A TELEMETRY SYSTEM FOR THE ZERO GRADIENT SYNCHROTRON (ZGS) ION SOURCE TERMINAL[*]

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ABSTRACT

An optical telemetry system provides for transmission of analog and digital signals from the preinjector ion source equipment enclosure to the ZGS Main Control Room. The analog channel employs a frequency modulated light beam to transmit pulse shapes that have rise times as fast as 0.6 μsec and that last for several hundred microseconds. Any one of the analog signal sources can be selected from the Main Control Room. The digital channel employs pulsed light beams to transmit information to and from the high voltage terminal. The digital measurements of source parameters are made on command from the ZGS control computer and the results are transmitted to the computer. At present, the digital system can handle as many as 24 signal sources.

Introduction

The preinjector ion source for the ZGS is operated at a potential of 750 kV above ground. This large voltage prevents the use of conventional wired control circuits that are referenced to earth ground. For this reason, manual adjustments have been accomplished by means of long insulated control rods. These rods, which extend from a panel at ground potential to the ion source equipment enclosure, can be turned to adjust the source parameters. The large meters, which have been used to measure these parameters, are mounted in the ion source equipment enclosure and are displayed in the Main Control Room via closed-circuit television.

This straightforward system has been satisfactory for manual operation, but it imposes restrictions on speed and accuracy. It is not suited for automatic logging or for online computer analysis and control.

For these reasons, a more versatile and accurate system was developed. This new system uses an optical telemetry channel for transmission of digital commands

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from the ZGS Main Control Room to the ion source equipment enclosure. Additional optical telemetry channels are used for transmission of the analog and digital signals from the ion source equipment enclosure to the computer and to the control-room displays. Provisions are made for using part of the digital commands for adjusting ion source parameters.

General Description

Each optical telemetry channel consists of a modulated light source, a light pipe and lens system, and a photomultiplier tube. The light source is a 5ZP16 cathode ray tube that is operated with a stationary and out-of-focus spot. The phosphor of this tube is characterized by extremely fast decay of the light level when the electron beam is cut off. The decay time is intensity dependent but is in the neighborhood of 50 nsec for decay to half intensity. This permits the telemetry channel to be operated at up to a 20-MHz pulse rate.

The light pipe is made from a commercial 3" polyvinylchloride (PVC) schedule 40 water pipe and is about 9' long. The electrical resistance of this material is so uniform that the full 750 kV can be applied from one end to the other without breakdown. Careful cleaning of the surfaces and drying of the interior are necessary. Four optical lenses are mounted at uniform spacings inside the pipe to increase the optical transmission. This increased transmission efficiency makes it possible to use low cathode ray tube intensity and low photomultiplier voltage.

Four optical telemetering channels have been combined with digital and frequency modulation electronics to make the system shown in Fig. 1. The Main Control Room contains the control computer, an analog display cathode ray tube, and a manual select panel. These are connected by cables to an "outside station" located at the grounded ends of the light pipes. This outside station contains logic circuits, the amplifiers necessary to drive the cathode ray tubes connected to the light pipes, and the amplifiers required to drive the coaxial cables that connect to the Main Control Room. The ion source equipment enclosure contains sample-and-hold amplifiers, a multiplexer, an analog-to-digital converter, an analog-to-FM converter, and auxiliary control circuits.

The system can be controlled by digital commands from either the 924A computer or from the manual select panel. Either source of commands can select any one of the signal sources for analog (FM) data transmission or any one of 24 signal sources for digital conversion and digital data transmission.

FM Telemetry (Analog)

Several of the voltages and currents associated with the ion source can vary during the period of injection into the ZGS. Digital measurements of these variations in voltages and currents would require an elaborate high-speed system. This is not justified since an oscilloscope picture, plus a few digital samples, will provide enough information to define malfunctions. For these reasons, an FM system is used to transmit a selected voltage or current to the input of an oscilloscope located in the Main Control Room.

The FM system is designed for signal levels of ± 10 V. It has an output rise time of 0.6 μsec when the input is a step. The frequency response for a 5-V peak-to-peak input is given in Fig. 2. This rise time and response have been obtained with a center frequency of the carrier of 10 MHz and with a swing of ± 4 MHz.

The block diagrams for the electronics of the FM system are given in Fig. 3A and 3B. The analog voltage is fed to the input of an integrated circuit operational amplifier. The output and feedback circuits of this amplifier provide two unidirectional currents that are equal to each other and that are linearly related to the input signal. Each of these output currents is fed to the base of a transistor in a free-running multivibrator and serves to adjust the frequency. In this way, the frequency of the multivibrator is linearly related to the analog input voltage.

Tests indicated that a linearity better than 0.2% could be achieved with an oscillator range of 3-7 MHz. Above 10 MHz, the linearity deteriorated so much that 2% was all that could be obtained if the upper frequency was 16 MHz. For this reason, the oscillator was left at 3-7 MHz; and the frequency was doubled to 6-14 MHz by triggering a single shot from both the positive- and negative-going edges of the oscillator wave. The duty cycle of the single shot was maintained at 50% by having a third current source from the modulating amplifier supply charging current to the timing capacitor.

The driver circuits for the cathode ray tube control grid are conventional transistor amplifiers. Conventional gain and bias adjustments are provided so that the cathode ray tube's intensity is zero in the absence of pulses. This is important because phosphor life is a function of use. In continuous flying spot scanner service, the P16 phosphor efficiency drops to 50% in about 16 h.

For this reason, a gating circuit has been provided as shown in Fig. 3A. The oscillator is gated on just before the ion source and for a period of 300 μsec. The ratio of on-time to off-time of the cathode ray tube is so low that the effective life is increased to several years. Additional effective life of the cathode ray tube is obtained by magnetically steering the electron beam off the tube axis. Once a phosphor is locally burned, the tube may be used again by rotating the cathode ray tube a few degrees so that the electron beam strikes a fresh phosphor area.

The FM demodulator shown in Fig. 3B contains a 931A photomultiplier, a conventional amplifier, limiter circuits for shaping the pulses, and a detector circuit. The detector circuit is based on charging and discharging a fixed capacitor to a fixed voltage each light pulse. The average charging current is then porportional to the frequency of the light pulses.

Figure 4 shows typical ion source operating data as it is displayed in the Main Control Room on a cathode ray tube. The signal-to-noise ratio of the transmission is 20:1 for full-scale deflection. Current transformer preamplifiers and voltage dividers are adjusted so that the input signals to the FM system are within the ± 10-V range.

Digital Telemetry

The digital data system located inside the ion source instrument enclosure is designed to be operated in a manner that is identical to that used for the other ZGS data stations. Normal acquisitions of data by the 924A control computer starts with the transmission of an address to a multiplexer. This address comes from the computer as a set of bipolar clock and data pulses on a single coaxial cable. Logic circuits and drivers convert this to a series of light pulses on a single light pipe. Optical clock pulses are equally spaced, and the first pulse in each train is a clock. Data pulses are located between clock pulses with a light pulse representing a binary "one," and no light pulse representing a binary "zero." The pulse pattern is similar to that shown in Fig. 5 for the transmission of the binary number 10011101011.

The multiplexer address register operates logic gates and switches to connect the selected input voltage to the output bus. This output bus feeds both the analog-to-FM converter and the analog-to-digital converter, as shown in Fig. 1.

The computer system then transmits a timing pulse to indicate that the selected input shall be measured. This pulse is transmitted over a second light pipe. This causes the sample-and-hold amplifier in the analog-to-digital converter to "hold." Conversion and data transmission to the computer over a third light pipe then begins. The optical clock and data pulse pattern sent from the ion source instrument enclosure is similar to that described above for the multiplexer address transmission. Figure 5 shows the pattern for a digital converter output for binary 10011101011.

Simultaneous FM transmission and digital measurements of the same variable are possible. This digital measurement may be taken at any time during the FM transmission period. In addition, digital measurements may be made many times during a ZGS accelerating cycle if desired.

The information that is to be digitized is limited to ± 10 V. The converter produces an 11-bit binary output, including sign, in less than 100 μsec. A number of computer programs are available for using and displaying these digital data.

Operation and Reliability

The accelerating column and the equipment inside the ion source equipment enclosure generate many kinds of noise. The main sources are: (1) the internal 400-Hz power generator, (2) high current and high voltage pulses, and (3) random column arc downs. These sources of noise caused a variety of problems.

The effects of these noise sources on the FM system were not limited to producing noise spikes on the output. Occasional surges and arc downs would produce failure of components. The field-effect transistors used for multiplexing were especially prone to failure. These were removed, and the multiplexing function is now performed by the diode bridge-type switch in the commercial multiplexer. Some of the integrated circuit operational amplifiers failed on arc down. These amplifiers are now better protected with diodes; powerline filters were added; and ground loops were minimized. These steps have been effective.

The errors in the digital measurements included variations due to converting at a random phase on the 400-Hz wave. AC ground currents and magnetic induction produced errors no larger than ± 20 mV. The errors were no larger than ± 10 mV for 80% of the recorded data. This maximum error is more than that specified for the converter but was not reduced by any of the filtering or grounding changes that were tried.

Some of the current surges and some of the arc downs cause the random loss of a bit in the digital system. This can cause errors of up to 100% and make the reading unusable. Electrical filtering has not eliminated this problem. We have been able to use computer software to recognize these one-time very large errors and ignore them. This is possible because periods of very high arc down activity caused this kind of error in less than 1% of the data.

Some of the arc downs caused failure in the digital equipment. This was more difficult to solve because of the many ways that failure could occur. Much of the digital logic used 2N705 transistors. These, because of their construction, were prone to failure by "punch through" from voltage surges. This was remedied by changing to another type of transistor, a 2N2905. Many of the failures were caused by transients induced on the powerline and coupled into the individual electronic chassis. This problem was overcome by filtering the powerline at the equipment rack. Two filters were used in series. Each gave 20-dB attenuation at 10 kHz and 120 dB at 100 kHz. No failure of the digital circuits has been experienced since these filters have been installed.

Sample-and-hold amplifiers have been used between the voltage sources and the multiplexer to permit simultaneous digital measurements of ion source parameters. These sample-and-hold amplifiers have a high failure rate because of the field-effect transistors used in the high impedance part of the circuit. We have not so far been able to reduce the failure rate of these amplifiers to an acceptable level. Several methods of protecting these amplifiers remain to be tested.

Other practices which are felt to have been beneficial are: (1) single-point grounding of the equipment and the instrumentation, (2) ventilation of the instrument dome, (3) zener protection of all instrument input lines, (4) current-limited power supplies with fast transient response, and (5) 90 Ω output drivers.

There was considerable effort not to enclose the equipment in a separate Faraday cage because of continued extensive ion source modifications. The telemetry system can be removed and replaced with a minimum of effort. Additional packaging efforts have been taken so that most of the digital equipment has been placed in a half rack, using the front and the back for efficient volume utilization.

Acknowledgements

We wish to thank Dr. Rolland Perry and the members of the Linac Group for their cooperation and assistance during the installation and testing of the system. We wish to acknowledge the contributions made by W. Barror, D. Voss, and C. Catino to improve the reliability.

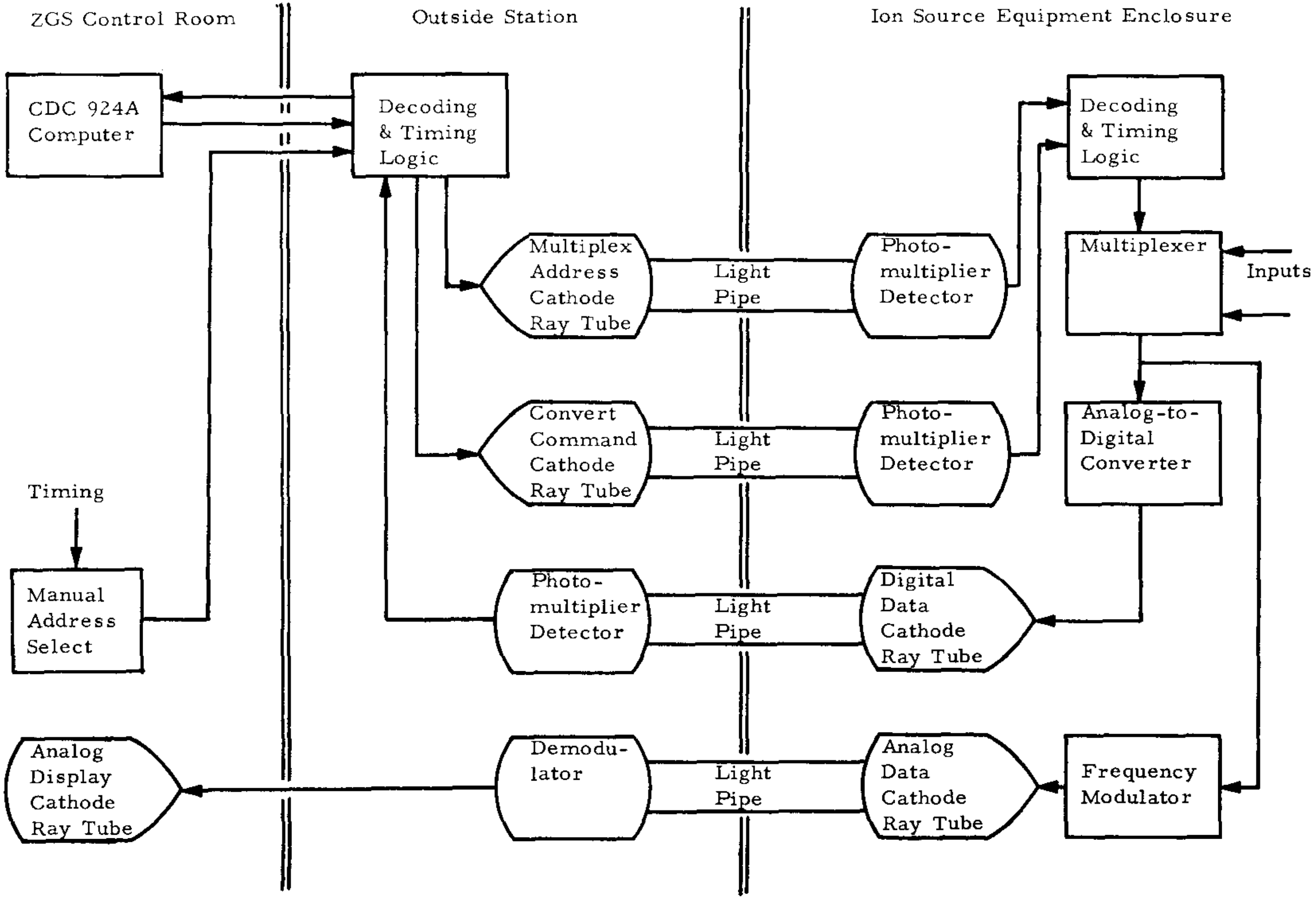

FIGURE 1 SYSTEM BLOCK DIAGRAM

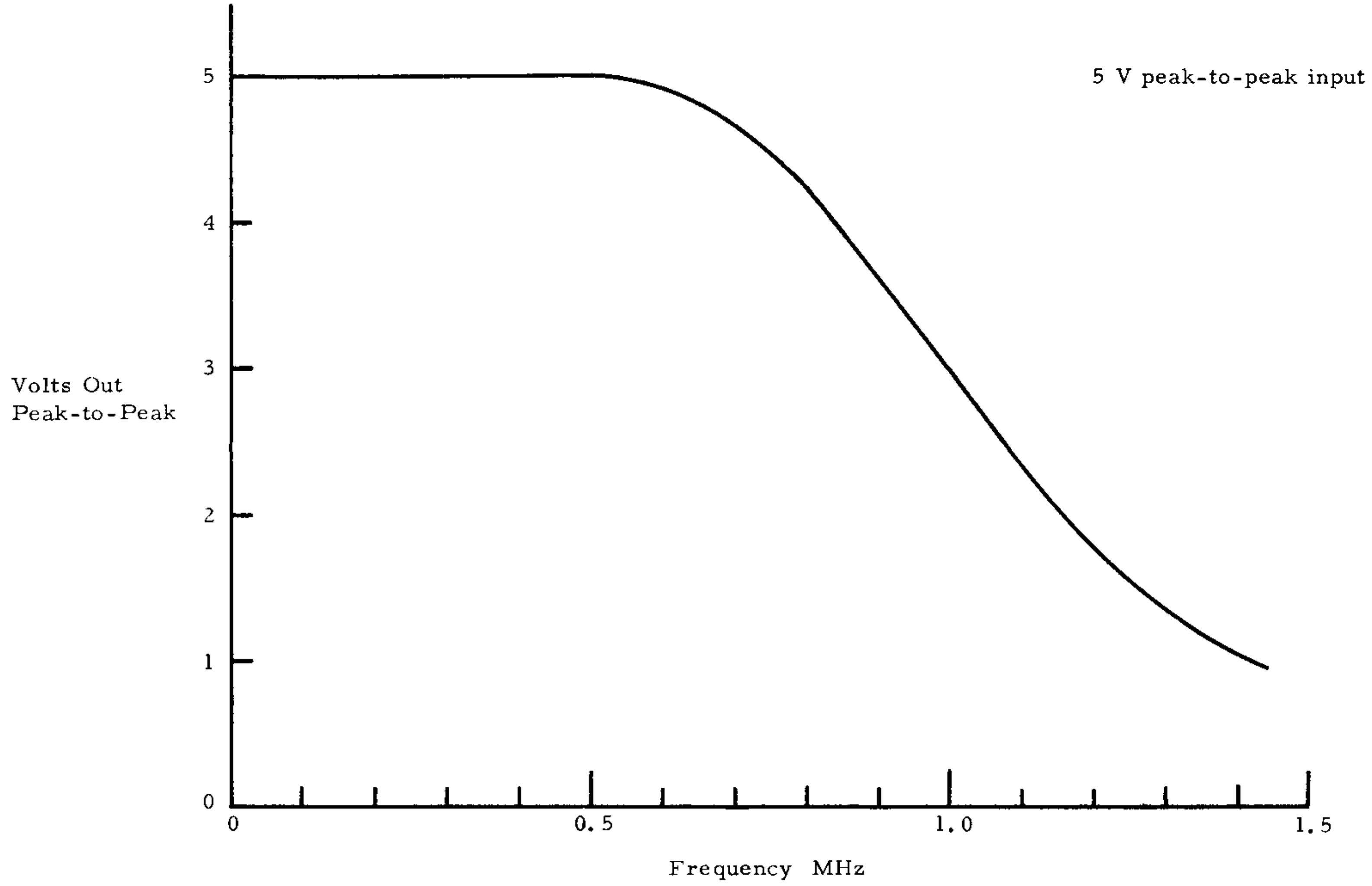

FIGURE 2 FREQUENCY RESPONSE OF FM TELEMETRY SYSTEM

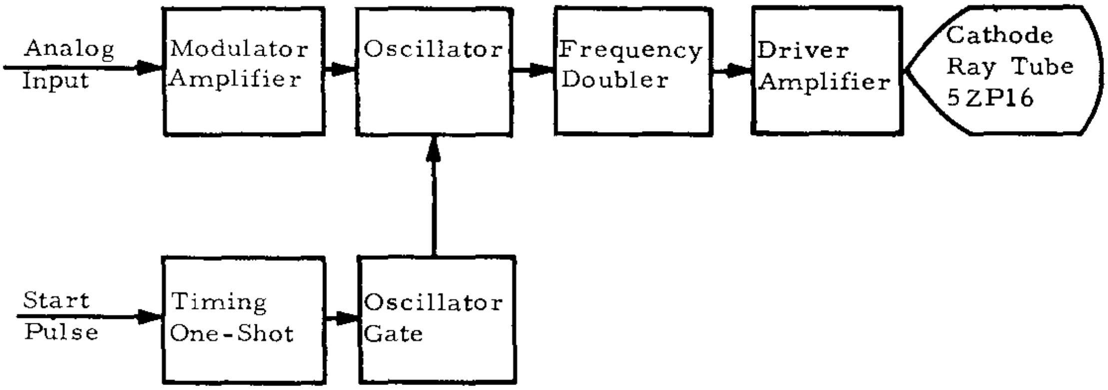

FIGURE 3A FREQUENCY MODULATOR (TRANSMITTER)

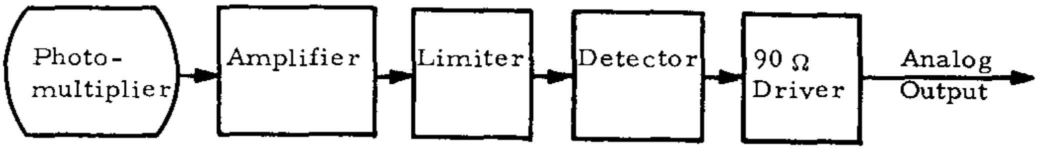

FIGURE 3B FREQUENCY DEMODULATOR (RECEIVER)

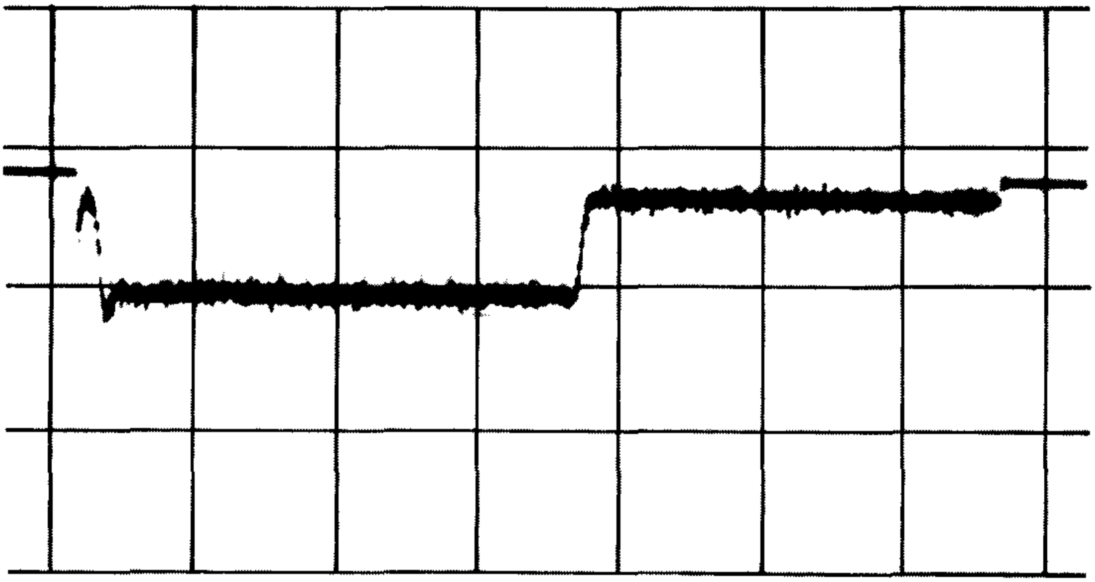

Fig. 4a. Modulator I current pulse. Horizontal: 50 μsec/cm; vertical: 10 A/cm.

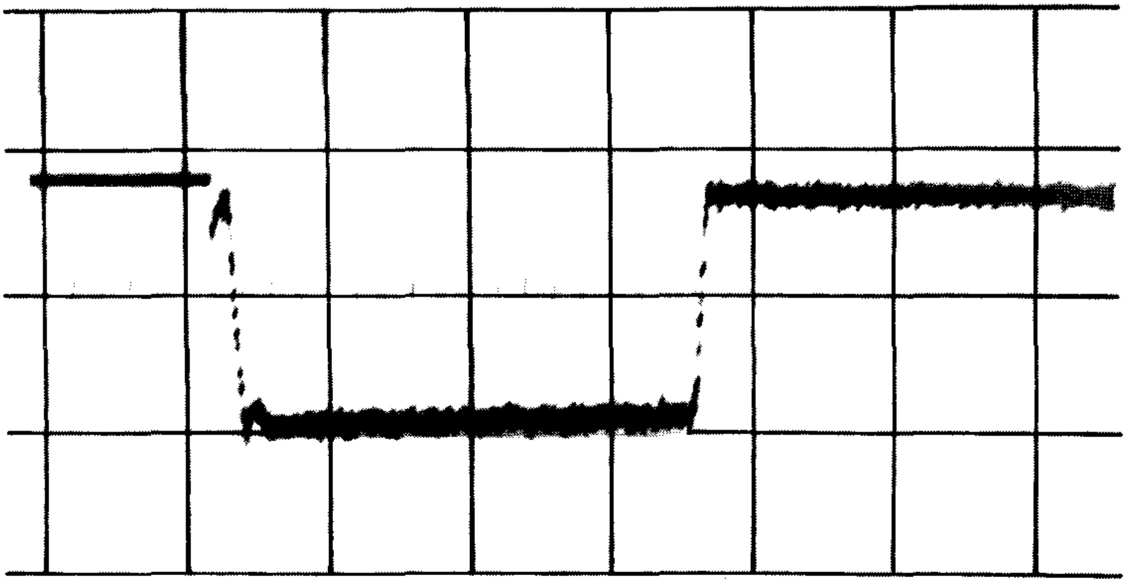

Fig. 4b. Modulator II current pulse. Horizontal: 50 μsec/cm; vertical: 10 A/cm.

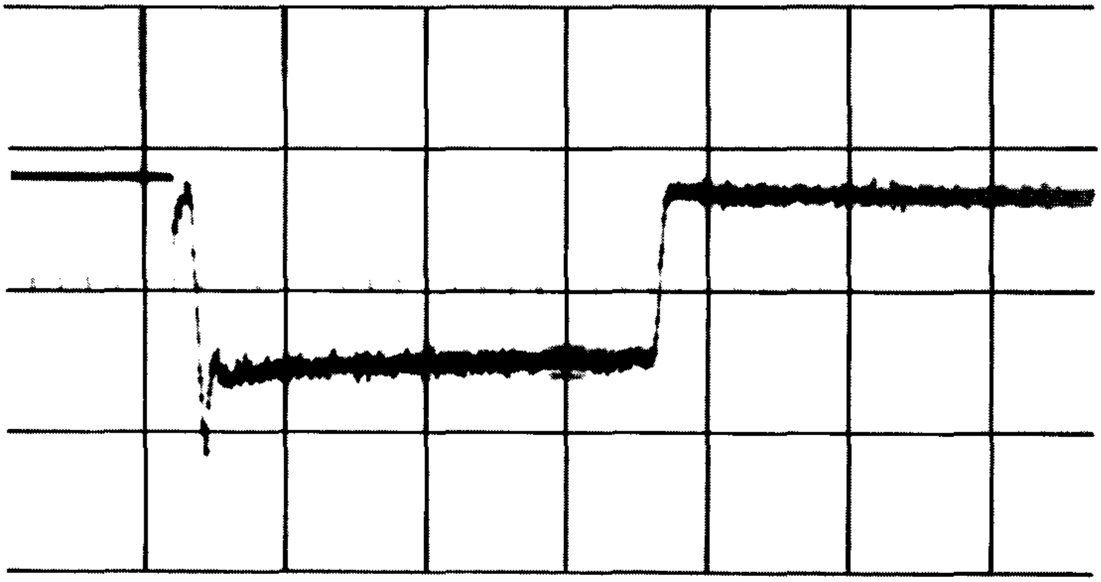

Fig. 4c. Extractor electrode current pulse. Horizontal: 50μsec/cm; vertical: 20 mA/cm. Electrons flow from electrode to the power supply.

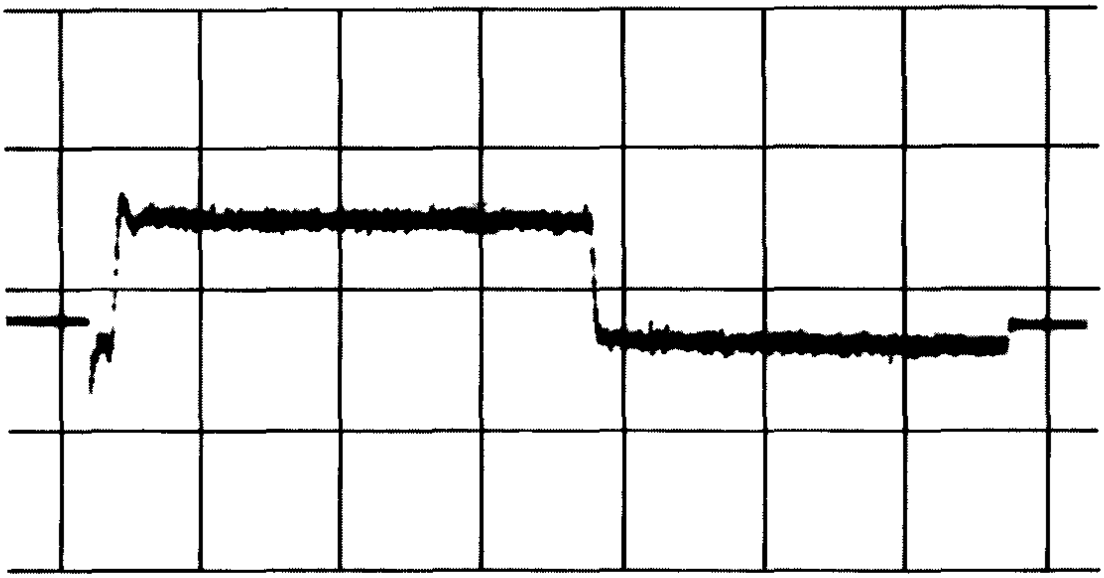

Fig. 4d. Focus II electrode current pulse. Horizontal: 50 μsec/cm; vertical: 20 mA/cm. Positive charges flow from the electrode to the power supply.

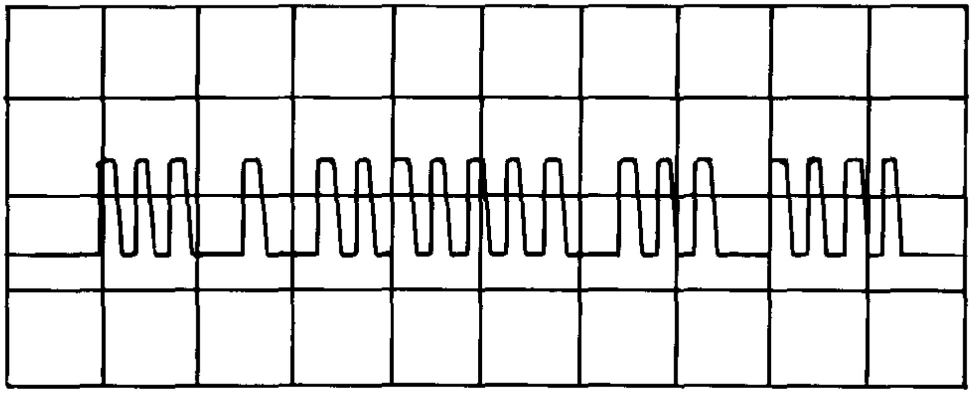

Fig. 5. Typical digital pulse pattern for binary 10011101011. Horizontal: 10 μsec/cm.

DISCUSSION

(The discussion of this paper follows LCO-055, "Telemetry of Control and Monitoring Signals Across a High-Voltage Interface Using Light Links," by Anthony R. Donaldson.)