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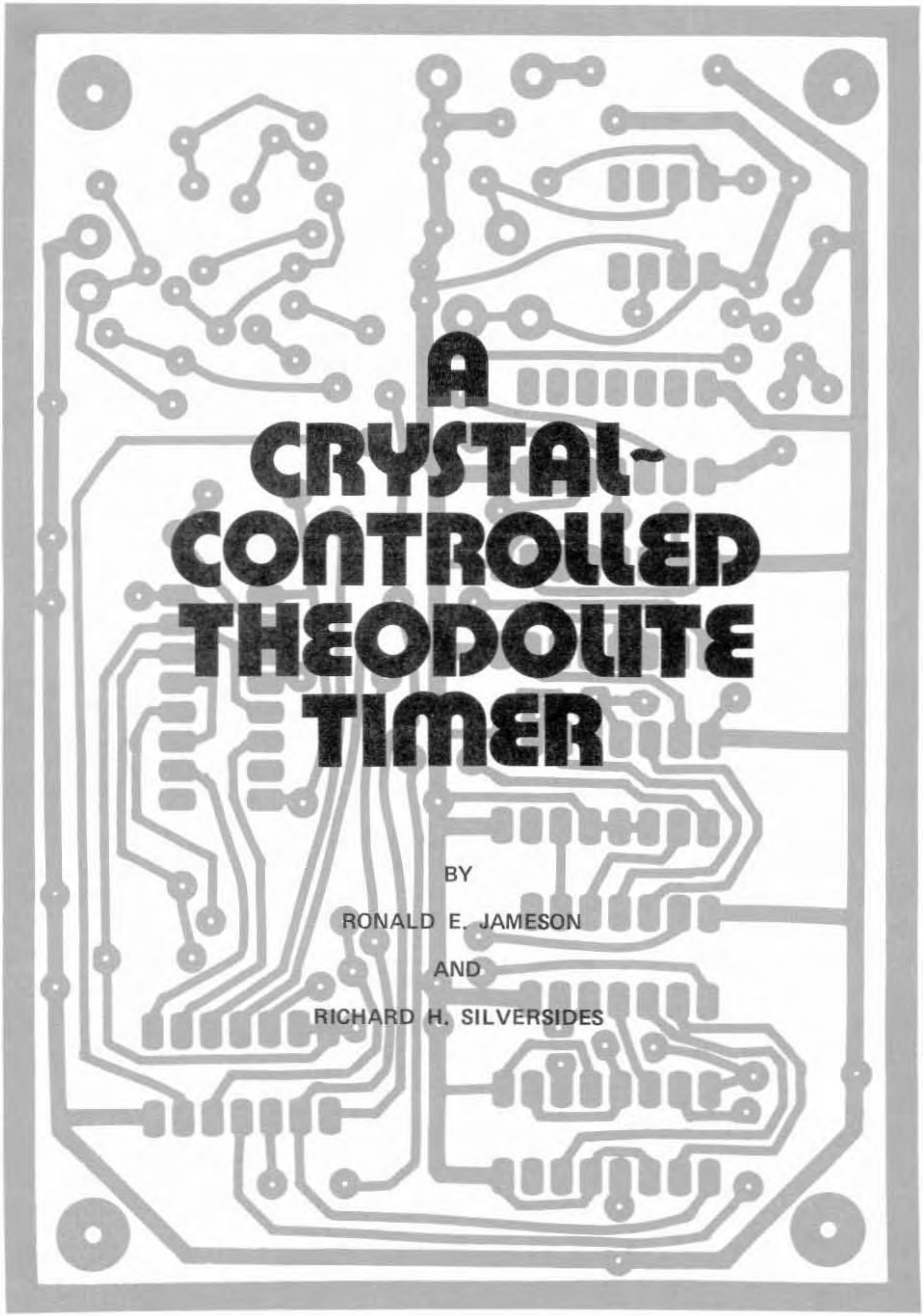

A CRYSTAL-CONTROLLED THEODOLITE TIMER

BY

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ABSTRACT

Details of a recently developed extremely accurate crystal-controlled theodolite timer are presented. Used in pairs during double-theodolite wind measurements, these timers avoid tying up telecommunication channels. The units are compact, rugged and reliable. Construction is straightforward and parts cost less than $50 per unit.

RÉSUMÉ

Détails d'une minuterie à théodolite d'une extrême précision, récemment mise au point. Utilisées par paires durant les mesurages de vents à double théodolite, ces minuteries évitent l'encombrement des canaux de télécommunications. Les unités sont compactes, solides et fiables. Leur construction est simple, et les pièces de chaque unité coûtent moins de $50.

INTRODUCTION

Measurements of wind speed and direction at upper levels of the atmosphere are usually made by releasing a balloon filled with hydrogen or helium. As the balloon rises and is moved along by the ambient wind, it is tracked by means of radar or optical theodolites. Successive fixes on the balloon's position are made at equal intervals of time and, consequently, information such as the balloon's trajectory and the wind velocity profile can be determined.

Radar methods give superior accuracy and resolution, and are not limited by cloudy weather conditions. Nevertheless, optical theodolite tracking methods are far more common, because of practical considerations such as availability of equipment, low cost and familiarity with the technique. Either one or two theodolites are used.

The single-theodolite method assumes a relatively uniform rate of ascent for the balloon, constant from one run to another (Middleton and Spilhaus 1953). It is a simple and useful technique for many purposes, but errors can be quite large. For example, Silversides (1974) noted a standard error of 12%, and Weiss (1969) found an error of 7% for rates of rise. Variation from one run to another can be substantial. Weiss (1969) found a variation of ± 20% in rates of rise at the 95% confidence level.

For more precise estimates, particularly in mountainous terrain where organized vertical motion is important, one must use the double-theodolite method. The two theodolites are usually separated by a baseline distance of about 1 to 2 km. Synchronous audible signals, either buzzers or bells, provide the stimulus for the theodolite operators to take readings. It is seldom practical to link the two stations by signal cable; consequently, synchronization of signals at the two stations is often obtained from a system consisting of a single audible signal source and two citizens band transceivers. Tying up a communications channel in this fashion leads to difficulties, the most serious being the loss of two-way communication between operators. Should the operator, without transmission capability, encounter difficulties in following the balloon, he cannot signal the other operator so that the run can be aborted. By the time that two-way communication is again established, one operator has wasted much effort and it may be too late to schedule a make-up run. This difficulty can be overcome by having another set of transceivers, but this solution is not always possible. Other significant problems are the high usage rate of batteries, owing to the excessive power demand created by a continuous transmission mode, and interference from other users of the communications channel.

An alternative method of obtaining synchronized signals is to use a pair of extremely accurate timing units. One unit is assigned to each theodolite. After initial synchronization, the units must be accurate enough to remain in synchronization for at least 2 hours. In addition to extreme accuracy, the ideal unit should be rugged, compact and inexpensive. Mechanical systems cannot meet these requirements, but electronic technology has so advanced that it is relatively easy to develop a suitable timer unit. This paper describes a theodolite timer unit, developed at the Pacific Forest Research Centre, which has been used successfully in field studies for over a year.

Figure 1. The theodolite timer.

GENERAL DESCRIPTION AND USE

One of the units is illustrated in Figure 1; in Figure 2, the cover has been removed from the plastic case to show the interior. The outside dimensions are 8 cm by 15 cm by 5 cm, and the total weight, including the battery, is about 279 g.

Three switches are located on the front panel: power, reset, and interval selection.

The power switch turns the device on and off.

The time interval selection switch provides a choice of two timing intervals. Choosing the 30 second interval results in a repetitive sequence of a long beep at 25 seconds, followed by a short marking beep at exactly 30 seconds. Choosing the 60 second interval results in a sequence of a long beep at 55 seconds, followed by a short marking beep at exactly 60 seconds.

The reset switch is used when two timers must be synchronized. This is done by depressing the reset switch on each timer and releasing them simultaneously. Synchronization should be checked by waiting one interval and ensuring that the marking beeps of each timer occur at the same time. Each timer may now be taken to its theodolite site and preparations may be made for releasing and tracking the balloon. It is important to remember that if either interval select switch is subsequently changed, the timer units must be again synchronized.

Although no problems have been detected suggesting a loss of synchronization between units, it is probably good practice to check synchronization of signals at the end of each theodolite run.

CIRCUIT DESCRIPTION AND THEORY OF OPERATION

As shown by the schematic drawing in Figure 3, the theodolite timer has four functional blocks: a clock unit or oscillator-divider, a 60-pulse counter, a 5-pulse counter and the audible alarm section.

Figure 4 provides circuit details.

The frequency of operation chosen for the crystal-controlled oscillator was 4, 194, 304 Hertz (Hz). The reasons for this choice are that 4, 194, 304 is an integral multiple of 2 (*i.e.,* $2^{22} = 4{,}194{,}304$), and the frequency stability of high frequency crystals is about ten times better than the low frequency crystals commonly used in commercially available watches and clocks.

The oscillator-divider integrated circuit chosen was the Intersil ICM7038A, which is a complementary MOS electronic clock circuit. It has a low power drain and is relatively insensitive to voltage variations in the power supply or to temperature variations. The frequency stability was further enhanced by placing a zener diode across the power supplied to the ICM7038A. Specifications (Anon. 1973) suggest that this circuit design should have a typical stability of about 0.1 ppm and our experience confirms this estimate. Since the output of this particular integrated circuit is lower than the transition levels of the remaining CMOS circuitry, a level translator, QI, was used to provide proper interface. The final stages of frequency division were provided by U2, a seven-stage binary counter, resulting in switch-selectable (SWI) clock periods of 0.5 seconds or 1 second for input to the remaining counting circuits. Ensuing division by 60 thus produces a final output period either 30 seconds or 60 seconds long.

The divide-by 60 counting sequence is provided by U3, U4 and U5. U3 and U4 are decade counters, with U4 being preset to the binary number 0100 after every 60 count sequence. When U4 goes to binary 0000, it is detected by the NOR gate U6A. The output of the NOR gate provides a pulse which is fed to the preset enable gate of U4, thus starting the 60-pulse counting sequence over again. At the same time this pulse is fed to the monostable U8A to initiate a 2.7 second interval used for the warning beep of the alarm.

The output of the NOR gate, U6A, also presets the counter U5 to the binary number 0101. In turn, the NOR gate, U6B, and the OR gate, U7B, enable 1 second pulses to be counted by U5. After 5 counts, the NOR gate, U6B, detects binary 0000 on the output of U5 and inhibits further counting. At the same time the pulse from U6B is fed to the monostable, U8B, to initiate a 0.2 second interval used to produce the marking beep.

The 2.7 second and 0.2 second pulses are combined through the OR gate, U7C, which controls a phase shift oscillator. The free-running frequency of

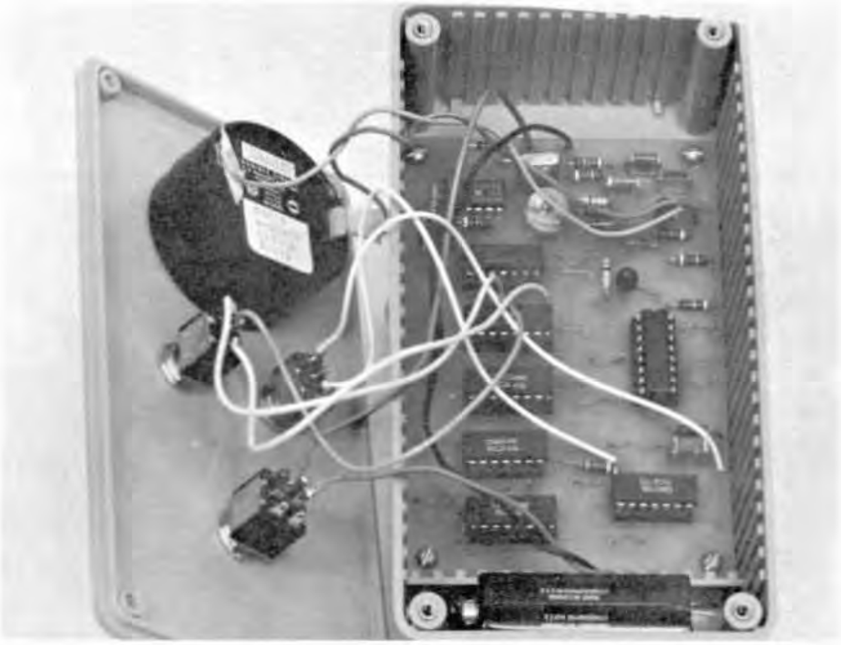

Figure 2. Interior view of theodolite timer.

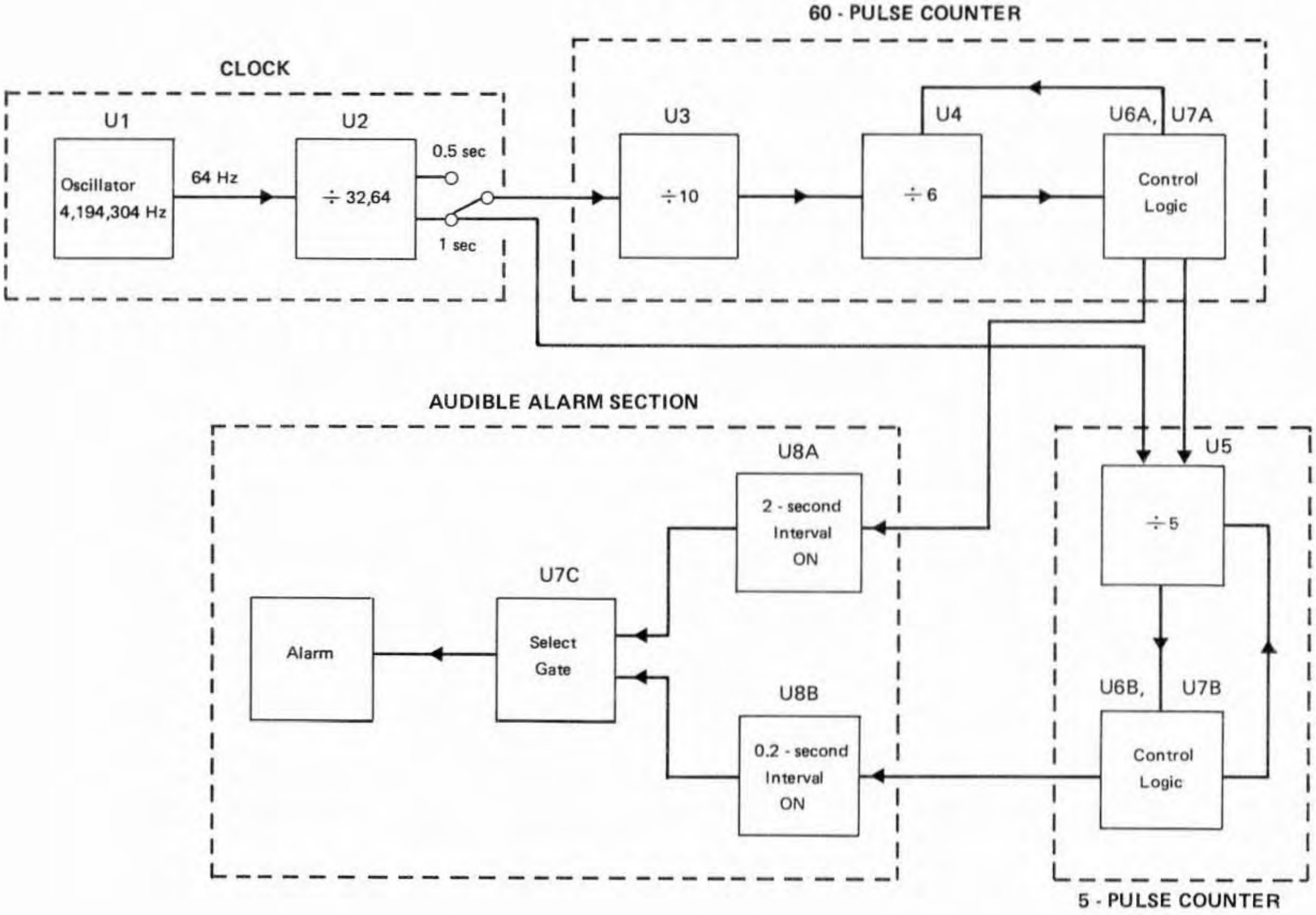

Figure 3. Functional block diagram of theodolite timer.

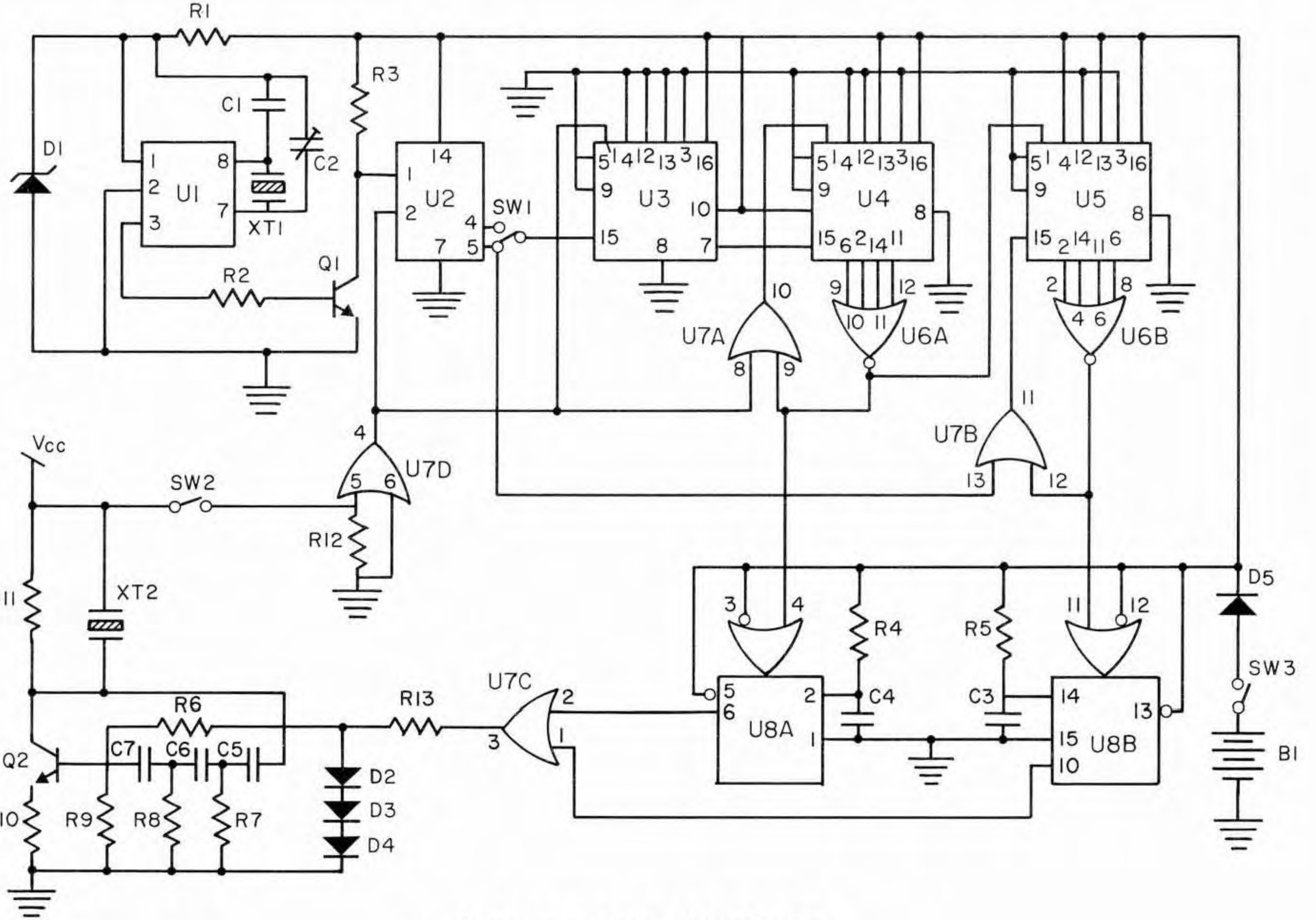

Figure 4. Circuit diagram of theodolite timer.

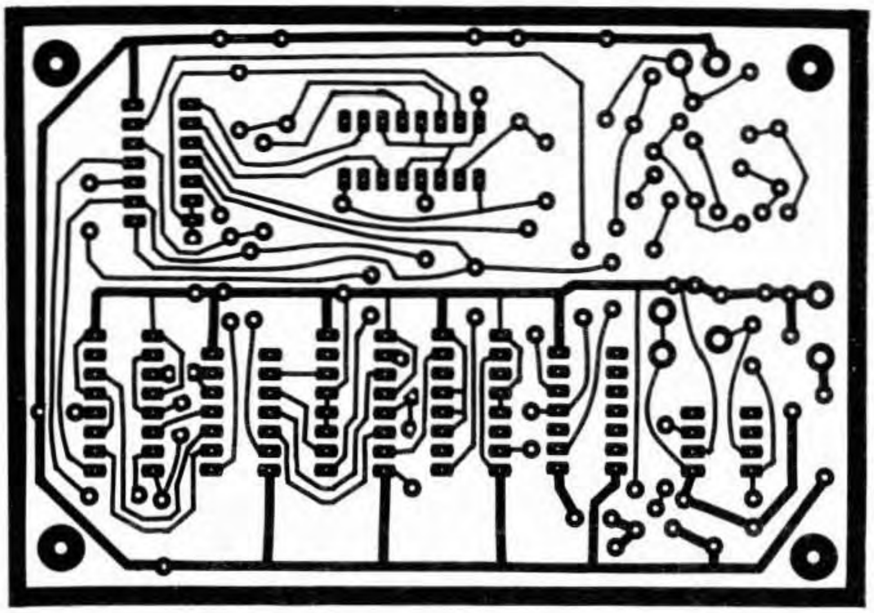

Figure 5. Printed circuit for the theodolite timer (full scale, viewed from printed circuit side of the board).

this oscillator is 2900Hz. It provides the drive for the piezoelectric alarm, XT2. The diodes, D2-D4, stabilize the bias voltage for Q2, ensuring better start-up of the oscillator.

The reset circuitry is controlled by switch SW2 and is buffered through U7D to the reset input of U2, the preset-enable gate of U3, and through the OR gate, U7A, to the preset-enable gate of U4.

The switch SW3 is the power switch and connects the battery to the timer circuit through diode D5. This diode provides polarity protection against improper battery connection.

The power supply for the theodolite timer may vary between 7 to 15 volts and still allow proper circuit operation. A 9-volt transistor battery should provide at least 30 hours of continuous service.

CONSTRUCTION

Other than normal precautions for handling CMOS devices, construction is straightforward and should present no problems. Figure 5 gives the pattern for the printed circuit board and Figure 6 shows the component layout.

Parts required are listed in Table 1. Total costs for parts, including battery is estimated at less than $50.

CALIBRATION

Adjustment of the trimmer capacitor, C2, is all that is required to calibrate the theodolite timer. This capacitor provides correct capacitive loading, allowing the crystal, XT1, to resonate at 4, 194, 304 Hz.

The test instrument required to make measurements and perform this adjustment is a universal time interval counter. Attaching the counter probe directly to the oscillator circuit would load the circuit and change the frequency of operation. Hence the probe must be attached at some point further along the chain of division where it is buffered from the oscillator. We used a Model HP 5300B/5308A Universal timer (Hewlett - Packard Ltd.), and the following steps in the procedure assume the use of a similar type of instrument:

1. Set function switch to period average B
2. Set time base to 10 u sec

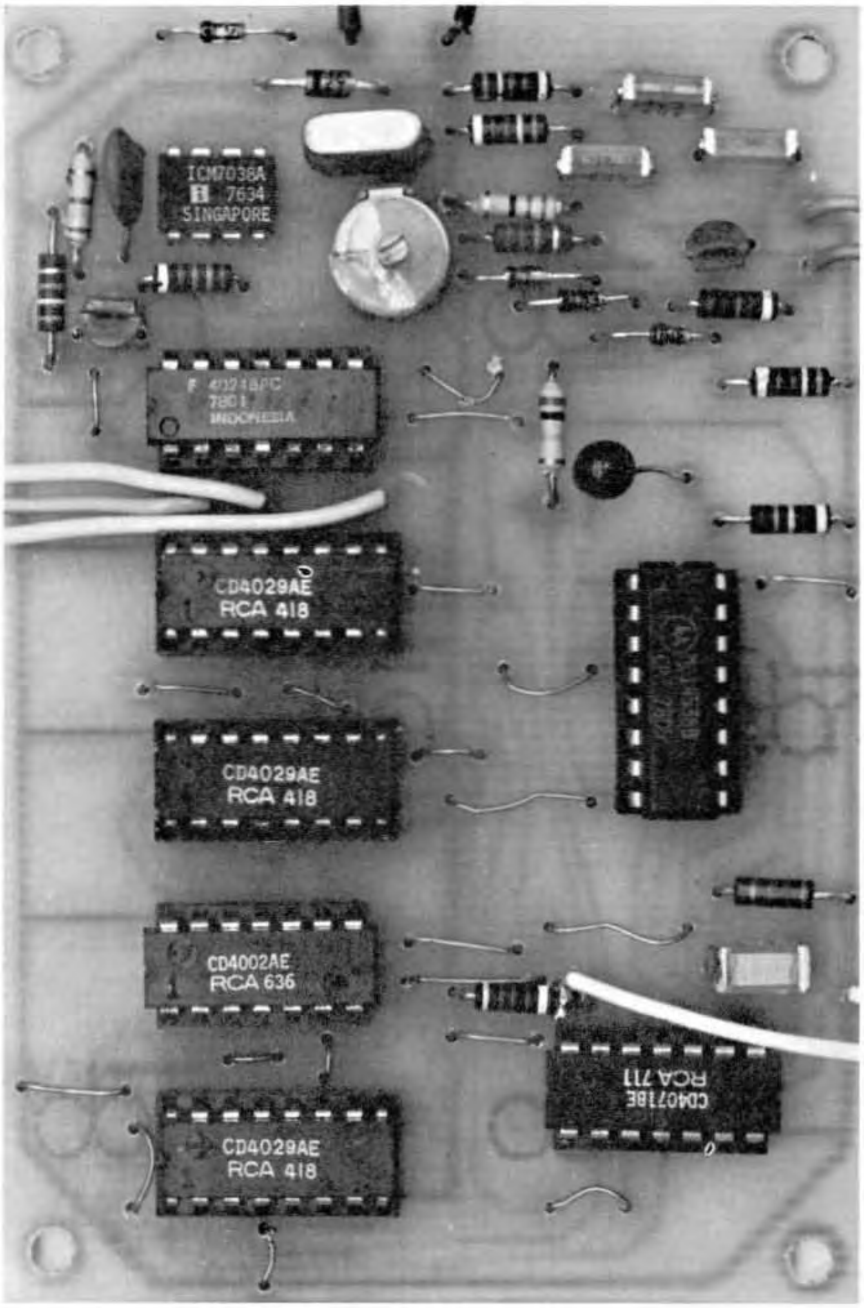

Figure 6. Enlarged photograph showing placement of components on the printed circuit board.

3. Set trigger slope to +
4. Set trigger level control slightly positive
5. Connect probe from channel B of the timer-counter to pin 3 or 4 of U1
6. The trimmer capacitor C2 is now adjusted until 15,625.00 u sec is displayed on the timer-counter

CONCLUSIONS AND RECOMMENDATIONS

While future optimization in design would no doubt lead to a more compact unit than the one described in this paper, there is little practical benefit to be gained in making the units much smaller. Instead, attention should be directed toward better switch security. The toggle switches are somewhat vulnerable to accidental movement while the units are being transported between sites. Good quality slide switches, locking arrangements and recessed access are possible alternatives that should be considered.

Experience has shown that the timer units described in this paper facilitate taking double theodolite observations under adverse conditions. They are simple and reliable units to use in the field, and because their performance has been satisfactory, no further developments are planned.

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TABLE 1. PARTS LIST FOR THE THEODOLITE TIMER

Capacitors

C1	30 pf styroflex	C4	10 uf tantalum
C2	5 - 60 pf variable trimmer	C5, C6, C7	0.0022uf styrene
C3	0.1uf styrene		

Diodes

D1	3.6 volt zener
D2 - D5	1N914 switching

Transistors

Q1, Q2	PN2222A NPN silicon

Resistors

R1	1800	R6, R9	22K
R2	56K	R7, R8, R11	6.8K
R3	68K	R10	22
R4	270K	R12	8.2K
R5	1.2M	R13	100K

All resistors are metal film 5% 1/8 watt.

Switches

SW1, SW2 SPDT subminiature toggle
SW3 momentary contact subminiature pushbutton

Integrated Circuits

U1	ICM7038A (Intersil)	U6	CD4002BE
U2	CD4024BE	U7	CD4071BE
U3, U4, U5	CD4029BE	U8	MC14538BCP (Motorola)

Crystals

XT1	4, 194, 304 Hz TXO crystal
XT2	Mallory SC628 audible warning alarm

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