PICATINNY ARSENAL TECHNICAL MEMORANDUM 1163

FEASIBILITY STUDY OF A MAGNETIC CORE COUNTING TECHNIQUE FOR VARIABLE TIME FUZING

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ACKNOWLEDGEMENT

Appreciation is extended to Mr. Warren Weilbaecher who contributed extensive technical assistance during the study.

SUMMARY

Recent investigation into the possible use of incremental magnetic core counting techniques indicates a potentially useful approach for a variable time fuze. The technique offers a wide range of flexibility with a high degree of accuracy.

INTRODUCTION

A limited feasibility study recently conducted for a remote settable time fuze for a volley fired missile has shown that magnetic core counting techniques are very applicable. A long term need has existed for such a fuze for use in bomb, rocket, and missile applications.

Based upon a particular set of requirements a breadboard model of a missile fuzing system was prepared which had the capability of being remotely set to times between 10 and 80 seconds in 0.1 second increments. The laboratory model consisted of a simulated launch control, including a presetter, and two separate fuzes. (See Figure 1).

Tests were conducted at ambient temperature and the results indicated that accuracies within system specifications can be achieved. It was demonstrated that the presetter could remotely set a multiple number of missiles with a different functioning time for each fuze. A significant feature of the magnetic core counting fuze is its capability of being repeatedly reset for different times. Only a fraction of a second is required to preset a fuze which can then retain that setting for an indefinite period of time.

Although no environmental or handling tests have been conducted with the items, the fuze being completely solid state should be extremely rugged. (Manufacturer's specs. confirm this statement). The only moving part required for the fuzing system is the Safety and Arming device to provide delayed arming and a zero time signal at missile launch.

There are a number of advantages to a fuzing system like the one studied. Remote setting capability, solid state timer, small size and 0.1% (nominal) accuracy are some of the salient features to recommend further development of the concept for other applications.

Although the feasibility study was directed toward a particular missile system with specific times, logic, etc., there is every reason to believe that the concept could be applied across the board to all types of ordnance arming and/or fuzing.

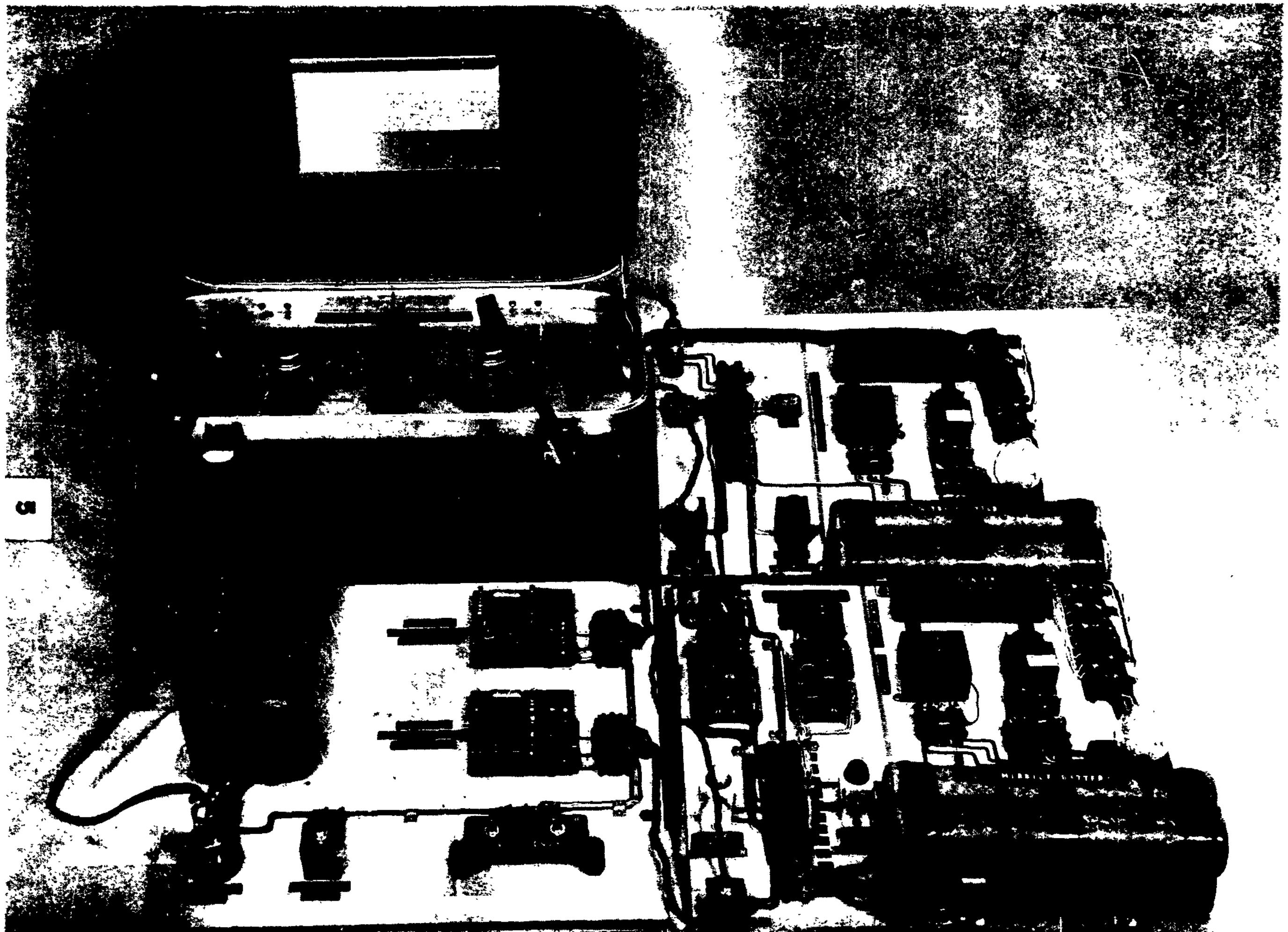

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Figure 1
Model Showing 2 Fuzes, Presetter, And Launch Control

CONCLUSIONS

1. Feasibility of a remotely settable magnetic core timer suitable for use in a variety of ordnance applications has been demonstrated.

2. The incremental magnetic core counting type fuze can provide a number of features which make it worthy of consideration for development as an end item.

3. The magnetic core timer offers accuracies not practical with mechanical timers.

4. The capability of remotely setting the magnetic core time fuze makes it a desirable item for volley fired systems where physical contact with the fuze is not always possible or where rapidity in setting in the field is required.

RECOMMENDATION

It is recommended that additional investigation be continued to determine temperature performance for the complete system.

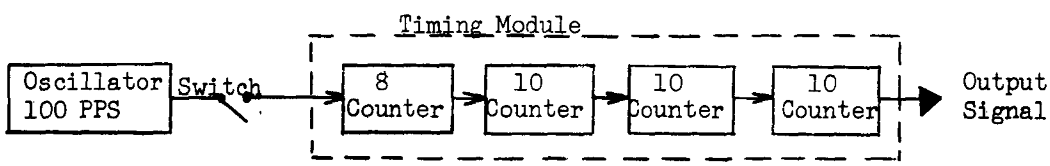
EXPLANATION OF TIMER OPERATION

The variable time fuze consists of three major components: the timing module or counter, the oscillator, and the presetter. (see Figures 2, 3, 4).

Time delays are achieved by counting a specific number of oscillator output pulses. The timing module (essentially a counter) has an 8,000 count capacity. Upon achieving its capacity in counts, the timing module produces an output signal which may be used to perform a fuzing function.

The presetter is primarily a pulse generator in which the number of output pulses it generates may be predetermined and controlled over a wide range. The presetter serves to alter the system time delay through preinsertion of a predetermined number of counts.

The timing module consists of four cascaded incrementally magnetized counting stages. A simplified block diagram of the oscillator and timing module can be used to illustrate the system's basic counting properties.



Each of the individual counting stages is such that it requires the indicated number of input pulses in order to generate an output pulse. (Eight input pulses are required to get an output from the eight counter; ten input pulses are required by each of the ten counters.) On this basis 8,000 oscillator pulses are required from the time the switch is closed to produce an output signal from the timing module. Since the oscillator generates pulses at a 100 pulse per second rate, the pulse delivered from the module occurs at eighty seconds after switch closure.

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Figure 2
Magnetic Core Counter

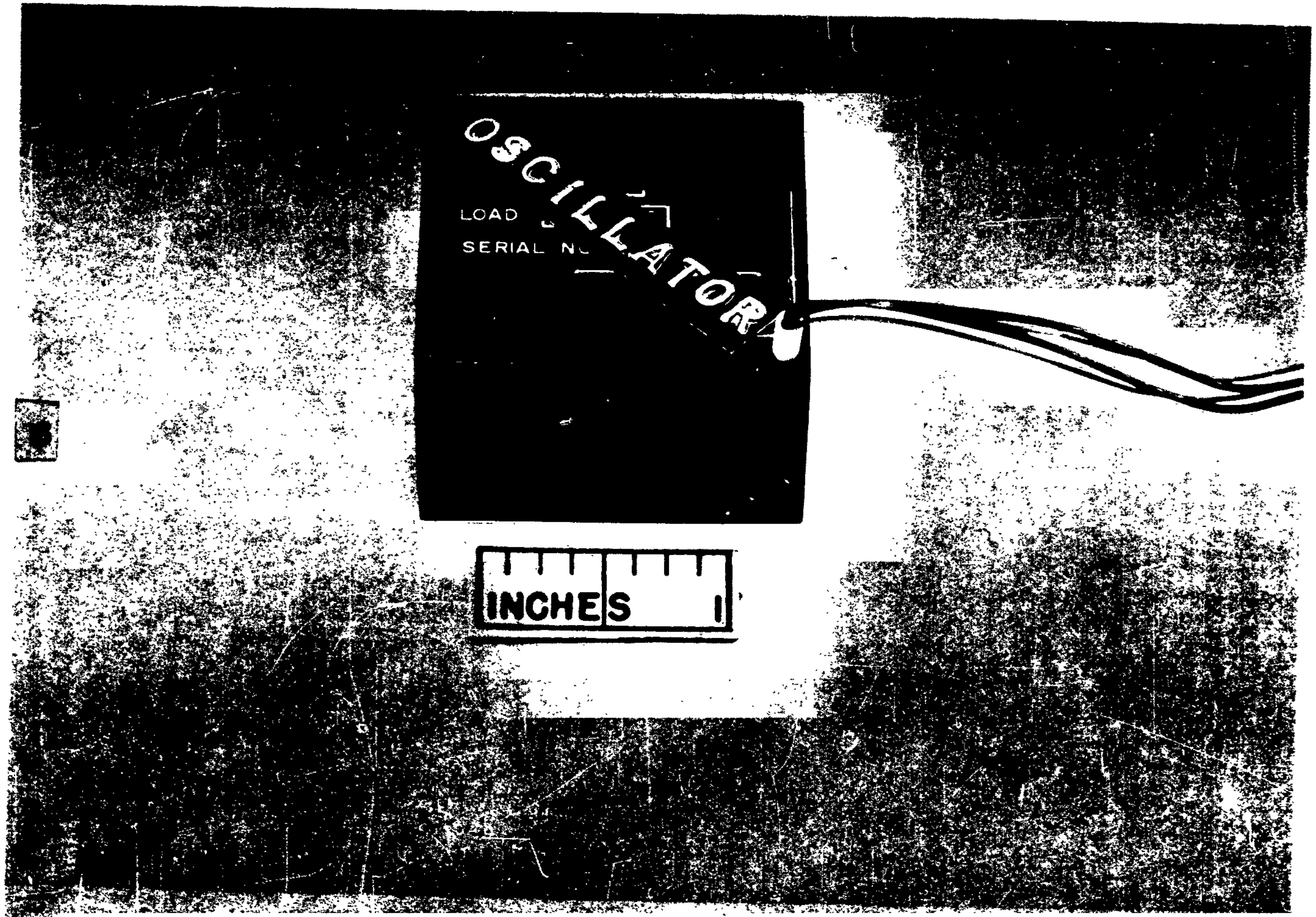

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Figure 3
Magnetic Oscillator

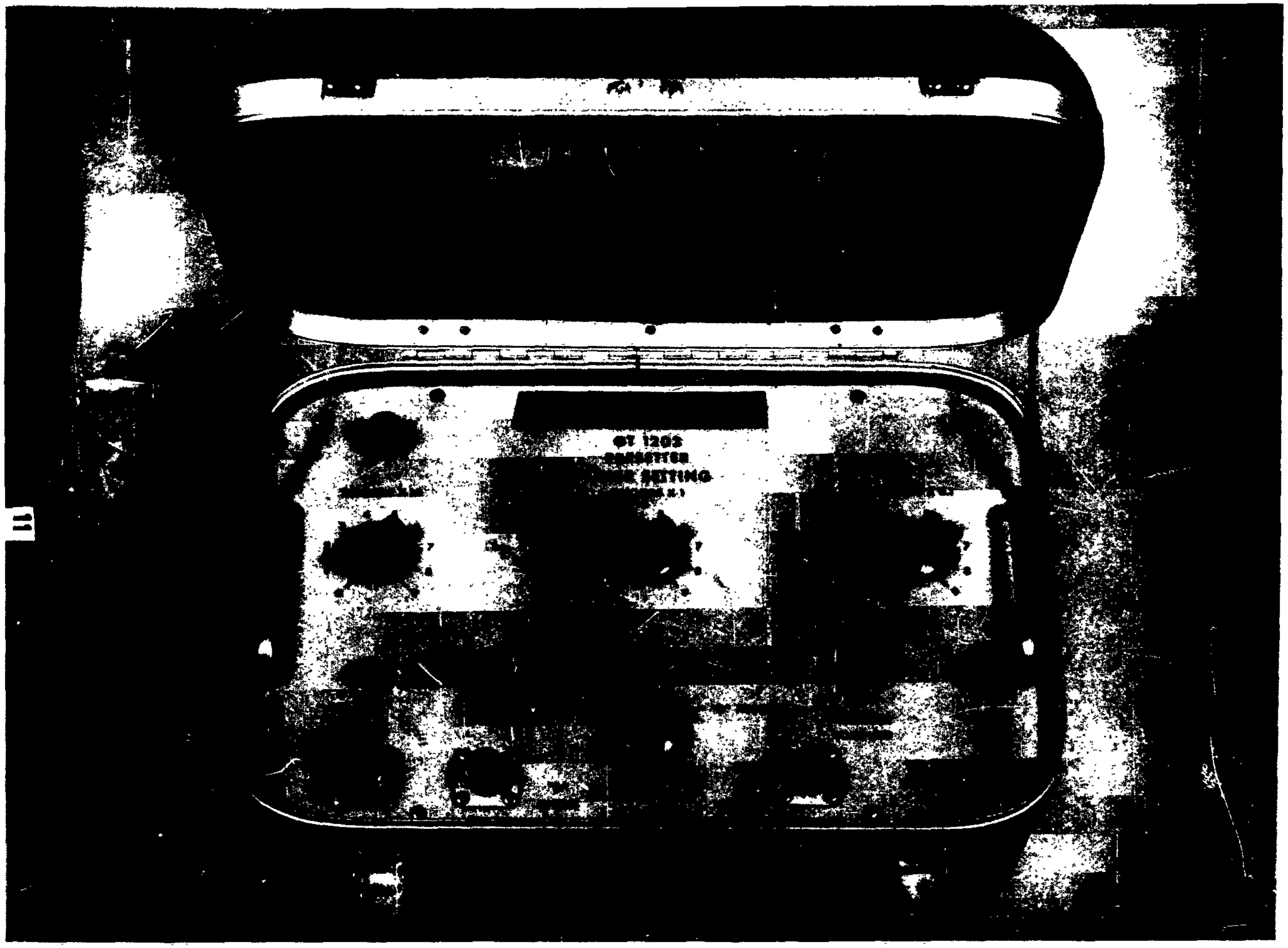

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Figure 4
Presetter

An important feature of the timing module is its inherent characteristic of "magnetic memory". This property is attributed to the magnetic saturable core which is incrementally magnetized to saturation by degrees with each succeeding input pulse. The core is stable at any degree of saturation and as a consequence the counter can retain counts indefinitely without applied power.

The property of "magnetic memory" makes it possible to "preset" counts in the timing module prior to initiating the desired delay period. By this technique a variable delay timer with a maximum delay capability of eighty seconds is obtained.

The presetter (See Figure 4) performs two operations by virtue of a single push button action. Upon depression of the insert button all cores in the timing module are reset to zero count. Release of the button permits a finite number of pulses or counts to be generated and stored in the timing module. The number of counts is determined by the setting of each of three rotary switches on the presetter panel. These switches are calibrated in seconds such that ten to eighty seconds of delay time can be obtained in 0.1 second increments. The cumulative dial setting is related to the number of preset pulses generated in the following manner:

$$\text{Dial Setting in seconds} = (8{,}000 - \text{Pulses preset}) \frac{1 \text{ sec.}}{100 \text{ osc pulses}}$$

This relation indicates that the presetter generates the "complement" of the desired number of pulses to be counted. In order to reduce the time required for the presetting operation, the pulse insertion rate is 10 KC.

The specifications of the three components described are provided for information. It should be noted that the operative environmental specifications for the airborne components (the timing module and the oscillator) are generally applicable to missile systems.

Timing Module Specification

The Timing Modules used for the study were purchased to meet the following specifications:

1. Range: 10 to 80 seconds.
2. Variability: 0.1 second increments throughout range.
3. Accuracy: 0.1% of set time.
4. Input Power: 28 $\pm$ 4 volts D.C.
5. Volume: 4 cubic inches maximum.
6. Operating and Storage Temperature: $+160^{\circ}F$ to $-65^{\circ}F$.
7. Counted Pulses:
    a. Input 2 to 5 volts DC into 130 ohms.
    b. 20 microsecond width.
    c. 0.5 volts per microsecond minimum rate of fall.

Presetter Specification

The specification for the Presetter was as follows:

1. Pulse Output: 0 to 7,000 pulses in 10 pulse increments.

2. Input Power: 28 volts D.C. $\pm$ 10%.

3. Output Selection: Switch to allow selection between 2 output channels.

4. Reset Capability: Presetter will automatically reset timer with which used to zero upon pressing of set button.

5. Time Selection: Selector knobs should be calibrated to read seconds for which associated timer is set.

6. Output Connection: Two each 5 conductor cables with plugs shall be provided for connection to timers.

7. Time to Set: 1 second maximum.

Oscillator Specification

The Oscillators purchased for the feasibility study were specified as being required to meet the following:

1. Input Power: 28 ± 4 volts D.C.

2. Frequency: 100 pulses per second.

3. Accuracy: 0.1% of nominal frequency.

4. Warm Up Time: Time to stabilize to specific frequency after application of rated voltage shall be one (1) millisecond maximum.

5. Output Pulses: Square Wave.

   a. 2 to 5 volts into 130 ohms (input impedance of succeeding stage).

   b. 20 microseconds minimum width of pulse.

   c. Fall time of pulse must be 0.5 volts per microsecond minimum.

6. Operating & Storage Temp. Range: +165°F to -65°F.

7. Duty Rating: Continuous.

8. Volume: 2 cubic inches maximum.

9. Weight: $4\frac{1}{2}$ ounces maximum.

10. Construction: Encapsulated in epoxy. In addition the following specifications were listed as those which the item would be required to meet if a feasibility study proved further development were warranted:

1. Waterproofness: MIL-STD-314.

2. Transportation Vibration: MIL-STD-303.

3. Salt Spray: MIL-STD-306.

4. Five Foot Drop: MIL-STD-358.

5. Temperature Humidity: MIL-STD-304.

6. Vacuum-Steam-Pressure: MIL-STD-305.

7. Fungus: MIL-STD-5272.

8. **Missile Vibration: MIL-STD-5272.**

TIMER ACCURACY DISCUSSION

In a system such as described above no inaccuracies are introduced by the digital counting components (the timing module and the presetter). The accuracy of the time delay generated is primarily dependent upon the error of the oscillator ($\pm$ 0.1% in the system studied*). Another error is introduced in the system, however, due to the fact that the time delay is initiated with the oscillator running. Thus the first counted oscillator pulse may occur as long after initiation as one cycle of the oscillator frequency.

The error equations for the system which accounts for the maximum of these two inaccuracies are as follows:

1. $$T.D.\ (act) = \frac{\sum P}{f_{(act)}} + \frac{1}{f_{(nom)}}$$

where: T.D. (act) = actual delay time.

$\sum P$ = total pulses counted during T.D. act.

$f_{(act)}$ = actual oscillator frequency.

$f_{(nom)}$ = nominal oscillator frequency.

2. $$\%\ error = 100 \times \frac{TD(act) - TD\ (nom)}{TD\ (nom)}$$

Assuming the high side error the following tabular summary results:

TD(nom) Sec		TD(act) Sec	% error
10	1,000	10.02	0.22
20	2,000	20.03	0.15
40	4,000	40.05	0.125
60	6,000	60.07	0.113
80	8,000	80.09	0.11

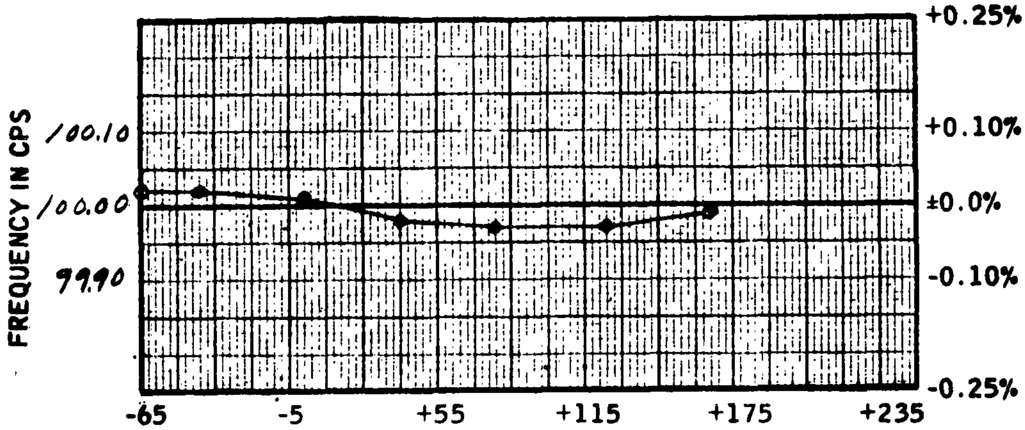
*Figure 5 is a typical calibration curve over the temperature range of +165°F to -65°F and is included for information.

MINNEAPOLIS HONEYWELL REGULATOR COMPANY
ORDNANCE DIVISION
600 - 2nd Street North Hopkins, Minnesota

MAGNETIC OSCILLATOR, 100 CPS

CUSTOMER Picatinny Arsenal **P.O. No** 28-017-A03-01441 **Date:** 9-24-62

MODEL NO. EXG 2343B12X1 **SERIAL NO.** 2



TEMPERATURE IN DEGREES FAHRENHEIT

TEMP IN °F	INPUT VOLTAGE 24V	28V	32V
- 65	100.02	100.02	100.02
- 40	100.02	100.02	100.02
0	100.01	100.01	100.01
+ 40	99.98	99.98	99.98
+ 80	99.97	99.97	99.97
+125	99.97	99.97	99.97
+165	99.99	99.99	99.99
+205			
+250			

COMMENTS

Pulse width varied from 42 to 30 microsec. over temperature and input voltage ranges.

DESIGN APPROVED [signature]

TEST APPROVED Al Home

Nominal Input Current @ 28.0 VDC Input and 80° F = 26.6 ma

Nominal Output Voltage @ 28.0 VDC Input and 80° F = 4.2 Volt P-P

Figure 5

It can be noted that the error is variable with delay time. The constant "one pulse" error becomes less significant, of course, at the longer delay times.

A large number of time delay measurements have been made on the system described in this report. The time delays were measured on a Hewlitt Packard 524B Counter capable of measuring to an accuracy of $\leq 10^{-5}$ seconds. The system was found to be well within the predicted accuracy in all measurements at a wide variety of delay settings.

It should be noted that the oscillator employed in this system has an extremely rapid warm up time (less than one millisecond). This property could be utilized to reduce the "one-pulse" error previously described by energizing the oscillator at first motion rather than at the time of thermal battery output. If this were done the Time Delay equation is modified as shown below and the system error approaches 0.1% even at the shortest delay time.

$$T.D. (act) = \frac{\sum P}{f(act)} \leq .001$$

MAGNETIC CORE TIMER ATTRIBUTES

The Magnetic Core Counter has a number of features which make it desirable for use in a high accuracy time fuze. A magnetic core counter can be designed to be factory set for any specific output time or for slightly additional cost to be field settable.

Since both the counter and the oscillator are solid state assemblies (they can be a single assembly), a time fuze using these components can be small in size and should be highly reliable. Being completely electrical in operation, the magnetic core fuze readily lends itself to being designed for repeated tests in the laboratory. This latter feature is often desirable from the standpoint of quality assurance or field surveillance.

The speed and ease of setting or resetting the fuze to a specific time might be a significant reason for use of a magnetic core timer. A round emplaced in the field and set for a certain functioning time may not be fired immediately. By the time the round is desired to be fired it could very well be that a different functioning time is needed. Such a situation could readily be accommodated by a magnetic core timer since only a fraction of a second is required between the instant the decision is made to function at a new time and accomplishment of the resetting.

Possibly an important reason for use of the subject type of fuze might be the ability to set the fuze remotely. This remote setting capability is desirable for speed but could become mandatory in a volley fired system where access to each round would be difficult and/or the time consumed in physically dialing a time into each round would be prohibitive.

One final attribute of the type of timer in question is the high degree of accuracy possible as described in another section of the report.

If the capabilities offered by the counting fuze are desired but the high accuracy is not needed the accuracy of the oscillator can be reduced for a savings in cost.

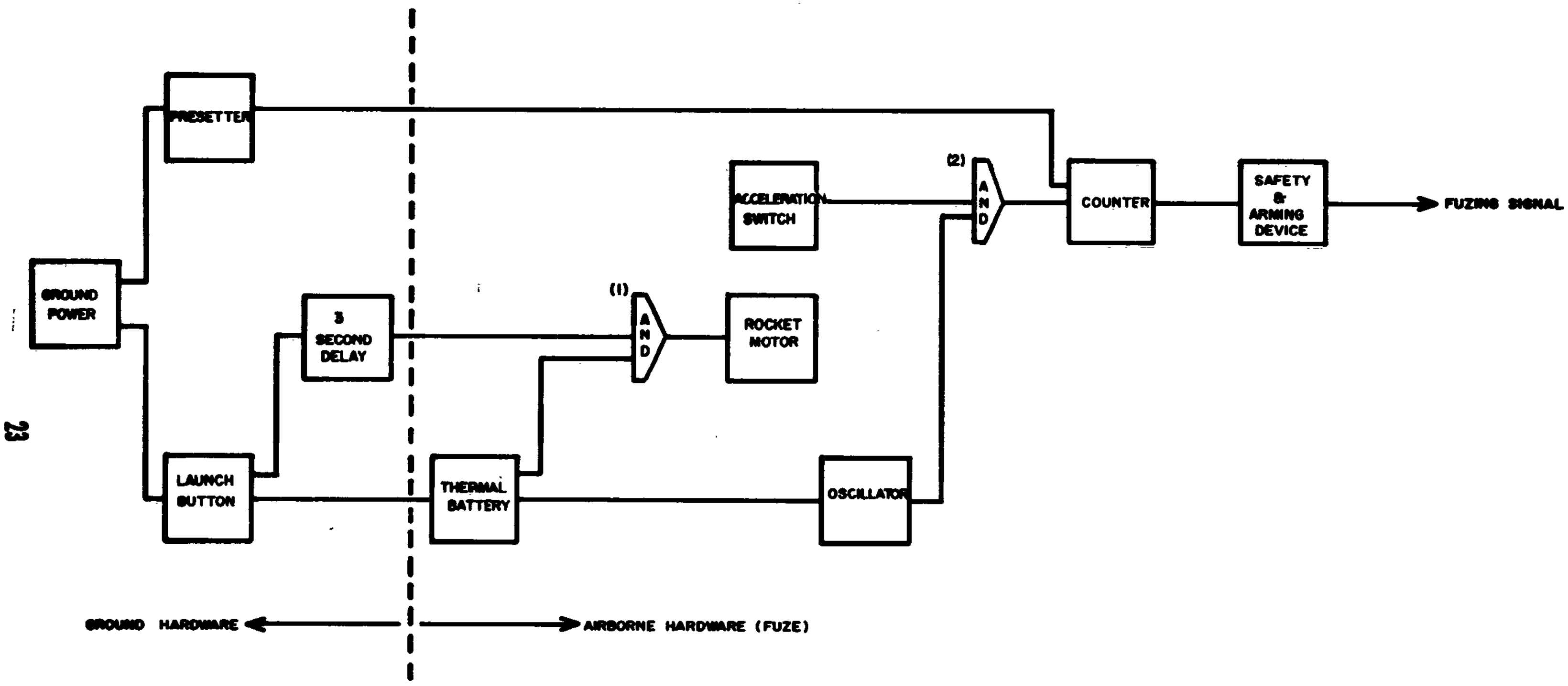
A TECHNIQUE FOR USE OF THE COUNTER IN A TIME FUZE

A breadboard model, Figure 1, of a typical application for the counting fuze was fabricated for test and demonstration of capability. It will be noted that the fuze models include a number of components such as relays, tell lights, reset switches, etc. which are not necessary for a tactical system but are required as a laboratory facility where explosive switches and thermal batteries are not practical. Figure 7 is a mock-up of a complete tactical missile fuze as it might appear bulkhead mounted. Figure 6 is a block diagram of the logic involved.

Actually, the breadboard model included two fuzes to demonstrate the ability of the presetter to set a multiple of missiles for different times. The description of operation, however, is limited to one fuze since the setting of a multiple number requires only that the presetter be connected to each successive fuze through appropriate switching prior to being set.

The system requires a 28 V.D.C. ground power supply for presetting operations. Assuming power is available, the Counter can be set and/or reset to any functioning time as often as desired. To insert the desired output time in the counter it is necessary to position three presetter dials (See Figure 4) to the proper digits. One dial sets the tens digit, the second sets the units digit and the third dial sets the tenths digit. For example:

Assume it was desired to have the fuze function after 23.4 seconds of flight.



BLOCK DIAGRAM OF LOGIC FOR FUZE SYSTEM

FIGURE 6

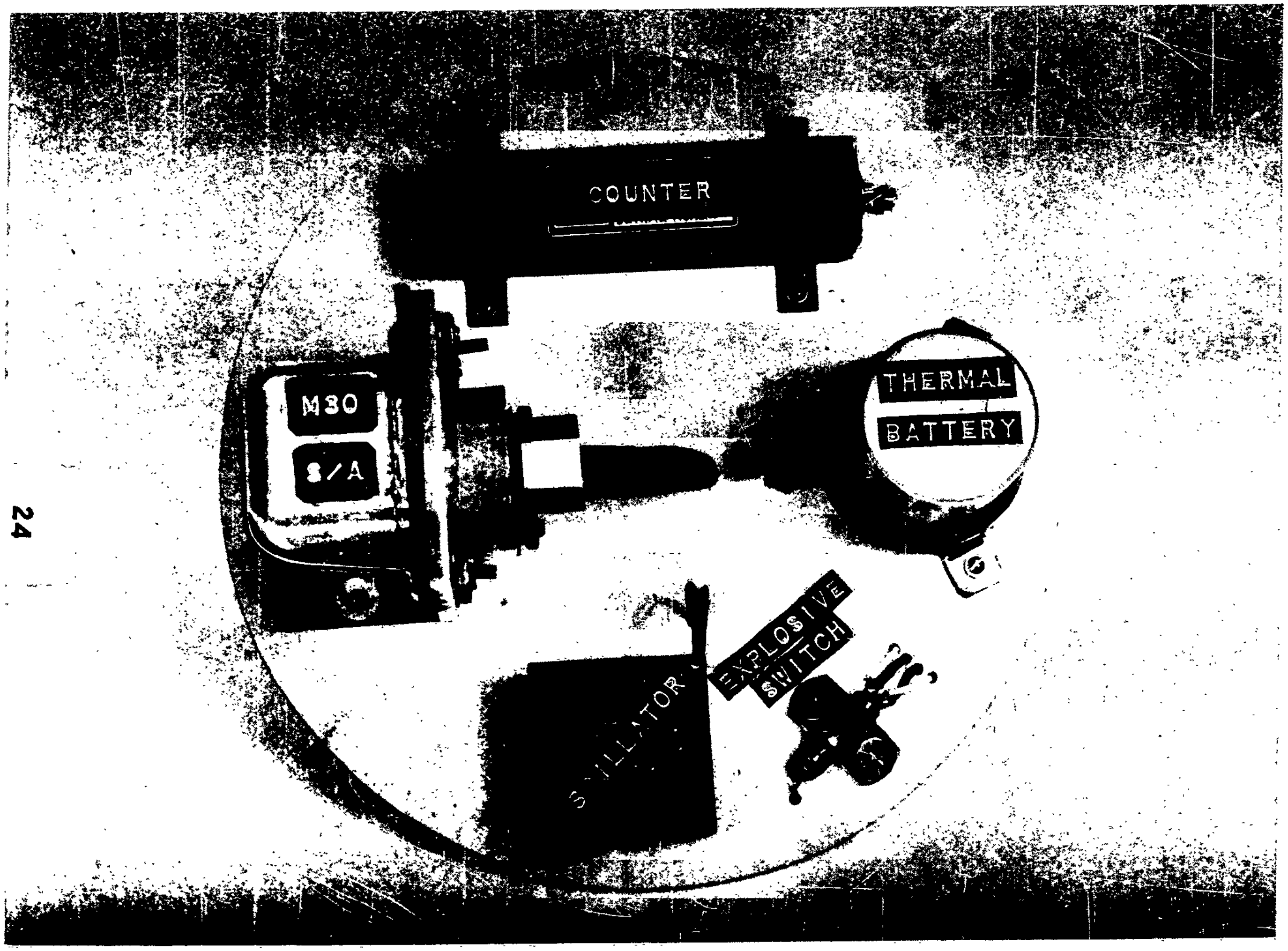


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Figure 7
Mock-Up Of Typical Tac .cal Fuze

Then:

1. The tens digit dial would be set to 2.
2. The units digit dial would be set to 3.
3. The tenths digit dial would be set to 4.
4. Finally, press and release of the insert button on the presetter would insert the above set time into the counter.

The missile with the fuze preset as described above is ready for launching. Pressing of a launch button initiates two actions. First, it fires the airborne thermal battery squib. Second, it starts a ground control R-C delay timer which delays ignition of the rocket motor to allow the thermal battery to build up to full voltage. The delay also allows the oscillator to stabilize in frequency, but only a very small portion of the delay time is required for the stabilization. An arbitrary 3 second delay was built into the model but this is probably higher than most applications would require.

Having pressed the launch button the missile is committed to go and the rocket motor would ignite 3 seconds later. At rocket motor ignition an acceleration switch would close and start the counter counting output pulses from the oscillator which was powered previously. In this way zero time is keyed to initial missile movement. After the preset amount of flight time the counter will provide an output signal through a Safety and Arming Device which is armed by that time An M30 S&A was used with the breadboard model.

The logic diagram in figure 6 shows two "and" gates for illustration purposes. In practice the gates as such do not exist but the effect is identical. The (1) gate would actually be an explosive switch which would be fired by the 3 second delay timer. Firing of the switch would unshort the rocket motor and place thermal battery voltage across the rocket motor ignition leads. The effective operations necessary before the motor can be ignited requires the function of the 3 second delay and the presence of thermal battery voltage.

Effectively the (2) gate exists in the counter. Closure of the acceleration switch gates on a circuit in the counter which can then accept pulses from the oscillator. Both the oscillator pulses and the acceleration switch closure must be present for the time pulses to be counted.

The acceleration switch in the model is a minor addition to the standard M30 S&A. Full deflection of the "G" weight at first motion closes a switch which provides the zero time signal for the counter.

DISCUSSION OF SIZE, ACCESSORIES, AND PACKAGING

Since the size of components will vary somewhat depending upon maximum time to be counted, thermal battery power requirements, etc., the discussion of size will be limited to those components which would be used in a system similar to the one which was breadboarded. The following necessary fuze components and approximate sizes are listed as a guide:

Thermal Battery - 1½" diameter x 3" long

Explosive Switch - 0.3 diameter x 1" long

Oscillator - 1½" x 1½" x 1"

Acceleration Switch and S&A - 3" x 1½" x 1½"

Counter - 1" x 1" x 4"

The magnetic core timer requires the availability of a continous 60 milliamps of current (28 ± 4 VDC) during its counting phase. Size restrictions on the thermal battery are controlled primarily by the power required to initiate the rocket motor and fuze detonator rather than the timer requirements.

A basic Safety and Army Device such as the M30 readily lends itself for use with the counter to provide both the necessary arming delay and with minor modification the signal indicating initial missile motion.

All components except the S&A are solid state types and would therefore be adaptable to either bulkhead mounting of individual parts or potting to reduce the number of assemblies. As used in the breadboard model the counter and oscillator were two separate items as a result of being furnished by two suppliers. However, there is no reason why the two items could not be combined as a single package.

COST CONSIDERATIONS

Since the techniques described in this report represent a new approach to a fuzing system, the following component costs are furnished as a cost guide. It is pointed out that the indicated costs for the counter and oscillator are based upon a buy of only two (2) of each item.

Counter - $780 each

Oscillator - $250 each

Explosive Switch - $5.00 each (approximate)

M30 S&A - $28.00 each (cost of unmodified MIL-STD item)

Thermal Battery - $50.00 each (approximate)

Total cost of the above components is $1,113.00. However, a cost of $78.18 has been quoted as a cost for the counter in production lots of 100,000. This is a cost reduction by a factor of 10. If the same reduction factor is applied to the magnetic oscillator, which appears to be reasonable, a production cost for the components in the outlined fuze is reduced to $186.00. This includes a $50.00 cost for the battery which is not normally considered to be a part of the fuze.

The cost of a single presetter designed and built specifically for this study was $2,000.00. Although there should also be room for considerable cost reduction in this area, the cost of the presetter is not a major consideration since it is a part of the ground equipment which would be used over and over again.

An approximate cost of the components used in the nominal 3 second delay timer, is $50.00. Here again, cost is not significant since the assembly is part of the launcher controls and is not expended.

It is pointed out that the above figures do not include assembly costs, miscellaneous small parts, etc., which do not amount to very much. The figures do imply, however, that a system of the type investigated should be reasonable based upon comparative costs of other fuzing systems in early development states. This latter statement is particularly true when the accuracy and variability of time provided by the system are used as a basis of comparison.

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