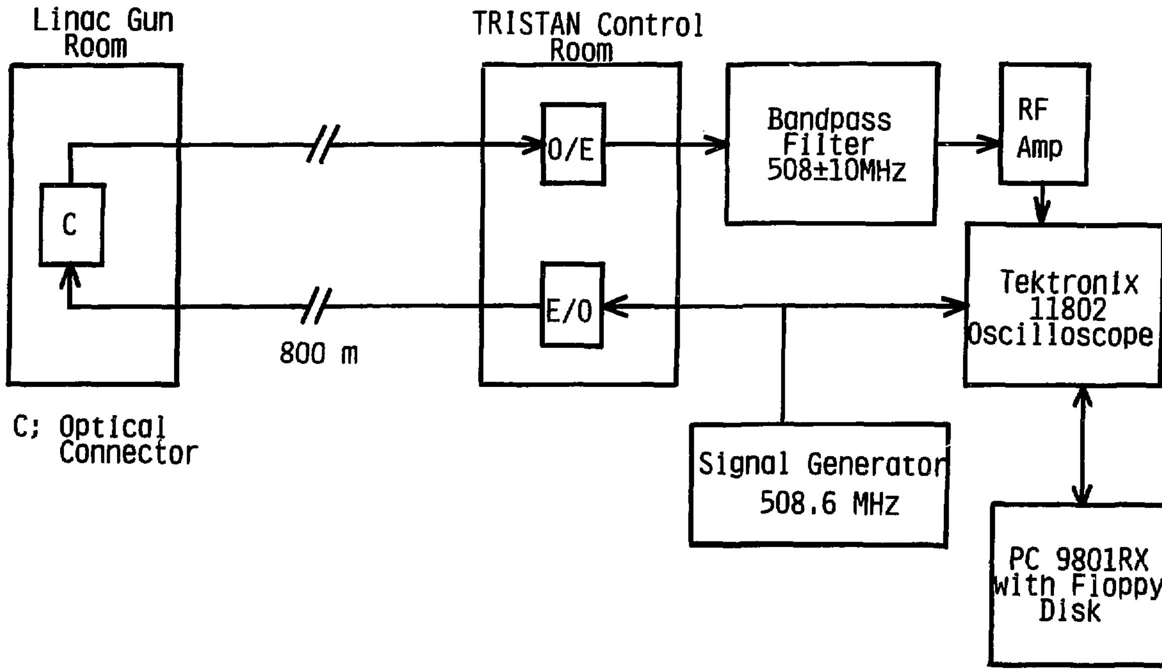

Fig.8 The circuit for the measurement of the timing accuracy

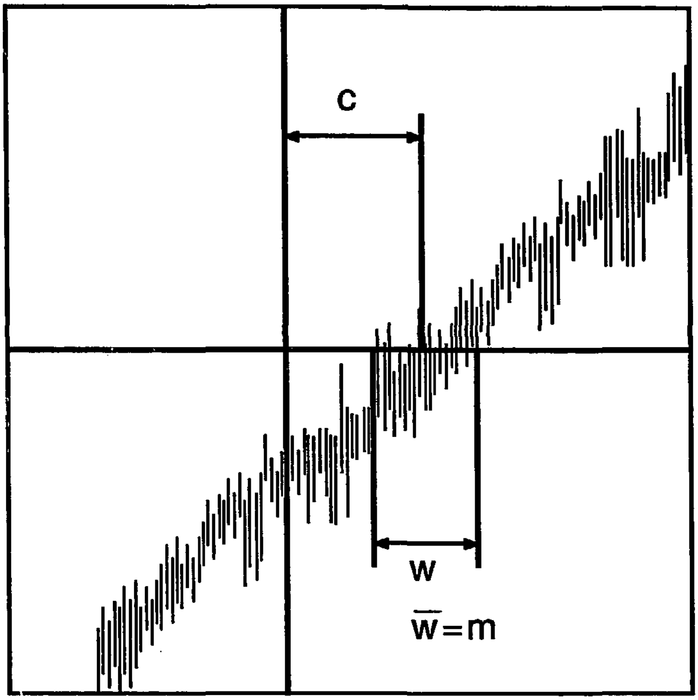

Fig.9 Jitter and drift parameters

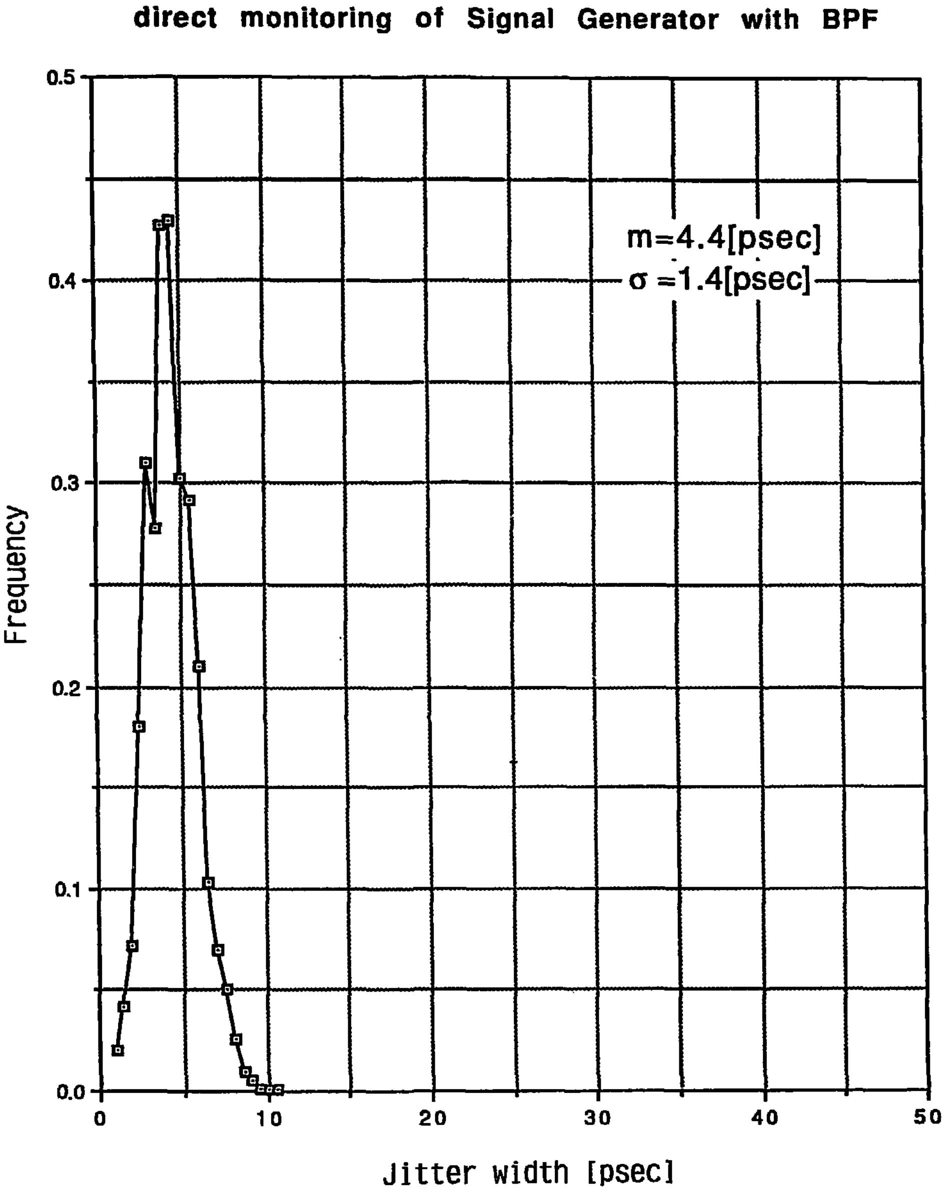

Fig.10(a)-1 Distribution of jitter width
(Direct monitoring of SG with BPF)

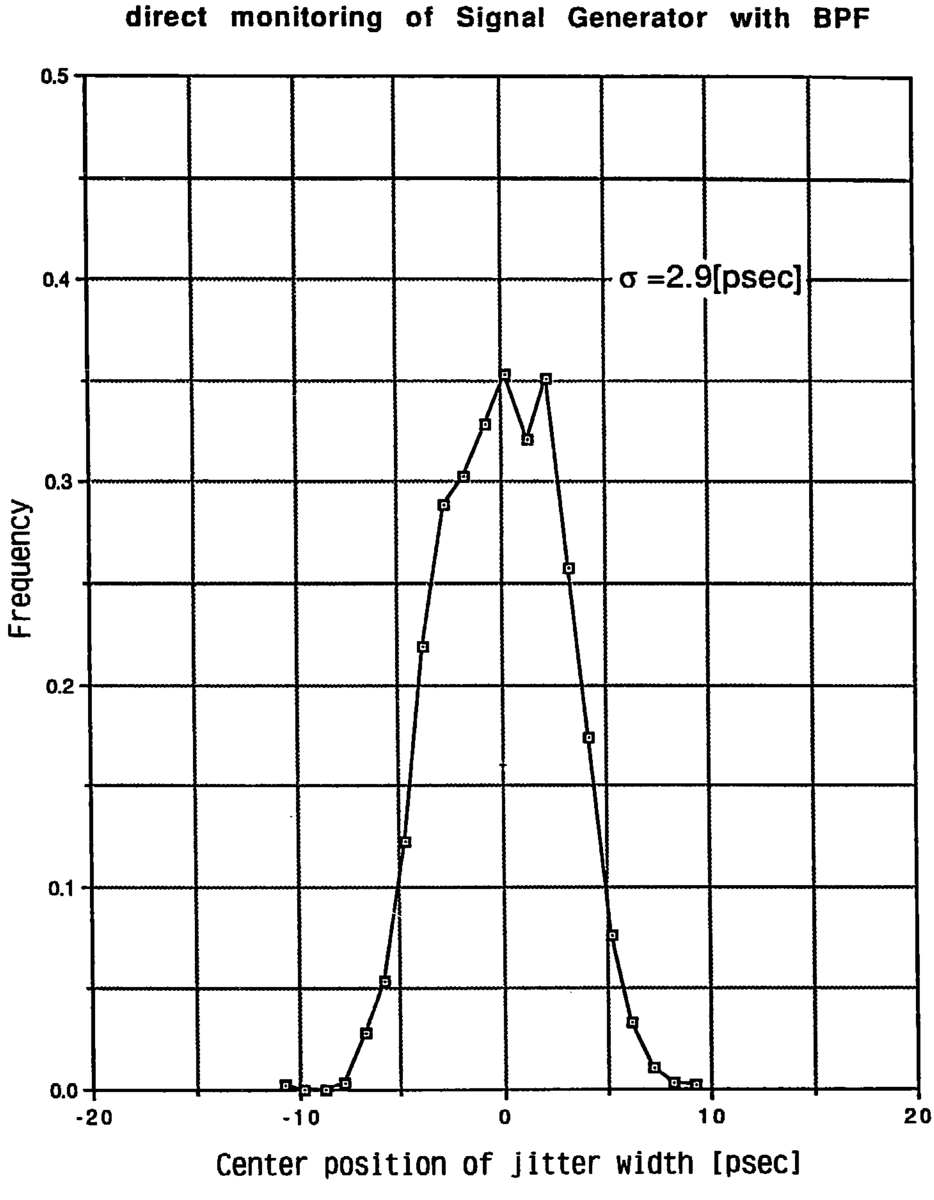

Fig.10(a)-2 Distribution of jitter center position
(Direct monitoring of SG with BPF)

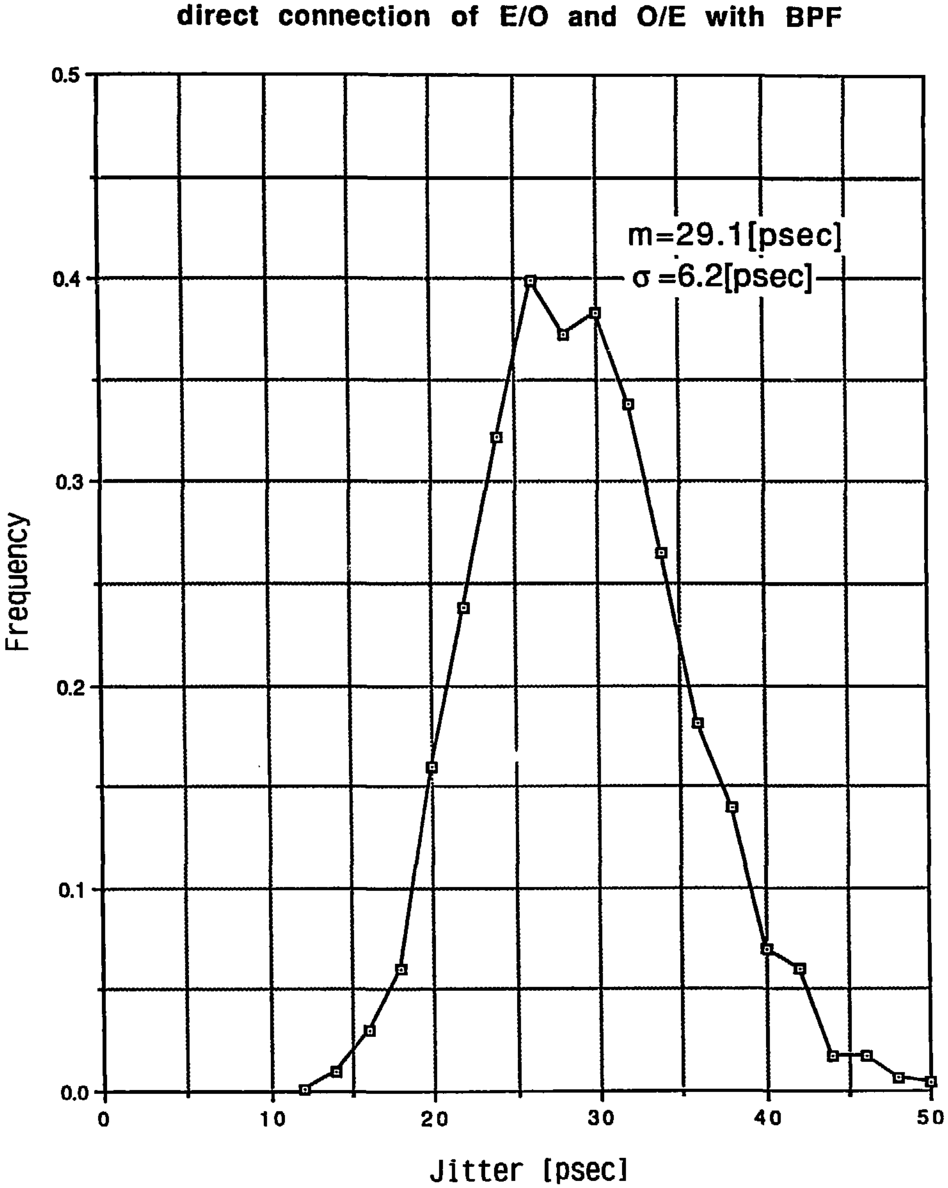

Fig.10(b)-1 Distribution of jitter width
(Direct connection of E/O and O/E with BPF)

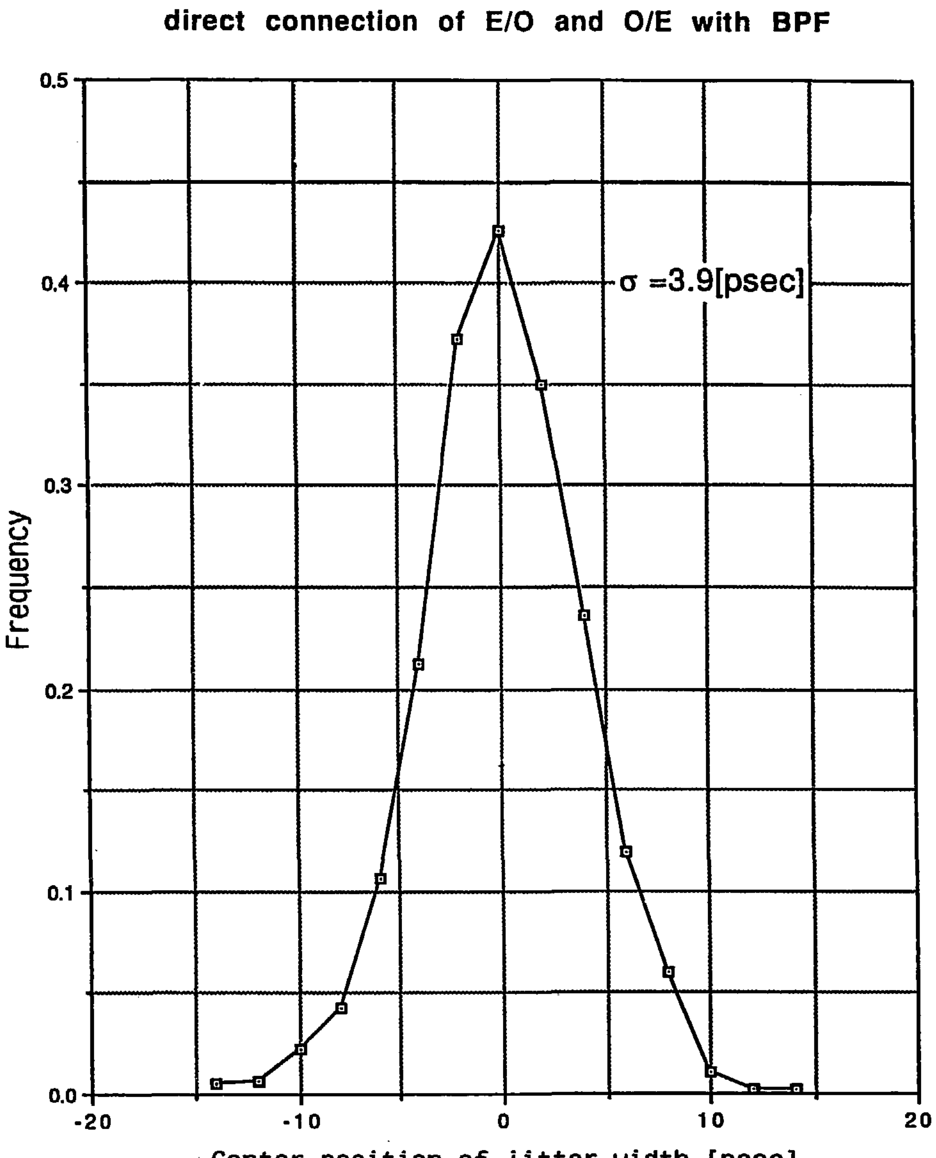

Fig.10(b)-2 Distribution of jitter center width
(Direct connection of E/O and O/E with BPF)

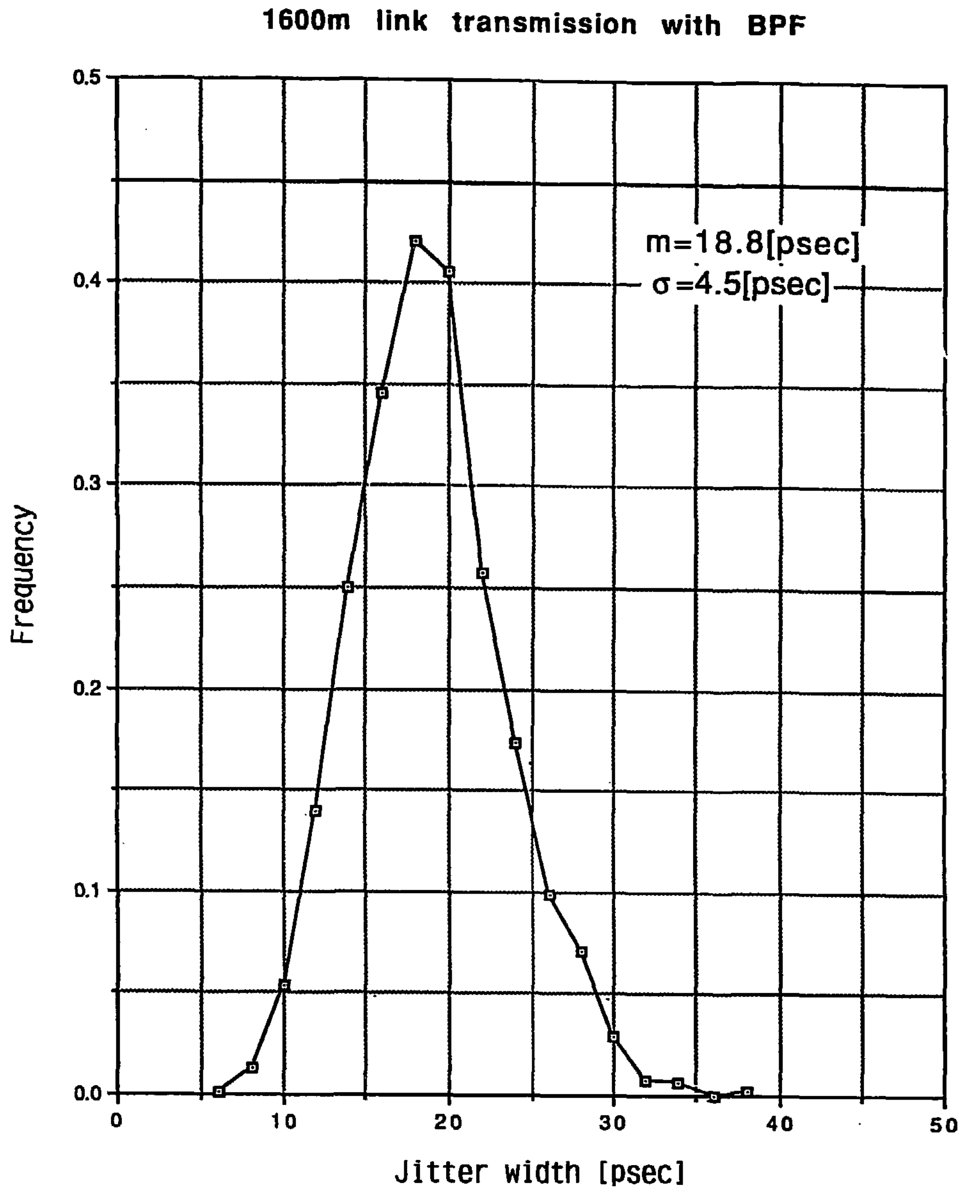

Fig.10(c)-1 Distribution of jitter width
(1600 m link transmission with BPF)

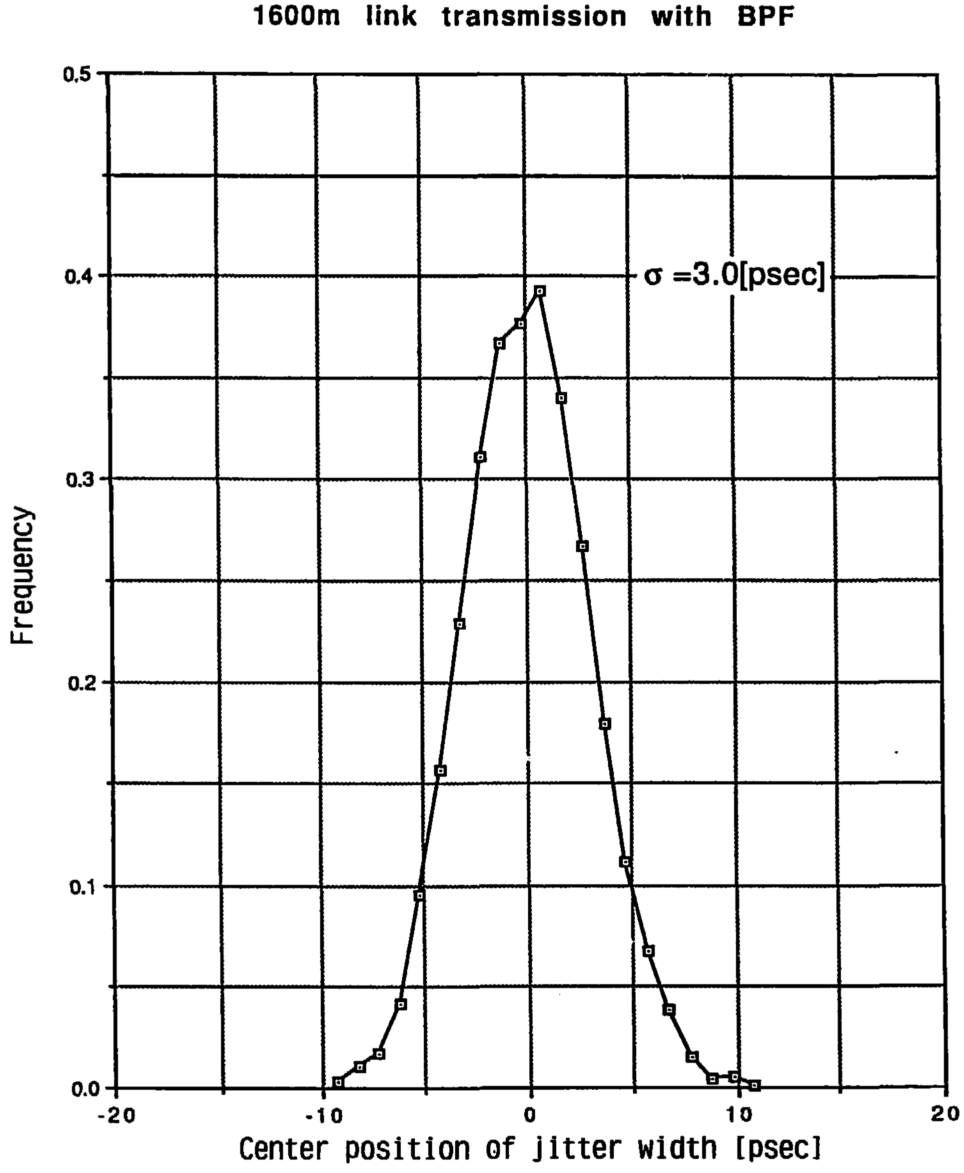

Fig.10(c)-2 Distribution of jitter center position (1600 m link transmission with BPF)

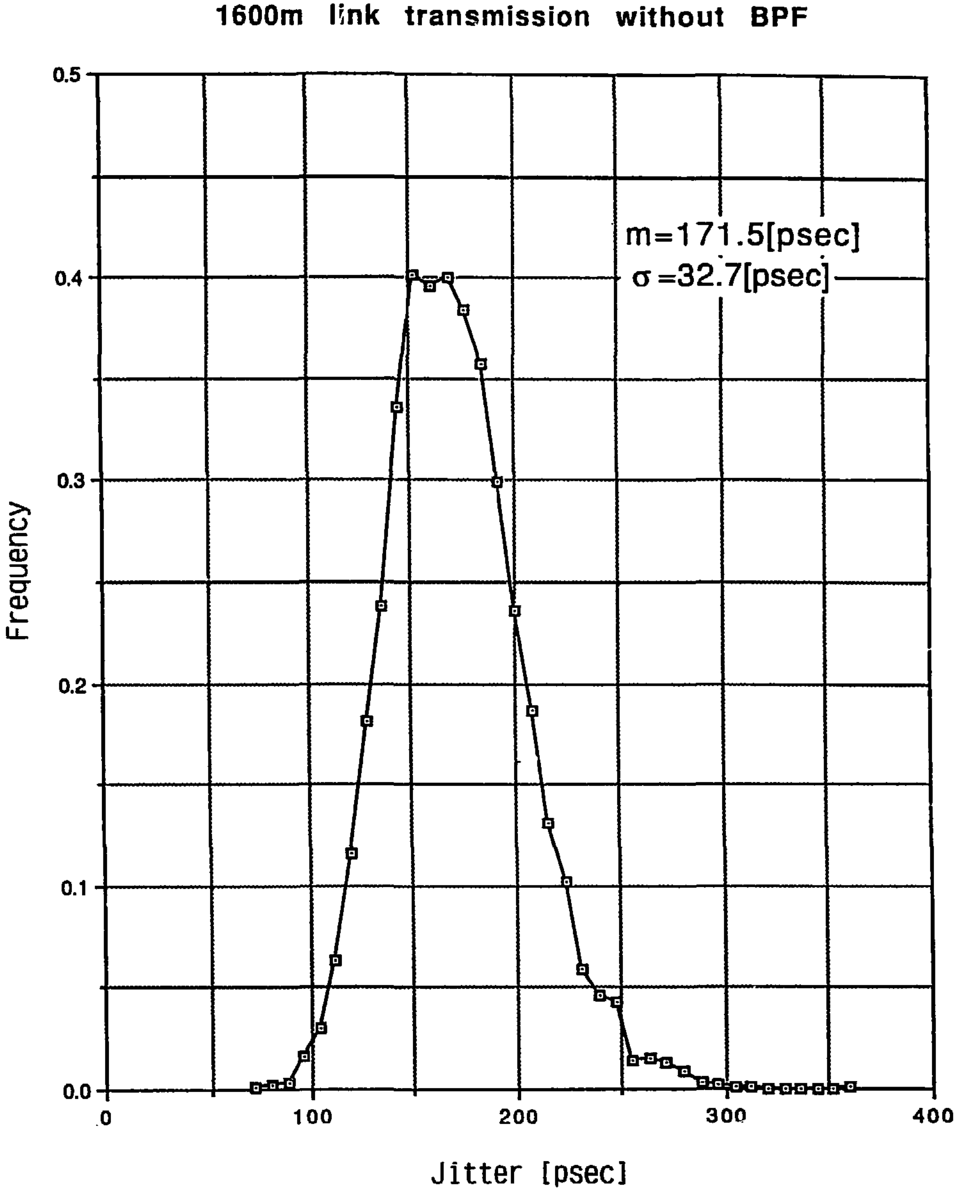

Fig.10(d)-1 Distribution of jitter width
(1600 m link transmission without BPF)

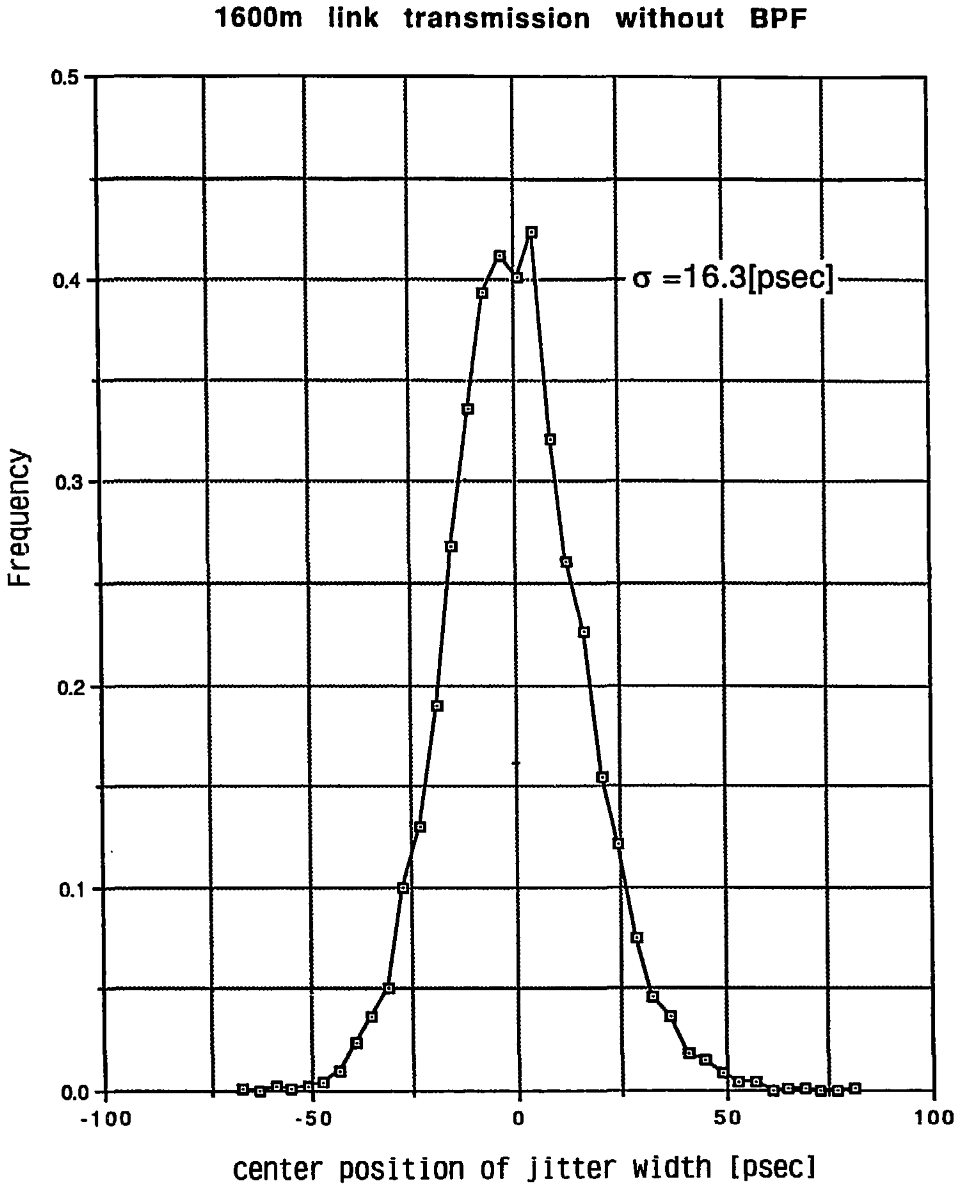

Fig.10(d)-2 Distribution of jitter center position
(1600 m link transmission without BPF)

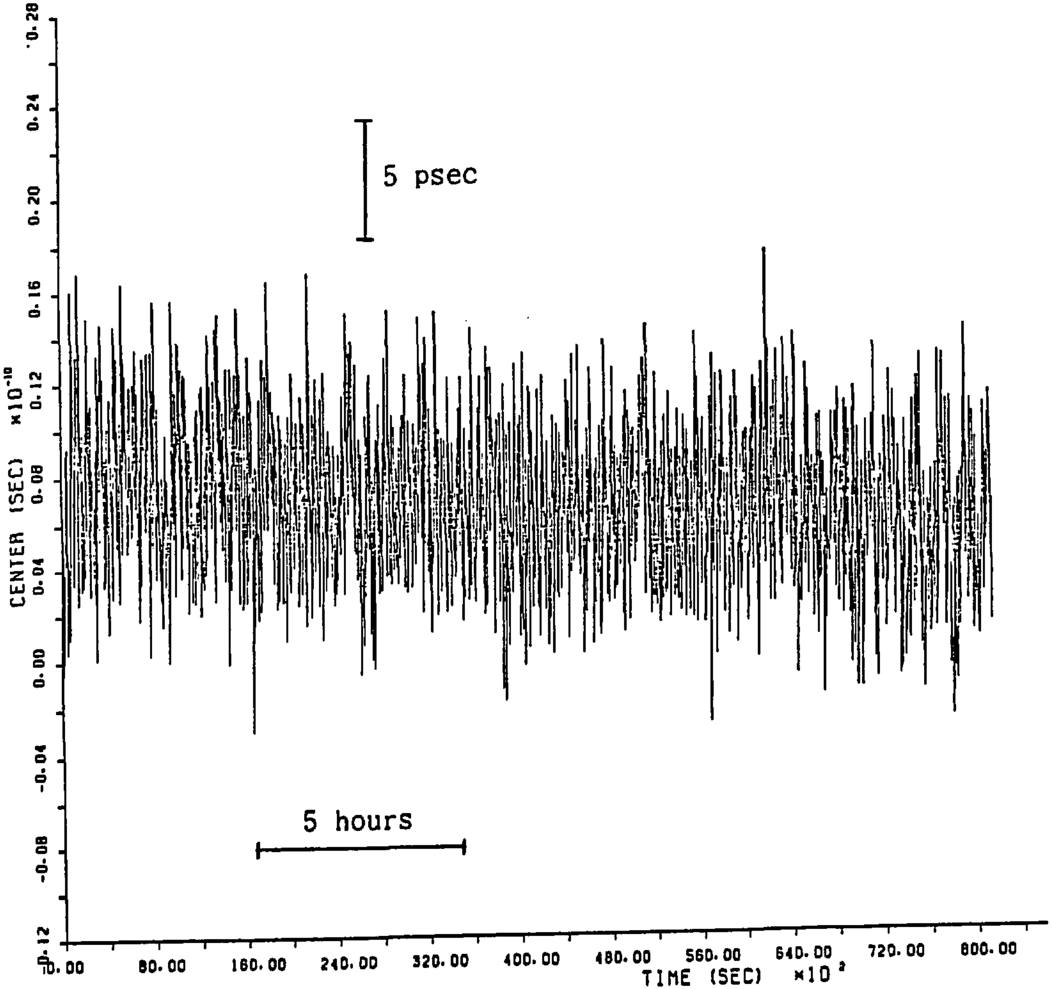

Fig.11 Jitter fluctuation over 24 hours