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INSTRUMENTATION FOR HARTMANN AND 20-L DUST EXPLOSIBILITY TESTS AT THE CANADIAN EXPLOSIVE ATMOSPHERES LABORATORY

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ABSTRACT

Flexibility and resolution are important factors involved in the timing and control of any electro-mechanical process. In dust explosion research this process involves the dispersion and ignition of a dust sample and the recording of explosion pressure versus time.

The recently designed and constructed control unit and the adaptation of a commercial signal conditioning unit is described in detail. Consideration throughout the design and construction stages has been given to flexibility, accuracy and resolution of the control process and to operator safety.

The result is a system which allows independent one millisecond control of the "air on time", "arc on time", and the "delay time", as well as considerable reduction in noise of the pressure signal. Also, the use of a digital oscilloscope allows the flexibility of data handling and storage associated with computer memory and magnetic media.

Key words: Hartmann apparatus; 20-litre vessel; Explosibility

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APPAREILLAGE UTILISE PAR LE LABORATOIRE CANADIEN DE RECHERCHE SUR LES ATMOSPHERES EXPLOSIVES POUR LES ESSAIS HARTMAN ET 20-L EN VUE DE DETERMINER L'EXPLOSIVITE DE LA POUSSIERE

par

K.J. Judge*

RESUME

La souplesse et la résolution sont des éléments importants de tout procédé électro-mécanique. Le procédé utilisé dans les activités de recherche sur les explosions de poussière comprend la dispersion et l'inflammation d'un échantillon de poussière et l'enregistrement de la pression de l'explosion en fonction du temps.

L'unité de contrôle qui a été planifiée et construite récemment et l'adaptation d'une unité commerciale de conditionnement de la signalisation font l'objet d'une étude détaillé. A toute les étapes de la planification et de la construction de l'unité, une attention particulière à été accordée à la souplesse, à la précision et à la résolution du procédé de contrôle ainsi qu'à la sécuité de l'opérateur.

Ces mesures ont permis de développer un système qui permet un contrôle en milliseconde autonome ponctuel de l'air, de l'arc et du délai. Ce sytéme réduit considérablemant le bruit émis par le signal indiquant la pression. L'utilisation d'un oscilloscope numérique facilite la manutention et le stockage des données provenant du système d'exploitation et des médias magnétiques.

Mots-clé: appareil Hartmann; contenant de 20 litres; explosibilité

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INTRODUCTION

This report describes the control and instrumentation equipment used for dust explosion testing at the Canadian Explosive Atmospheres Laboratory (CEAL). This equipment was developed in order to provide improved precision and resolution, plus better control over experimental parameters. The report is intended as a technical reference and includes detailed descriptions, wiring diagrams and the theory of operations for the in-house designs.

The control and instrumentation equipment for dust explosion testing at CEAL consists of a timing control box, a strain gauge control box, a strain gauge pressure transducer, and a digital oscilloscope. It is the timing control box and the strain gauge control box which are of in-house design and are described in detail in this report.

REQUIREMENTS

In the standard Hartmann or 20 litre tests a dust sample is dispersed by a burst of air from a pressure chamber through a solenoid valve either prior to or after the initiation of an arc (1,2). An explosion may occur depending on the concentration and composition of the dust. These apparatuses are used to determine minimum and maximum explosible concentrations, explosion pressures, maximum rates of pressure rise, and minimum ignition energies. For determining the minimum ignition energy of dust samples the arc may be initiated just after the dispersion of the dust. In order to be able to study the effects of various parameters, the arc on time, the solenoid open time, the delay between the initiation of the electrode spark and the opening of the solenoid (or vice-versa), must be able to be varied independently and accurately.

Before the development of the circuitry described in this report, an RC timer relay had been employed to provide the necessary delay between the initiation of the arc and the opening of the solenoid valve. Opening the solenoid valve allows a volume of compressed air to disperse the dust. The time that the solenoid valve remains open determines the final pressure reached in the explosion chamber and should thus be operator-adjustable. The resolution, repeatability and accuracy of this timer were not acceptable for the work being attempted.

An arc, which is in effect a wide band transmitter, results in signal pick-up by the transducer and cables and is recorded as rather large spikes by the oscilloscope. To eliminate this extraneous signal, it would be desirable if the arc could be turned off shortly after ignition of the sample occurs. Also, all reasonable effort should be made to reduce other noise such as 60 Hz and logic switching spikes. This would result in a cleaner signal and, in the area of maximum pressure rise, would allow a better determination of the tangent to the curve of pressure versus time.

Because of minimal lab space, a control box which is suitable for all experiments was designed and constructed. This will control all of these parameters and provide ample room for future modifications and additions.

OVERVIEW OF EQUIPMENT

The three components of the equipment set-up are shown in Figure 1. These are: the Timing control box (bottom left); the strain gauge control box (top right); the digital oscilloscope (center and bottom right).

The timing control box gives the operator precise timing control of the various parameters of the test apparatus. The control box activates relays according to the settings of the panel switches. This control gives the necessary flexibility to accommodate different testing techniques and varying explosion characteristics.

The strain gauge control box acts as an interface to the digital oscilloscope. Incorporation of a Honeywell Strain Gauge Control Unit (Model 1885-SGC) and various power supplies and circuitry provides the necessary excitation voltage, signal conditioning and amplification for the transducer (a Bell and Howell CEC1000, 100 psig).

The digital oscilloscope samples the signal from the strain gauge control box and converts this analogue signal to digital values which are stored in its memory and displayed on a screen. The oscilloscope is a Nicolet 4094A mainframe with a 4562 digitizer and an XF-44 dual disk drive.

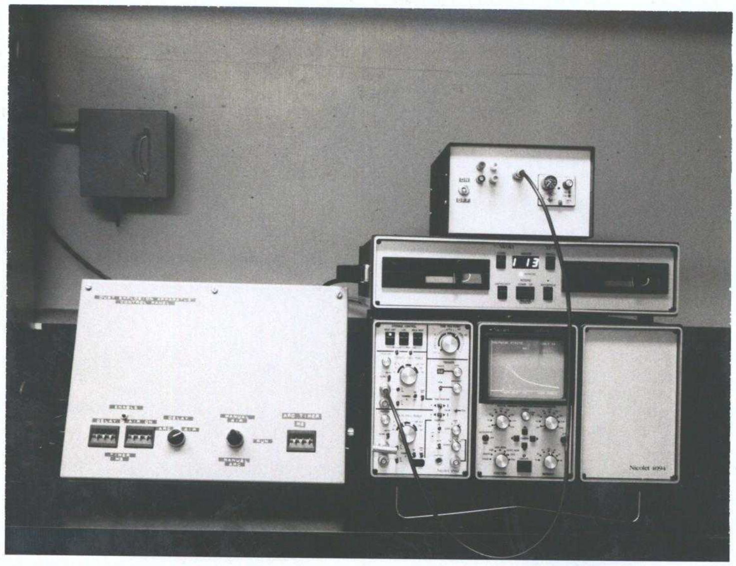

Fig. 1 - System Equipment

Fig. 2 - Timing Control Box Front Panel

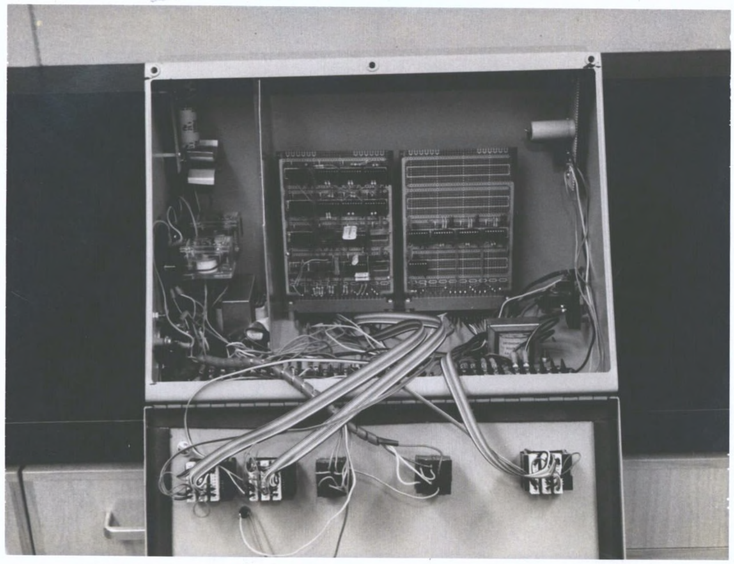

Fig. 3 - Control Box Interior Layout

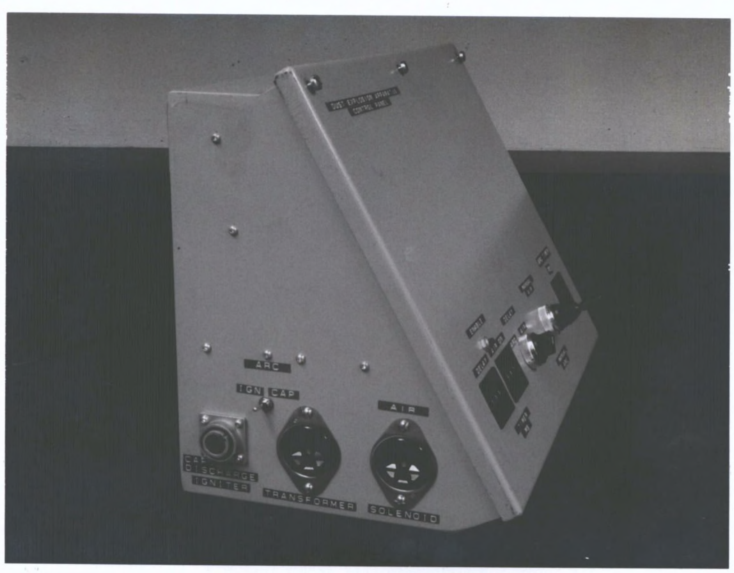

Fig. 4 - Control Box Side Panel Connectors

PC10C3

TIMING CONTROL BOX

The timing control box consists primarily of three counters and a clock. The counters are set using individual three digit thumbwheel switches on the front panel (Fig. 2). The clock is tuned for a one millisecond period and, thus, the counters can be set from 1 to 999 ms. Each counter has a specific function viz. air-on time, arc-on time and delay time. Two relays are activated by signals from the counters and make contacts which operate the solenoid valve and the ignition source.

The box contains four circuit cards (Fig. 3), two of which are power supplies (top left and lower right). The others provide the clock, timers and output amplifiers for the relays (bottom rear). The relays are on the left inside wall of the box, as are the output connectors. A metal divider is located between the relays and the logic boards. This divider acts to shield the boards from spikes radiating from the relay contacts.

Figure 5 shows the routing of signals throughout the timing control box. The function switch initiates the timing process sending a signal to the "delay" selector switch or, for manual operation, directly to one of the relays. This selector switch sends the signal directly to one relay path and a delayed signal to the other. The amount of delay is selected by the operator using the front panel thumbwheel switches. The relay paths each contain a timer which are also set using thumbwheel switches and determine the length of time that the relays will

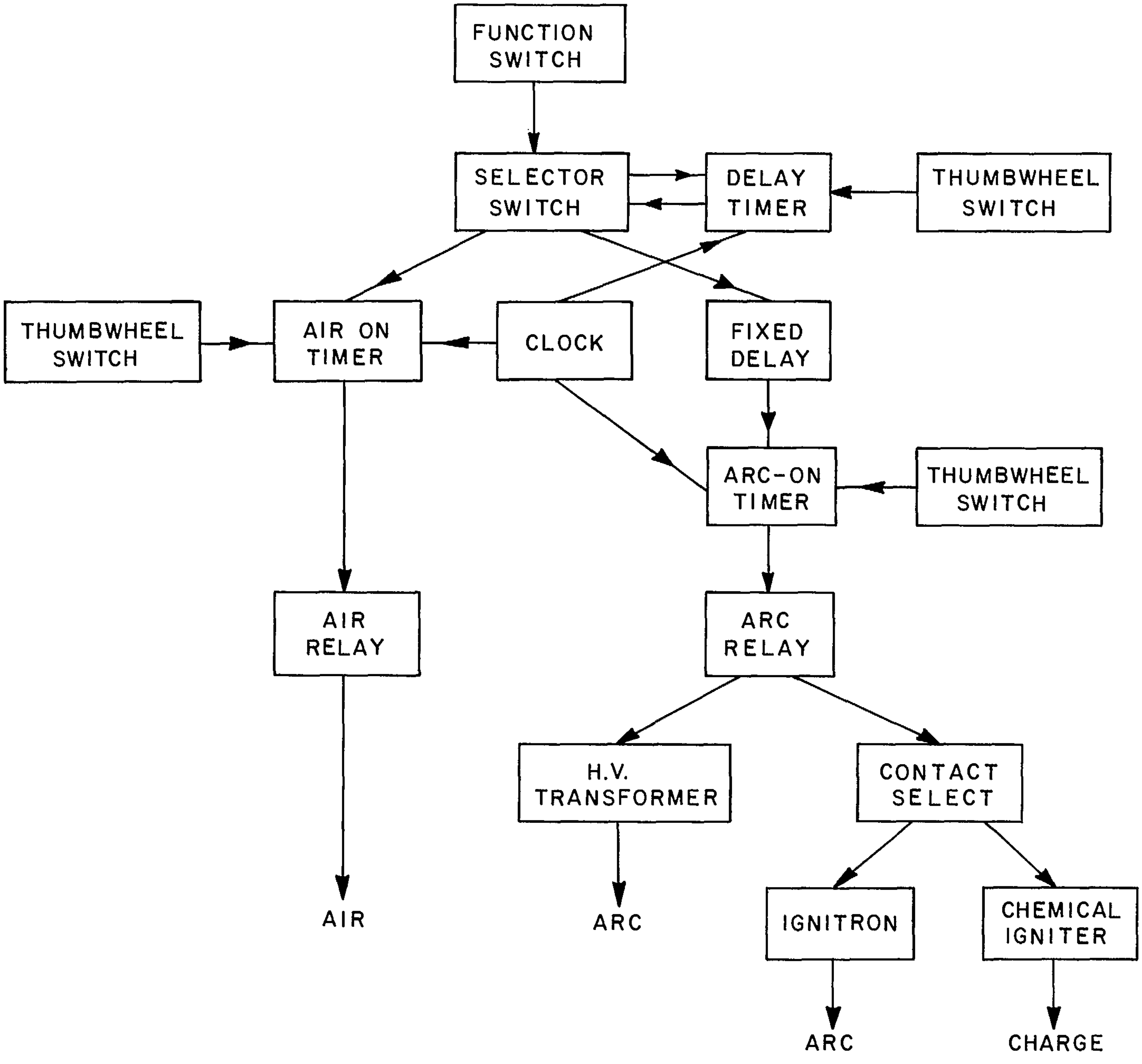

Fig. 5 - System Timing Flow Diagram

remain activated. The arc path contains a further delay which is internally adjustable. This timer is used to remove any timing difference between the solenoid valve actuation time and the arc/charge activation time, which may be significant in capacitive discharge experiments. Also, a contact select switch (Fig. 4) in the arc path connects either a short circuit or voltage supply across the relay, allowing the operator to perform capacitor discharge tests or use chemical igniters for 20 litre tests.

CONTROLS AND CONNECTORS

A front panel dial switch (SW1) allows the operator to select air or arc delay and a 4-position toggle switch (SW2) selects automatic timing of the testing process or manual operation of the arc or air functions while the fourth position is not used. A momentary switch (SW3) acts as a safety switch which interrupts power to a pair of relays. This switch must be depressed and held during tests to permit operation of the relays. To depress the "Safety" switch and operate the "Run" switch requires the use of both hands and thus reduces the chance of the operator touching high voltage wires during a test.

Three thumbwheel switches, with three digits each, (TWS1, 2 and 3) located on the front panel are used to select the time in ms for the: delay between the arc and the dispersion; solenoid valve to be open; and arc to be left on.

Three methods of ignition that might be employed are; continuous arc transformer (standard); capacitor discharge (used for minimum ignition energy tests); and chemical igniter (20 litre vessel). The arc transformer operates from 110 Vac; the remote discharge unit triggers from a contact closure; and the chemical igniter requires about 5 Vdc at 1.5 A. For safety reasons two "Arc" connectors (A4P1, 2) are used to separate the 110 Vac connection (A4P1) from the two low voltage connections (A4P2). A two position toggle switch (A4SW4) allows the operator to select between a simple contact closure (for the capacitive discharge) and a supply voltage (for the chemical igniter) at the low voltage connector (A4P2). A third connector (A4P3) provides 110 Vac for the solenoid valve. These three connectors and the toggle switch are located on the left side of the control box.

Toggle switch (A4SW5) is the power on/off switch and is located on the right side of the box near the rear.

PRINCIPLES OF OPERATION

Timing and Control

A dual monostable multivibrator (A2U1) acts as a 1 ms clock and is tuned using a 10K ohm 10-turn potentiometer (A2R5) to give a period of 1.00 0.01ms. Operation upon start-up is ensured through the delay of pin 2 going high (A2R1 and A2C1). This "Clock" signal is used by all three counters.

When the "Operation Mode" switch (A2SW2) is moved to the "Run" position, automatic operation of the internal circuitry takes place. The "Run" signal is routed via the "Delay Select" switch (A2SW1) directly to either the "Arc" or "Air" control path according to the switch setting. If the switch is set to "Air" the signal is routed directly to the "Arc" path and vice-versa (see appendix 1).

The signal is also sent to the "Run Delay" circuitry, through 10K ohm limiting resistor (A2R6). The "Run Delay" consists of three binary decade counters (A2U4, 5 and 6) and control gating (A2U2 and A2U3). The resetable flip flop (A2U2-1) gates the "Reset" pulse from the counters and the "Run" pulse to inhibit the counters until the "Run" pulse is received. The nor gate (A2U3-1) acts to block the "Clock" pulse to the counters until the "Run" signal has been received from the flip flop. The nor gate (A2U3-2) gates the "Carry Out" bits from each counter to reset the counter after the value set by the front panel thumbwheel switch (TWS1) has been reached. The "Run Delayed" signal (rising edge) is returned to the "Delay Select" switch which, in turn, directs this signal to the control path selected by the "Delay Select" switch ("Air to Air" or "Arc to Arc") resulting in the delay of that timing path.

The "Air" signal is gated (A2U2-2, A2U7-1, 2, A2U8, 9, 10 and TWS1) the same as the "Run" signal. The "Air" input current is limited by a 10K ohm (A2R33) resistor and pulled down by a 10K ohm (A2R32) resistor. The limiting resistor will limit the input current when the "Air" signal is connected directly to the "Run" signal and the pull down resistor provides a low level input until the signal is received. The low going signal from pin 2 of the flip flop (A2U2-2) controls the gate of a fet (A2Q1) through a 10K ohm limiting resistor (A2R59). This fet controls the "Air Relay" (A4L1) and stays on until the counter reaches the preset value of the thumbwheel (TWS2). Two diodes, one on board (A2D1-1) and one in the relay (A4D1-2) protect the fet from a large back emf when the relay is turned off. Both normally open contacts are used to switch 110 Vac to the "Air" connector (A4P3). Capacitor A4C5g suppresses noise from the relay contacts.

The "Arc" signal is delayed by a circuit to allow for the timing difference between the solenoid valve and the arc transformer, chemical igniter or ignitron. This delay is performed by a dual monostable multivibrator (A2U11) and adjusted by a 50K ohm 10-turn potentiometer (A2R64). The resulting "Arc Delayed" signal is treated the same as the "Air" signal (A3U12-1, A3U13-1, 2, A3U14, 15, 16 and TWS3). Capacitors A3C5d-f have been added to slow the rise time of their respective pulses, and to filter excess noise. The resulting "On Timed Arc" signal, through a limiting resistor, controls a fet (A2Q2). This fet controls the "Arc Relay" as described for the "Air Relay". One normally open contact is used to switch 110 Vac to one "Arc" connector (A4P1). Capacitor A4C5h suppresses noise from this contact. The other normally open contact either shorts the contacts or applies a 5Vdc signal, depending on the position of the output switch (A4SW4), to the other connector (A4P2).

Power Supplies

The timing control box accepts 110 Vac nominal line voltage and develops three regulated dc voltages (12 and two 5 Vdc). The 12 V and one of the 5 V supplies are tied to one transformer (A3T1) and form "Power Supply 1". The other 5 V supply (Power Supply 2) is run from a separate transformer (A3T2) but shares a common ground.

On "Power Supply 1", the 12 V supply operates the relays and the 5 V supply is used during 20 litre tests when a chemical igniter is being used. These supplies are separated from the logic 5 V supply so that any voltage drop while firing the igniter or operating the relays will not affect the logic circuits and cause misfirings. 14 VRms is taken from transformer A3T1 to the input terminals of full-wave rectifier A5CR1. The rectified voltage is filtered by capacitor A5C6 and routed to voltage regulators A5VR1 and 2. Output capacitors A5C7, 8 help transient response.

"Power Supply 2" provides 5 V power for the logic boards. Power is taken from transformer A3T2 to the input terminals of full-wave rectifier A5CR2. The rectified voltage is filtered by capacitor A5C9 and routed to voltage regulator A5VR3. Output capacitor A5C10 helps transient response.

STRAIN GAUGE CONTROL BOX

GENERAL

The strain gauge control box was developed to replace the Honeywell 1885 CRT Visicorder which uses photographic paper to record input signals versus time during tests. This paper is expensive and fades with time. The digital oscilloscope stores data in its memory which can be magnified and scanned before saving it on disk. This allows previewing of results or test set ups, thus storage media is not wasted. Floppy disk storage is also relatively cheap and reuseable. Having the data in a digitized form allows manipulation of the waveform using available software, such as a smoothing or a derivative function. The large and cumbersome Visicorder and cabinet occupied valuable laboratory space and only one Strain Gauge Control (SGC) unit was being used. Therefore, the necessary power supplies and connections were provided in a smaller box and the Visicorder removed from the lab.

PRINCIPLES OF OPERATION

Examination of the schematic drawings for the SGC unit revealed that only three power supplies and one line clock were needed to operate the module. However, it was decided to make a separate supply for the analog circuits in order to reduce the noise on the line voltage resulting from the logic circuits and thus obtain a cleaner signal. The four power supplies required are: 12 Vdc: and two +5 Vdc.

Timing

The line clock is required to be high for 19.5 s and low for 0.5 s. This signal is provided by a dual monostable multivibrator (A6U1) set up as an oscillator and tuned via a 10K ohm 10-turn potentiometer (A65R5). A start up circuit (A6R1 and A6C1) ensures operation at power up.

Modification of the SGC module

To provide better resolution for the "Calibration Supply Control" the 10K ohm dial potentiometer in the SGC unit was replaced with a 2K ohm potentiometer of the same manufacture and the appropriate series resistance to make up the difference. The result is a five-fold increase in resolution over a narrower range 0-20 mV, which corresponds to 0-938 KPa (0-136 psi) of the transducer. The actual setting is now one fifth of the dial reading.

Power Supplies

The strain gauge control box accepts 110 Vac nominal line voltage and develops four regulated dc voltages (12 and two 5 Vdc). All supplies are tied to one transformer (A6T3) and form "Power Supply 3". The 12 V supplies power to the analog circuits while one 5 V supply is used for logic in the Honeywell SGC unit and the other is used by the clock circuit in the box.

14 VRms is taken from transformer A6T3 to the input terminals of full-wave rectifier A6CR3. The rectified voltage is filtered by capacitors A6C11 and 12 and routed to voltage regulators A6VR4 and 5 which provide 12 V. Output capacitors A5C15 and 16 help transient response.

The 12 V power supply is further filtered (A6C13 and 14) and acts as input voltage for the two 5 V regulators A6VR6 and 7. Output capacitors A6C17 and 18 help improve transient response.

CONCLUSIONS

The compact system described in this report allows easy and accurate operation of the dust explosion equipment, with the operator able to change the parameters at will. The pressure trace can now be obtained in digital form to a precision of 0.7 KPa (0.1 psi). The explosion pressure and maximum rate of explosion pressure rise can be easily obtained from the oscilloscope. Early indications are that the noise on the signal has been significantly reduced and is about one fifth the magnitude from before.

ACKNOWLEDGEMENTS

The writer wishes to extend his appreciation to Dr. K. Mintz for his supervision of this project and to Ms. J. Folta for preparing the diagrams.

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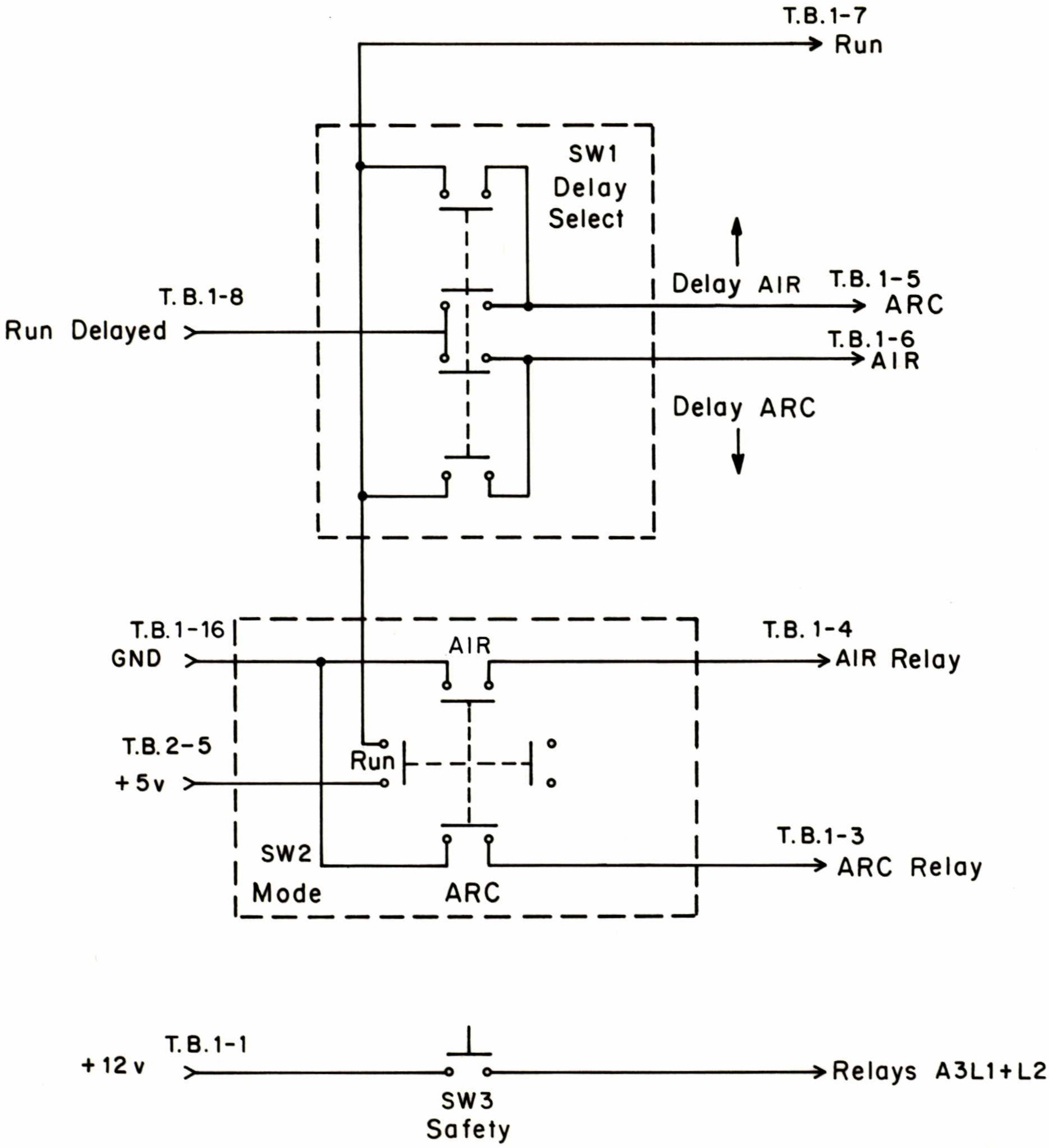
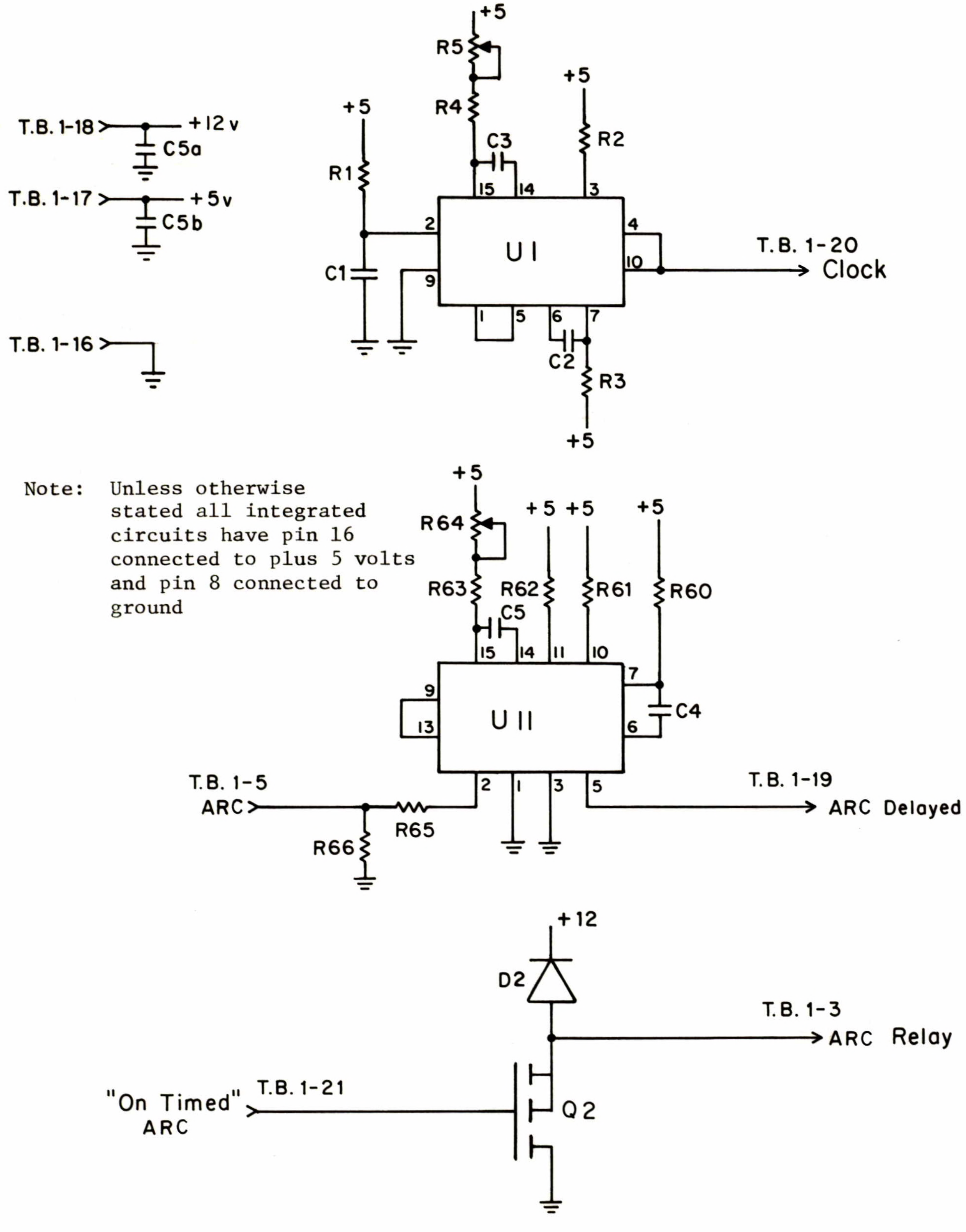
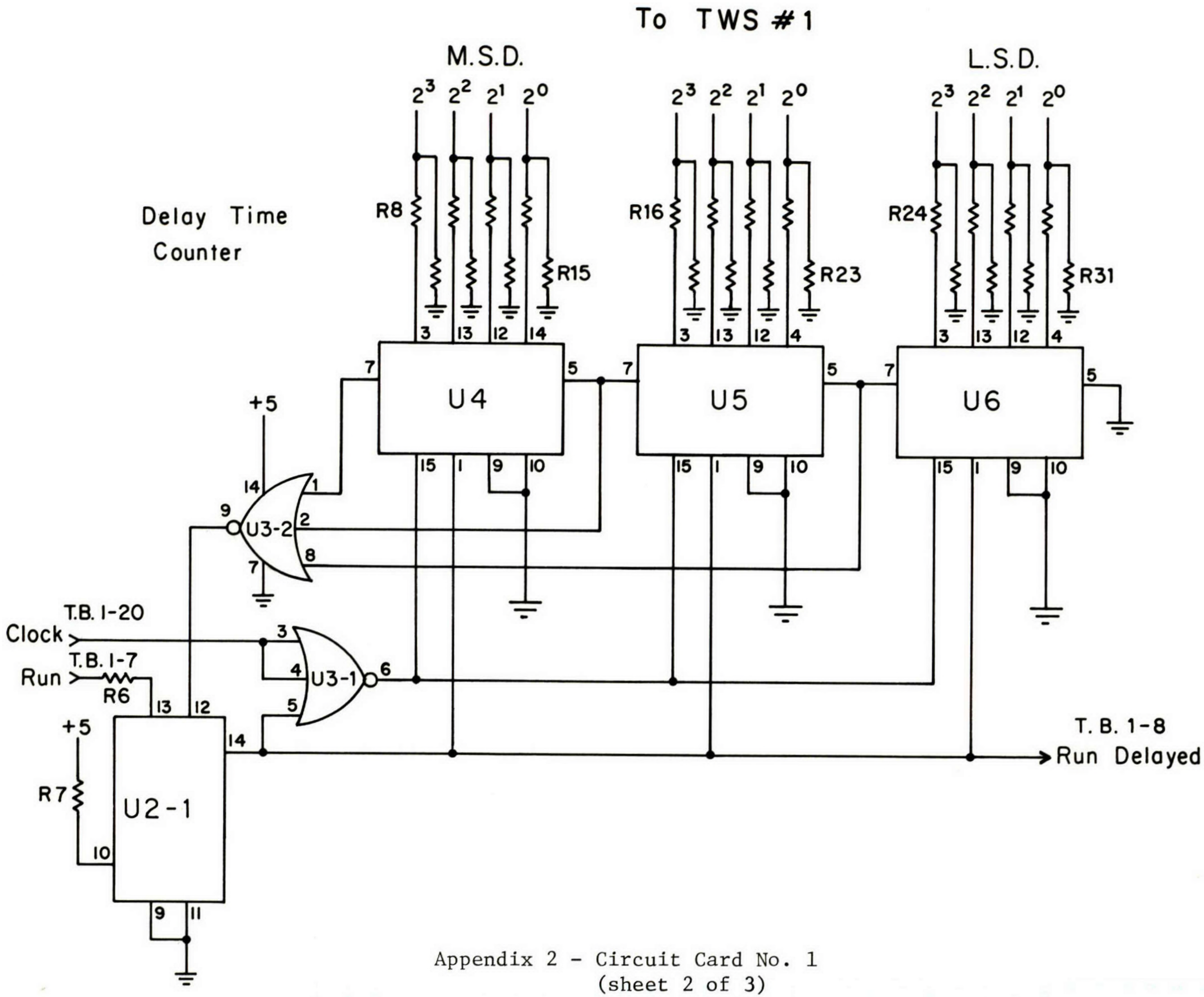


Appendix 1 - Front Panel Wiring

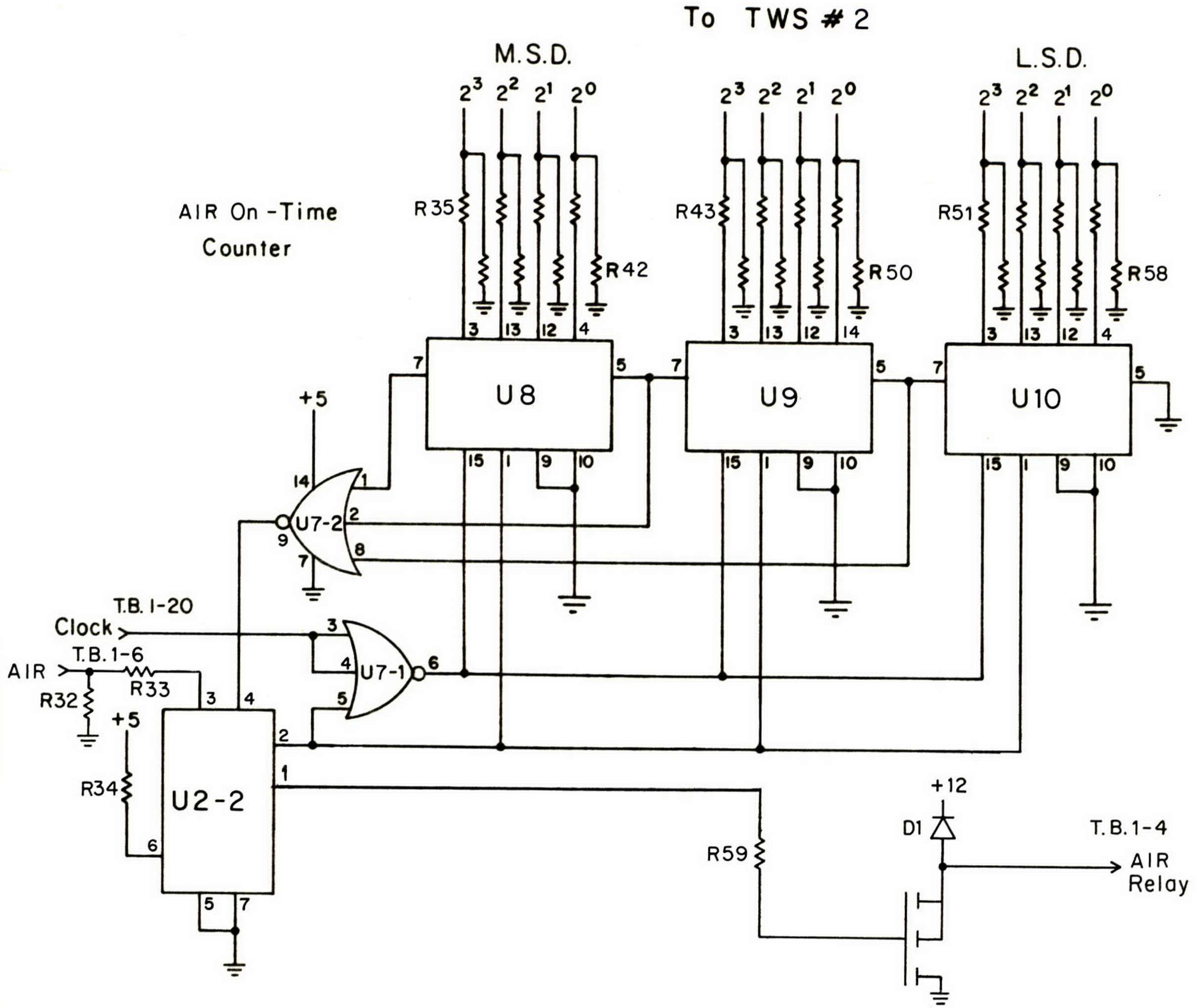


Note: Unless otherwise stated all integrated circuits have pin 16 connected to plus 5 volts and pin 8 connected to ground

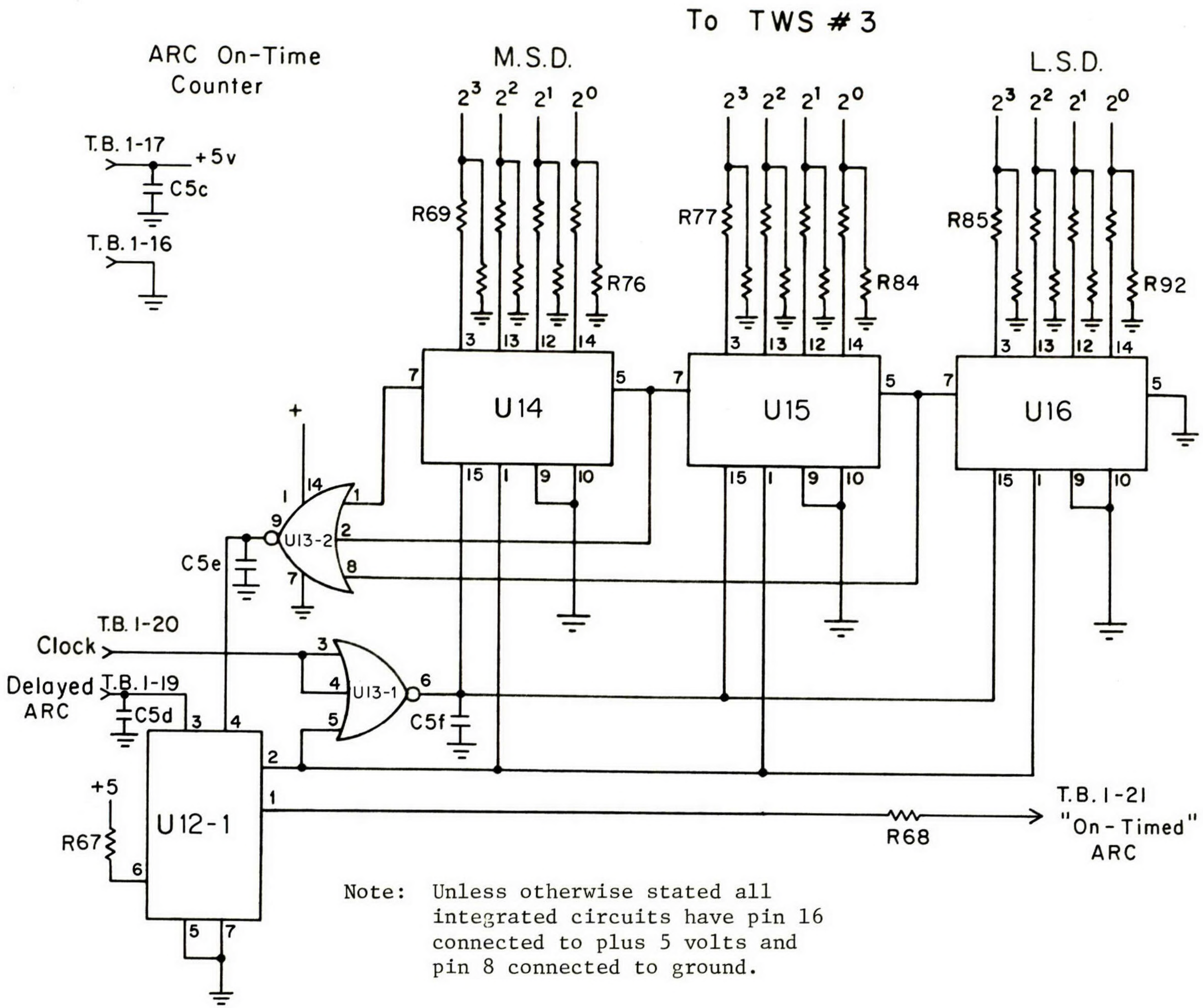
Appendix 2 - Circuit Card No. 1
(sheet 1 of 3)



Appendix 2 - Circuit Card No. 1
(sheet 2 of 3)

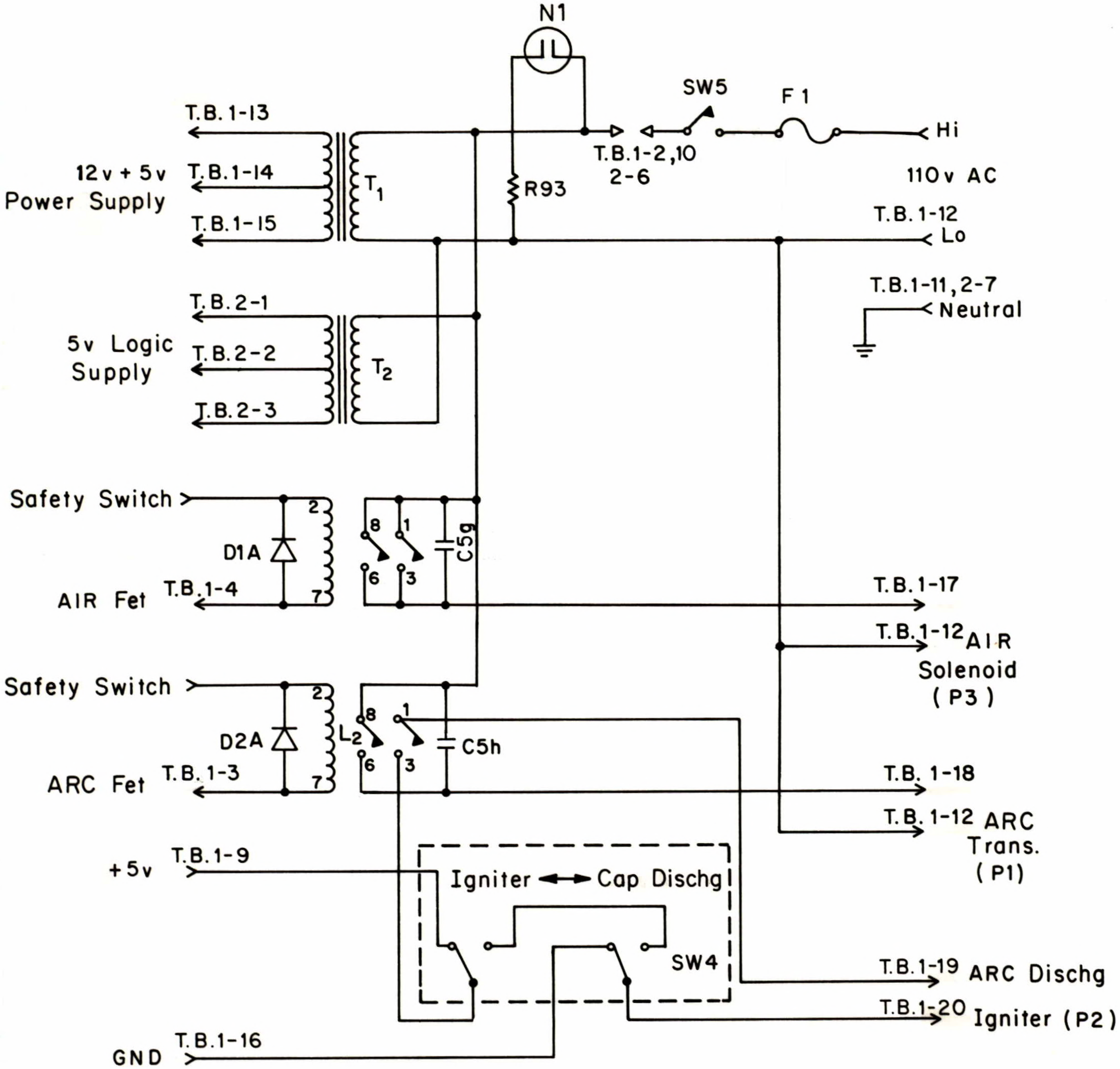


Appendix 2 - Circuit Card No. 1
(sheet 3 of 3)

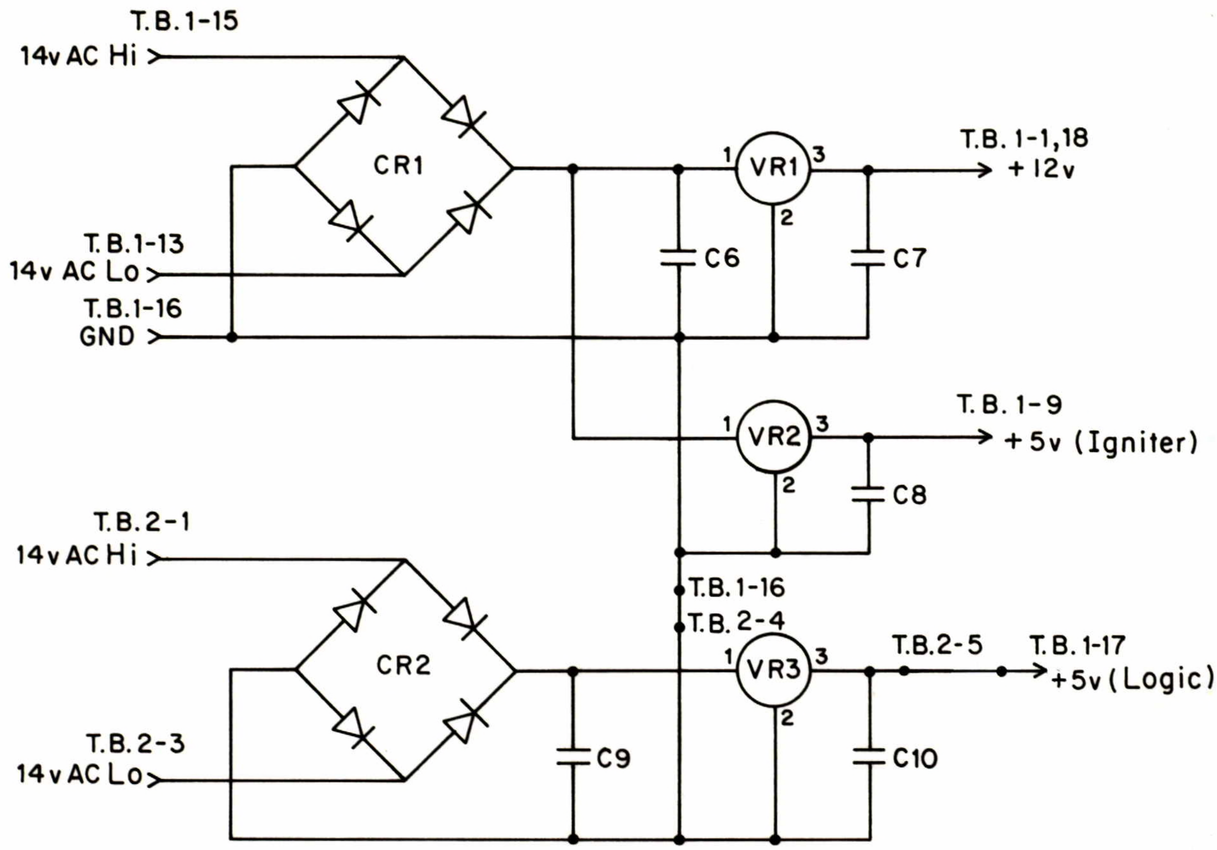


Note: Unless otherwise stated all integrated circuits have pin 16 connected to plus 5 volts and pin 8 connected to ground.

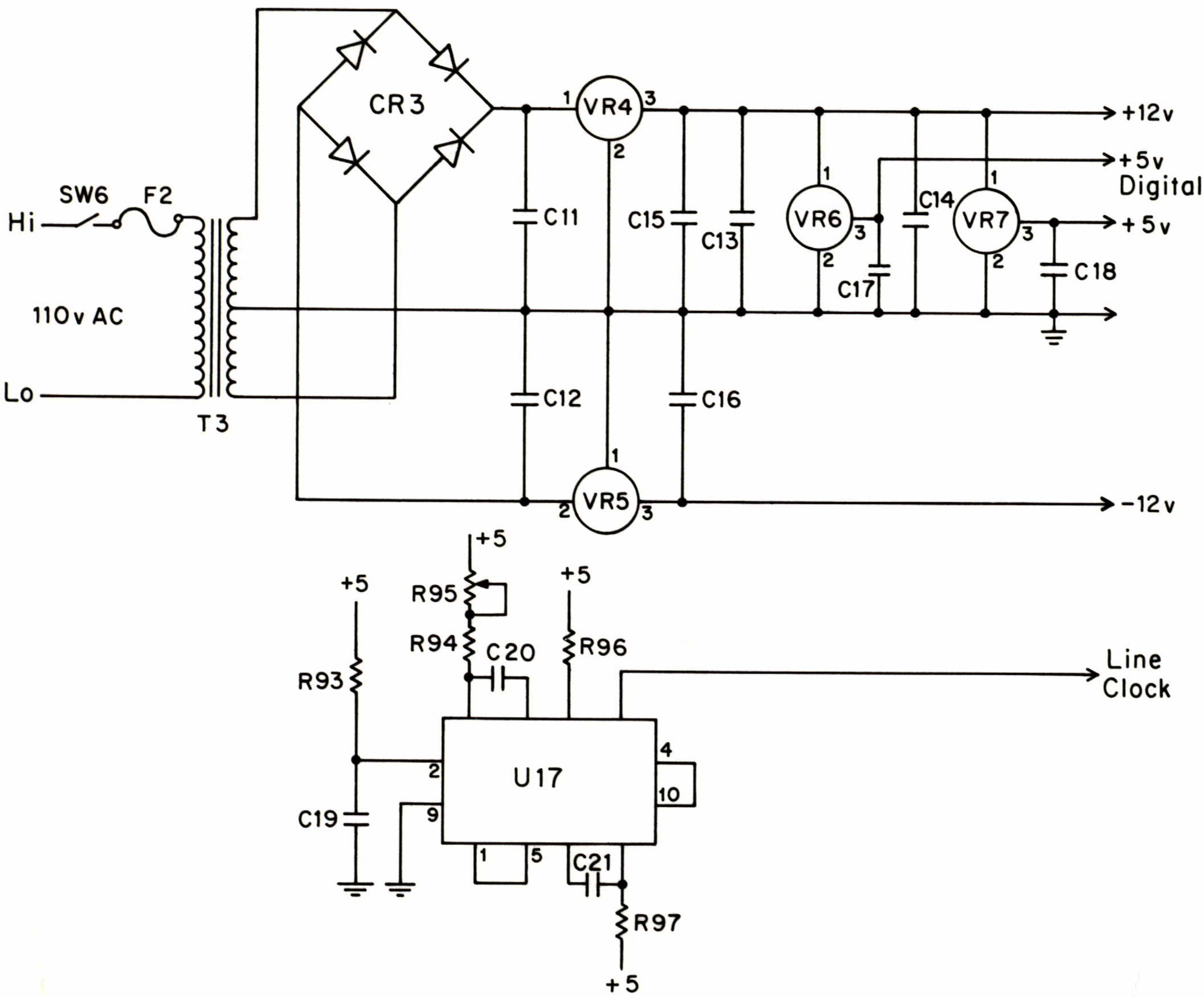
Appendix 3 - Circuit Card No. 2



Appendix 4 - Cabinet Wiring



Appendix 5 - Power Supply



Appendix 6 - Strain Gage Control Box Wiring

Parts List

Schematic/Component	Description	Part no.
A1SW1	Switch, DPDT center off	
A1SW2	Switch, joystick	
A1SW3	Switch, SP momentary	
A1TWS1-3	Switch, 3 digit decade, thumbwheel (not shown)	
A2U1	Integrated circuit, dual monostable	MM74LS221J
A2U2	Integrated circuit, dual flip flop	CD14027BCN
A2U3	Integrated circuit, dual 3-in nor	CD14025BCN
A2U4-U6	Integrated circuit, counter	CD14029BCN
A2U7	Integrated circuit, dual 3-in nor	CD14025BCN
A2U8-U10	Integrated circuit, counter	CD14029BCN
A2U11	Integrated circuit, dual monostable	MM74LS221J
A2R1-R3	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A2R4	Resistor, fixed, 5.6K ohm, +/- 10%, 1/8 W	
A2R5	Resistor, variable, 10K ohm, +/- 10%, 1/8 W	
A2R6-R58	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A2R59	Resistor, fixed, 1.0K ohm, +/- 10%, 1/8 W	
A2R60-R62	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A2R63	Resistor, fixed, 2.2K ohm, +/- 10%, 1/8 W	
A2R64	Resistor, variable, 50K ohm, +/- 10%, 1/8 W	
A2R65,R66	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A2C1	Capacitor, 3.3 uF, +/- 20%, plastic	
A2C2	Capacitor, 2 - 47 nF, +/- 10%, metal polyester	
A2C3	Capacitor, 47 nF, +/- 10%, metal polyester	
A2C4	Capacitor, 3.3 uF, +/- 20%, plastic	
A2C5	Capacitor, 1 uF, +/- 10%, metal polyester	
A2C5a	Capacitor, 100 uF, +/- 10%, tantalum	
A2C5b	Capacitor, 100 uF tantalum, 10 nF ceramic (as req.)	
A2D1,D2	Diode, 1 A, 1000 V	1N4007
A2Q1,Q2	Mosfet, N-channel, 1.8 A	VN67AF
A3U12	Integrated circuit, dual flip flop	CD14027BCN
A31U13	Integrated circuit, dual 3-in nor	CD14025BCN
A3U14-U16	Integrated circuit, counter	CD14029BCN
A3R67-R92	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A3C5c	Capacitor, 100 uF, +/- 10%, tantalum	
A3C5d	Capacitor, 150 pF, +/- 20%, metal polyester	
A3C5e	Capacitor, 180 pF, +/- 20%, metal polyester	
A3C5f	Capacitor, 56 uF, +/- 20%, metal polyester	

Parts list (continued)

Schematic/Component	Description	Part no.
A4R93	Resistor, fixed, 56K ohm, +/- 10%, 1/8 W	
A4C5g	Capacitor, 2 - 10 nF, +/- 20%, ceramic	
A4C5h	Capacitor, 10 nF, +/- 20%, ceramic	
A4D1A,D2A	Diode, 1 A, 1000 V	1N4007
A4T1	Transformer, low voltage, type C	166L14
A4T2	Transformer, low voltage, type C	166G10
A4L1,L2	Relay, octal, DPDT	MK2EP-UA-DC12
A4F1	Fuse, 1 A	
A4SW4	Switch, DPDT	
A4SW5	Switch, SPST	
A4N1	Lamp, neon	NE2J
A5C6	Capacitor, 3.3 mF, +/- 20%, electolytic	
A5C7,C8	Capacitor, 3.3 uF, +/- 20%, plastic	
A5C9	Capacitor, 3.3 mF, +/- 20%, electrolytic	
A5C10	Capacitor, 3.3 uF, +/- 20%, plastic	
A5CR1,CR2	Bridge rectifier, 6A	MBA960-2
A5VR1	Voltage regulator, 12 V, 1.5 A	LM340T12
A5VR2	Voltage regulator, 5.0 V, 1.5 A	LM340T5.0
A5VR2	Voltage regulator, 5.0 V, 1.5 A	LM340T5.0
A6U17	Integrated circuit, dual monostable	MM74LS221J
A6R93	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A6R94	Resistor, variable, 10K ohm, +/- 10%	
A6R95	Resistor, fixed, 1.5K ohm, +/- 10%, 1/8 W	
A6R96	Resistor, fixed, 10K ohm, +/- 10%, 1/8 W	
A6R97	Resistor, fixed, 8.2K ohm, +/- 10%, 1/8 W	
A6C11-C14	Capacitor, 3.3 mF, +/- 20%, electrolytic	
A6C15-C18	Capacitor, 3.3 uF, +/- 20%, ceramic	
A6C19	Capacitor, 3.3 mF, +/- 15%, plastic	
A6C20	Capacitor, 10 nF, +/- 10%, plastic	
A6C21	Capacitor, 1.0 uF, +/- 20%, ceramic	
A6CR3	Bridge rectifier, 6A	MBA960-2
A6VR4	Voltage regulator, 12 V, 1.5 A	LM340T12
A6VR5	Voltage regulator, -12 V, 1.5 A	MC7912CT
A6VR6,VR7	Voltage regulator, 5 V, 1.5 A	LM340T5.0
A6T3	Transformer, low voltage,	
A6F2	Fuse, 1A	
A6SW6	Switch, SPST	