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LASER RANGING TO LUNAR RETROREFLECTORS : a) SIGNAL DETECTION, LOCATION IN RANGE-TIME, AND TIMING PRECISION. b) LASER PULSE UNIFORMITY AND TIMING.

by

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Laser Ranging to Lunar Retroreflectors : a) Signal Detection, Location in Range - Time, and Timing Precision. b) Laser Pulse Uniformity and Timing.

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Given August 4, 1967 at the O. E. Group Seminar.

Reference : Second Supplement to the Proposal for Laser Ranging to Optical Retroreflectors on the Moon (submitted to NASA on 9 January 1967).

I. Signal Detection

The average signal return was shown to be 16 photons for the design under consideration. The average number and distribution of the photoelectrons released from the photocathode were found by assuming that the quantum efficiency was known (e.g. 10% by enhancement techniques) and the distribution was Poisson with the relevant mean (e. g. 1.6 photoelectrons for the above case). Goodman[1] and others[2] have pointed out that the signal return for the array of retroreflectors will not be constant (e. g. 16 photons), but will be Bose - distributed about the expected return. The detection statistics are being re- calculated on this basis. In effect, one has the expected value slightly less than half the time so that more than twice as many firings are necessary to be as confident that a signal has been detected (e. g. one expects 16 or more photons only 38% of the time). The higher returns from the Bose distribution could be used to advantage as discussed in II.

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1. J. Goodman Proc IEEE 53 , 1688 Nov 1965

2. J. Faller, D. Currie, ...

II. Signal Location in Range - Time (Coarse).

The range is expected to be known to 0.3 km (1000 nsec) at the beginning of the experiment and thence somewhat better at the beginning of each successive search period. If there were no noise, the coarse - ranging procedure described in the Supplement II could be quite easily implemented. However, the noise can be quite high ($R_B = 2 \times 10^7$ Photons / sec whereas $R_D = 2 \times 10^4$ photons / sec). Thus, several photoelectrons of noise will occur randomly in the initial range gate on each firing. The number of firings required to locate the signal was calculated on the basis of Poisson statistics. The number required for the folded Bose - Poisson process is now being calculated. The results will probably show that the number of firings will have to be increased by about two.

The larger the amplitude returns (either average or Bose distribution fluctuations) will carry valuable information which cannot be used with a single PMT - discriminator detector. The information could be preserved by using a linear fanout after the PMT and using discriminators set at 1, 2, and 3 photoelectrons respectively. How to make use of this extra information has not been followed up although it should not be too difficult. However, we will see later why it is best to restrict our attention to single - photoelectron detection.

III. Signal Timing Precision.

After locating the signal in range - time, we proposed a complicated analogue - to - digital processing system to do the precise timing. It is worthwile to re - explore here the possibility of doing the precise timing with the simpler system used in the coarse - ranging. The laser output pulse is assumed to be constant in amplitude, shape, and occurrence. In such a case, the center of the pulse should be able to be located to at least one- tenth of its width (~1 nsec). There is also hope that nanosecond laser pulses may become available for use in the radar. These circumstances mean that the timing of the released photoelectrons must be done to much better precision. The limit to this timing is set by inherent PMT transit time spreads due to the variation in direction and magnitude of the released - photoelectron's velocity. (e.g. 0.3 nsec)

The immediate problem one meets in the use of a discriminator is its deadtime. The detection of the first signal photoelectron precludes the detection of a second one following within the deadtime of the discriminator ($\gtrsim 5$ nsec). Faller has proposed a way to solve this particular problem. The use of the proper number of small - diameter PMT's in place of one larger PMT will ensure that one return pulse will yield no more than one photoelectron <u>at each photocathode</u>. This suggestion also solves the problem of how to separate closely - spaced photoelectrons in the A to D proposal. (Single-photoelectron pulses may not have a constant shape). It should be pointed out that the enhancement device may not be quite as useful with the small - diameter tubes as with larger diameter tubes.

Another timing problem still exists with the discriminator, however. A recent study[3] has pointed out the relative advantages and dis - advantages of three types of discriminators. These are the leading edge type, the conventional crossover type and the fast crossover type. The leading edge discriminator has the smallest time dispersion due to pulse - height variation (i. e. Walk) for small pulse height variations ($<1.7:1$). The leading edge discriminator triggers at a set voltage level (e. g. FWHM). "Walks" of less than 0.45 nsec have been measured for the small dynamic range case using the equipment shown in Figure 1. The pulse height variation is often controlled by working at low detection efficiency (i.e. selected range of pulse heights). The "jitter" in the electronics is least for the leading edge discriminator.

When one wishes to discriminate over wide dynamic ranges (i.e. work at high efficiency), one uses a fast crossover discriminator. This discriminator essentially differentiates the pulse, triggers on the leading edge for pulse height discrimination, and then yields a timing pulse when it again triggers at the zero - crossing of the differentiated pulse. Ortec has built such circuits using the PMT's of Figure 1 and found a "walk" of 0.73 nsec for a 40 : 1 dynamic range (FWHM). It is, of course, necessary that the pulse be of

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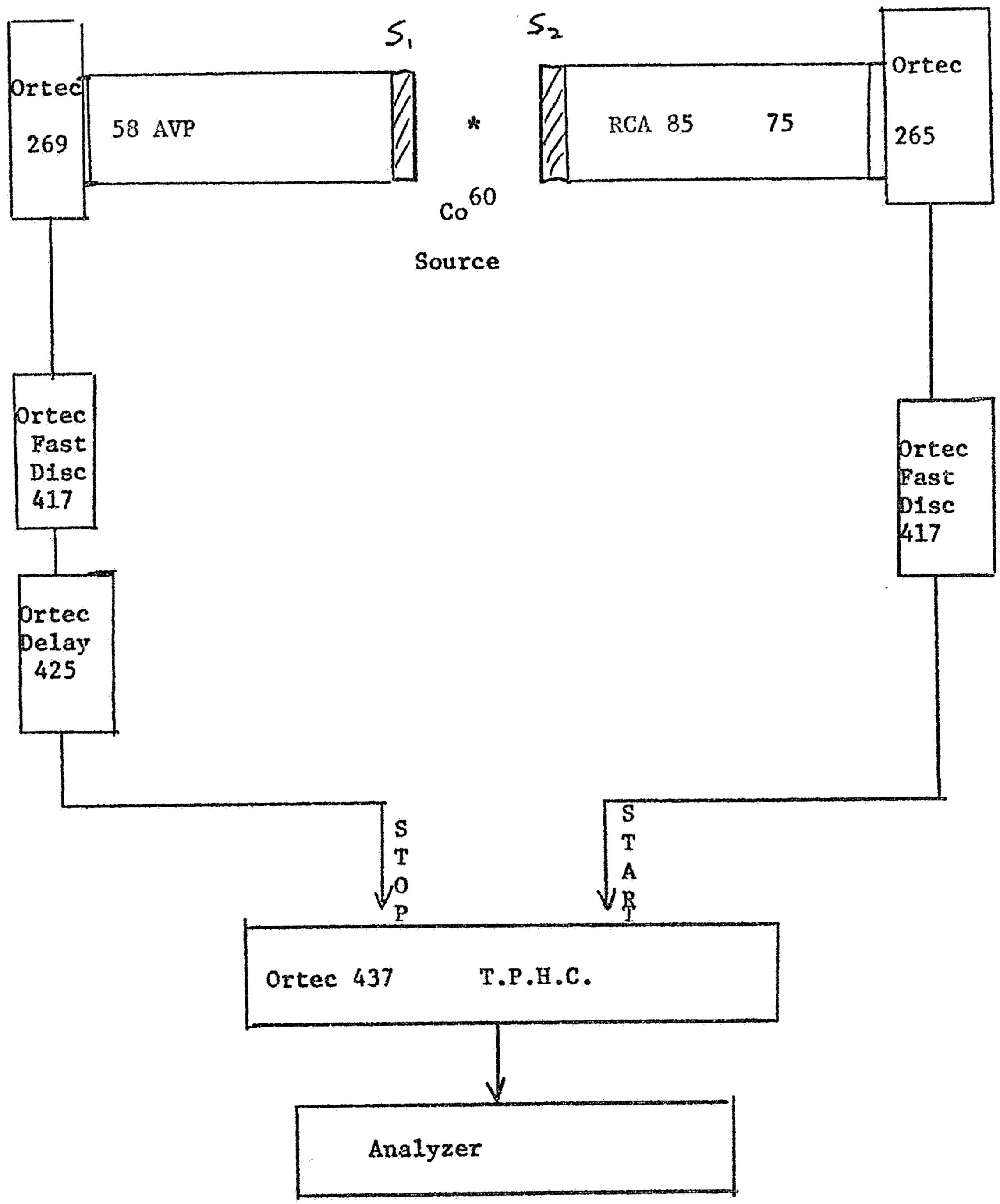
3. C. W. Williams, "Timing with PMT's Ortec News, March 1967

Figure 1 : Leading Edge Timing



S: NATON 136 Plastic Scintillator

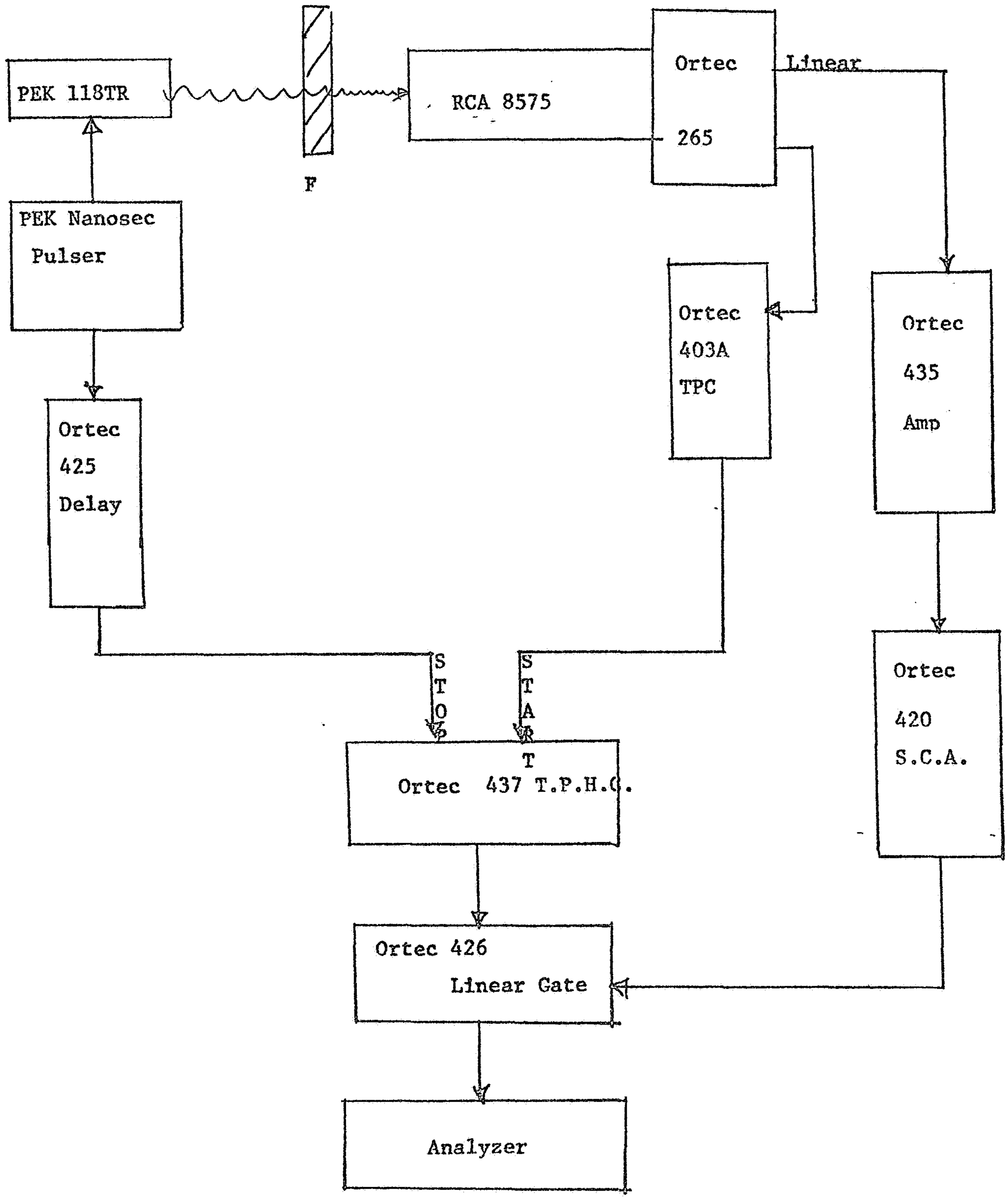
uniform shape although not of uniform pulse height. The "walk" in fast crossover discriminator was measured using a circuit diagram similar to Fig 1, but with Ortec 264 and 268 PMT bases respectively and 403A Time Pickoff Controls in place of the 417 Fast Disc's. The "walk" in the leading edge discriminator for 40 : 1 variations in pulse height is quoted to be 1.3 nsec.

The "single photoelectron signals" are known to have relatively wide pulseheight variations so that the fast crossover discriminator is the choice for the precision timing of the moon return. What is not known is whether or not the single photoelectron pulse shape is uniform enough. To study this question we propose to test the fast crossover discriminator (Ortec 265 and Ortec 403A T. P. C.) for single photoelectron pulses. One could use the fast crossover version of Fig 1 if one of the light signals were attenuated to the correct level to yield single photoelectron pulses. The Ortec 265 provides a linear signal from the PMT that can be used to identify the pulse heights of the single photoelectron pulses as done in Fig 2. However, it will be more convenient to use a nanosecond light pulser (PEK Labs Inc.) which will provide both the short light pulse and an electrical timing pulse. Fig 2 shows the equipment we will use to test the fast crossover discriminators. If the discriminator is satisfactory, the bundle of small PMT's each with their own bases and discriminators will be a more convenient method for the precision timing of the moon return than the proposed A to D method. If it is not satisfactory as is, each PMT - Discriminator chain will need its own single channel analyzer (Ortec 420) to limit the range of pulse height variations.

An alternate test circuit might consist of only the 265, 403A, and the proper oscilloscope. One would look at thermal photoelectrons from the photocathode by triggering the oscilloscope with one of the 403A timing signals and displaying the linear single - photoelectron signal and the other 403A timing pulse on the dual- trace oscilloscope.

The major road - block to the use of the simpler precision timing method is that there are no suitable PMT's available. EMR has a small - diameter PMT available which is adequate in every respect except transit time spread. RCA has several small - diameter PMT's adequate in every respect except gain (e. g. RCA 8644 is a ten - stage tube). A suitable PMT should be available under contract. The RCA 8644 is being used for single photoelectron counting in the upper atmosphere optical radar work, but this is made possible by the slow timing which is adequate for these purposes and which allows the use of low noise amplifiers.

Figure 2 : Test Circuit for Fast Cross-Over Discriminator



F: Filter

IV. Laser Pulse Uniformity

We have assumed that the laser pulses will be uniform in amplitude, shape, and occurrence. In fact, it may be somewhat difficult to design a Q-chopped laser with these properties. I have just issued University of Maryland Technical Report # 695 commenting on a proposed AFCRL multipulse, Q - chopped laser radar. They proposed to increase the efficiency of operation by extracting a number of Q - chopped pulses during one laser pumping cycle. I examined a "typical laser" and showed the limitations of such a proposal due to the short-term temperature rise in the laser rod during pumping. It is not possible to overcome these heating problems during a single pump period. However, the requirement of only one laser pulse per pump period (at a fixed time) allows the laser rod to cool between firings. A water - bath with a temperature control unit ($\pm$ 0.5°C) should be able to maintain the laser rod temperature so that its gain and hence the uniformity of the Q - chopped pulse in amplitude, shape, and delay from initiations are maintained.

The time jitter in the Q - chop initiation time is another problem. Jitters of $\pm$ 10 nsec are currently being quoted (Korad Pockets Cell Q - switch K - QS2). This jitter (and delay from initiator) can be eliminated by detecting the outgoing laser pulse in a similar manner to the return pulse. In this case, if the pulse is uniform in amplitude and shape, the leading edge discriminator may be used for timing. There is more than enough light around so that we would use a photodiode (e.g. ITT F 114W) rather than a PMT. If the amplitude of the laser pulse is not relatively constant, its shape will change radically and so the fast crossover discriminator would not be useful. Such variations could only be accounted for by very sophisticated cross - correlation techniques using the transmitter pulse sizes and shapes in conjunction with the sizes and arrival times of the return pulses.