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AN ANALOG SYSTEM FOR FAST LIGHT CURVE REGISTRATION

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ABSTRACT

An electronic system for recording fast light curves is described. The system employs a two track magnetic tape recorder for intermediate storage of photometer and time signals and reproduces these on cathode ray oscilloscope screen as an analog record; a quartz clock incorporated in the equipment provides time resolution of better than a millisecond in light curve profile analysis. The accuracy and limitation of the equipment in photoelectric records of occultations have been discussed.

Key Words : fast photometry—lunar occultations

1. Introduction

Photometric studies of certain astronomical events necessitate systems where fast varying light curves need be recorded with little distortion. The scale and degree of precision needed vary with the type of experiment and is ultimately limited by the photon statistics with the available observing equipment. For experiments with lunar occultation observation in optical wavelengths, high precision in the determination of timing and large bandwidth of the recording system becomes imperative, and special arrangements are needed to store and faithfully reproduce the transient information. Use of on-line computers for such purposes has been successfully employed (Nather, 1970), so also of multitrack magnetic tape recorders (Poss, 1970). We are describing a compact system employing only a two track tape recorder, wherein precise measurements of timing of events and shapes of fast light curves have been made possible, by recording several simultaneous bits of information in different frequency bands in the two tracks.

The theory of application of lunar occultation observations in measurement of structure and dimensions of extended systems has been discussed in detail in literature (Hazard, 1970; Nather and McCants 1970). For optical systems, the task for the observer consists of accurately recording light variations over a period of a few milliseconds at the instants of immersion and emersion. As the actual instants of immersion or emersion may vary from the predicted time owing to several factors, it becomes necessary to extend the period of vigilance to a minute or so around the predicted instants. The system designed should be capable of storing this length of high speed information and later reproduce the relevant portion in a form which can be processed for further analysis.

The timing precision aimed in the present equipment is one millisecond which is considered ample for the light collecting set up presently in use for lunar occultation observations. The bandwidth employed in the amplifier-modulator systems is much wider, thereby enabling interpolation at closer sampling points, where the signal to noise ratio permits such an operation e.g. in the case of bright star occultation. Subsequent experience with actual recording of the light curves of occultation events by this system has amply proved the versatility and capability of the system.

2. The System Design

The recording and reproduction system is schematically shown in Figures 1 and 2. A standard photometer attached to telescope generates the basic information which frequency modulates a 5 KHz carrier and this is recorded on one track of a two track tape recorder. A crystal clock followed by a divider chain generates a train of pulses of p.f. 10^4 per sec., as well as bunches of 1 KHz signal at 1 sec intervals, which are mixed by a digital logic gate combination and recorded on the second track of the tape recorder. To tie the timing pulses with standard time signal broadcasts, a throw over switch enables the standard time signals to be recorded just before and after the occultation event in the first track. This arrangement also permits voice recording of some details of the event, e.g. star number, date and approximate time etc on the same tape immediately prior to the event. The tape recorder used for this set up is a modified Grundig TK 30 tape recorder later replaced by a BEL studio recorder, with a tape speed of 38cm s^{-1}. As a standard spool contains 540 metres of tape, ample capacity for information storage is available.

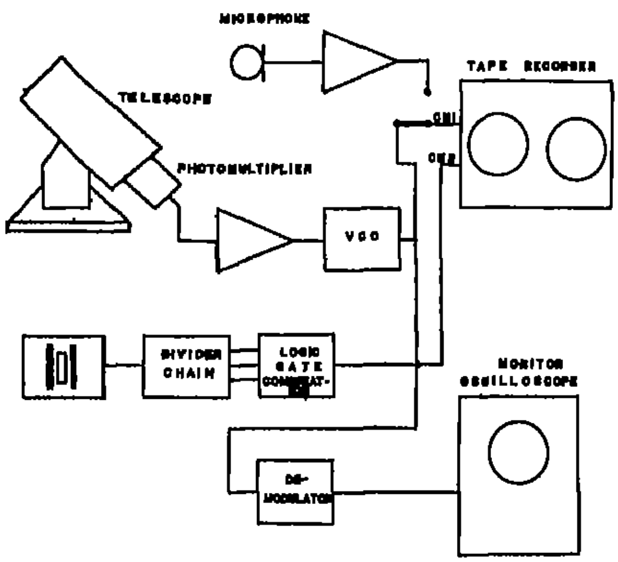


Fig. 1. Recording system

After recording the light curve, the reproduction in analysable form is done by a specially designed replay system. The record is obtained in the analog form on the CRT screen of an oscilloscope (Tektronix type 533A or ECIL OS 768) together with timing pulses. The oscilloscope is used with the 4 channel plug-in module in the chopped mode and set for triggered single trace operation.

Processing of the photometer and timing signals are done by the demodulation and filtering by circuits meeting the linearity and fidelity of response needed. The photometer signal is ultimately fed into one channel (usually channel No.3) whereas the timing pulses are fed into the two adjacent channels (Channel Nos.2 and 4). The first channel is reserved for display of same characteristic information pertaining to the events. This channel shows several relevant details of the occultation event in seven segment number display.

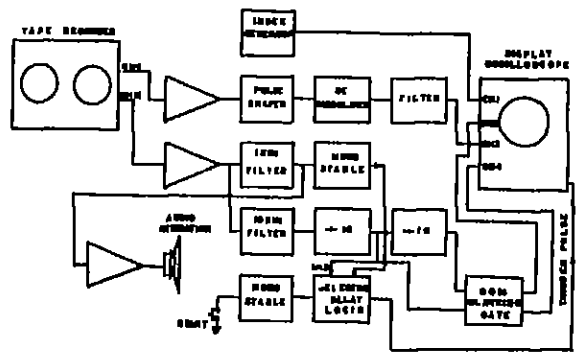


Fig. 2. Replaying system

For scaling the display with the necessary timing precision requires a reasonably fast trace on the screen. The standard rate of trace adopted in our system is 1 cm per 10 ms on the screen, which results in the millisecond pulses appearing at 1 mm spacings. The full trace requires slightly more then 100 ms; it is, therefore, imperative that an arrangement for controlling the start of the single trace be available so that the relevant portion of the light curve remains well within the frame. This is achieved by incorporating an arrangement of logic gates, by which a suitable delay between start of the trace and any arbitrary fixed reference instant can be set.

The arrangement for this selective delay generator is shown in Figure 3. As soon as the start button is pressed, the counting starts from the next full second; the counter continues counting millisecond pulses until the total count coincides with the figure set by the thumbwheel switch. At that instant the counting stops and a trigger pulse is generated which starts the CRO sweep.

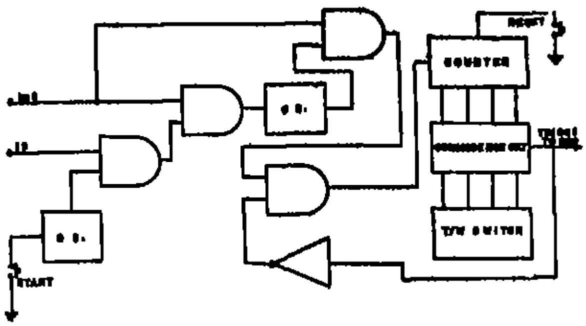


Fig. 3. Selective delay logic

A few additional features are included for convenience of operation. A monitor oscilloscope continuously monitors the photometer output level and enables the observer to actually see the light level changes during immersion or emersion. In the replay arrangement, the recorded seconds pulses operate a LED visual indicator, as well as produce audio pips, to enable the operator to audio-visually count the seconds from a suitable reference instant and activate the start button of the selective delay circuit. Also, in the millisecond pulse display arrangement, to facilitate counting, every tenth pulse is blanked out by an appropriate output pulse in the counter chain.

3. The Electronic design

The individual blocks of the system have been made up mostly by I. C. chips, supplemented by transistors where the power or buffering requirement necessitated use of these. The I.C.s most used are 74-series Signetics digital chips and some linear op-amps from the same manufacturers. The transistors and crystals used are from BEL and remaining components are also of indigenous origin. The printed cards are produced in our own laboratories.

3.1 Signal Channel

The arrangement for amplification and frequency modulation of the photometer signal is shown in Figure 4. A Signetics 741 linear op-amp is used as a pre-amplifier, in somewhat unconventional manner. The input impedance has been kept low (1K), thereby enabling the use of a long cable straight from the photomultiplier on the telescope. This is possible only because the light levels encountered are quite high, the limitation in faintness of measurement being dictated by the sky background illumination, which is often high in the vicinity of the moon. No separate pre-amplifier has been found necessary adjacent to the photometer in this arrangement. The pre-amplifier has variable gain in discrete steps of 2, 5, 10 and 50, the amplification being selected depending on the conditions of any particular event. This is followed by a driver amplifier stage with a high gain; variation in gain is possible in this stage also by selecting different feed back resistors by means of a selector switch. This stage has some potentiometric control for adjusting the output voltage level referenced to ground, by means of which optimum frequency modulation performance of the succeeding VCO stage and tape recorder can be set for any particular event. It is important to point out that the levels of illumination of both the object and background may vary over wide limits in different occultation events.

The voltage controlled oscillator employs a Signetics 565 I.C. chip. This is a versatile phase-locked loop (Signetics, 1972), which has been used as a free running VCO in our circuit. The free running frequency is controlled by the combination of input signal and level setting and has been set for operation with the range 5 KHz-10KHz. The output of the VCO is fed to the tape recorder through a transistor buffer emitter follower.

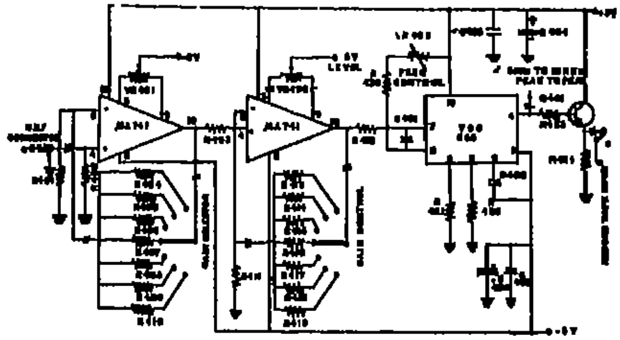
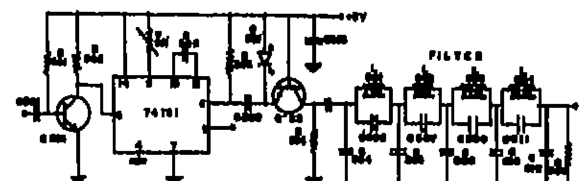


Fig. 4. Photomultiplier amplifier and voltage controlled oscillator

The arrangement of signal demodulation in the replay system is shown in Figure 5. Replayed signal from the tape recorder is pulse-shaped and demodulated by a pulse counting discriminator arrangement. To make the replayed signal compatible to the TTL logic in the Signetics 74121 Monostable Multivibrator chip, transistor level changing circuit has been employed. The discriminator employs a diode-condenser combination followed by a transistor in common base configuration, and yields an output voltage proportional to the rate of arrival of pulse (Frost, 1965). A 4-section Cauer low pass filter employing ferrite-pot core inductors, with a pass band below 4.5 KHz removes the carrier, but allows the fast variations to pass through to output.



~R~ Means leads going either in or out of printed boards

Fig. 5. Demodulator

3.2 Timing Channel

The basic oscillator employs a mounted quartz crystal and generates 100 KHz with good stability. As standard time pips are recorded within a few minutes of any recorded event, extreme high precision and stability are not essential. The generated frequency has been measured by standard laboratory equipment and has been found to be within ± 20 Hz under extreme conditions likely to be encountered.

The oscillator consists of a Signetics μA 709 with the crystal in its feed back loop and feeds a chain of 7490 decade counters through a transistor interface. Tappings at appropriate points bring out pulse trains with repetition frequencies of 10^4, 10^3 and 1 which are mixed by a mixer amplifier and fed to the tape-recorder. As 1 pps is too low a frequency for tape recorder registration, 1 KHz signal is pulse modulated by the 1 second pips by means of 7408 AND-gate before sending it to the mixer. The circuit arrangement is shown in Figure 6.

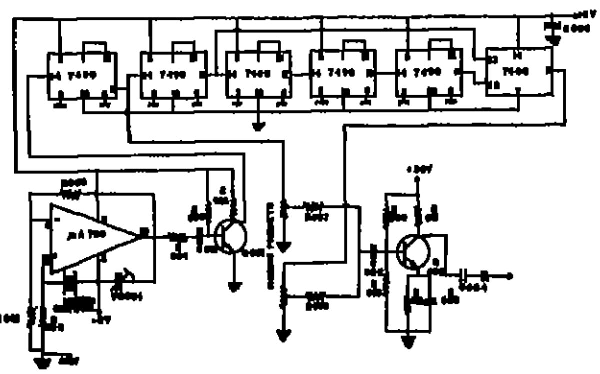


Fig. 6. Crystal oscillator and II channel recording amplifier

Signal is fed in parallel to two selective amplifiers, employing μA 741 linear I.C. chips with twin T networks in their feed back loops. The first channel passes 1 KHz; bursts of 1 second repetition frequency of this signal pass on to pulse shaper circuits in the selective delay circuit. The second channel passes the 10 KHz signal on to another 7490 decade counter, which in its turn produces 1 millisecond pips. The circuit is illustrated in Figure 7.

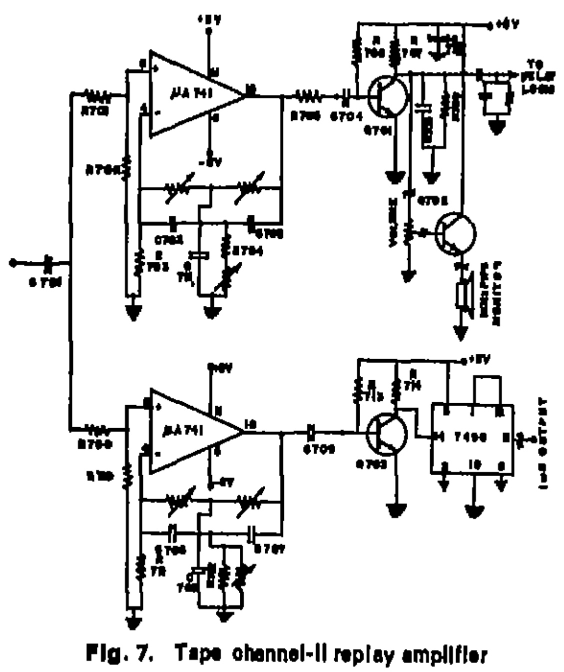


Fig. 7. Tape channel-II replay amplifier

3.3 Selective delay generator

Detailed circuit of this unit is given in Figure 8. The monostable multivibrators used are Signetics 74121 chips, 7408 Quad 2-input AND gates and 7490 decade counters provide the hardware for the counting logic. Three 7486 Exclusive OR gates compose a three digit coincidence circuit. Two thumbwheel switches together with 7404 inverter generate the programme of delay.

3.4 Auxiliary sub-systems

Bursts of 1 KHz signal at prf of 1 per sec received from timing channel amplifier is fed to a monostable multivibrator (74121) through a transistor interface, which generates pulses of 250 ms duration at 1 pps. An LED indicator lamp connected to the $\bar{Q}$ terminal of the chips gives visual flashes. The bursts are also amplified by a 2N1481 transistor amplifier and a small speaker provides the seconds pips for audio monitoring. The LED part is shown in Figure 8, while the audio amplifier and speaker is shown in Figure 7.

To provide each photographic record with an identifiable index, visual display of some characters are made by the top trace of the 4 trace oscilloscope. The principle employs television type raster generation and synchronised intensity control of the scanning spot by a set of fast clock pulses. Detailed account of this system is described in Appendix 1 of this paper.

The power supply for all digital I.C. chips are by a regulated circuit providing + 5 volts at 500 mA. Full wave bridge rectifier employing BEL BY 127 diodes and Signetics μA 723 regulators driving a power transistor compose this circuit. For the linear I.C.'s a separate supply of -5 volts (regulated) is similarly provided.

4. Observational Procedure

The system can be used in conjunction with a photometer or a scanner in place of the standard amplifier pen recorder arrangement. The equipment is completely self contained; only additional equipment needed being the photometer and its H.T. power supply; also, for time-signal registration a good quality communication receiver set is desirable.

The procedure for recording an event consists of measuring the star and sky deflections on the monitor

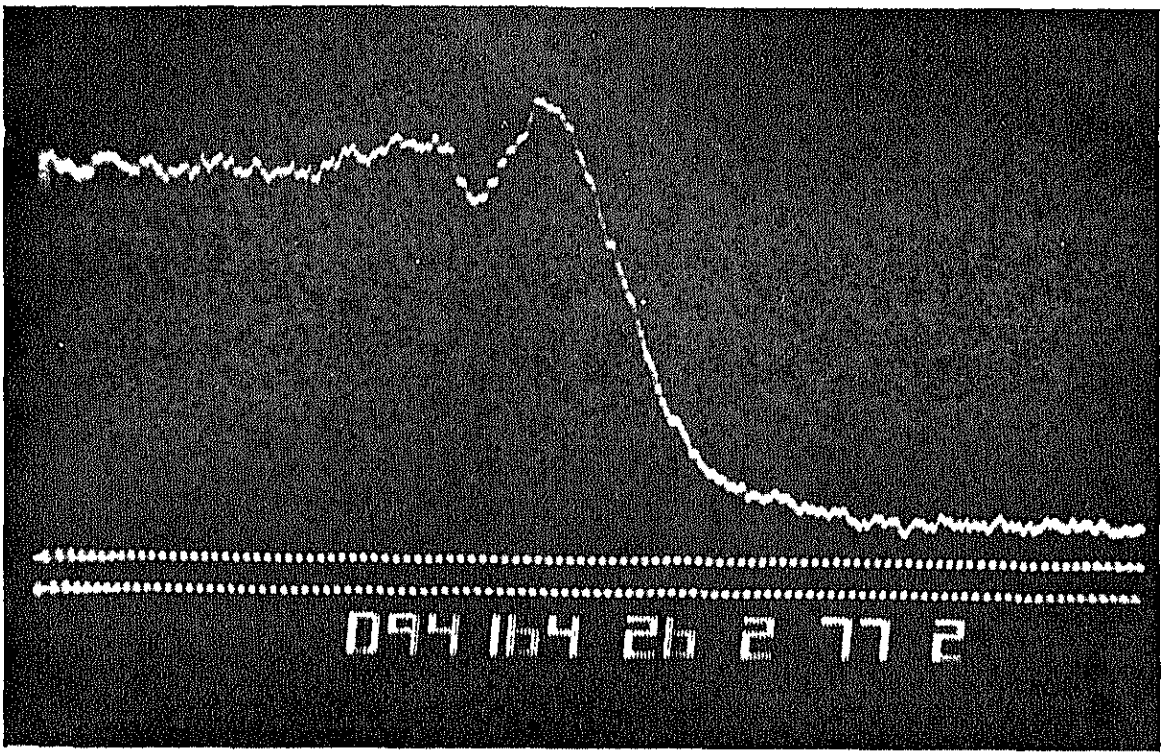


Fig. 9. Light Curve obtained by the system during a immersion event.

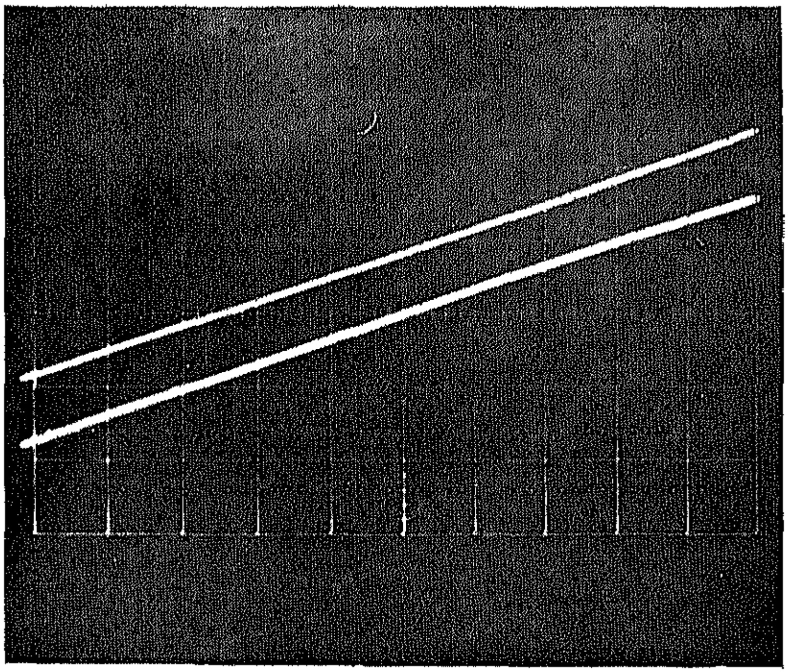


Fig. 10. C. R. display of linearity of the system The lower trace is the reproduction of the upper trace.

Bhattacharyya and Sundareswaran (*facing page 72*) oscilloscope and adjusting the output level for optimum contrast. The size of the diaphragm is selected consistent with the stability of telescope drive and seeing conditions; the smaller diaphragms providing better signal to noise ratio. About two minutes before the predicted instant the tape recorder is started and the throwover switch changed to microphone position. The details of the event are read out on the microphone, and standard time signal pips, together with their voice identification recorded. The switch is changed over to the photometer signal, and the recorded output monitored on the oscilloscope. The event can be visually detected on the scope. As soon as the event is over, the switch is thrown over to the microphone position, the event announced and another set of time pips recorded. The recording is then stopped.

The procedure of play back is as follows. The tape is re-run and the event identified on the oscilloscope. The approximate position on the tape, where the relevant portion of the light curve is located is also determined. A reference mark is introduced on the record in such a way that the number of full seconds between the reference mark and the event is known. The tape is wound back once more and played. The timing channel seconds pips are audio-visually displayed and can be counted. Count is started after the reference mark is passed; if n is the number of full seconds between the reference mark and the event, then after (n-1) counts the operater presses the start button of the selective delay generator. The unit opens up with the next seconds pip (i.e. at the n^{th} second), and after lapse of the set delay of a known fraction of a second, the relevant part of the light curve appears on the screen, together with the millisecond pulses. A camera is employed to photograph this single trace on the oscilloscope screen. One such record of an immersion event is reproduced in Figure 9. The exact delay needed to get the event at the screen centre, can easily be determined after a few trials before photographing the trace.

5. Reliability of record

As reliable measurement of the fine details of the light curve is essential for the purpose of the experiments, the performances of the instrument have been subjected to rigorous laboratory tests. Although the amplifiers used before modulation have ample bandwidth, the process of modulation and recording introduce considerable limitation. We have recorded fast ramp with 1 millisecond rise time and compared the reproduced waveform with the original input. The departure from linearity in this process has been found to be less than 1% which is insignificant compared to the noise inherently present in this type of experiment. Figure 10 shows the original and reproduced traces of a standard waveform at the input and output terminals of our equipment.

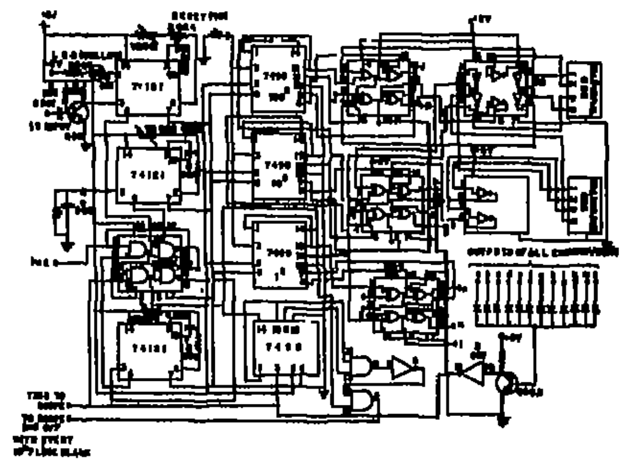


Fig. 8. Selective delay logic and blanking circuit

Precision of timing an event in our experiments is usually done by model fitting methods similar to those described by Nather and McCants (Nather and McCants, 1970). In such a method the seeing noise usually limits the accuracy of determination of immersion and emersion timings. In an ideal case, in the absence of seeing fluctuations, the accuracy of timing is limited by the stability of the oscillator. In the present case the variation is found to be rather high, although the effect is small compared to other uncertainties of the occultation measurements. Elaborate laboratory measurements have shown that a random variation of ± 2 Hz is present in our basic oscillator clock. The presence of standard time pips at the two ends of a record, permits correction due to mean deviation of the clock frequency, but the random variations introduce an uncertainty, which may be as high as 2.5 milliseconds, when the nearest comparison standard time pips are 1 minute away. In a future model, we propose to improve on this limitation.

This lack of high stability, however, has negligible effect on the shape of an occultation light curve. The relevant portion of any light curve, even under extreme circumstances rarely exceeds 100 ms; the cumulative errors over this duration do not exceed a small fraction of a millisecond.

Appendix 1

Plate Index Generator

A system for digital display of some of the parameters of the occultation event has been incorporated in the equipment described in this paper. The input device is a set of 11 buttons by which numbers 0 through 9 and space can be entered. The sequential information in the coded form is stored in a 64 bit scratch pad memory The stored information is released and modulates the intensity of a CRO beam covering a narrow strip on the screen to produce the information in digital form. As the read pulses are synchronized with the sweep, the pattern is stationary and can be photographed. The arrangement of the digital logic elements is shown in Figure A. A pair of 7420 NAND gates used as encoders generates 4 line BCD signal which gets recorded in a 82S25 scratch pad memory, the addressing pulse being generated by a simple counter 7493. An arrangement of logic gates enables a sequence of numbers to be registered in successive locations in the memory pad.

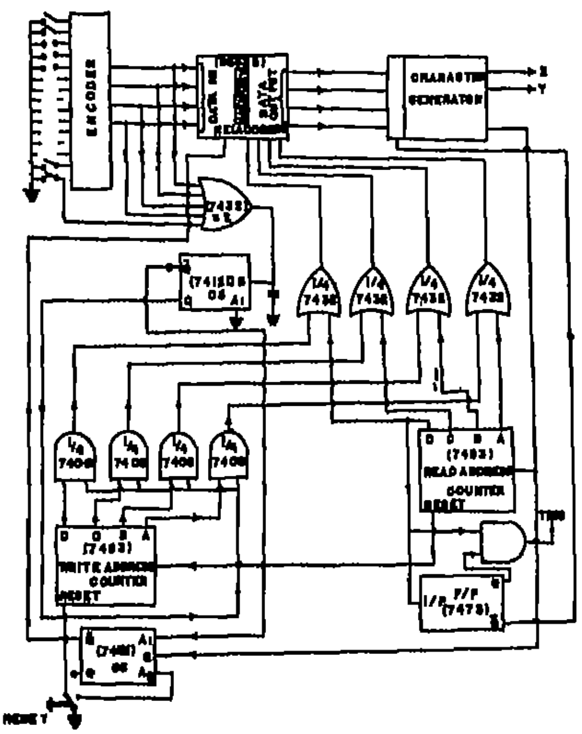


Fig. A. Plate Index Generator

The "read" pulse is generated periodically from the basic clock oscillator. The stored information in different memory locations is sequentially read and transferred to the character generator. This is done by a separate read counter 7493, which advances the address to the next location after information in any memory location is read.

The display of the stored information is done by the character generator subsystem. This consists of UJT oscillator generating 80 KHz clock rate followed by a chain of counters. A saw tooth waveform at 10 KHz rate is generated which sweeps the CRO spot in Y direction. A slower horizontal sweep is generated by a parallel chain of counters, determining the physical sizes of the letters formed.

The counter outputs are decoded by three input-NAND gates (7400) and two decoder chips (7445). The outputs of this decoder combination produce brightening pulses which are applied to the CRO Z input. The arrangement is schematically shown in Figure B.

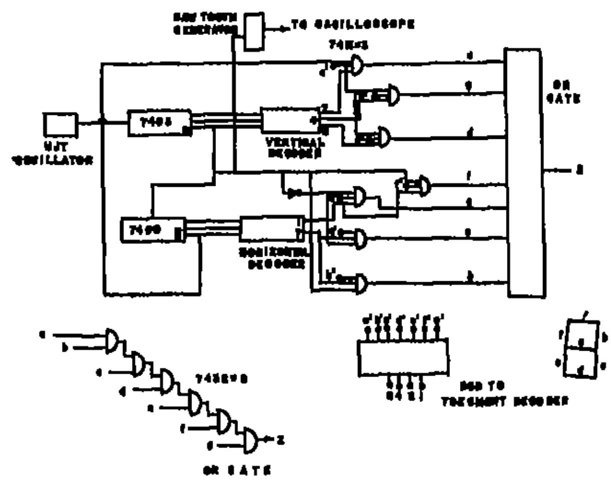


Fig. B. Character Generator

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