MEASUREMENT OF DELAY VARIATION IN DIGITAL COMMUNICATIONS NETWORKS

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Abstract

A method to measure the slow delay variations (wander) in digital transmission networks, while normal traffic is in progress, has been developed. The measurement system uses the TV-broadcast system as a common reference time base. There is no need to loop back the lines nor to prepare them in a special way for the measurements. The system is observing the traffic on the transmission lines in a passive mode. Measurements has been carried out on an optical 140 Mbit/s point-to-point transmission system of 50 km length.

1. Introduction

The importance of timing and synchronization in integrated digital communications networks has been a subject of research, development and sometimes controversy for many years. Reference (1) describes a network timing concept for the Swiss digital network, based on the hierarchical master-slave principle and using triple redundant timing generators at each major node. The design principles of the frequency control loops linking a slave node to its master over a 2 Mbit/s PCM line have been discussed in reference (2). It is stressed there that the optimum design requires knowledge on

a) the characteristics of the slave clocks
b) the delay variations expressed e.g. by their spectral density.

Methodes for testing clocks under various operational conditions have been proposed (3). However, reliable data on the path delay variations are more difficult to obtain, since it ist not easy to organize long-term path delay measurements on operational transmission systems. Only jitter measurements on the lowest hierarchy PCM links are known (4). Determining the path delay variations of an operational system, without looping back the signals, requires an adequate reference line. The well known technique for clock comparison (5), (6) and our many years experience therewith encouraged us to use the TV-broadcast system as a common reference time base.

2. Television System

In the television system the synchronisation pulse is generated by the studio which produces the program. Generally it has been derived from a quartz - or a rubidium oscillator and then distributed by means of microwave links to the different TV-broadcast stations. Therefore a relative timing information is available throughout the country, without making any modification on the TV-system. In an ordinary TV-receiver there is neither an adequate amplitude stabilization nor an adequate level stabilization, and the picture information affects the synchronization pulse. More sophisticated TV-receivers (Block diagram Fig. 1) with a special clamping circuit and a line selector have been developed. The radiofrequency section is composed of commercially available modules including automatic frequency control and automatic gain control facilities. After the separation of the sound and picture signals, a video limiter eliminates the picture information. A special clamping circuit is used to stabilize the black level immediately following the synchronisation pulse. Then, an electronic switch selects the synchronisation pulse of the arbitrarily chosen line no. 16 (a line without picture information) (7).

Two of these TV-receivers have been tested over a long period using the signals from the same broadcast station in a setup shown in Fig. 2. The measurements show variations of less than 3 ns a day. The variations from day to day are less than 8 ns. These variations are due to daily adjustements of the synchronization and video level at the TV-studio. This effect requires a good match (symmetry) of both TV-receivers. The measured temperature sensitivity in the ordinary temperature range from 10°C to 30°C is less than 0.4 ns/°C. Similar receivers have also been successfully in use for many years for clock comparison within Switzerland and with the Bureau International de l'heure in Paris.

In order to test the time stability of the TV-distribution system the two receivers were tuned to different UHF-channels (No 40 and No 50) distributing the same TV-program supplied over different microwave links (Fig. 3). Channel 40 is supplied by a path via Zürich (dashed line) and Channel 50 via Geneva (solid line). The total path difference is 670 km and incorporates 12 microwave links. Measurements over 3 months showed total time variations smaller than 20 ns. Simultaneously at three critical points (Pèlerin, La Dôle and Chasseral) the automatic gain control of the microwave links was recorded, but no correlation to the delay variations could be detected. This experiment demonstrated the excellent time stability of the TV-distribution system.

3. Principle of measurement

The principles for measuring delay variations of digital transmission lines using the TV-distribution system as a time reference are shown in Fig. 4. At site 1 the frame pulse of the digital transmission (2.048 Mbit/s hierarchy) is extracted and divided to obtain a pulse repetition period of 40 ms. This pulse represents the clock of the transmitting PCM equipment at site 1. Let's suppose that a TV-synchronisation pulse is transmitted at time T_S from the TV-station and the path delay to site 1 is τ_1. Then the TV-sync pulse arrives at receiver 1 at time

$$T_{E1} = T_S + \tau_1 \qquad (\tau_1 = \text{path + receiver delay})$$

A time interval counter measures the time difference T_{d1} between the TV-sync pulse and the frame pulse T_{clock},

$$T_{d1} = T_S + \tau_1 - T_{clock}$$

At site 2 the frame pulse is extracted from the incoming data stream (2.048 Mbit/s). The time of arrival corresponds to the clock time T_{clock} delayed by the transmission path τ_L. For site 2 the following equations are valid:

$$T_{E2} = T_S + \tau_2 \qquad (\tau_2 = \text{path + receiver delay})$$

and the time interval counter reads

$$T_{d2} = T_S + \tau_2 - T_{clock} - \tau_L$$

Taking the time interval measurements at the same time instant (i.e. the same TV-sync pulse) the difference between the readings of the two counters is:

$$\Delta T_{1-2} = (\tau_1 - \tau_2) + \tau_L$$

This difference is proportional to the path delay τ_L and its variation, as long as the TV path delay and the receiver delay remain stable, as shown in section 2, therefore:

$$\Delta T_{1-2} = const + \tau_L$$

4. Measurement system

In order not to disturb the PCM transmission, special demultiplexers are used, which are connected parallel to the transmitting and to the receiving line (Fig. 5). These demultiplexers contain circuits for dividing the frame repetition rate (500 Hz) by a factor of 20 to 25 Hz (corresponding to the 40 ms sync pulse period). A computer initiates the demultiplexers and controls the time interval counters so that they measure at the same time instant at both measurement stations. To improve the measurement resolution, a time interval averaging mode with a measuring time of 100 s is used. After a measurement the computer reads the data from both counters, starts a new measurement, checks the data for plausibility, calculates the time difference and stores the data on a disc for further availability. The first measurements were carried out with both measurement-stations in the laboratory, using a looped back 2.048 Mbit/s symmetrical pair of about 10 km length. The initial delay on the PCM-path was 38'172 ns and diminished during the observation time of one month for 100 ns. Assuming a temperature coefficient of delay of 3 ns/km x °C (2) for a symmetrical pair with paper isolation, the measured delay variation corresponds to a temperature change of about 3° C which appears to be plausible.

5. Field measurements between distant sites

When measuring a transmission path in the field, both measurement systems are located at different sites (Fig. 6) and they have to be remotely controlled by the computer using modems and leased telephone lines. Special attention has to be paid to the initialization and synchronization problems because there are some undefined delays in the interfaces and the modems used for triggering the measurements. The distance between the two sites is about 50 km and the same TV-station could be used as a common time reference. The measurements were carried out on a 140 Mbit/s optical fibre transmission system, which was operating during this time for commercial data transmission. Up to now measurements on a period of more than 6 months have been collected and various effects could be observed. There are days where short-term delay variations up to ± 50 ns can be observed (Fig. 7) and other days where the delay variations are as small as ± 5 ns (Fig. 8).

Pending further investigation we suppose that these variations originate in the waiting time jitter of the multiplex systems using positive justification (bit stuffing).

The long-term delay variations (wander) of the transmission path mentioned have not yet been significantly determined, (Fig. 9) as an optical fibre shows a very small temperature coefficient of 0.035 ns/km x °C (2).

6. Measurements on digital switching centers

In Switzerland a hierarchical master-slave concept is used for the timing of the digital network (Fig. 10) (1). The first timing measurements on switched data signals were carried out on an output line of a switch located at a 2nd order center (Center A in Fig. 10) and on a 3rd order switch (Center B in Fig. 10). The regenerated clocks of the output data streams were compared directly with a cesium clock. Fig. 11a shows the timing variation of a PCM-output (2.048 Mbit/s) of switch A and Fig. 11b similar measurements at switch B. Two characteristics must be mentioned: first, there is a timing degradation of the digital signal; further, there are quiet periods and periods with significant time fluctuations. The cause of these phenomena is not yet known in detail and will be subject to further investigation.

7. Conclusion

We have described a time delay measurement system which allows long-term observation of the path delay and its fluctuation on digital transmission lines carrying actual traffic. The main advantage of this method is that it can be implemented by means of picking up the signal at both ends and thus without interferring with the network operation. Other methods known to us up to now did require some interferring action in the operation, such as connection of special clocks or loop back of the circuits. The first experience has shown that the delay measurements can be used as a highly sensitive diagnostic tool. Some of the observed anomalous delay variations might indicate independent failures of some equipment along the line, which can not be detected by means of the usual bit error rate measurements.

The authors gratefully acknowledge the many helpful discussions with Dr. P. Kartaschoff and his support.

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Proc. 17th PTTI Conf pp 287 - 300, Dec 1985

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pp 428 - 430 (Nov. 1976)

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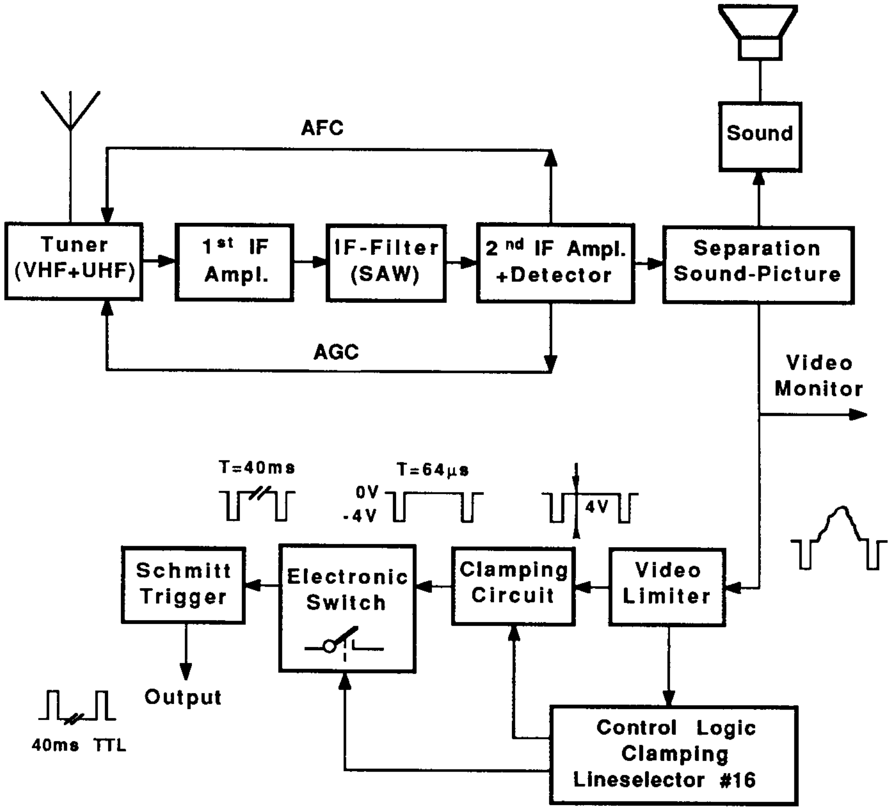


Fig.1 Schematic of TV-Receiver

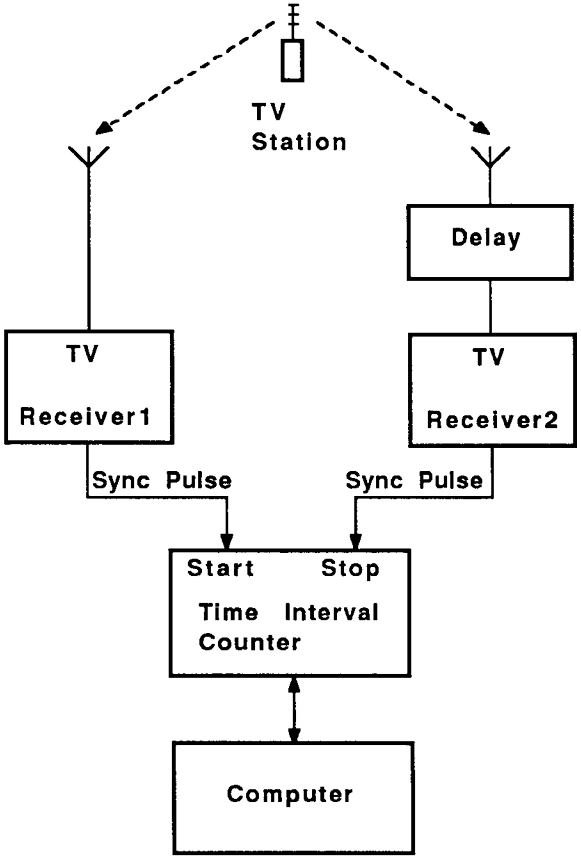


Fig.2 Setup for the Stability measurements of the TV-Receivers

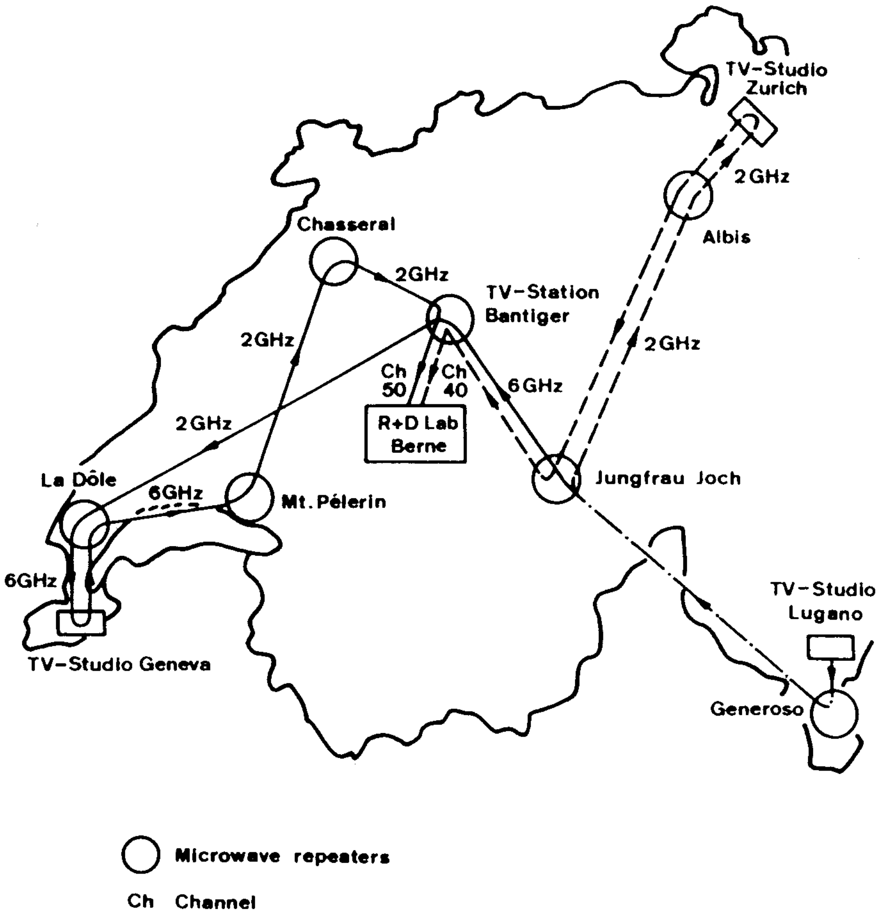
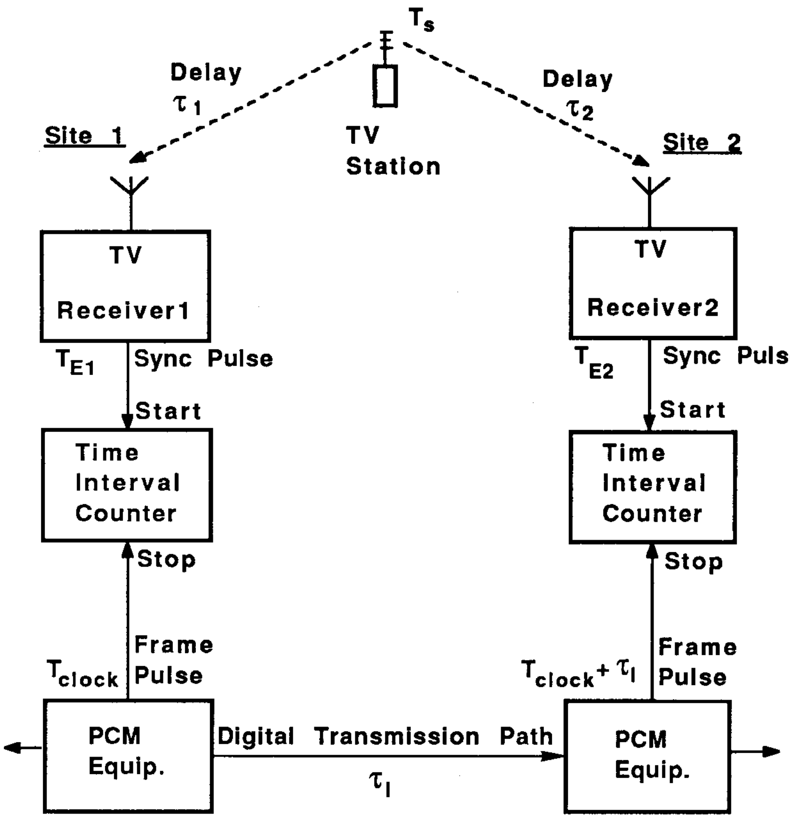


Fig.3 Microwave path for testing the time stability of the TV-distribution system



Time Intervall: Site 1 $T_{d1} = T_s + \tau_1 - T_{clock}$

Site 2 $T_{d2} = T_s + \tau_2 - T_{clock} - \tau_l$

Time difference $\Delta T_{1-2} = (\tau_1 - \tau_2) + \tau_l$

$\Delta T_{1-2} = const + \tau_l$

Fig.4 Principle of Measuring Delay Variations of Digital Transmission Pathes

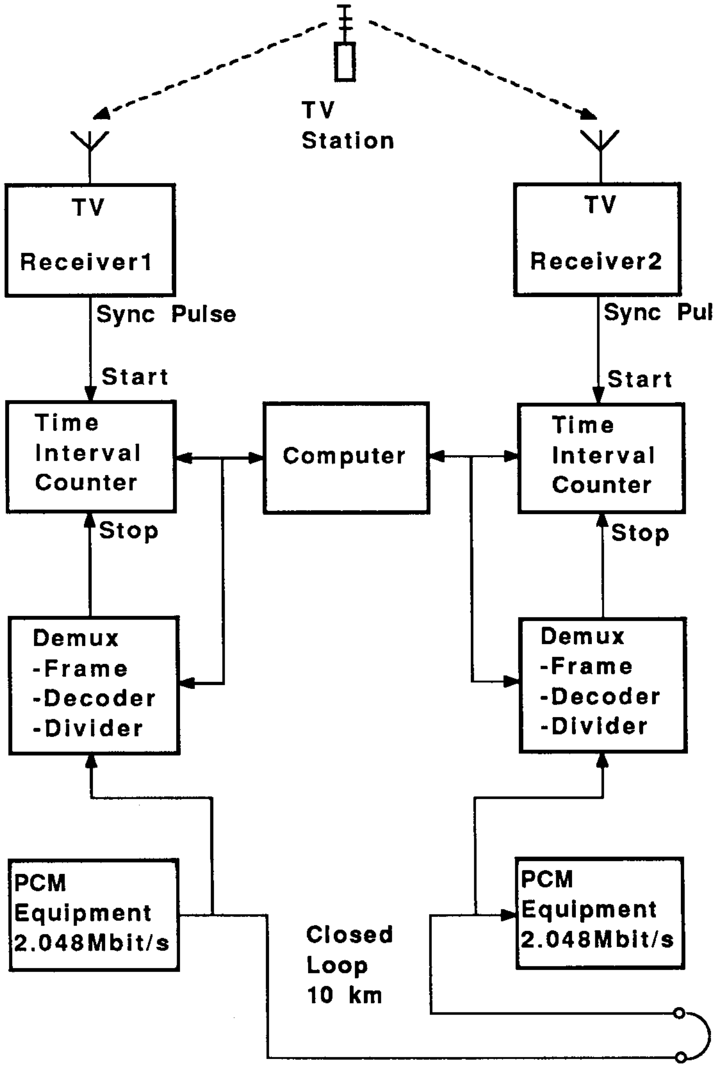


Fig.5 Setup for Closed Loop Measurements

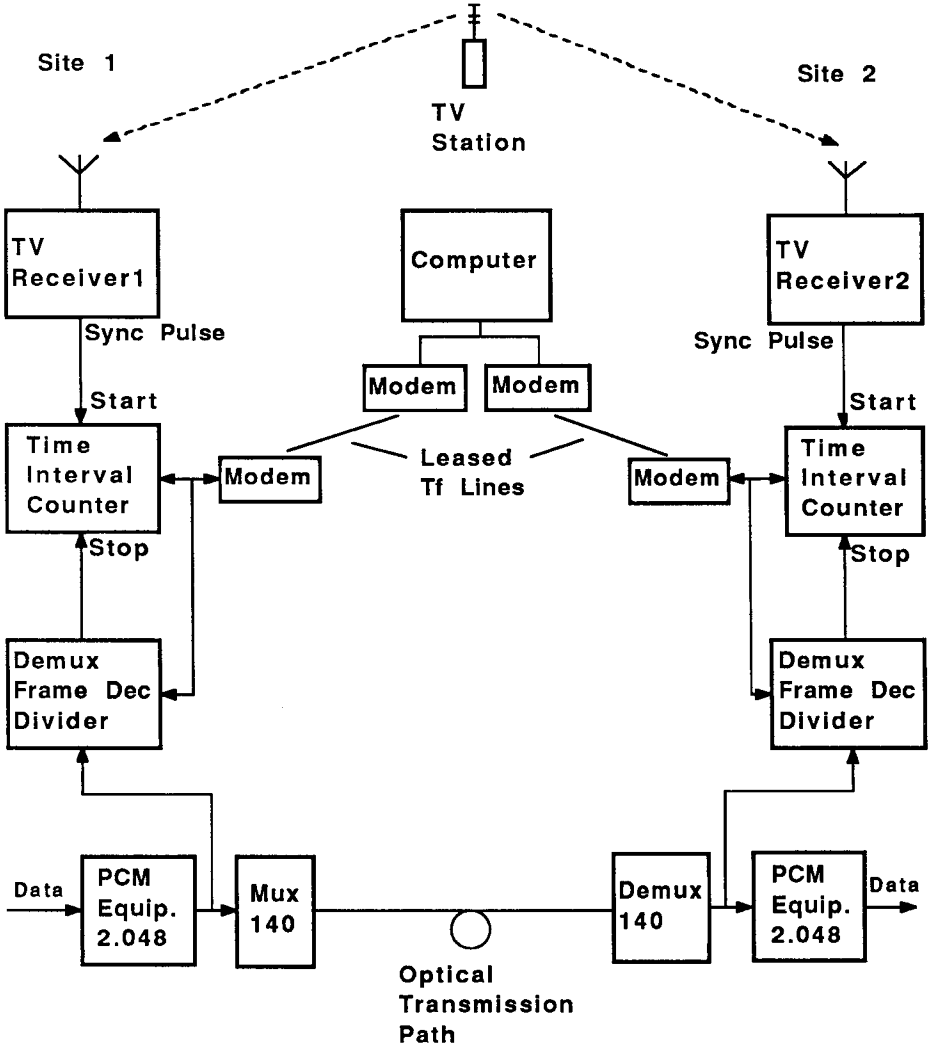


Fig.6 Setup for Field measurements

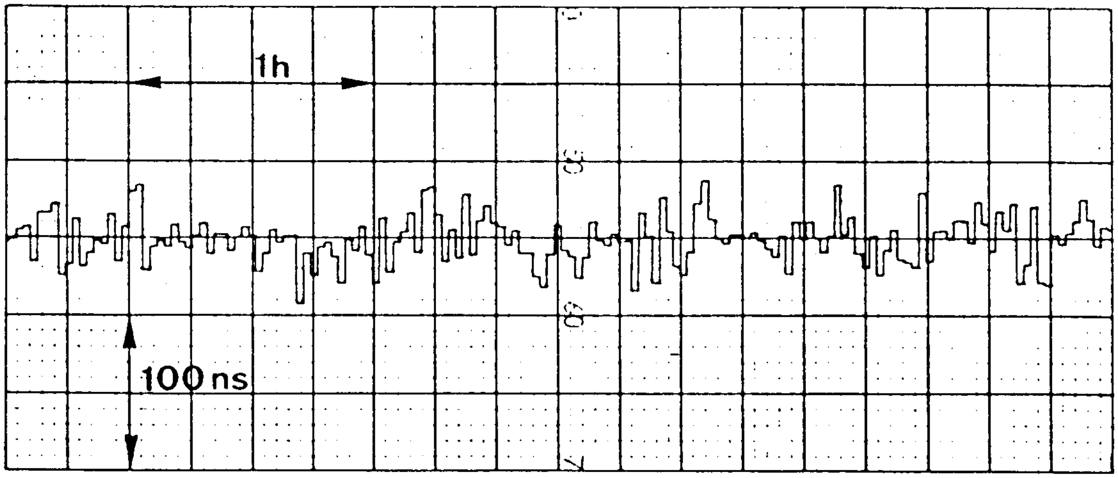


Fig.7 Short-term Delay Variations on a 140Mbit/s Optical Fibre Transmission Line, disturbed period (14.10.87)

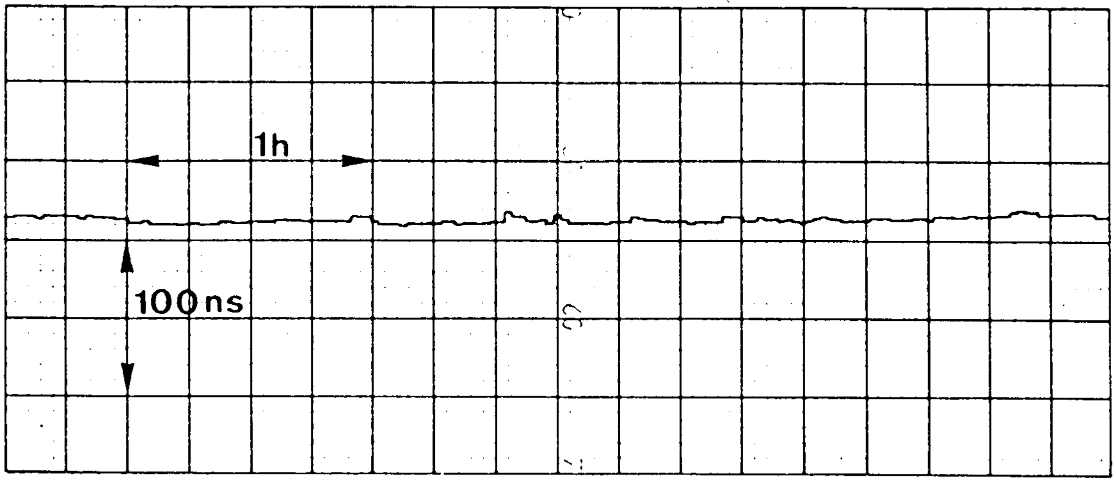


Fig.8 Short-term Delay Variations on a 140Mbit/s Optical Fibre Transmission Line, quiet period (1.11.87)

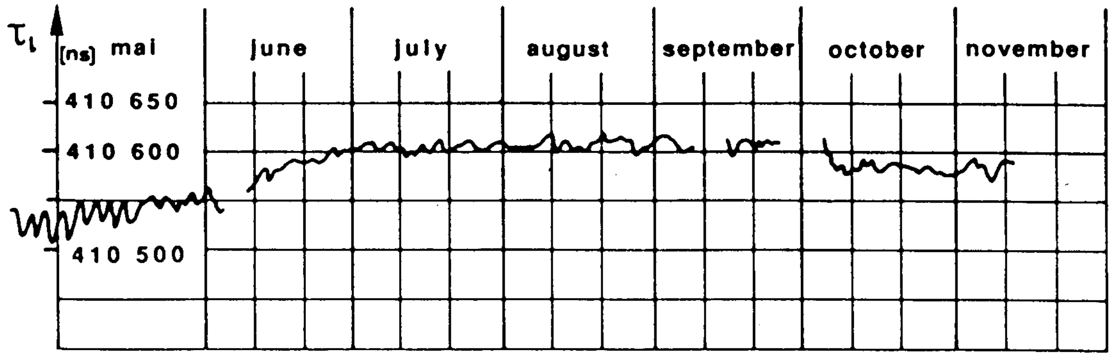


Fig.9 Long-term Delay Variations on a 140Mbit/s Optical Fibre Transmission Line (mai to november 1987)

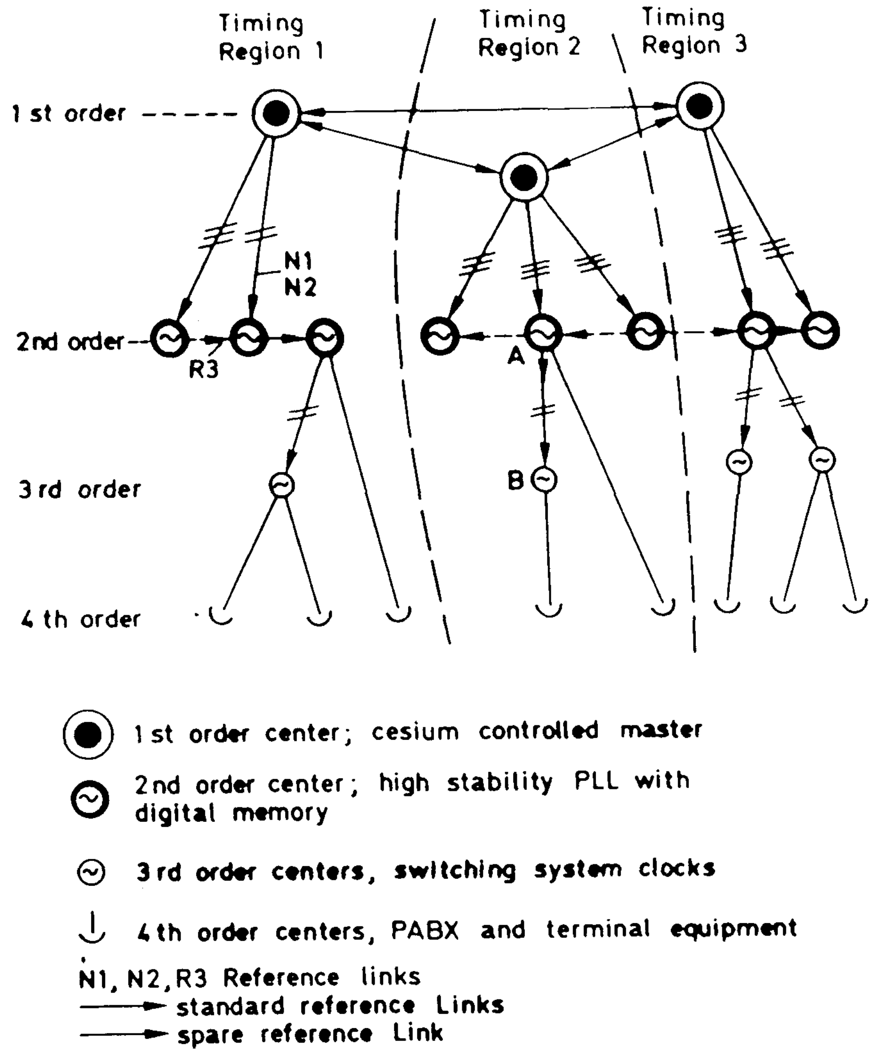


Fig. 10 Timing Network Structure

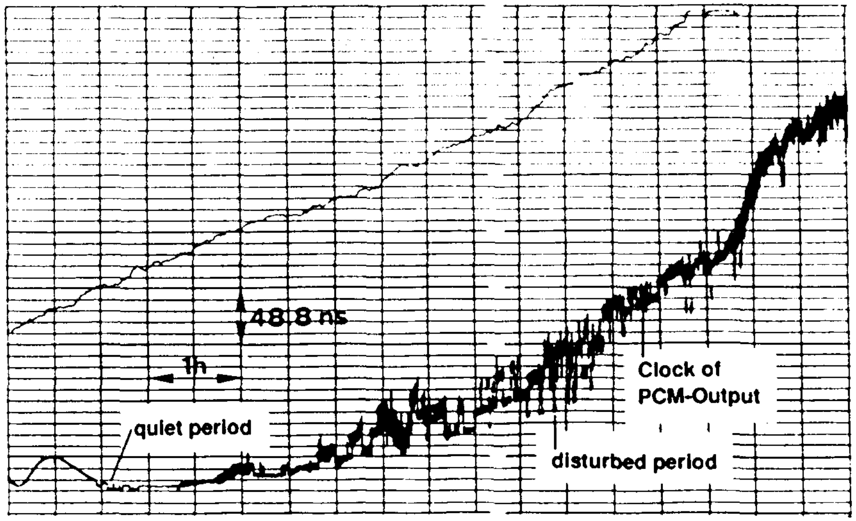


Fig.11a Timing Variation of a PCM-Output (2.048Mbit/s) of a Switch connected directly to a 2nd Order Center

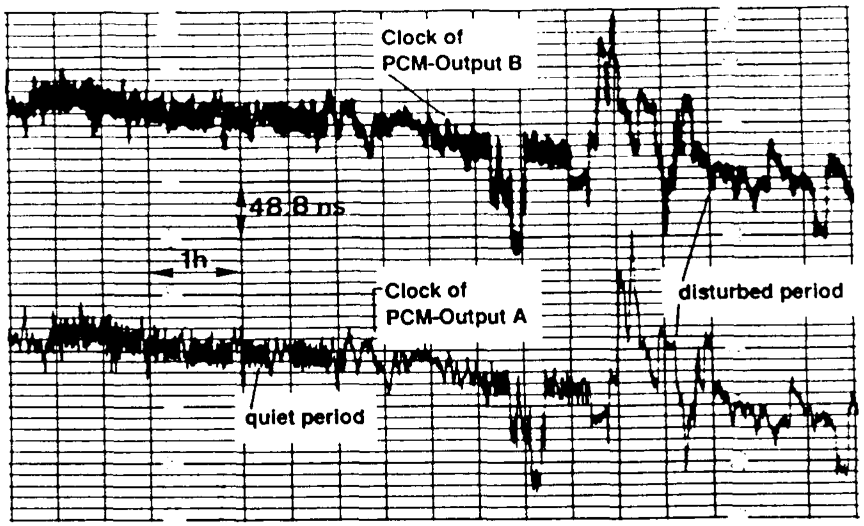


Fig.11b Timing Variation of a PCM-Output (2.048Mbit/s) of a 3nd Order Switch

QUESTIONS AND ANSWERS

Albert Kirk, Jet Propulsion Laboratory: Have you found out what causes the quiet periods and the noisy periods?

Mr. Hilty: Not yet. We have not yet collected enough data. We have seen days where there were small variations for a few hours and then a period of large variations.

Mr. Kirk: You don't know whether it is equipment or some other influence.

Mr. Hilty: We think that it is from the time signal, but that hasn't been proven.