Optic Data Link for Tevatron Synchronization System

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Abstract

A fiber optic data link for the synchronization systems of the Fermilab accelerator has been designed, produced and tested. The link uses one multimode fiber in a previously installed cable. This link is capable of simultaneously delivering a 7.5 MHz biphase encoded clock signal and a 53 MHz RF signal to 30 service buildings distributed around the 6.28 km circumference accelerator ring. An accumulated time jitter at the far end of the link is less than ± 2 ns while a variation of the carrier or RF is about 300 kHz.

I. INTRODUCTION

The Fermilab Accelerator Timing and Synchronization System is comprised of four clock signals. Three of these are separate beam synchronous clocks (BS CLK) which are synchronized to the actual beam revolution frequencies (or equivalently, to the accelerating RF) of the Main Ring, Tevatron protons, and Tevatron antiprotons. The serial clock signal can carry timing markers, or "events", encoded in a biphase (or modified Manchester) code onto the 7.5 MHz (53 MHz RF divided by 7) carrier.

A serial data repeater system [1] has been used to accommodate distribution of each BS CLK. The repeaters are positioned at each of the thirty service buildings located throughout the 6.28 km Tevatron ring accelerator. A coaxial cable is used as a communication medium between the repeaters. The original coaxial cabling supporting the accelerator controls has existed for a long time. Recently there was an upgrade of the Control System, and fiber optic communication links have been implemented [2]. This allowed adding new links for the upgraded system and avoiding the disadvantages of a gradual degradation of the coaxial cable's characteristics.

A twenty-four fiber trunk cable with multimode graded index fibers (62.5/125 µm) was installed throughout the accelerator ring. Its full length is nearly nine kilometers, a mean length between two service buildings is about 300 meters. An optic data link for 10 Mbps biphase encoded data was designed and installed to replace an original serial CAMAC interface [4]. That link is split, each leg connecting half of the ring length using 15 repeaters. The repeaters used inexpensive optic transmitters and receivers at 820 nm. With an edge skew less than one nanosecond per repeater, the link containing 15 repeaters operated without error at the far end.

While this amount of jitter is acceptable in these cases, for timing synchronization purposes with new requirements of accuracy it is not tolerable. Besides, delivering of low level RF signals is also desirable. A new optic data link (ODL) has been designed which is capable of delivering a 7.5 MHz biphase encoded BS clock signal and the 53 MHz RF signal simultaneously on one fiber.

II. REALIZATION

To achieve time error of ± 2 ns, conventional optic data links should use a single mode fiber, expensive laser transmitters, high speed optic receivers, high speed retiming circuits in repeaters, and a stable carrier with frequency deviation less then 0.1%. Our solution is based on using of the existing multimode fiber cable and takes into account:

- large quantity of repeaters (30) and a relatively short distance between repeaters
- a relatively low data rate (7.5 Mbps biphase data with 15 MHz clock)
- a very small jitter (± 2 ns, relative to the 132 ns period of BS CLK)
- a large variation of carrier (up to 300 kHz variation of 53 MHz RF)
- use of a single fiber for both BS CLK and RF signal
- unipolar +5 V power supply.

To decrease accumulated time error, including slow pulse width distortion and fast jitter due to fiber and components of repeaters, retiming of the distorted signal is used in a number of the ODL repeaters. A clock recovery and data retiming circuit (CRDR) is utilized. Our choice is the Analog Device AD800-52 integrated circuit for 52 Mbps NRZ data. Output jitter of this circuit is about twenty degrees of the nominal data rate period (data pattern 1010...) and increases in any other patterns in accordance to decreasing of the number of transitions in the signal.

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Since this ODL is intended to deliver both BS CLK and RF CLK simultaneously we have to encode these signals with a code which can provide a minimal jitter while providing data retiming and RF CLK recovering in each repeater. This 53 Mbps NRZ encoded signal is obtained when the 53/2 MHz square wave stream (RF divided by 2) is modulated by the 7.5 MHz biphase BS CLK signal. Each time slot of biphase BS CLK signal is marked on the pulse stream as missing a level change during one RF period. A zero time slot is marked by missing two level changes. Such a signal has 50% duty factor and the maximum number of transitions that will provide minimal pulse width distortion and jitter.

The enco module which converts BS CLK biphase data to 53 Mbps encoded data is installed ahead of the ODL at the F0 service building as shown in Fig. 1.

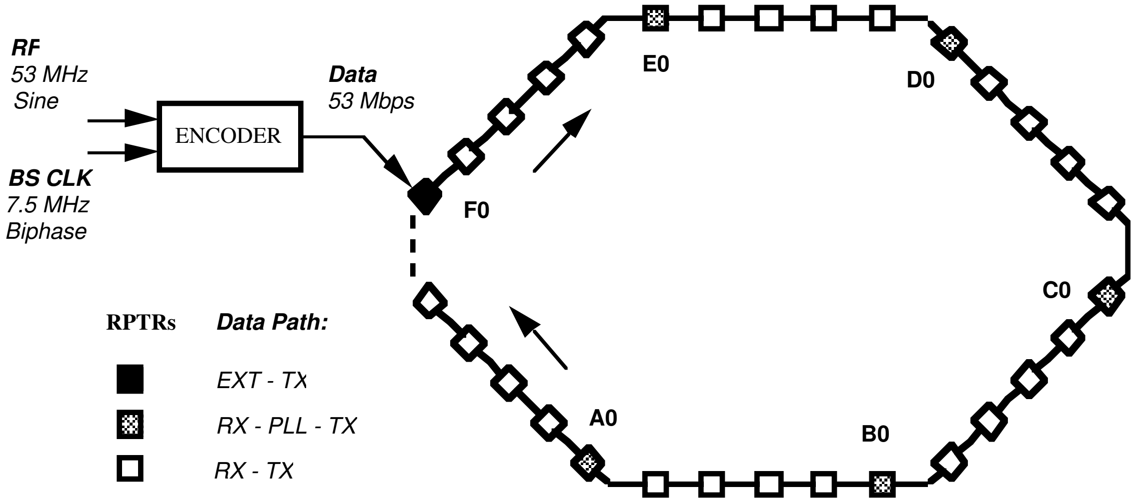

Fig. 1. Diagram of the optic data link.

An electrical 53 Mbps signal is applied to the first fiber optic repeater. It transmits the 53 Mbps optic signal at 1300 nm wavelength via the 62.5/125 µm multimode graded index fiber to other repeaters located in 30 service buildings. Each repeater provides regeneration of the optic signal, decods the 53 Mbps signal to biphase BS CLK and 53 MHz RF CLK, and drives electrical signals to the control system hardware. A few of the repeaters (zero-buildings in Fig. 1) provide retiming of the signal transmitted through the ODL to decrease time error. The number of such repeaters depends on properties of the fiber and the repeaters , and could be reduced.

A diagram of the repeater is shown in Fig. 2. Optic receiver RX and transmitter TX are AT&T ODL series II 125 Mbps 1361RX and 1261TX respectively [3]. They operate at 1300 nm wavelength and are compatible

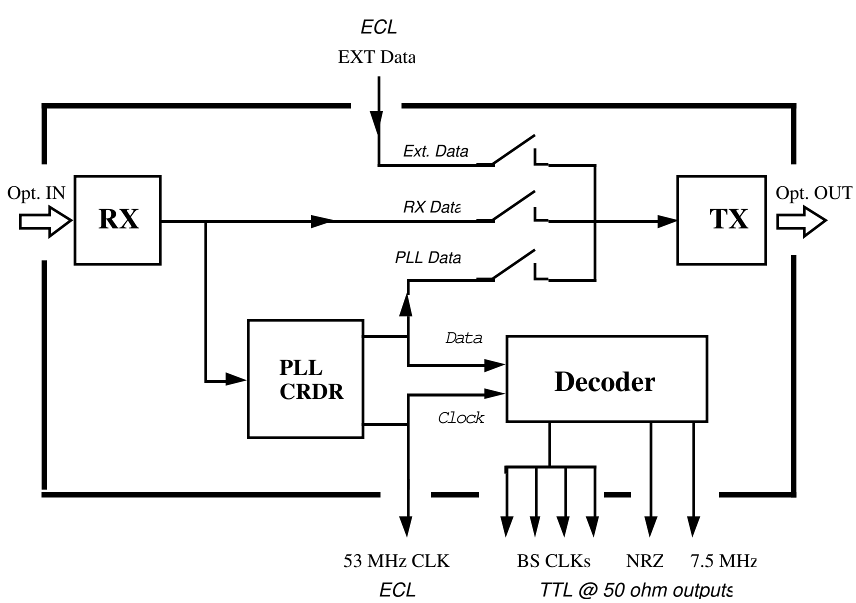

Fig.2. Diagram of the repeater.

with PECL 10HK logic. The repeater can transmit either external electrical 53 Mbps data, received data from RX, or retimed data from the PLL clock recovery and data retiming circuit (Analog Devices AD800-52) [4]. The recovered clock goes to a repeater output as the 53 MHz RF CLK. The BS CLK output signals come from the decoder circuit which is comprised of a programmable chip, ALTERA EPM 5032-16 (85 MHz toggle speed).

Additionally, the decoder supplies NRZ data obtained from BS CLK, and 7.5 MHz CLK signals for possible use in future control system hardware. All decoded output signals are compatible with existing hardware. The repeater uses a single +5 V power supply voltage, includes ECL 10HK logic and ECL to TTL translators. The printed circuit board of the repeater is compatible with the fiber optic repeater chassis used for existing optic links allowing simplicity of installation of the new ODL.

III. TEST RESULTS

The optic data link including 30 repeaters was produced, installed at the Tevatron accelerator and tested. Without PLL retiming the total time error including jitter and pulse width distortion is ± 6 ns. When PLL retiming was on in repeaters at the zero locations only (five repeaters) this error was 1.8 ns (peak to peak) for RF CLK output and 2.9 ns for BS CLK output. These results depend upon the frequency variation of the RF carrier which is about 300 kHz for the 53 MHz Main Ring RF. To obtain these results, the maximum bandwidth AD800-52 data retiming circuit should be selected.

Long term stability was measured during two months when the ODL delivered the real Tevatron BS CLK and RF CLK for D0 experimental facility. Data obtained by experimenters show that the drift of position of the RF CLK and BS CLK relative to accelerator beam was 2 ns and 3.2 ns respectively, i.e. less than for the same signals transmitted on the copper cable repeater system.

IV. CONCLUSIONS

The optic data link for the beam synchronization clocks and accelerator RF low level signals has been designed, produced and tested. It provides for delivering of 7.5 MHz biphase encoded BS CLK and 53 MHz RF to 30 service buildings throughout the Tevatron accelerator with time jitter less than ± 2 ns. This link uses existing multimode fiber cable installed at Tevatron. Such ODL can be used for three synchronization systems - Main Ring (MRBS), Tevatron (TVBS), and Anti-Proton (APTVBS).

REFERENCES

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