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TEVATRON SERIAL DATA REPEATER SYSTEM

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Summary

A ten megabit per second serial data repeater system has been developed for the 6.28km Tevatron accelerator. The repeaters are positioned at each of the thirty service buildings and accommodate control and abort system communications as well as distribution of the Tevatron time and energy clocks. The repeaters are transparent to the particular protocol of the transmissions. Serial data are encoded locally as unipolar two volt signals employing the self-clocking Manchester Bi-Phase code. The repeaters modulate the local signals to low-power bursts of 50 MHz rf carrier for the 260m transmission between service buildings. The repeaters also demodulate the transmission and restructure the data for local utilization. The employment of frequency discrimination techniques yields high immunity to the characteristic noise spectrum.

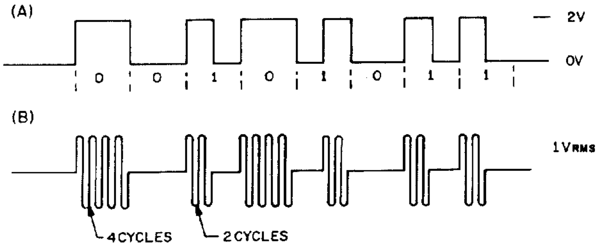

Fig. 1. A Manchester Bi-Phase coded eight bit burst of data as A) digital two volt pulses and as B) bursts of 50 MHz carrier for transmission between service buildings.

Design Perspective

The demand of designing a new control system for the Tevatron and requisite improvement of existing control facilities called for a fresh look at the various serial data communication schemes. A bipolar phase-reversal technique had seen, heretofore, wide implementation at Fermilab for bit serial transmissions. This technique, which relies on voltage discrimination at the receiver, is self-clocking and relatively simple to interpret as evidenced by scores of decoding circuits. However, the bipolar phase reversal technique has a practical speed limit of two megabit/sec, typically requires discrete and higher power devices, and yields a self-clock that is subject to phase slip.

The sensitive nature of a superconducting accelerator demands a communication scheme that is error free and extraordinarily reliable. Additional considerations of speed, mode of transmission, ambient noise, distance between repeater stations, versatility and cost also guided the development. These constraints and their particulars led to the choice of the Manchester Bi-Phase code and the modulation of an rf carrier for transmission of the code between accelerator service buildings.

Serial Link Implementation

The Manchester Bi-Phase Code

The Manchester Bi-Phase code is a unipolar self-clocking code characterized by a signal transition at the beginning of every data cell. If there is no signal transition at the midpoint of the data cell, the information content of the cell is defined as "zero." If there is a signal transition at the midpoint of the cell, the cell content is defined as "one." The implementation of this convention is straightforward for bit transfer rates of up to 10 megabit/sec.

Various factors directed the development toward the high end of the speed range. A primary consideration was to improve control system capability and response time by increasing process command and data throughput. Accordingly, a 10 megabit/sec rate for serial transfers was chosen. Bursts of data at this rate are characterized by 50 and 100 nsec pulses. Faster rates challenge the use of conventional LSTTL devices at the link interface level, while not gaining appreciable net speed due to large, fixed cable delays.

Transmission Techniques

Transmission of such high speed pulses is best realized in a properly terminated coaxial system for lengths as short as a meter. The 74S140 device can easily drive 50 and 100 nsec pulses into a 50 ohm line at a two volt level. An appropriate receiver for these signals is the Signetics 521A comparator. Noise levels are, of course, variable throughout the accelerator control environment, though typically not so severe as to preclude safe transmission of direct coupled serial data for up to a few tens of meters. The aforementioned devices have proven quite adequate as interfaces to a coaxial system of such length in a reasonable noise environment. This technique is low power which has obvious advantages and also simplifies transmitter and receiver designs.

Transmission of data between service buildings, a distance of some 260 meters on average, requires a more effective technique. Utilization of a 19 conductor 3/8" Andrew Heliax cable for these transmissions was predetermined. This cable, which is direct buried between service buildings, offers a superior mode of transmission characterized by uniform impedance, low loss, and 100% electrostatic shielding. The single disadvantage of this particular cable is that the outer conductors of the individual cables are not isolated from one another. The use of commonly employed transformer coupling techniques to improve noise margin is, therefore, precluded. The Bi-Phase code chosen, at any rate, is not readily adapted to transformer coupling.

Noise entering the transmission system must, therefore, be treated as a single-ended signal superimposed upon the link signals. The frequency domain of system noise is expected to range from a few hertz to several megahertz. Beam and rf acceleration frequencies are typically very low-level at the control environment. Amplitudes of the noise components across this spectrum can be measured but may be expected to vary with machine operation, cable location, and new equipment installation. Maximum noise levels are, therefore, difficult to estimate.

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Present links, which are transformer coupled, transmit at ±10 volt levels. Receiver designs are based on amplitude discrimination of the transmitted signal. These links have been adequate in noise immunity. Amplification of 10 megabit/sec Bi-Phase signals in a similar convention would require 10 to 20 volt signal levels into 50 ohms with rise times of 1000 to 2000 volts/μsec. The design of such an amplifier is not insignificant. The problems associated with amplitude discrimination techniques for long-line transmission of fast data led to alternate consideration of frequency discrimination techniques.

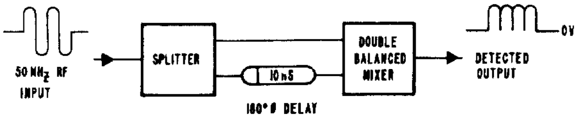

Fig. 2. Repeater frequency discrimination technique.

Frequency Discrimination

The use of frequency discrimination techniques results in near total immunity to the extant noise spectrum while not requiring high power transmissions. Realizing that most noise frequencies extend only to a few megahertz, a carrier frequency can be chosen well above the noise spectrum. A receiver tuned to this carrier will reject lower frequency noise components.

A carrier frequency of 50 MHz was chosen. Though there is a significant attenuation of 7db between service buildings, a driver level of 1 V_{rms} yields ample signal for detection at the receiver. Broadband filters at the receiver are necessary due to the data density and requisite rise time response. Nonetheless, carrier and noise bands are sufficiently separate to permit the required broadband filter.

The rf carrier is synchronously gated by the digital code as shown in Fig. 1. The use of a double balanced mixer as a FM-AM detector, as shown in Fig. 2, presents a unique solution to the problem of carrier detection. The received rf transmission is first split. One splitter output is directly applied to the mixer while the other is delayed 10 nsec by a lumped delay line before connection to the mixer. The 10 nsec delay represents a 180° phase shift at 50 MHz and is the primary tuning element of the system. All frequencies below 30 MHz are detected as negative signals at the mixer output, thus yielding broadband noise immunity. The mixer output peaks positive for inputs at the tuned carrier frequency. For the given parameters of the implemented transmission system, the peak value of the detected signals is approximately +400 mV.

Repeater Hardware

The basic repeater module consists of the frequency discriminator, a broadband low-pass filter, pulse width restructure circuits, and a synchronously gated rf transmitter. The filter is three stage and constant impedance with a 3db cutoff at approximately 40 MHz. Signal rise times of better than 10 nsec are achieved. The filtered signal is then applied to a 521A comparator with threshold set at +100mV for translation to TTL compatible levels. This detection scheme yields a natural degradation of pulse width requiring restructure to nominal values of 50 and 100 nsec before application to the final transmitter stage. It is important to utilize a synchronously gated carrier frequency to preserve jitter-free extraction of the encoded clock.

The repeater system is housed in a 5-1/4" high NIM bin providing desirable modularity. A twelve slot bin is capable of supporting ten individual links. Two slot positions are allocated to a plug-in power supply providing necessary plus and minus five volts.

Two basic types of repeater modules are available. A Fan-Out module provides four parallel lines of demodulated link data. A Fan-In module or's up to four lines of data to the link. Fan-Out modules facilitate the transmission of CNAF commands and data to control system CAMAC crates, and the distribution of the Tevatron time clock. Fan-In modules accommodate return of CAMAC crate responses and block transfer data to the host computer facilities. These modules are fully transparent to the particular protocols of these data transmissions. Two additional repeater modules are under development for the Tevatron abort system and energy clock.

Conclusions

The Tevatron serial data repeater system has been operational in the A-sector of the main accelerator since early fall of 1980. Performance has been excellent to date with neither hardware failures nor any detected interference from existing electrical noise. The link will be fully implemented around the ring this year. Use of this repeater system is also anticipated in a future upgrade of the Booster control system.

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