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Signature Bruce E. Ivey

Date Dec 20, 1976

A DIGITAL COUNTING SYSTEM FOR HIGH SCHOOL SCINECE

by

BRUCE EARL IVEY

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My patient wife also deserves a note of thanks for her help and encouragement.

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ABSTRACT

This paper describes a low-cost digital counting system designed for use in high school science classes. The system consists of a central counter and three accessories which can be used with it. The main counter, or scaler, uses a 4 1/2 digit numeric display and contains its own power supply. It is used for measuring time, frequency and nuclear decay rates.

The accessories are a light meter for measuring light intensity, an anemometer for measuring wind speed, and a time-of-flight module. This third accessory uses two photodetectors to measure the motion of an object as it breaks a light beam.

Instructions or illustrative examples are given for twelve different uses for the system.

Chapter 1

INTRODUCTION

In recent years educators have been including more and more student experimentation in science classes, thus putting into practice the idea that students learn best that which they experience. There are, however, several requirements which must be met for this to be true--(1) the experiments must be simple enough for the students to understand, (2) the experiments must be accurate enough to effectively illustrate the concepts being studied, (3) the experiments should not be so time consuming that they exceed the students' span of interest, or take time away from other subjects and (4) the equipment needed must be affordable, or the experiment can't be done in the first place.

The measurement system presented in this paper helps to meet these requirements (in the areas where it can be used) by having simple controls and a large, easy-to-interpret digital readout. It also costs much less than a commercially available collection of similar instruments would.

The system consists of a central counter or scaler and several accessories which plug into it. The counter alone can be used for timing, and to measure the frequency of a signal. When connected to a Civil Defense Geiger Counter it can be used to measure nuclear count rates and find half-lives. An accessory light meter is used to measure relative light intensities, either instantaneously or for day-long periods. An anemometer accessory measures the wind's velocity, and therefore its energy, and a time-of-flight module uses photocells to measure the velocity or acceleration of an object. The system achieves small size and weight by using transistor-transistor logic (TTL) integrated circuits and seven-segment light-emitting-diode (LED) numeric displays for the readout. Table 1.1 summarizes the functions of the system.

Table 1.1

Summary of System Functions

Quantity Being Measured	Detector	Processor	Readout
Time	Human	Scaler	Scaler
Frequency	Scaler	Scaler	Scaler
Nuclear decay	G-M tube	Geiger counter, scaler	Scaler
Light intensity	CdS cell	A-D converter, scaler	Scaler
Wind Speed	Anemometer	LED-photocell pair, scaler	Scaler
Mechanical movement	Phototransistor	Pulse-gating circuit, scaler	Scaler

Units are available commercially which can make the same measurements, but no one makes a system which integrates so many uses in one counting unit. Also, a collection of commercially available instruments would cost in the neighborhood of $300 to $400, while the total parts cost for this system is under $120. It is planned that parts kits will be available through the Math-Science Resource Center at Montana State University.

The following sections of the paper will describe each of the parts of the system in turn, and will give examples of its use.

Chapter 2

COUNTER

The counter described in this section is the heart of the system--it is necessary for the use of any of the other parts, since it contains the readout and power supply.

POWER SUPPLY

The power supply consists of a pair of 8 volt transformers, a full-wave bridge rectifier, a filter capacitor and an LM309 voltage regulator to maintain a constant 4.9 volts to power the integrated circuits. These are connected as shown in Figure 2.1. The components are mounted on a printed circuit board which lies at the bottom of the box containing the counter, except for the voltage regulator, which is mounted on a heat sink at the rear of the box.

For those who already have a power supply an alternative is available, using only the capacitor, LM309 and a protection diode. This can be powered by any unregulated source of from 8 to 35 volts DC.

COUNTING CIRCUIT

The logic diagram of the counter is shown in Figure 2.2, and the printed circuit layout is given in the appendix. It will help to follow the logic diagram in the explanation which follows.

The input signal is fed into the counter by an input jack at the left of the mounting box. A current-limiting resistor, R-3, and a 4.3 volt zener diode protect the Schmitt-trigger input gate, IC-1. The signal going to IC-1 comes either from an external accessory via a 1/4 inch stereo phone plug, or from the internal 100 hz oscillator (described in the section on the light meter) when a plug is not in place. The count is controlled by the start/stop circuit in the lower left of the diagram. IC-2 and IC-3 comprise a bistable circuit which is activated by switches S-1 and S-2. This bounceless circuit also gates IC-4, which is used to drive the count indicator, LED-1.

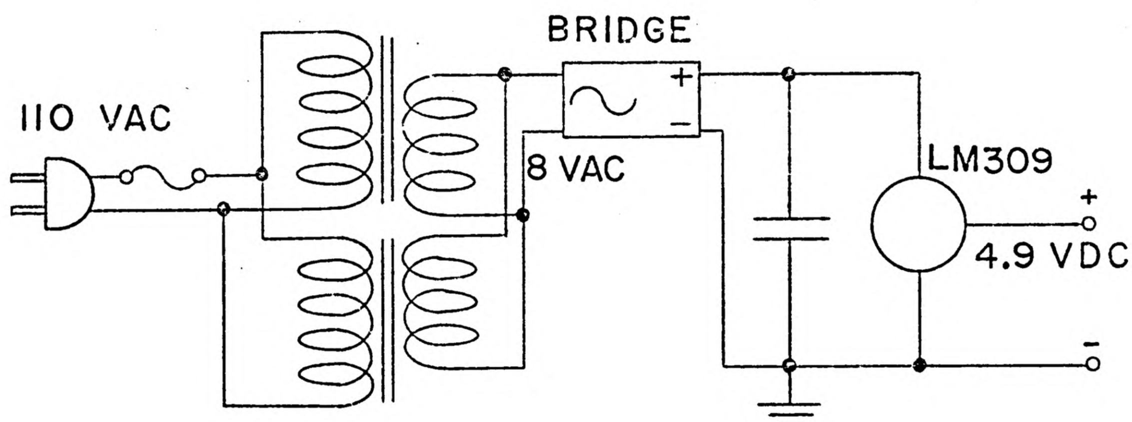


Figure 2.1

Power Supply Circuit

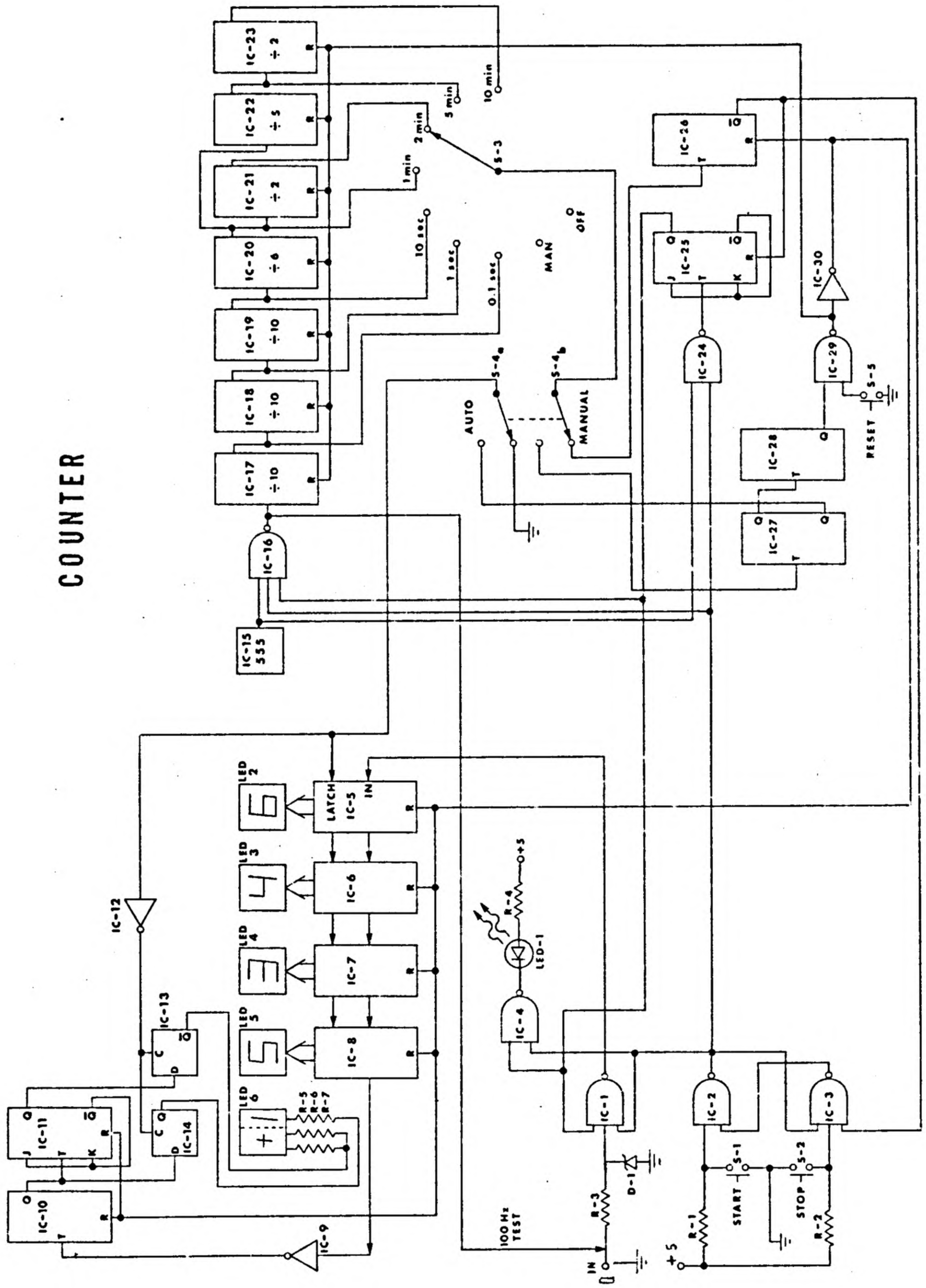


Figure 2.2

Counter Logic Diagram

Signals which pass through IC-1 are fed to the count string made up of IC-5 - IC-13. The first four IC's are type 74143, which combine a decade counter, latch, seven-segment decoder and driver in one 24 pin package. Current limiting resistors for the LED's are also included in the IC, so the parts count for this part of the counter is low. The "+1" display is driven by the two flip-flops IC-10 and IC-11. IC-13 and IC-14 are latches which are used for the same memory function (described below) as the latches in the other counters. This leading display needs separate current-limiting resistors to protect the LED's.

TIMING CIRCUIT

The oscillator for the timing circuit is an SN72555 timer. The frequency of this timer is determined by two resistors and a capacitor (not shown in the logic diagram), and an explanation of their function is given in the circuit description for the light meter. For accurate measurements in the automatic mode, the frequency of the timer must be adjusted to 100 hz. This can be accomplished without test instruments by using a clock with a sweep second hand. Begin by activating the counter manually for 5 second time intervals, and adjust the small potentiometer in the back of the circuit board until the count for the 5 seconds is close to 500. By using smaller adjustments and successively longer time intervals, the frequency can be brought very close to 100 hz. Note that the automatic time intervals cannot be used for this adjustment, since they use the frequency from the 555 oscillator for their time base--the expected number of counts will always be obtained, no matter what the frequency is.

The signal from the 555 is gated through IC-16 and goes into the divider string made up of IC-17 - IC-23. As the signal goes through these IC's, it is divided to give the various preset time intervals which are selected by the rotary switch S-3. The signal from IC-15 is gated to ensure that the time interval selected starts on the beginning of one of the 0.01 second time intervals. Of course, this would never be detected in the longer time intervals, such as 1 minute, but at the 0.1 second setting the error could be as high as 10 percent if this precaution were not taken.

The command to gate IC-16 comes from IC-25, which also gates IC-1 at the same time. Thus, the timing circuit divider string and the main counter are turned on at the same time.

When S-4 is in the manual reset position, as shown in the logic diagram, the end of the timing interval causes IC-26 to stop the counter by gating IC-3. The counter is then locked in the off position until the reset button, S-5, is pressed. This resets the two count-control flip-flops, IC-25 and IC-26, and the count can then resume. Also, the latch feature in the main counter is disabled in the manual reset position by having $S\text{-}4_a$ grounded.

In the automatic reset position, the signal from the time intervals is routed by switch $S\text{-}4_b$ to a pair of monostable multivibrators, IC-27 and IC-28. When the signal comes in, the first of these briefly sends an impulse to the latch circuit via $S\text{-}4_a$, and this causes the latches to hold and display the numbers currently in the counter. About 10 milliseconds later IC-28 sends a reset pulse to the counters through IC-29 and IC-30. The counter now starts accumulating a new total while the displays show the previous one. Thus, in this mode the displays are always one step behind the counter, and no time is lost while reading the displays.

FRONT PANEL DESCRIPTION

The design of the front panel is shown in Figure 2.3. At the top left of the panel is the 4 1/2 digit numeric display, with a maximum capacity of 19999. If this number is exceeded the plus sign (+) at the left end of the display turns on to indicate an overflow, but the scaler will keep on counting. Thus, if one is watching the display to see how many times it has overflowed, the count can be extended. The readout uses 0.43 inch red LED seven-segment displays, and is readable at distances of up to 20 feet.

At the right center of the panel is the main function-selector switch. Along with being the power switch (for counters with a built-in power supply) this controls the mode of operation--whether the

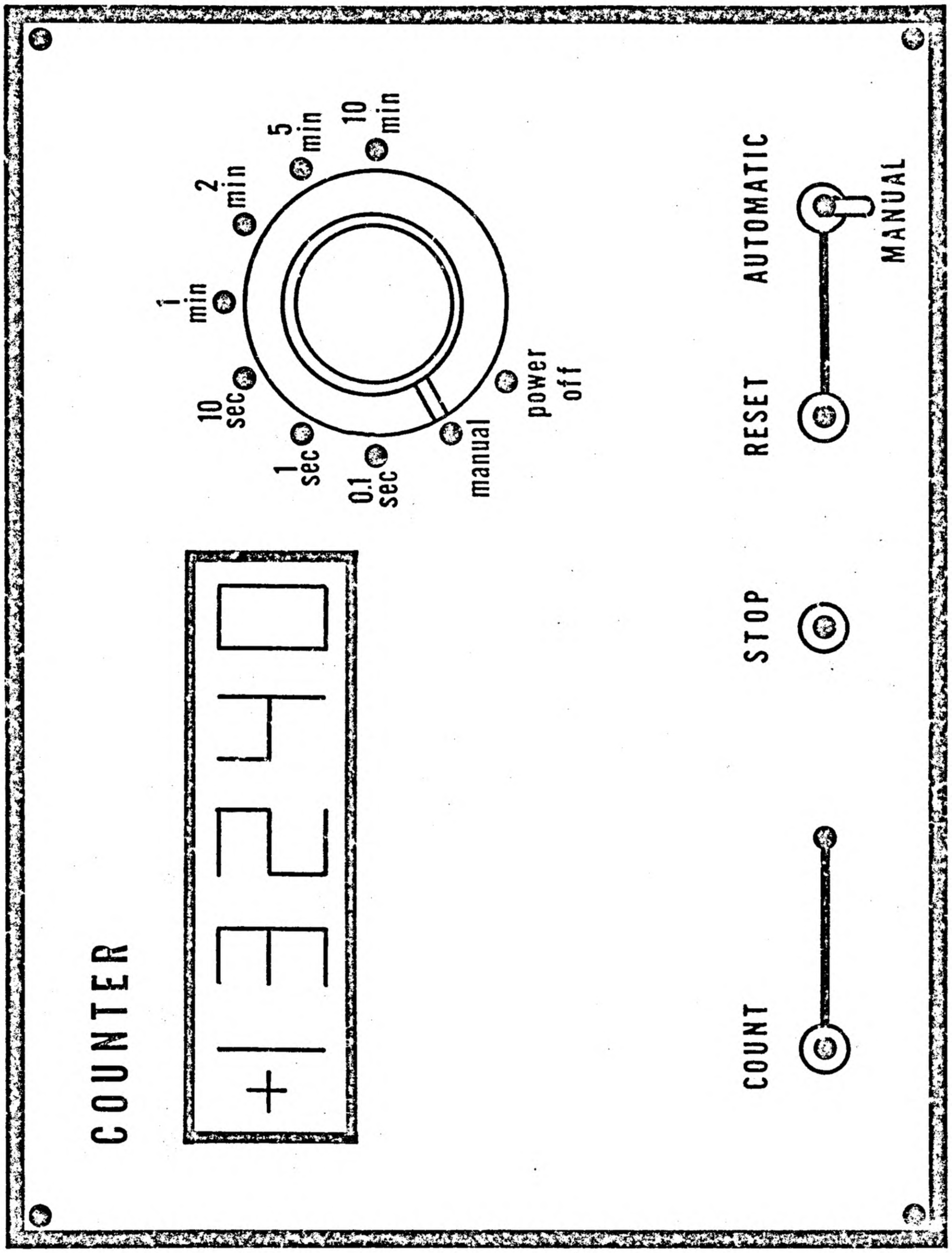


Figure 2.3

Counter Front Panel

count will be for a certain preselected time interval, or will be controlled manually.

The switches at the bottom right of the panel determine the operation of the reset. In the manual position the reset button is depressed to clear the display. In the automatic position the counter will reset itself, and successive counts will follow each other without interruption.

At the bottom left and bottom center are the controls which start and stop the counter when it is being operated in the manual mode. The small LED by the count switch indicates that a count is in progress.

USES OF THE COUNTER

Along with being the power and display unit for the accessories, the counter can be used independently for three types of measurements--timing, frequency determinations and counting with a radiation detector.

Timing

Once the 555 timer has been adjusted as described above, the counter can be used as a stopwatch which counts in 0.01 second intervals. This is possible because the 100 hz signal from the oscillator is internally connected to the counter's input any time there is no plug in the jack at the left side of the box. Both the rotary mode selector switch and the reset selector switch are set at manual, and the count is controlled by the count and stop switches.

Frequency Counting

To measure the frequency of an audio generator or other source, one must connect the source to a standard 1/4 inch stereo phone plug as shown in Figure 2.4. Note that the signal is connected to the center contact. The end contact is not used because it supplies the current to power the other accessories.

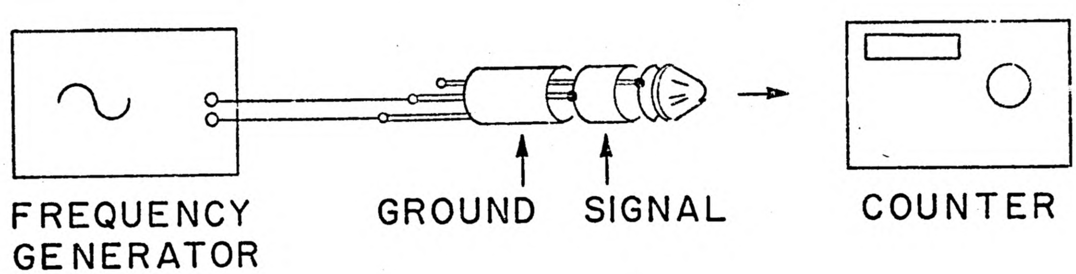


Figure 2.4

Connecting the Counter to a Frequency Generator

For audio frequencies, setting the mode selector on 1 second and the reset selector on automatic will give continuous counts which read directly in hertz (cycles per second). Frequencies up to 200 Khz can be measured by using 0.1 second time intervals. If the numbers are changing so rapidly that they are hard to read, single 0.1 second counts can be taken by using the 0.1 second setting with manual reset.

Nuclear Radiation

To use the scaler to count nuclear events, a standard Civil Defense Geiger Counter (CDV-700) is used as the primary detector. These are often available on a loan basis from local Civil Defense offices. This is connected to the scaler by means of the cable provided in the parts kit, as shown in Figure 2.5. The counter can be controlled manually, or any of the preset time intervals can be used with or without automatic reset.

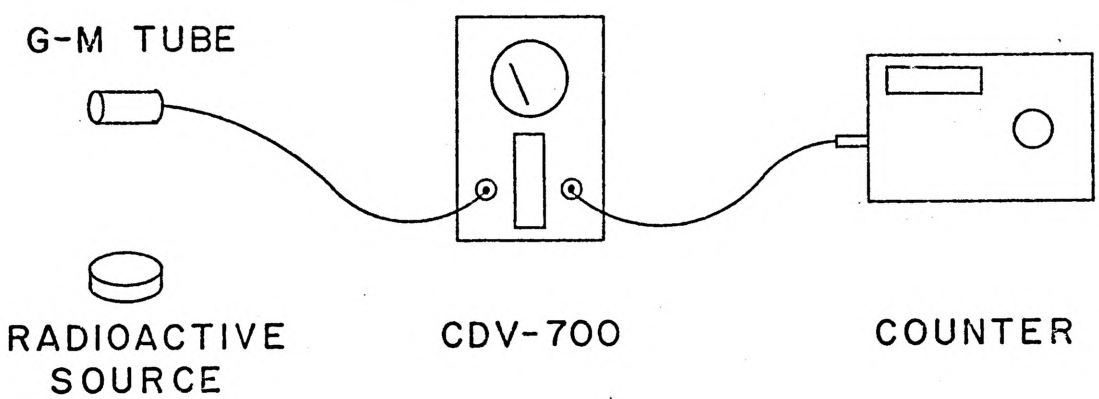


Figure 2.5

Connecting the Scaler to a Geiger Counter

In the first example 100 counts of 10 seconds each were taken to show the random nature of radioactive decay. These were then plotted in a histogram, giving an approximation to a normal distribution, as shown in Table 2.1 and Figure 2.6.

Table 2.1

Radioactive Decay--100 10-Second Counts

445	469	508	474	496	513	510	497	482	479
466	566	515	500	492	477	499	482	513	480
511	451	457	485	471	498	477	475	481	511
524	495	465	492	520	496	483	466	469	493
492	484	515	492	471	517	450	494	519	524
479	488	426	466	492	457	532	474	493	461
464	511	500	473	493	510	465	501	495	496
469	504	441	506	476	510	493	542	480	572
489	455	471	501	511	489	493	508	491	465
507	530	489	549	528	482	483	472	484	482

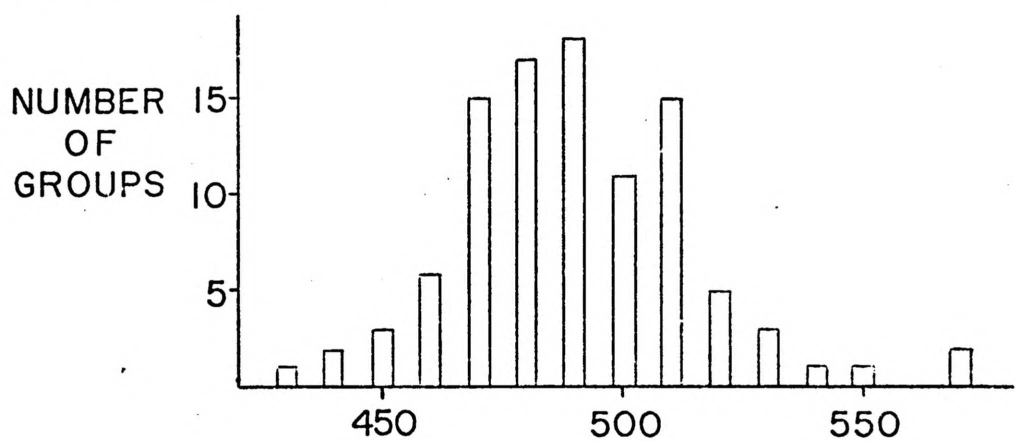


Figure 2.6

Frequency Distribution of 100 10-Second Counts

The second example shows the usefulness of the preset time intervals with automatic reset. The task is to find the half-life of an unknown radioactive substance. Since the half-life was known to be fairly short, 10 second time intervals were used. By using the automatic reset, no time was lost between counts, and the full number of counts could be used. After the counts were taken, it was noticed that the half-life was on the order of a few minutes, so the counts were grouped in sixes, giving a one minute time scale and better statistics. The data and the semi-log graph to determine the half-life are shown in Table 2.2 and Figure 2.7.

Table 2.2

Activity of Unknown Radioactive Sample

Time (Sec)	Counts	Time (Sec)	Counts	Time (Sec)	Counts	Time (Sec)	Counts
10	1676	70	1322	130	1004	190	773
20	1585	80	1244	140	943	200	733
30	1548	90	1171	150	948	210	727
40	1469	100	1138	160	857	220	683
50	1141	110	1090	170	849	230	638
60	1347	120	1160	180	787	240	623
	9036		7125		5388		4177

In this example the half-life of 2.8 minutes was obtained from a sample which is readily available commercially in the form of a "Minigenerator" in science supply catalogs.

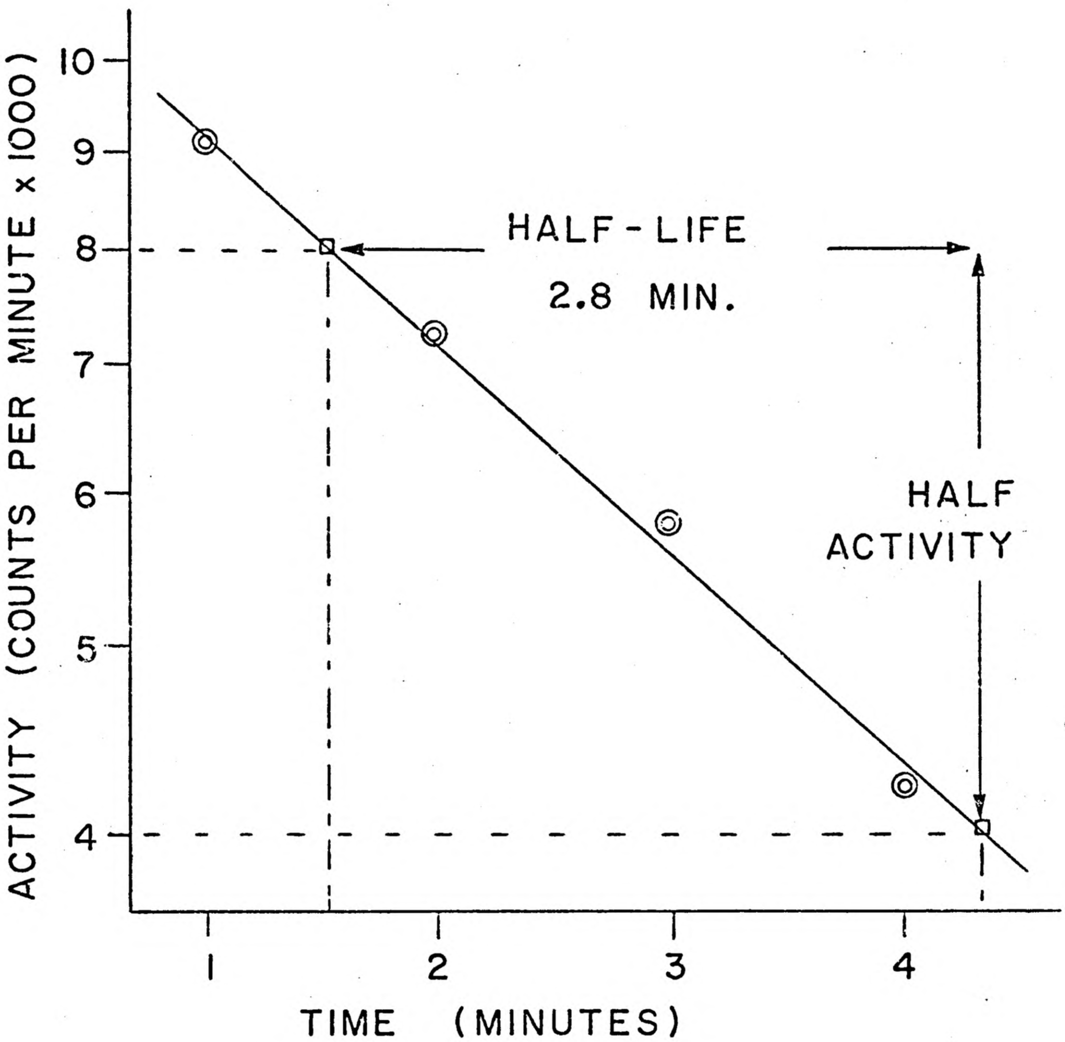


Figure 2.7

Semi-Log Graph to Determine Half-Life

Chapter 3

LIGHT METER

The light meter attachment is an analog-to-digital (A-D) converter whose function is to produce a steady stream of pulses whose frequency is directly proportional to the intensity of the light falling on the detector. This signal is then counted by the scaler, and if the counts are taken for consistent time intervals, the counts will be proportional to the light intensity.

CIRCUIT DESCRIPTION

A simplified schematic diagram for the light meter is given in Figure 3.1. The circuit uses an SN72555 timer integrated circuit. When connected as shown in the diagram, this circuit functions as an astable multivibrator whose frequency of oscillation depends on the three components R_a, R_b and C. An approximate value for the frequency of oscillation is given by the formula

$$f = \frac{1.44}{(R_a + 2R_b)C} .$$

The formula can be understood by noting how the circuit functions. The capacitor C is charged by current moving through resistors R_a and R_b. When the charge on the capacitor reaches 2/3 of V_{cc}, as detected at point Y, an internal switch is closed, connecting point X to ground, and the capacitor discharges through R_b. This continues until the charge on C is reduced to 1/3 of V_{cc}, at which time the switch opens and the capacitor starts to charge up again. Thus, as the size of the capacitor or the resistors is increased, the capacitor will charge more slowly, giving a lower frequency.

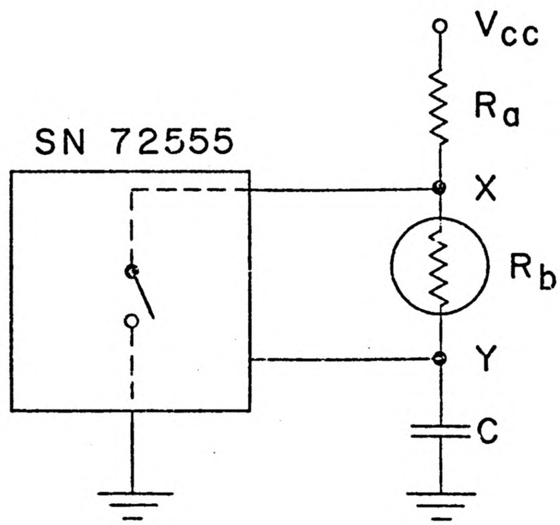


Figure 3.1

Light Meter Circuit

In our circuit, C and R_a are held constant, so the frequency depends only on $1/R_b$, which is the resistivity of R_b. Fortunately, the resistivity of a CdS photoresistor is directly proportional to the light intensity falling on it, so the frequency of the circuit is directly proportional to the light intensity, with one small problem--

the resistance of R_a. This is minimumized by using a small value for R_a, 100 ohms, while the resistance of R_b, the photocell, varies from 10 megohms (in the dark) to 10,000 ohms (in bright sunlight). Thus, the error introduced by the presence of R_a is less than one percent, which is better than the linearity of the photoresistor.

During long count periods, the pulse rate of the meter would overflow the scaler's capacity, so a "divide by 1000" option is provided, as shown in Figure 3.2. This is accomplished by three 7490 decade counters in series, and is selected by the use of a toggle switch on the front panel. The printed circuit layout is shown in the appendix.

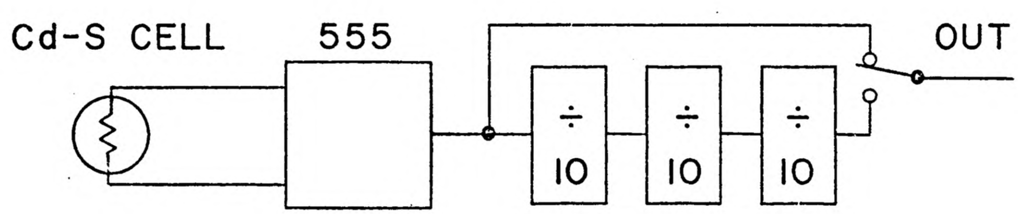


Figure 3.2

Light Meter Logic Diagram

FRONT PANEL DESCRIPTION

The front panel, shown in Figure 3.3, has only two items of interest to the user--the CdS photocell and a toggle switch. The CdS photoresistor, located in the left center of the panel, is the light receptor for the module.

The switch selects between the normal pulse rate (for a given light intensity) or one which is one thousand times slower. This slower rate is useful for obtaining an integrated measurement of the average intensity over long time periods--a situation which would overflow the counter at the normal pulse rate.

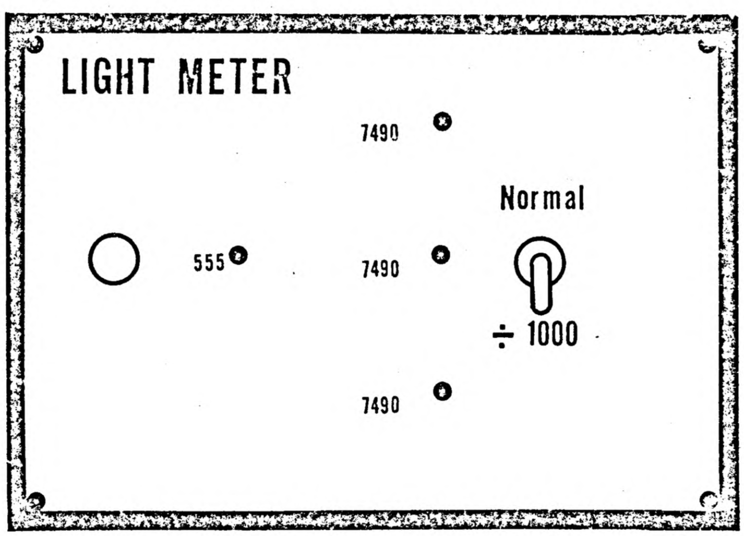


Figure 3.3

Light Meter Front Panel

USES OF THE LIGHT METER

The use of the meter is similar to frequency counting--plug it into the counter, place the photocell in the light, set the scaler for 1 second automatic readings and read the intensity.

As an example, the meter was used to measure the relative intensities at the film plane of the object and reference beams while making a hologram, and then the two beams were adjusted until the ratio of the two was 1 to 3. See Table 3.1.

Table 3.1

Relative Light Intensities While Making a Hologram

	Before Adjustment	After Adjustment
Reference Beam	106	37
Object Beam	12	12

The second example used the slower frequency rate to measure the relative intensities of sunlight on two different days. To keep from having to turn the meter into the sun as it moved, a white table tennis ball was split in half and mounted over the photocell. This gave a more even response to light from different directions. The meter was then mounted in a fixed position so that sunlight would fall directly on it for most of the day, and the count was taken. On both days the counter was started at the same time before sunrise and stopped at the same time after sunset. The difference between the two twelve hour periods, one cloudy and one clear, is evident in Table 3.2.

Note that the intensity readings produced by this meter are arbitrary, which for most uses is sufficient. One could obtain a conversion factor for calibration to a known scale by using a light source of known luminosity at a measured distance from the detector. The only way to change the scale of the meter itself would be to use a different CdS cell or change the size of the capacitor.

Table 3.2

Light Intensities On Two Days
(x 1000)

Sunny Day (Scattered Cirrus)	Cloudy Day (Cumulostratus Overcast)
10,592	438

Chapter 4

ANEMOMETER

The anemometer used in this set is similar to most in its basic construction--a rotating axle with four spokes which have cups mounted at the ends. The purchasing department may think it a bit strange, but the cups are the "eggs" which are the containers for Leggs panty hose. They are make of reasonably sturdy plastic and are the right size and shape. The spokes and the axle (which is a 3/8 inch threaded rod) are not critical, but it was found that high quality ball bearings are expensive and hard to obtain. The bearings must turn with almost no friction if the unit is to operate well at low speeds.

The electrical circuitry of this unit, however, is different than most. The detector is a light-emitting diode - phototransistor pair with a small separation between them. A clear plastic disk with radial markings is fastened to the axle, and this turns between the pair as shown in Figure 4.1. The markings on this "strobe disk" trigger the electrical circuit at a frequency which is proportional to the rotational speed of the wind cups.

The unit gives readings in miles per hour or kilometers per hour, depending on the number of markings on the strobe disk.

CIRCUIT DESCRIPTION

The LED and phototransistor come as a matched pair in a single housing, so alignment or spacing is no problem. The switching transistor and resistors, shown in Figure 4.2, provide shaped logic pulses to the counter. It was found that if a long line is used to connect the anemometer to the counter, one must add a capacitor between the output and ground to eliminate electrical noise.

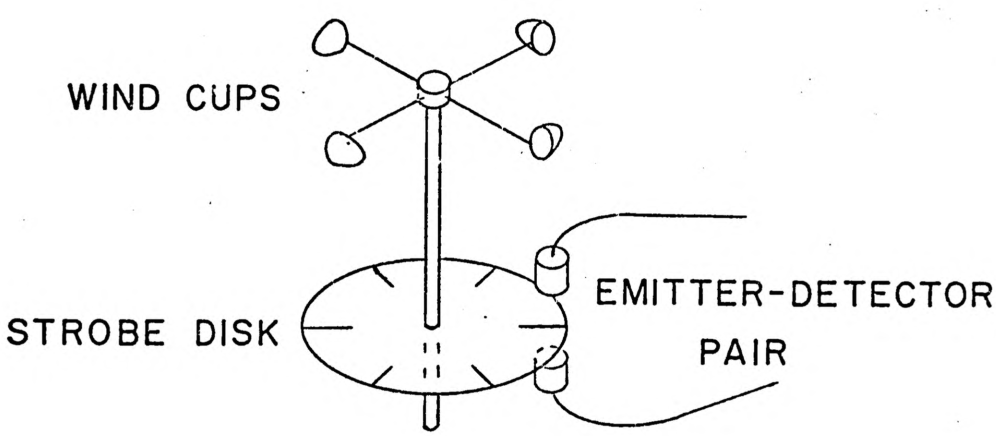


Figure 4.1

Anemometer Arrangement

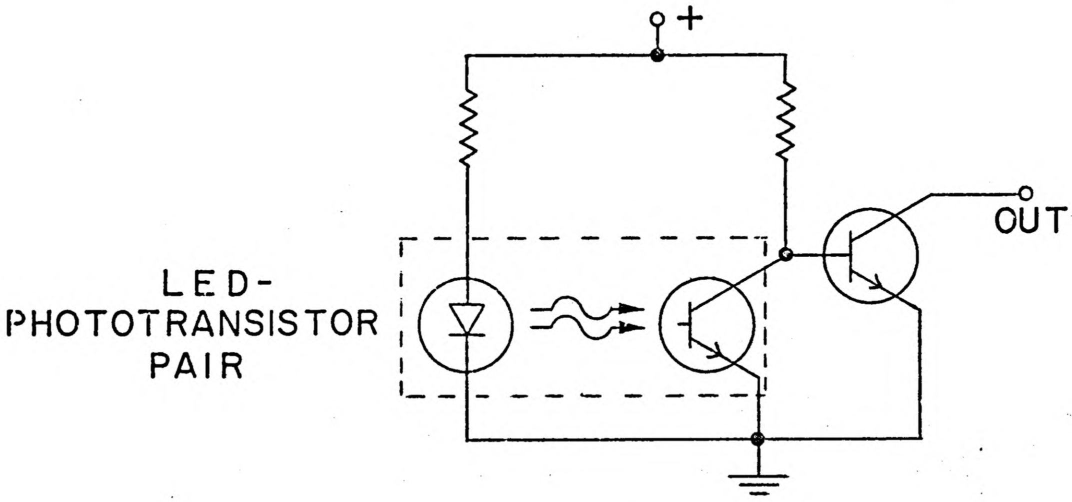


Figure 4.2

Anemometer Circuit

Chapter 5

TIME-OF-FLIGHT MODULE

The time-of-flight module uses one or two phototransistors for its detectors. The output is either pulses which directly follow the light-dark patterns hitting the phototransistor, or a series of pulses whose duration is determined by the light falling on the detectors. In the second case, the frequency of the pulse string can be either 10 Khz, which gives reasonably large counts for short time intervals, or 100 hz, which will not overflow the counter's range for longer measurements.

CIRCUIT DESCRIPTION

As shown in Figure 5.1, the detectors for the circuit are transistors Q-1 and Q-2, which are actually photodarlingtons--a phototransistor and a Darlington amplifier combined.

The output of Q-1 is connected to IC-1, a Schmitt trigger chosen to eliminate jitter as the shadow of an object is just crossing the detector. R-1 provides a moderate amount of adjustment in the light intensity needed to activate the circuit by varying the voltage at the input to IC-1. The circuit for the second phototransistor is similar, and the outputs of the two Schmitt triggers are now combined and inverted to give two choices at S-1--activate the circuit when

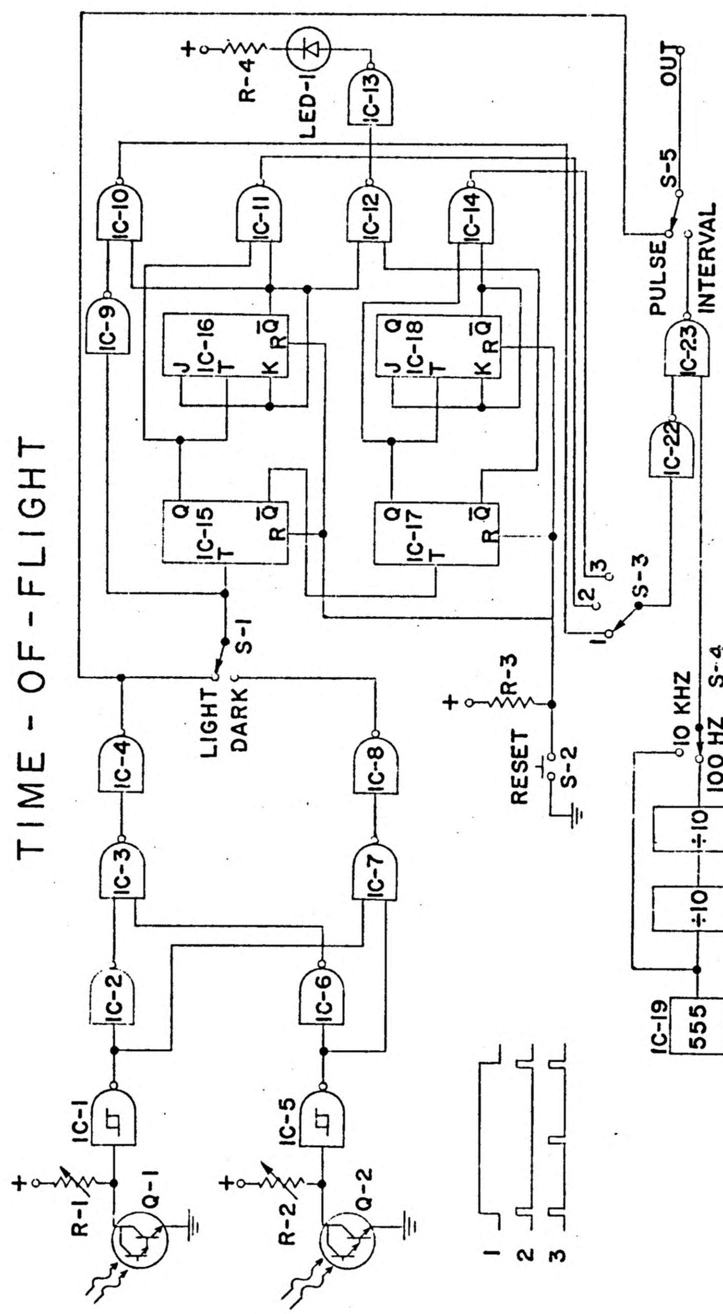
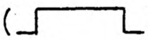


Figure 5.1

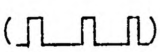
Time-of-Flight Logic Diagram

either detector is darkened, or activate the circuit when either detector comes into the light.

At this point there are two choices. The first is to set switch S-5 in the pulse position, in which case the signal out is a copy of the light-dark patterns hitting the detector. The second choice, using the interval setting, will use flip-flops IC-15 - IC-18 to send out a string of pulses whose duration is determined by the light hitting the detector and the mode in use, as selected by switch S-3.

The first mode () times the duration of a single shadow. (In all these descriptions, changing the light-dark control will reverse the operation.) The main use for this setting would be to find the time it takes for an object to cross in front of one of the detectors.

The second interval mode () sends a series of pulses to the ouptput starting when an object first passes one detector, and ending when it passes the second (or when it passes the first detector the second time). The main use for this setting would be to time the large-scale movement of an object, such as timing the fall of a weight.

The third setting () starts sending pulses when an object first passes the detector and stops when the object passes the third time. At first, this seems rather useless, but it is just what is needed for timing periodic motion, such as the swing of a pendulum.

By timing a complete cycle, this setting avoids the problems of placing the detectors in exactly the right spot, as would be needed to time periodic motion using the second interval setting and only one-half of a cycle.

In all three of the interval modes the module is locked in an "off" condition at the end of one count cycle until the reset switch, S-2, is pressed. This avoids the problem of having a second count destroying the reading from the first count before the first one was recorded. LED-1, the "ready" indicator, tells when the module has been reset so it can accept a new count. Notice that resetting the time-of-flight module does not return the main counter to zero. This makes it convenient to average several readings by simply letting them accumulate in the scaler.

The series of pulses sent out by the interval mode operations is produced by IC-19, a free-running 555 timer operation at 10 Khz. The two decade counters IC-20 and IC-21 divide the pulse by 100, and switch S-4 selects between the 10 Khz and the 100 hz signals. This series of pulses is then gated on and off at IC-23 by the instructions coming from the flip-flops by way of S-3 and IC-22.

FRONT PANEL DESCRIPTION

The layout of the front panel is shown in Figure 5.2. The switch in the upper left selects between the pulse mode of operation or the three interval modes. The rotary switch to the right chooses which of the three interval modes will be used. The light-dark switch, which determines whether the module will start when the detector comes into the shadow or when it comes into the light, is in the left center. The lower left switch selects either the high or the low frequency. The reset button in the lower right is what one presses to set the module in the ready condition for the next count, and this is indicated by the LED near the pushbutton. The sensitivity controls for the detectors are recessed beneath the front panel in the center right, and these are accessible by the use of a small screwdriver. The two detectors connect to the module by two phono jacks in the left side of the box.

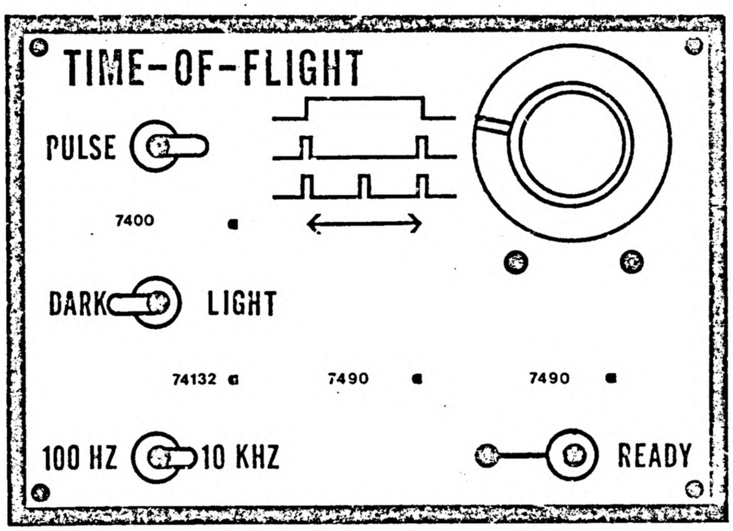


Figure 5.2

Time-of-Flight Module Front Panel

USES OF THE TIME-OF-FLIGHT MODULE

Four uses for this attachment will be given--finding the rotational speed of an object, checking a camera's shutter speed, timing the fall of an object and finding the period of a simple pendulum.

Finding the Rotational Speed of an Object

For this measurement, we will use the pulse mode of operation, since we want to see how many revolutions the object makes in a given time period. The setup is shown in Figure 5.3.

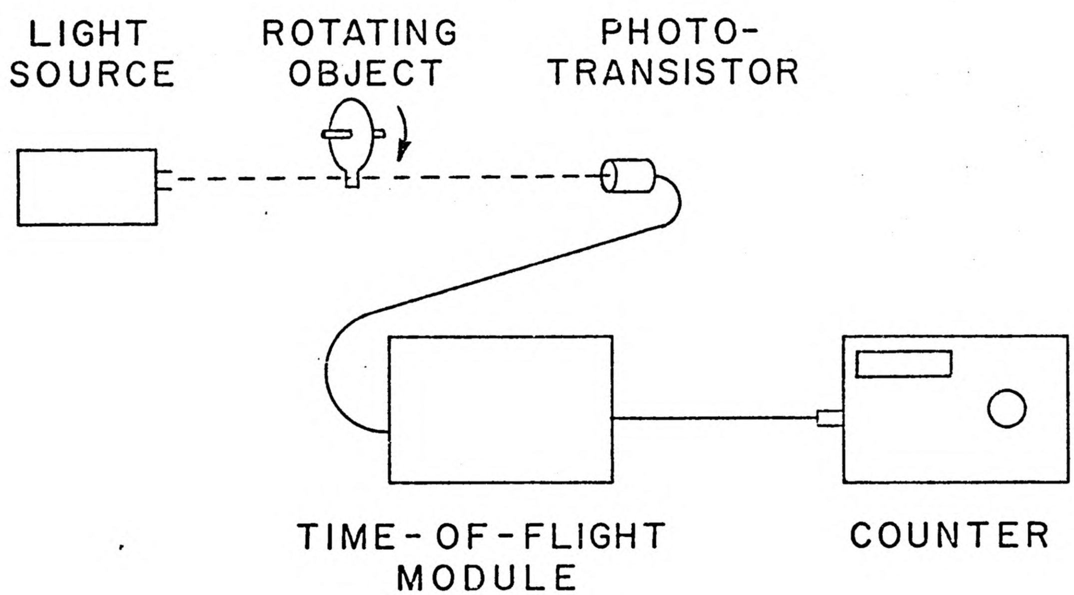


Figure 5.3

Finding the Rotational Speed of an Object

Notice that some kind of "flag" to interrupt the light beam will need to be added if the shape of the object will not do this. The setting of the light-dark control is immaterial, since it does not matter whether one counts as the flag enters the light beam or leaves it. The other controls are not used.

The counter could either be used in the automatic mode, say for 10 second intervals, or it could be controlled manually. In our example, a small piece of cardboard was taped to the top of a centrifuge and a flashlight was used as the light source. Using 10 second automatic time intervals, counts of 563 were obtained, which makes the rate of rotation 3378 rpm.

Checking the Shutter Speed of a Camera

For this measurement, the first of the three interval settings is used--the one in which the module produces a series of pulses for as long as the phototransistor is light (or dark, if the light-dark switch is set that way). The arrangement is shown in Figure 5.4.

The back of the camera must be open to let the light through, and the lens of the camera should be removed. If this is not possible, adjust the height of the camera, light source and phototransistor so the detector is brightly illuminated when the shutter is open. If the camera has a focal-plane shutter, the detector should be positioned as close to it as possible so a clean shadow will be cast on the phototransistor. To obtain reasonable accuracy with a focal-plane shutter at the faster speeds, a narrow slit should be fashioned to fit just in front of the detector. With a between-the-lens shutter this is not as critical--just center the detector in the opening.

The counter will of course give the shutter speeds in 0.01 or 0.0001 second intervals instead of the familiar fractions, so conversions will need to be made. To check the camera's consistency, several measurements at each speed should be made. Table 5.1 shows a check on a Pentax Spotmatic.

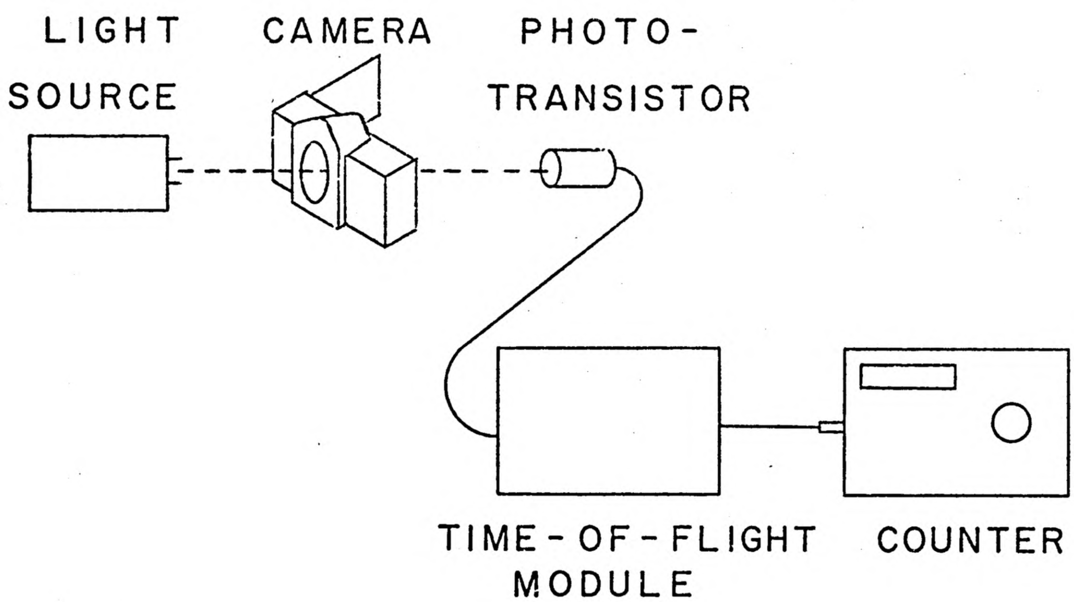


Figure 5.4

Arrangement for Checking Shutter Speeds

Table 5.1

Checking the Shutter Speeds of a Camera

Shutter Speed (sec)	Decimal Equivalent (sec)	Measurements (taken at 10 Khz)				Average (sec)	Shutter Error (%)
1	1.0000	9586	9494	9601	9618	0.9575	- 4
1/2	0.5000	5062	5163	5081	5032	0.5085	+ 1
1/4	0.2500	2682	2691	2662	2732	0.2692	+ 8
1/8	0.1250	1311	1291	1273	1318	0.1298	+ 4
1/15	0.0667	648	654	651	651	0.0651	- 2
1/30	0.0333	367	363	365	363	0.0365	+10
1/60	0.0167	147	166	167	136	0.0154	- 8
1/125	0.0080	105	104	104	102	0.0104	+30
1/250	0.0040	54	58	58	54	0.0056	+40
1/500	0.0020	28	29	30	28	0.0029	+45
1/1000	0.0010	15	14	17	16	0.00155	+55

Timing the Fall of an Object

In this experiment we will use the second of the time interval settings, so the module will send a series of pulses starting when the object passes the first phototransistor and ending when it passes the second. Note that this will only work if the separation of the two detectors is larger than the object, so the shadow of the object is off the first detector before it reaches the second. The experimental arrangement is shown in Figure 5.5.

This could probably be done with one light source at a fairly large distance from the object and detectors, but some parallax error would be introduced. In any case, the detectors should be as close to the object as possible, as long as care is taken not to hit the lower one. Also, some arrangement for cleanly releasing the object is necessary, so that friction does not impede its initial movement. The top detector is positioned so the object's shadow will cross it as soon as the release occurs. One can expand this to include the final velocity of the object by using the lower phototransistor and the first interval setting to determine a Δt measurement. The height of the object would be Δx, and the velocity would be $\Delta x / \Delta t$.

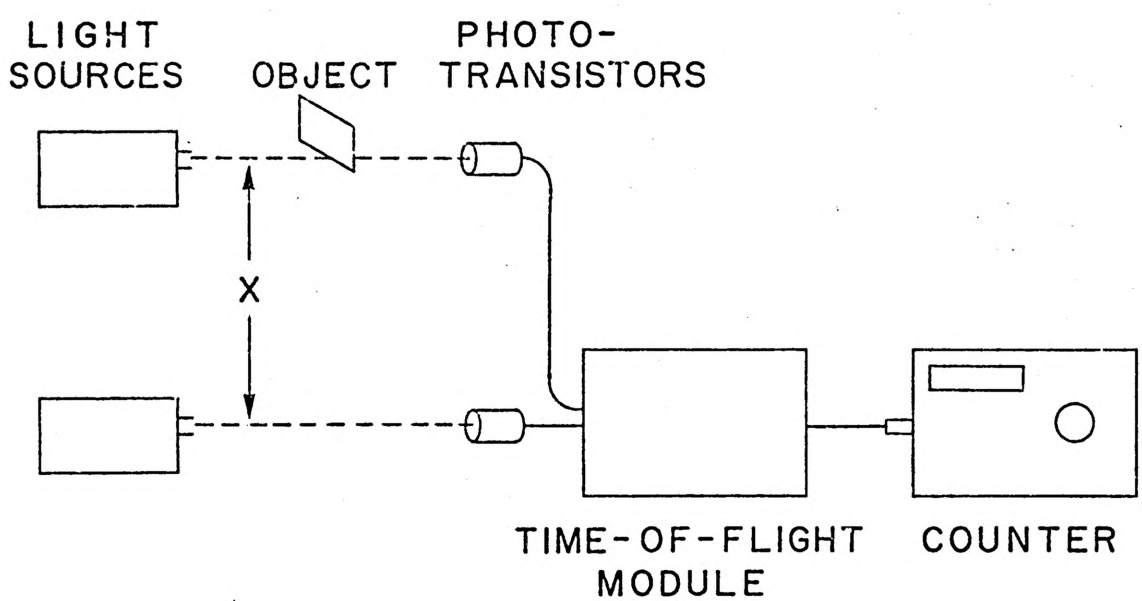


Figure 5.5

Timing the Fall of an Object

The standard use for a measurement such as this is, of course, to determine a value for "g", the acceleration of gravity. It can also be used, however, for less common things, such as finding the muzzle velocity of a B·B gun, or the terminal velocity of a falling balloon, as illustrated in Table 5.2.

Table 5.2

Finding the Terminal Velocity of a Balloon

x (m)	t (sec)	v (m/sec)
.05	.08	.63
.10	.15	.67
.20	.28	.71
.40	.45	.89
.60	.63	.95
1.00	.98	1.02
1.50	1.48	1.01

Terminal velocity = 1.02 m/sec (approximately)

<u>Finding the Period of a Simple Pendulum</u>

Only one detector is needed for this measurement, since the object keeps moving past the same spot. The third interval setting is used, and pulses will be sent to the counter starting when the shadow first crosses the detector, and ending when the shadow crosses it the third time. This measures one complete period. Because of this arrangement, it does not matter where the phototransistor is positioned along the arc of the pendulum's swing, as long as the object passes it going both directions. If the object is large or the amplitude of the swing very small, the detector may have to be positioned behind the supporting string, rather than behind the object itself. The arrangement is shown in Figure 5.6.

In high school classes, the period of a pendulum is usually considered to be independent of its amplitude, but with this arrangement the small difference in period which accompanies larger angles is easy to measure, as Table 5.3 shows.

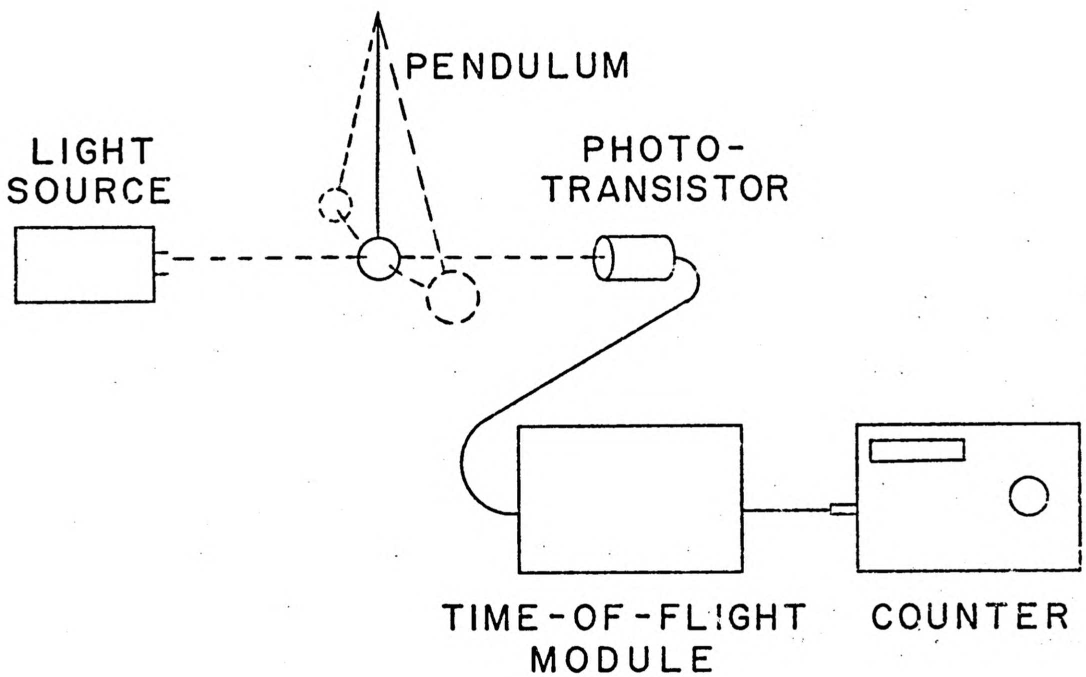


Figure 5.6

Finding the Period of a Pendulum

Table 5.3

Variation of a Pendulum's Period with Angle

Angle of Swing (deg) [a]	Theoretical Period (sec) [b]	Measured Period (sec) [c]
1	2.0071	2.0073
5	2.0080	2.0083
10	2.0109	2.0157
20	2.0220	2.0212
40	2.0700	2.0713
60	2.1540	2.1529
80	2.2830	2.2842

[a] Measured from the vertical

[b] Using $l = 1$ m, $g = 9.8$ m/sec^2

$$T = 2\pi\sqrt{\frac{l}{g}}\left(1 + \left(\frac{1}{2}\right)^2 \sin^2\frac{\theta}{2} + \left(\frac{1}{2}\right)^2\left(\frac{3}{4}\right)^2 \sin^4\frac{\theta}{2} + \cdots\right)$$

[c] Length of the pendulum adjusted to make first period match

Chapter 6

CONCLUSION

This paper has presented a low cost, easy-to-use digital counting system, and examples of how it can be used.

As with most new developments, this system is continually being scrutinized and revised. Dr. John Amend and the author are currently discussing the possibility of changing the integrated circuits from the present TTL type to CMOS, a newer family of IC's which use less current, and therefore require smaller power supplies.

Other accessories are also being discussed. One possibility is a digital thermometer using newly available temperature-sensitive transistors. Another idea is a pH meter attachment.

It is hoped that this system and its descendants will be found useful in the science classroom.

APPENDIX

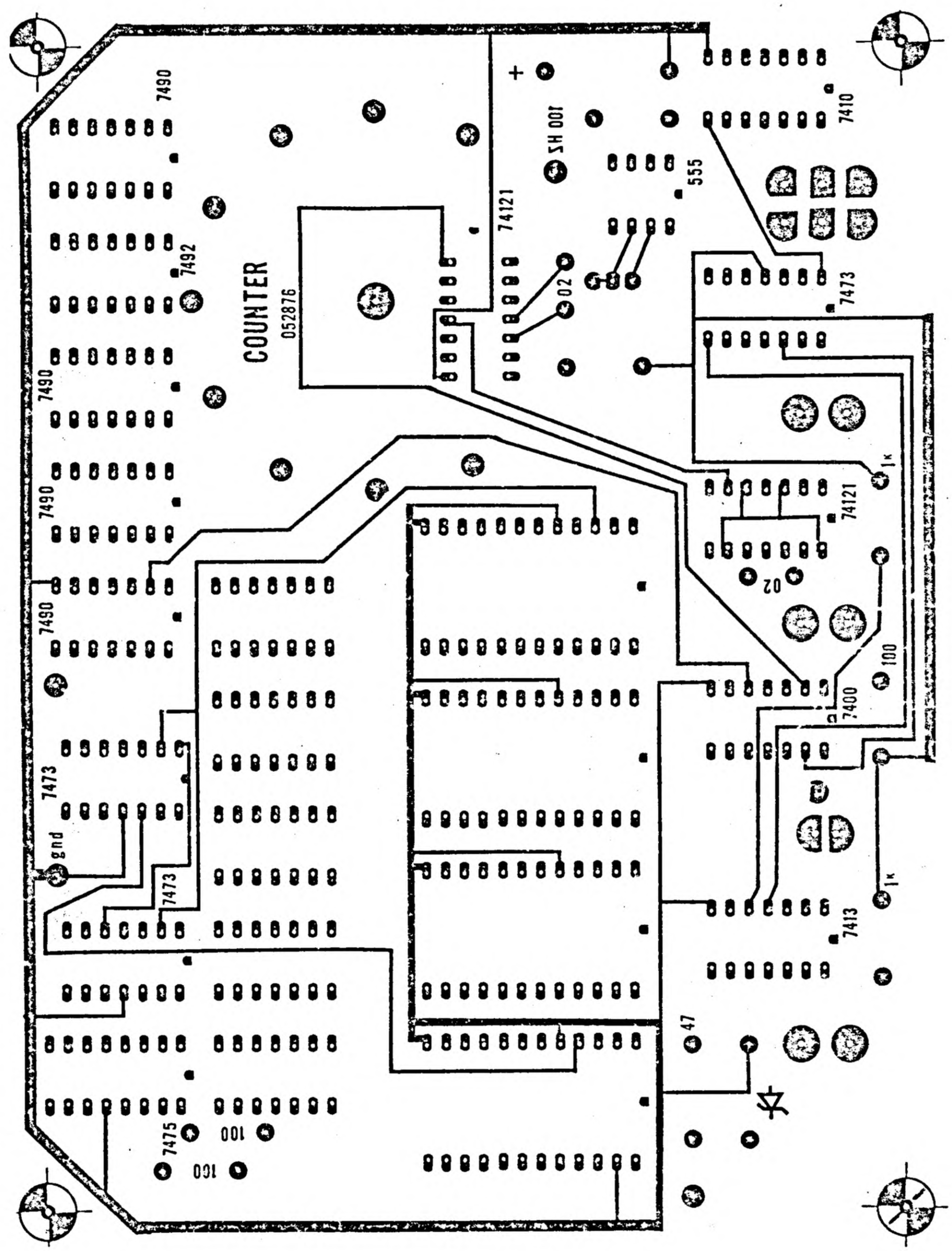


Figure 6.1

Counter Printed Circuit Layout--Front Side

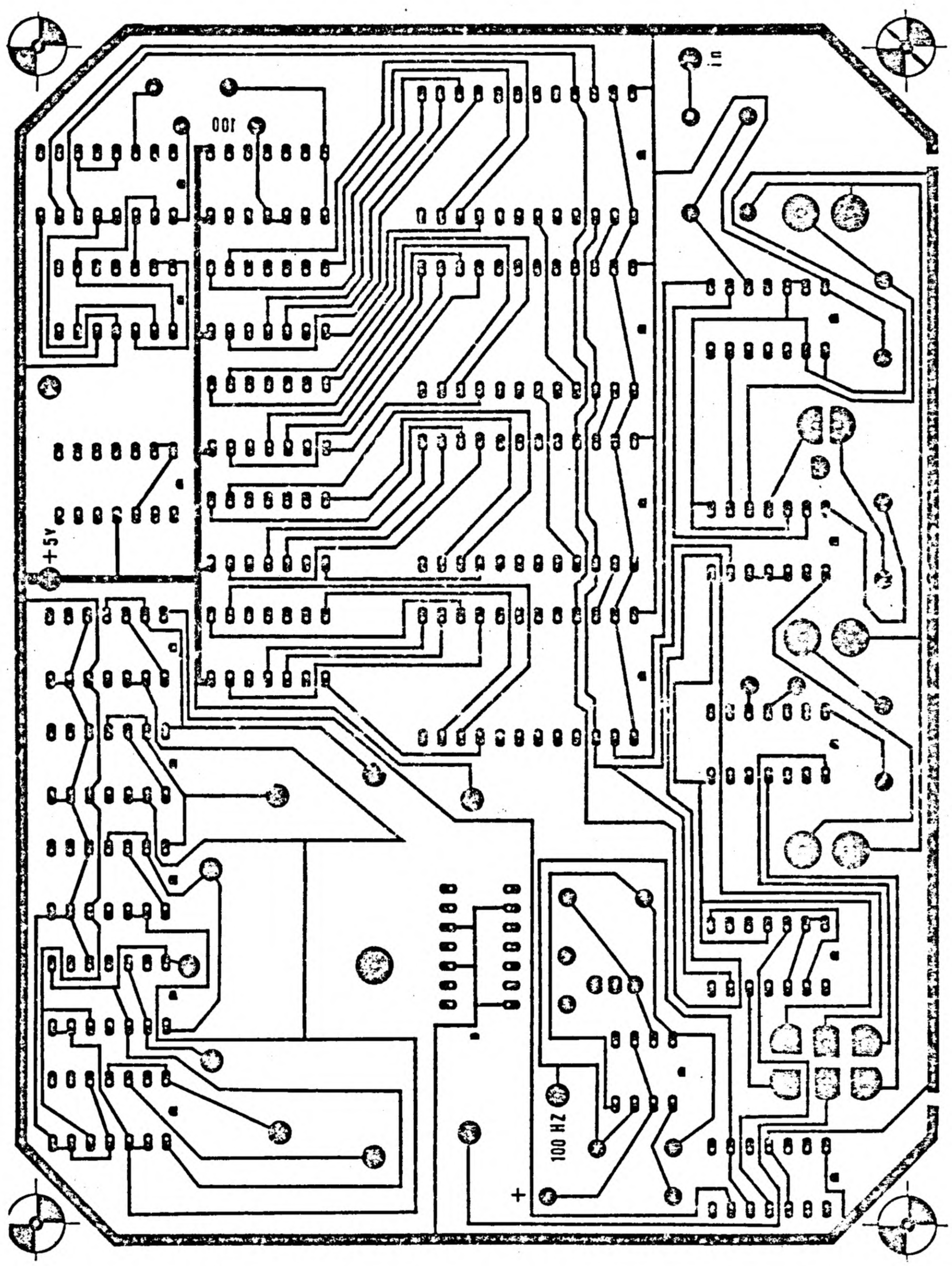


Figure 6.2

Counter Printed Circuit Layout--Reverse Side

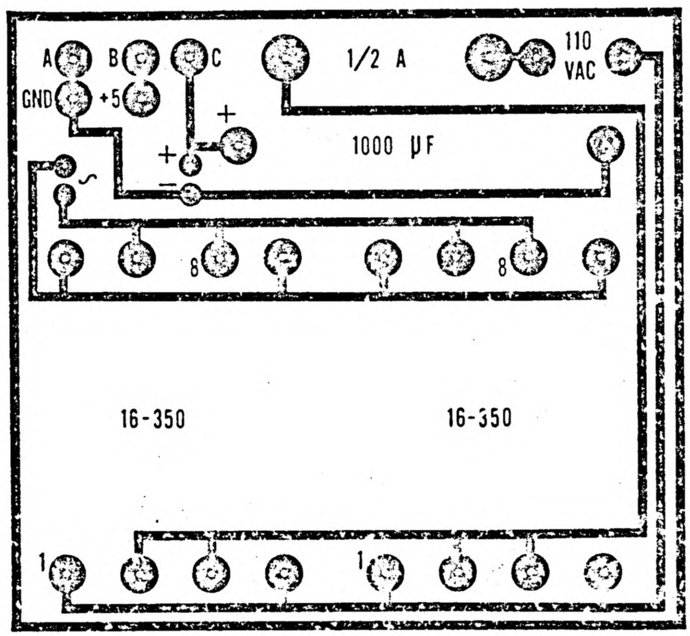


Figure 6.3

Power Supply Printed Circuit Layout

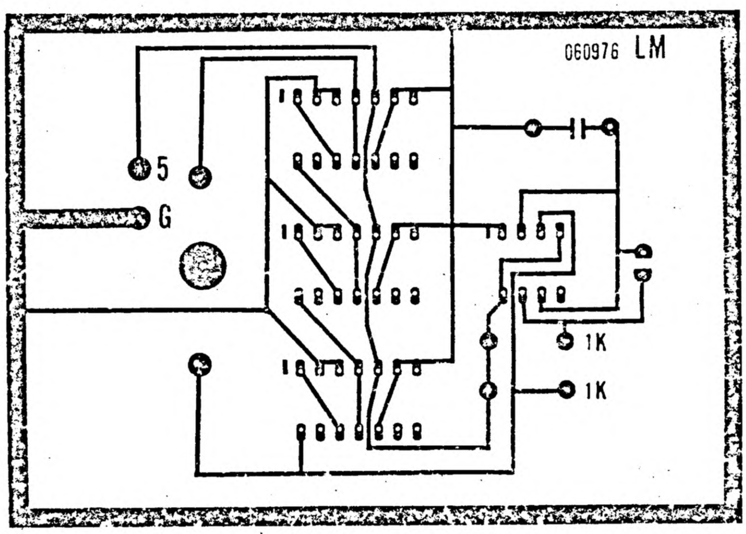


Figure 6.4

Light Meter Printed Circuit Layout

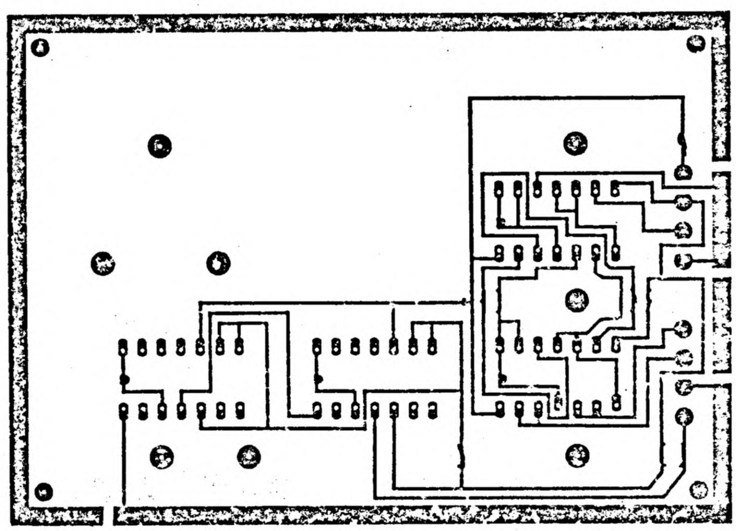


Figure 6.5

Time-of-Flight--Reverse Side of Front Panel

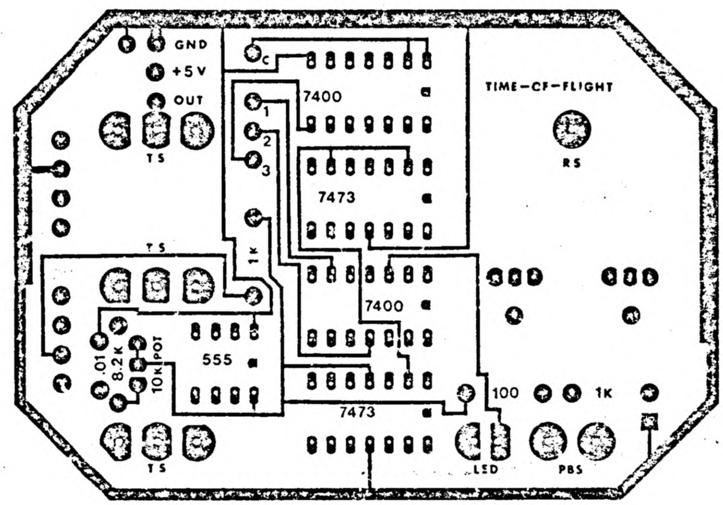


Figure 6.6

Time-of-Flight Printed Circuit Layout--Front Side

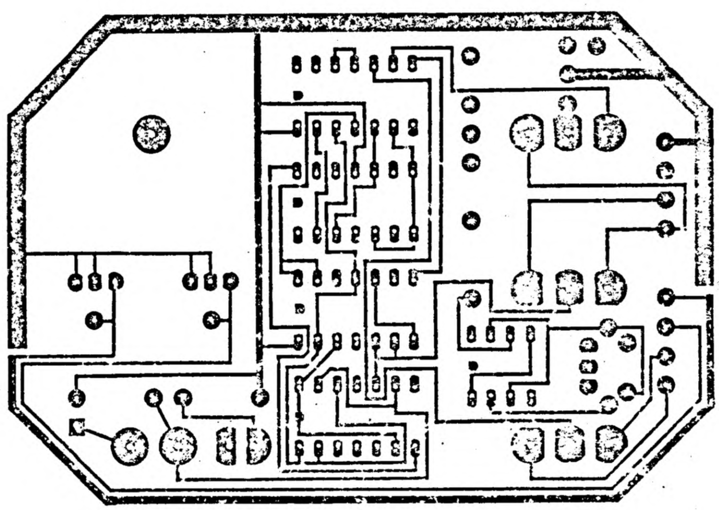


Figure 6.7

Time-of-Flight Printed Circuit Layout--Reverse Side