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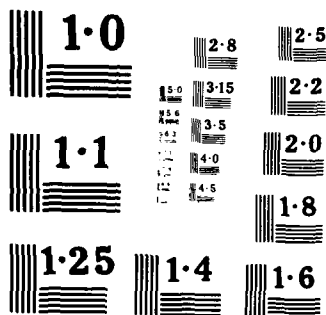   N62269-83-C-0250

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Modification P00004

NO. 5814498

BASIC ISSUE DATE 3 June, 1986

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=≡♦Lockheed *Advanced Marine Systems*
SAN DIEGO

ADVANCED LINE CONTACTOR

FINAL REPORT

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

A breadboard and two prototype Advanced Line Contactors (Hybrid mechanical contactor and transistor switch) have been fabricated and successfully tested. These units are able to turn-on, carry, and turn-off continuous load currents between zero and 400 Adc at 270 Vdc. For non-continuous overload currents of 600 Adc, they are able to turn-on and turn-off three times in two minutes.

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SUMMARY

1. A breadboard and two prototype Advanced Line Contactors (ALCs) have been fabricated and successfully tested to contract requirements.

2. The ALCs are able to turn-on, carry, and turn-off continuous load currents between zero and 400 Adc.

3. The ALCs are able to turn-on and turn-off (three times in two minutes) non-continuous overload currents of 600 Adc.

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I.   INTRODUCTION.

The Advanced Line Contactor (ALC) Functionally Equivalent
Prototype (FEP) is designed to switch on, carry, and switch off a
load current of 400 Adc in a 270 +/- 5 Vdc circuit. In an
overload condition, the ALCFEP is capable of switching on and off
a load current of 600 Adc. The ultimate application for the ALC
is in a 270 Vdc aircraft electrical distribution system.

The ALCFEP is a hybrid contactor that consists of an
electromagnetic relay (a mechanical contactor) connected in
parallel with a transistor power switch.

The transistor power switch initiates and terminates the ALC load
current, while the electromagnetic relay (EMR) maintains a low
contact voltage drop during the period between load current
initiation and load current termination.

This system is designed to take full advantage of the superior
switching ability of the power transistor and the exceedingly low
contact voltage drop of the electromagnetic relay. This provides
efficient, arcless, and bounceless high power switching action.

A photograph of the ALCFEP is shown in Figure 1. The outside
dimensions of the unit is 8.2 inches high, 8.1 inches wide, and
7.5 inches deep. The outside volume is 498.2 cubic inches and
the weight is 22 pounds. The bottom plate of the ALC is mounted
to the air frame structure by four 5/16 inch bolts.

Figure 1 shows the high current terminals A1, A2, and G and the
low current multi-pin connector J4. As shown in the connection
diagram in Figure 2, the 270 +/- 5 Vdc input voltage (or LINE) is
connected between terminals A1 (+) and G (-); and the output load
is connected between terminals A2 (+) and G.

The control signal input is a zero to 10 +/- 1 mAdc current
command and is connected to pins R1(+) and R2(-); J4-3 and J4-4
of connector J4, respectively. When the input control signal is
above 9 +/- 0.9 mAdc, the internal circuitry permits load current
to flow between terminals A1 and A2.

When the input control signal is below 1.0 +/- 0.1 mAdc, the
internal circuitry will not permit load current to flow between
terminals A1 and A2 .

In the event that the circuity between terminals A1 and A2
becomes degraded, a 28 Vdc (at 40 mAdc, maximum) failure signal
output will be generated. The presence of the failure signal
indicates that either the internal leakage current between
terminals A1 and A2 has reached 2 mAdc or that contacts in the
electromagnetic relay have been welded together. The purpose of

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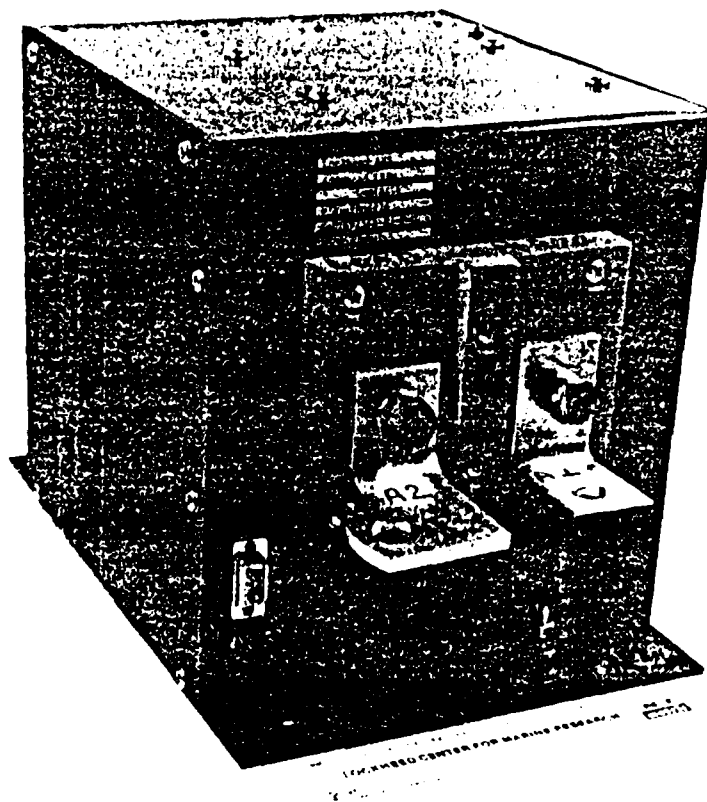
Figure 1.   Photograph of Advanced Line Contactor

2

DC INPUT
VOLTAGE
270 ± 5VDC
AT
0 TO 400 ADC
(600 ADC
OVERLOAD)

DC OUTPUT
VOLTAGE
AT
0 TO 400 ADC
(600 ADC
OVERLOAD)

LOAD

ADVANCED
LINE
CONTACTOR

P4 J4

RI 3
R2 4
MI 1
M2 2

CONTROL SIGNAL INPUT
0 TO 10 ± 1 MADC

FAILURE SIGNAL OUTPUT
28 VDC AT 40 MADC MAX.
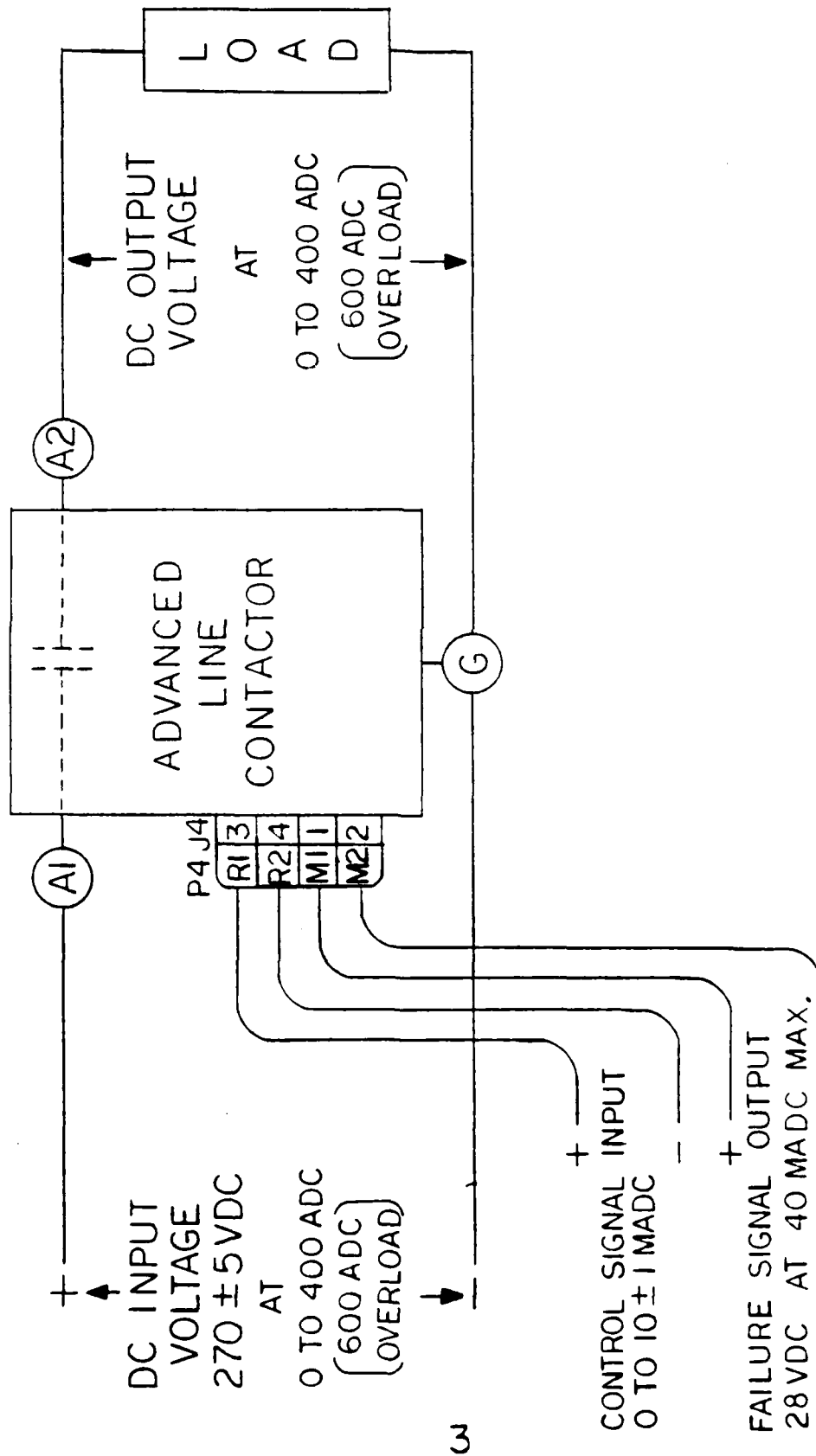
FIGURE 2.   CONNECTION DIAGRAM OF ADVANCED LINE CONTACTOR.

the failure signal is to warn service personnel to refrain from
coming into contact with the supposedly de-energized output of
the ALC.

Figure 3 shows the transient characteristic of the 270 Vdc input
source voltage. It indicates that:

    (1)   the steady-state voltage varies:

        (a) +/- 5 Vdc for rated load (400 Adc) and

        (b) +/- 10 Vdc for 125% rated load (500 Adc);

    (2)   the maximum transient voltage due to load or fault
        removal is:

        (a) 350 Vdc and

        (b) has a maximum duration of 33 milliseconds; and

    (3)   the minimum transient voltage due to load application
        is:

        (a) 200 Vdc for rated load (400 Adc),

        (b) 175 Vdc for 125% rated load (500 Adc), and

        (c) has a maximum duration of 34 milliseconds.

The design of the ALC is such that proper operation is maintained
for the transient and steady-state dc input voltage variations
shown above.

Table I reviews the input/output design goals of the Advanced
Line Contactor.

<center>II. SYSTEM CONFIGURATION.</center>

The system block diagram for the Advanced Line Contactor is shown
in Figure 4. It consists of six (6) functional subsystems:

    (1) Input Suppressor,

    (2) Hybrid Contactor,

    (3) Output Suppressor,

    (4) Leakage Current Detector,

    (5) Control Logic, and

    (6) Low Voltage Power Supply.

<center>4</center>
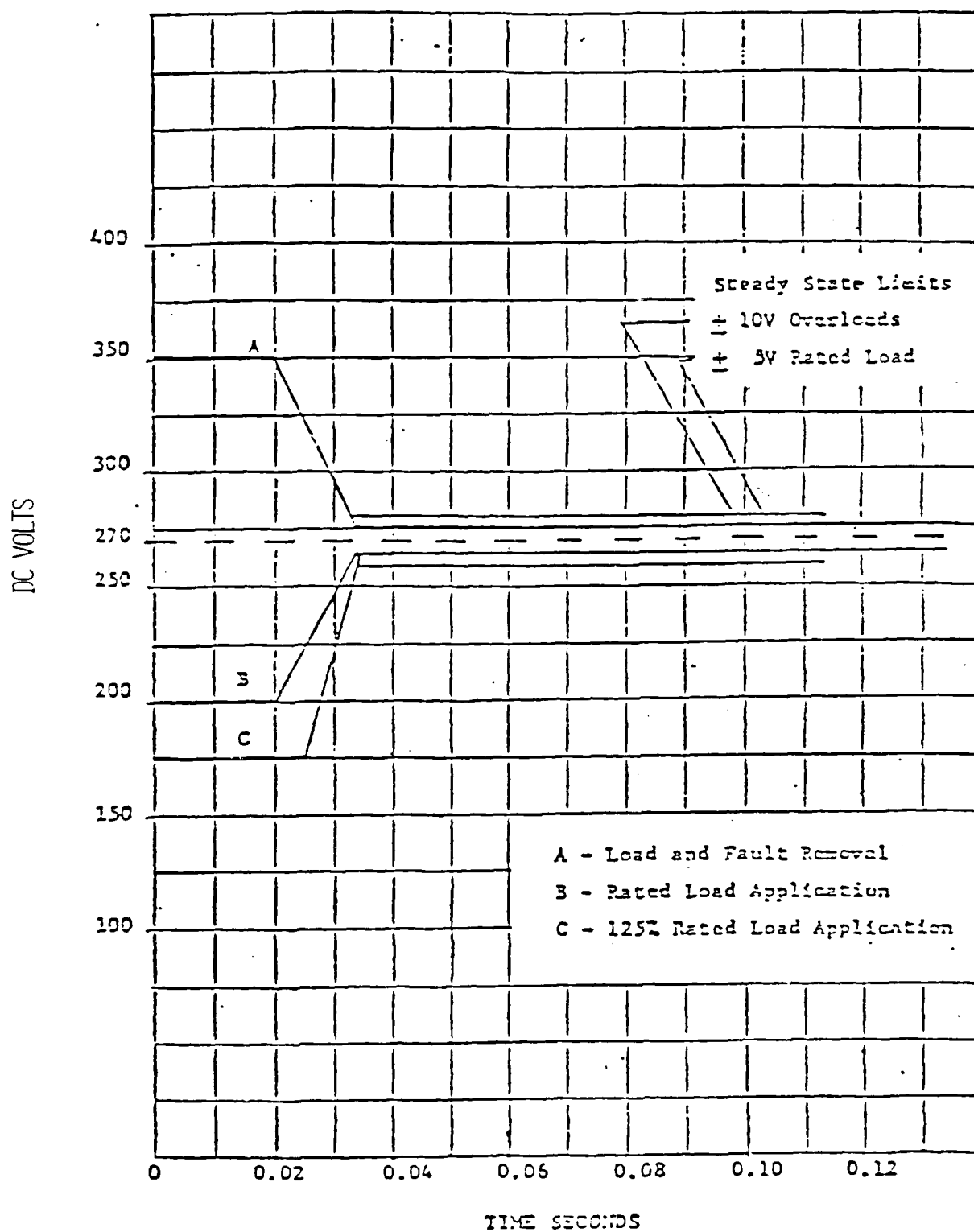
FIGURE 3. TRANSIENT CHARACTERISTIC OF 270 VDC INPUT VOLTAGE.

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TABLE I

INPUT/OUTPUT DESIGN GOALS OF ADVANCED LINE CONTACTOR

<u>INPUTS</u>:   <u>TERMINALS</u>:

DC INPUT VOLTAGE: A1 (+), G (-)
    270 +/- 5 Vdc   Steady State Rated
                 Load 400 Adc
    270 +/- 10 Vdc Steady State
                 Overload 500 Adc
    See Figure 3 for transient
       voltage specification

    0 to 400 Adc nominal

    600 Adc maximum overload

CONTROL SIGNAL INPUT: R1(+): J4-3
    0 to 10 +/- 1 mAdc into input   R2(-): J4-4
               resistance of 732
                  ohms +/- 1%
    EMR Turn-on: Above 8.1 mAdc
                 (or 6.0 Vdc)
    EMR Turn-off: Below 2.3 mAdc
                 (or 1.7 Vdc)

<u>OUTPUTS</u>:   <u>TERMINALS</u>:

DC OUTPUT VOLTAGE: A2 (+), G (-)
    270 +/- 5 Vdc - 250 mV
    Steady State Rated Load 400 Adc

    270 +/- 10 Vdc - 300 mV
    Steady State overload 600 Adc

    0 to 400 Adc normal

    600 Adc maximum overload

FAILURE SIGNAL OUTPUT: M1(+): J4-1
                                    M2(-): J4-2

    Outputs 28 Vdc at 40 mAdc Max. if:
        (1) Dc output leakage current
            is between 2 mAdc and
            4.85 Adc; and/or
        (2) Auxiliary contacts
            indicate that the
            Electromagnetic Relay
            contacts are welded closed.

6
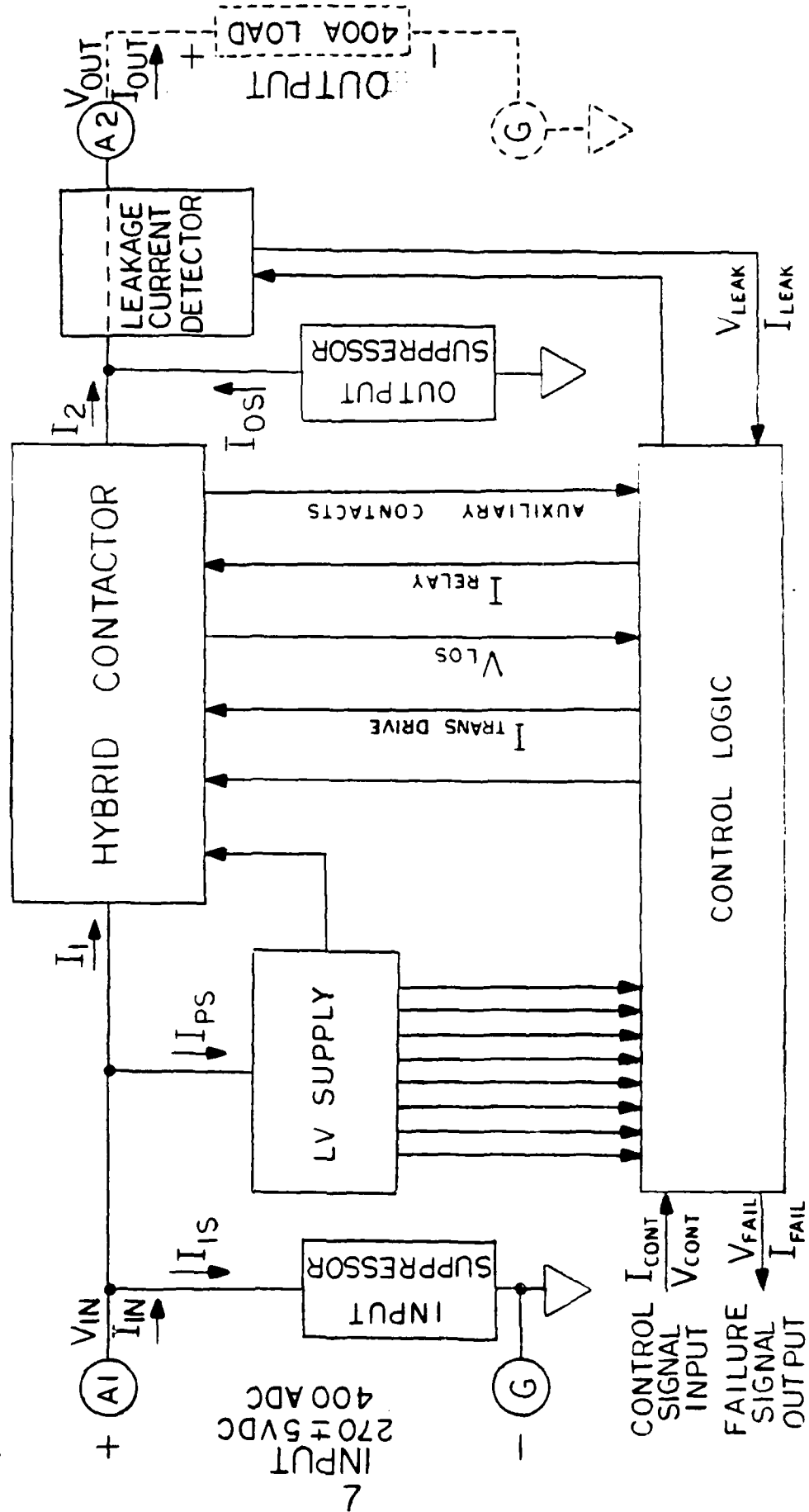
FIGURE 4. SYSTEM BLOCK DIAGRAM OF ADVANCED LINE CONTACTOR.

1. INPUT SUPPRESSOR, HYBRID CONTACTOR, AND OUTPUT SUPPRESSOR.
The input suppressor, the hybrid contactor, and the output
suppressor work together as a team. When the hybrid contactor
interrupts the load current (flowing from the dc input source to
the dc output load), the input and output suppressors provide
alternate current paths that permit an orderly release of the
stored energy associated with the input and output circuit
inductances. Interrupting the load current (in an inductive
circuit) without the use of the input and/or output suppressors
exposes the hybrid contactor to a very large voltage transient.
In a mechanical contactor, this voltage transient causes the
contacts to arc upon opening.

2. LEAKAGE CURRENT DETECTOR. The leakage current detector
monitors the ALC output load current. This sensor is to detect a
leakage current of 2 mAdc when the ALC is in the off or open
condition. The sensor output is fed into the control logic which
generates a failure signal output. The purpose of this scheme is
to inform service personnel that a potential lethal electric
shock hazard may exist on the ALC output terminal A2.

3. CONTROL LOGIC. The control logic provides the necessary
functions to control the hybrid contactor in response to the
control input signal. These functions include the generation of
the transistor power switch base drive current and the voltage
and current required for the relay coil driver. The control
logic also provides a failure signal output in the event that:

     (1) the ALC output leakage current reaches 2 mAdc, or

     (2) a welded contact condition exists in the hybrid
         contactor.

4. LOW VOLTAGE POWER SUPPLY. The low voltage power supply
converts the 270 Vdc (nominal) input voltage into various dc low
voltages that are divided into isolated groups. These isolated
voltages are used by the hybrid contactor, the leakage current
detector, and the control logic.

                III.   INTERNAL FUNCTIONS OF SUBSYSTEMS.

1. INPUT SUPPRESSOR CIRCUIT. The circuit, as shown in Figure 5,
consists of the two International Rectifier power zener diodes
connected in parallel across the 270 Vdc dc input voltage. Each
zener diode consists of four zener junctions connected in series.
The clamping voltage of the input suppressor is below 500 Vdc
(which is to protect the switching transistors in the transistor
power switch) and above 350 Vdc (which is the maximum specified
transient or spike voltage from the dc input source). The
clamping voltage, and the allowable suppressor dissipation, is a
function of its junction temperature, and thus is a function of
the dc input source inductance. In a paper design, it was

                                8

Figure 5. Dc Input Suppressor Schematic Diagram.

estimated that the maximum permissible input inductance for the
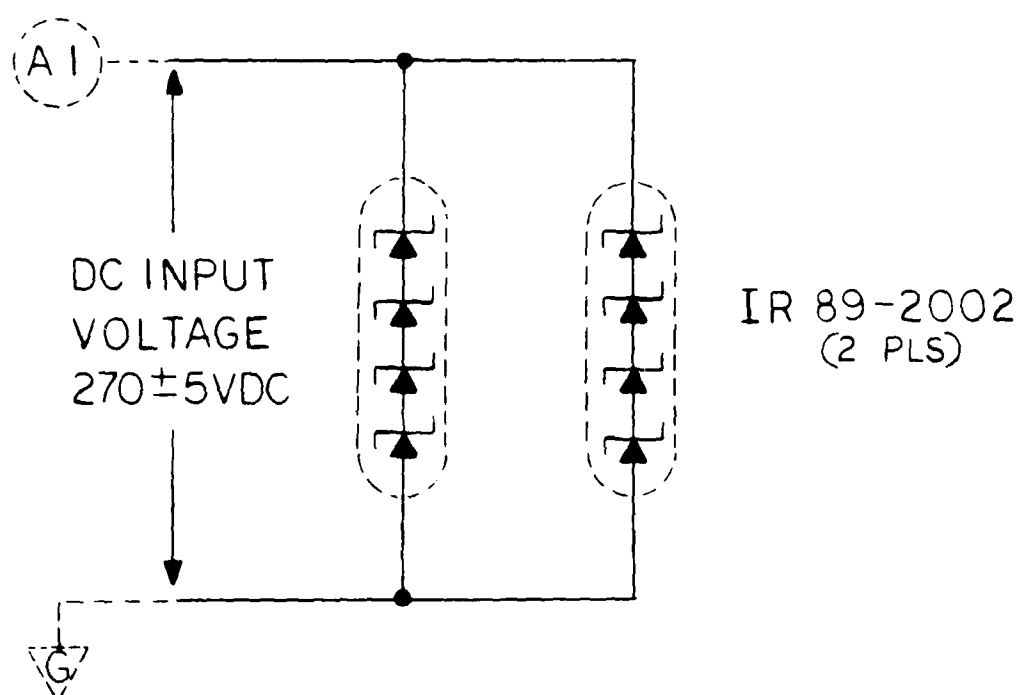dc source is 1.5 mH. This has not been confirmed in laboratory
testing.

2. HYBRID CONTACTOR. The hybrid contactor is essentially a
transistor power switch connected in parallel with an
electromagnetic relay. A functional block diagram of the hybrid
contactor is shown in Figure 6. The transistor switch energizes
the load circuit before the contacts of the electromagnetic relay
close. Similarly, the transistor switch de-energizes the load
circuit after the contacts of the electromagnetic relay open. In
this manner, the relay contacts are never required to open or
close load current (thereby reducing contact arcing to a
minimum); the contacts are only required to carry the steady-
state current (and take advantage of the low contact voltage drop
of the electromagnetic relay). (The relay coil drive shown in
Figure 6 will be discussed below.) The rated load current is 400
Adc, with a 600 Adc overload capability.

     a. Transistor Power Switch. The transistor power switch,
shown in Figure 7, is made up of 112 Solitron 500 volt, 10 amp
transistor chips connected in parallel. There are 56 transistor
packages, and each package contains two transistor chips. Each
transistor is fused in such a manner that proper operation will
be maintained in the event of a transistor failure. For the 600
amp overload condition, 43 transistor packages are required (7
amps per chip) for satisfactory operation, thus 13 transistor
packages could fail with no degradation in operation.

For the transistor power switch to operate properly, it is
important to reduce the storage time of the individual paralleled
transistors to a minimum, such that the transistors turn-off
together. This is accomplished by using:

     (1) A modified Baker clamp circuit that limits the base
          drive current to the transistor power switch such that
          the paralleled transistors are not fully saturated; and

     (2) an active transistor power switch base-emitter carrier
          sweep-out circuit.

A resistor-capacitor "snubber" circuit is connected across the
collector-emitter of the transistor power switch to absorb any
remaining voltage spike that the input and output suppressors
missed during the switching period.

     b. Electromagnetic Relay. The electromagnetic relay was a
laboratory prototype developed by Hartman Electric Manufacturing
exclusively for the ALC application. An outline drawing of the
Hartman electromagnetic relay is shown in Figure 8. It is rated
to carry 400 Adc with a maximum contact drop of 175 mV. It has
an overload rating of 600 Adc. This relay features double break
contacts, low contact transfer time, a magnetic arc blow-out
scheme, and an economizer coil system. (The mechanical
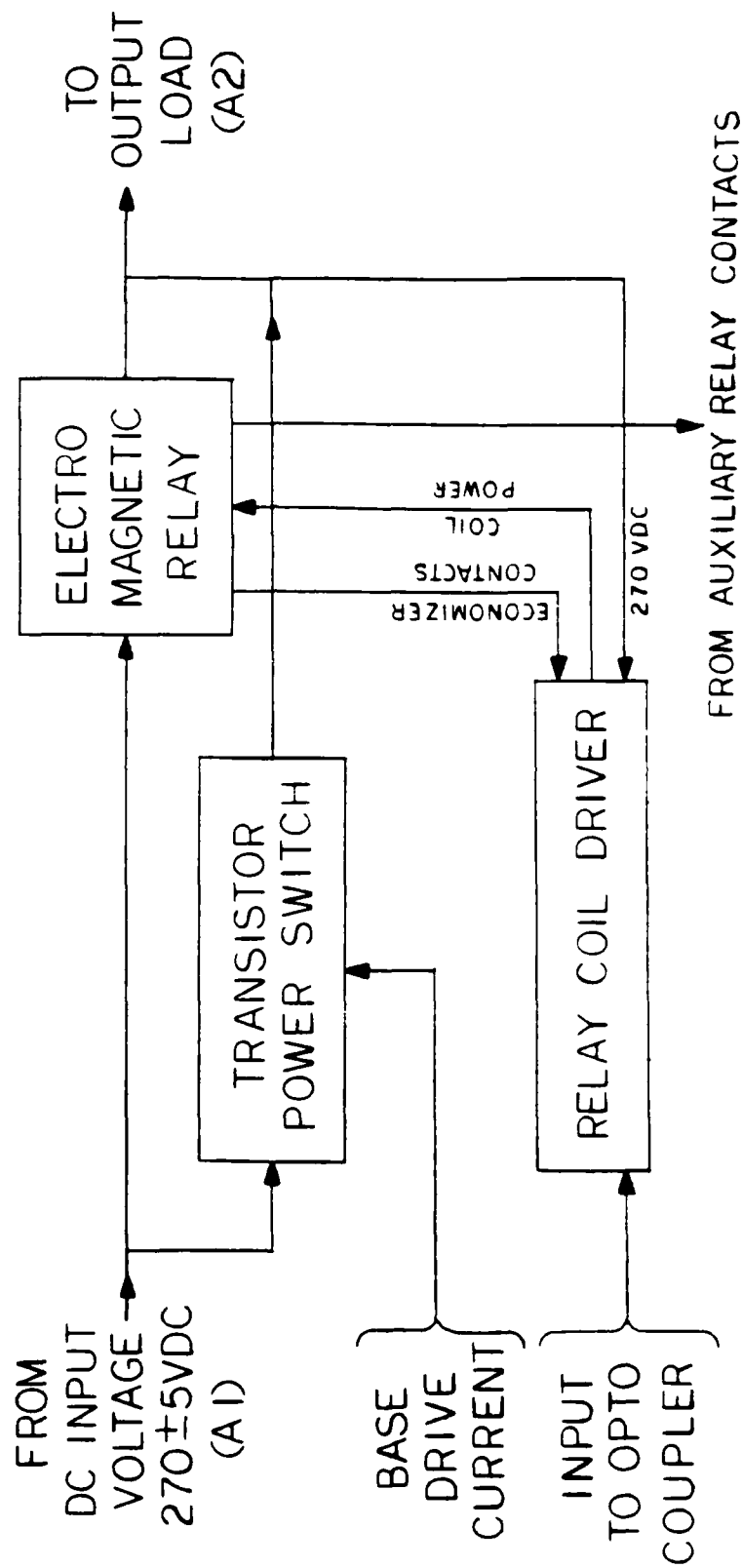
FIGURE 6. FUNCTIONAL BLOCK DIAGRAM OF HYBRID CONTACTOR.
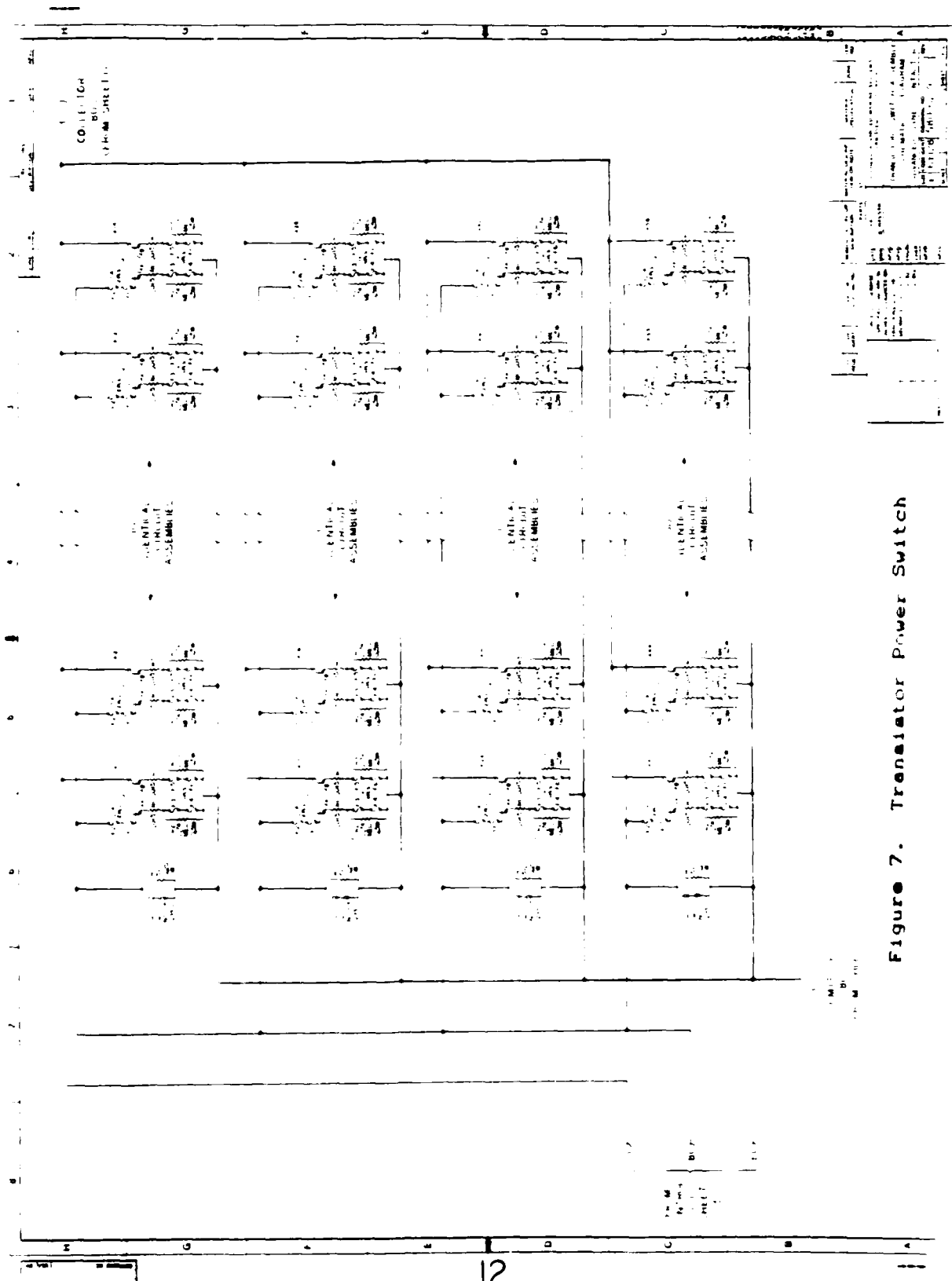
Figure 7. Transistor Power Switch

Figure 8.   Outline Drawing of Hartman Electromagnetic Relay

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economizer coil switch was replaced with a transistor switch to
improve reliability.)

A pivoted lever mechanism was developed that increased the
contact transfer velocity, such that the operate time of the
relay is approximately 20 to 30 milliseconds. The design goal
was 50 milliseconds.

In the normal ALC steady-state on condition, the relay contacts
carry the load current. To interrupt load current, the following
sequence takes place:

      (1) In the first few microseconds, when the relay contacts
           initiate opening, load current is transferred from the
           relay contacts to the transistor switch;

      (2) the transistor switch continues to carry the load
           current until the relay contacts complete their travel
           (20 to 50 milliseconds later); and

      (3) the transistor power switch is then turned off.

The relay has a magnetic arc blow-out function that will ensure
that the load current is efficiently interrupted, in the event of
a failure in the power transistor switching action. (Note: this
blow-out function is not required during normal ALC operation.)

The magnetic arc blow-out consists of a magnetic field being
applied to the electric arc between the opening contacts in such
a manner as to elongate the arc. This elongation has two effects
which ultimately cause the arc to extinguish. These effects are

      (1) the arc is cooled since the arc cooling mechanism is
           improved by the increase in surface area, and

      (2) the voltage to maintain the arc is increased by the
           increase in arc length.

The magnetic field is produced by a set of permanent magnets that
are in proximity to the contacts.

The economizer coil system consists of two coils connected in
series as shown in Figure 9. Coil #1 has a small number of turns
of large diameter wire (low dc resistance) and coil #2 has a
large number of turns of small diameter wire (high dc
resistance). Coil #1 is designed for only momentary (50 to 100
milliseconds maximum, e.g.) application of 270 Vdc; while coil #2
is designed for continuous application of 270 Vdc.

The 270 Vdc input voltage is initially applied to coil #1 which
will produce a large magnetic field that is proportional to the
ampere-turns of coil #1. This magnetic field causes a large
accelerating force to be applied to the relay armature, which
ultimately results in a rapid contact transfer. When the contact
transfer is complete, the 270 Vdc input voltage is applied to the
two coils connected in series. The resulting ampere-turns is
only a fraction of the initial ampere-turns, but it is more than
enough to produce the proper magnetic force to hold the contacts
closed.

When the dc input voltage is applied to coil #1, the steady-state
current is approximately 2 Adc; when it is applied to the series
combination, the steady-state current is approximately 55 mAdc.

The relay coils can not be energized until the transistor power
switch is turned-on, which is a safe guard in the event that the
transistor power switch fails to turn on. The upper junction of
coil #1 is connected to the output terminal of the ALC, A2.

A low current 2 Adc transistor switch (Q20) is connected to the
junctions between coil #1 and coil #2 and the 270 Vdc return.
When this transistor switch is turned-on, coil #1 is energized.

A second low current transistor switch (Q22) is connected between
the lower end of coil #2 and the 270 Vdc return. When this
transistor switch is turned-on, and transistor switch Q20 is
turned-off, coil #2 is energized. (Due to the low resistance of
coil #1 and the high resistance of coil #2, most of the 270 Vdc
is dropped across coil #2.)

To close the relay contacts, both transistor switches (Q20 and
Q22) are initially turned on (which only energizes coil #1).
Transistor switch Q20 will be turned-off when the normally closed
auxiliary contacts of the relay open. Coil #2 will then hold, or
seal-in, the main contacts of the relay.

When the relay coils are turned off by transistor switch Q22, the
stored energy of the relay coils is dissipated by the dc
resistance of the coils and the forward voltage drop across the
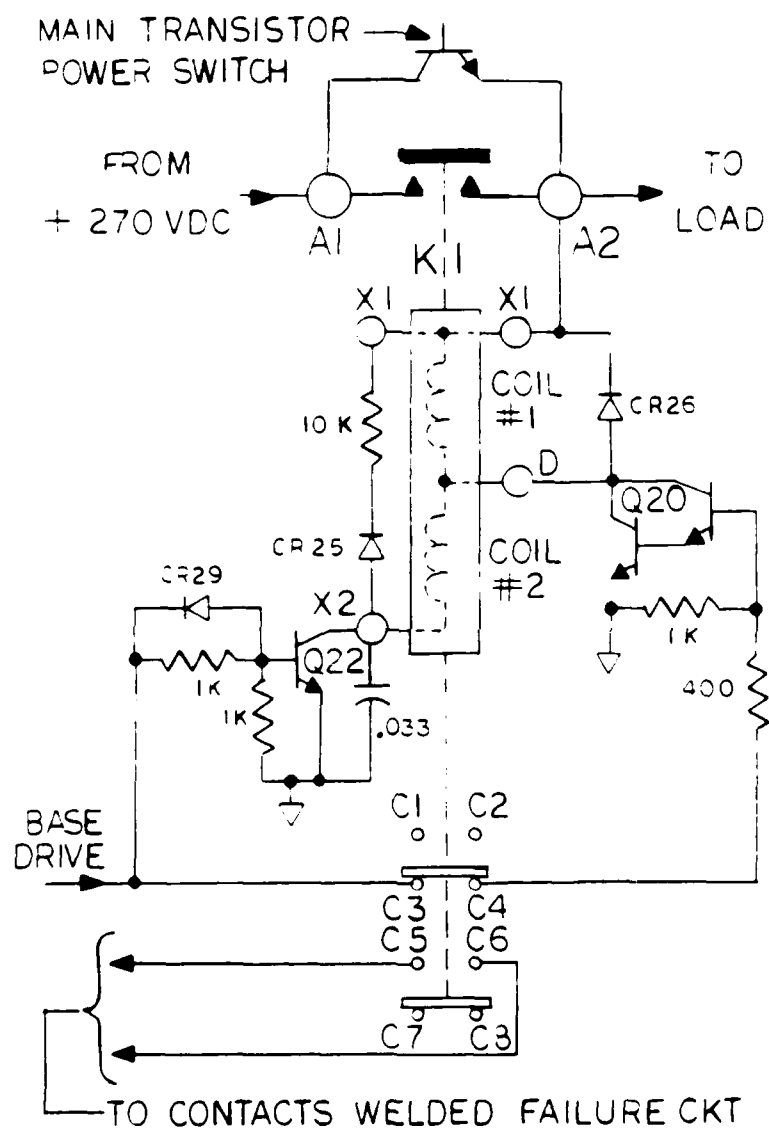free wheeling diodes.

Figure 9.   Relay Economizer Coil Switching System

3. OUTPUT SUPPRESSOR CIRCUIT. The circuit, shown in Figure 10,
consists of four fast recovery diodes connected in parallel
across the output load circuit of the ALC. When the transistor
power switch interrupts the flow of current from the dc input
source (terminal A1) to the output load (terminal A2), the
release of the stored energy in the output circuit inductance
tends to maintain a current flow through the load. With the
output suppressor in place, this current free-wheels or
circulates through the load and the diodes of the output
suppressor, and will eventually decay to zero. The allowable
dissipation is a function of the total output load inductance.
In a paper design it was estimated to be a maximum of 1.2 mH.
This has not been confirmed in laboratory testing.

4. LEAKAGE CURRENT DETECTOR. The leakage current detector
monitors the dc load current from the ALC output without any
electrical connection. It thus provides electrical isolation
between its input and output circuits. This is a proprietary
item and is purchased from American Aerospace Controls, Inc. An
outline drawing and data sheet are shown in Figure 11. It is
designed to sense current over the range of 0.2 to 5 mAdc with an
accuracy of +/- 4% over a temperature range of +/- 75 degrees C.
It has a linear output of 1 Vdc/mAdc to 8 mAdc. The maximum
output voltage is 10 Vdc and is obtained from 10 mAdc to 4.25
Adc. Above 4.25 Adc the sensor output drops to zero. The
detector is rated to withstand 1000 Adc steady-state with no
damage. (It is limited to a current-time rate of change of 50 A
per microsecond and a voltage-time rate of change of 50 V per
microsecond. If these limits are exceeded, the sensor may
"lockup" and fail to give an output. The sensor can be reset by
cycling on and off the + 28 Vdc supply. Because of the
difficulty of generating these current- and voltage-rates of
change in the laboratory no tests have been conducted to observe
this "lockup" problem. In the normal laboratory testing that has
been done, no "lockup" problem was noted.)

5. CONTROL LOGIC. The functional block diagram of the control
logic is shown in Figure 12. The primary function of the control
logic is to properly turn-on and turn-off the hybrid contactor in
response to the control signal input.

The turn-on sequence for the hybrid contactor is to:

        (1)   turn-on transistor power switch;

        (2)   energize electromagnetic relay coil;

        (3)   close contacts of electromagnetic relay;

        (4)   transfer load current from transistor power switch to
              contacts of electromagnetic relay; and

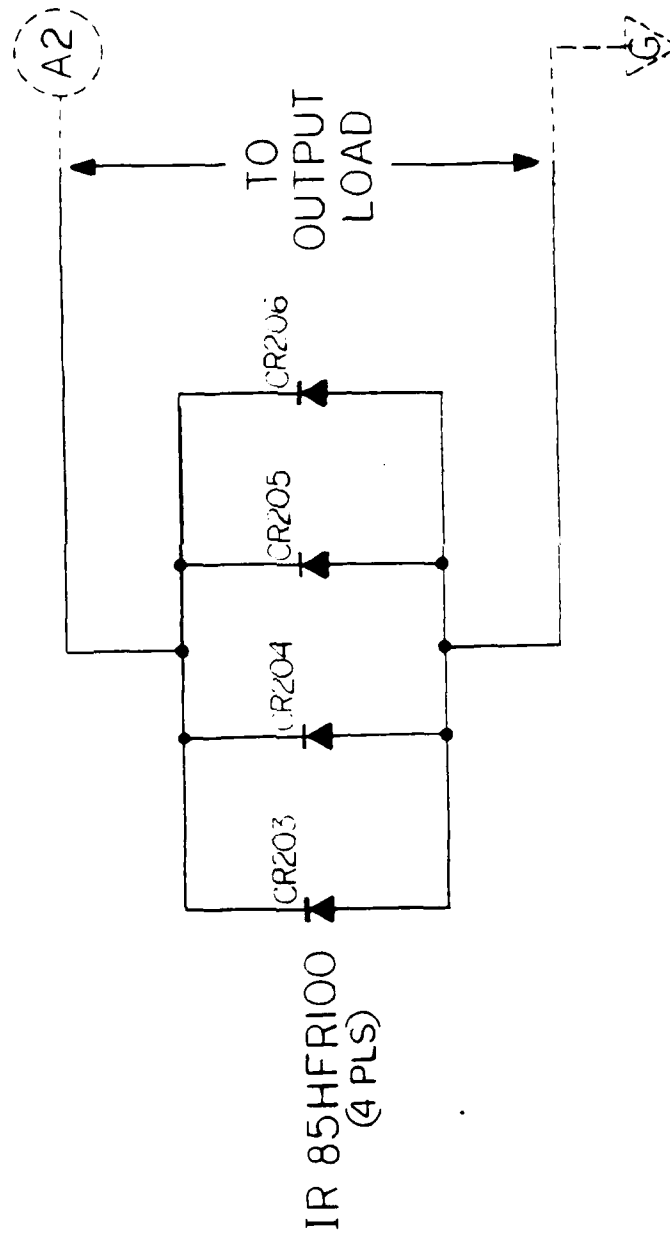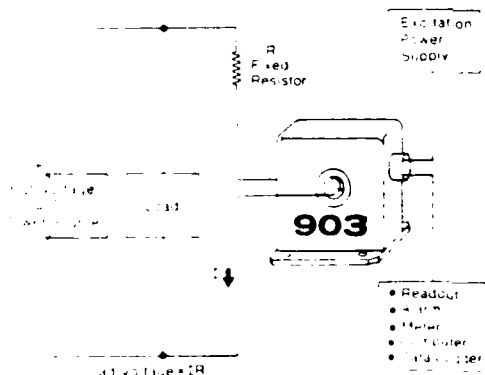   (5)   remove power transistor base drive (Baker Clamp).

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FIGURE 10. OUTPUT SUPPRESSOR SCHEMATIC DIAGRAM.

DESCRIPTION

Series 903 Sensors are used for the measurement control or detection of low levels of D.C. current. The sensing of D.C. current flow is accomplished without breaking into or electrically connecting to the D.C. current conductor. This is particularly important for many measurement applications including those that require non-intrusive measurement for system safety when used on high voltage lines.

The 903 Series utilizes a saturable toroidal core to sense the magnetic flux associated with the current flow. A proven detection and signal conditioning circuit produces an extremely stable, accurate and repeatable output signal over a wide ambient temperature range.

In normal operation the current carrying cable is passed through an insulated tube in the sensor. The sensor requires a +28V D.C. excitation voltage to power the detection and signal conditioning circuits. Models are available covering D.C. input current ranges of 0 to 5 milliamps to 0 to 5 amps. Two grades are available for military and industrial applications. The sensor can withstand steady state overloads up to 1000 amps.

for measurement & control applications

FEATURES

Complete Electrical Isolation

Zero Insertion Loss

Linear D.C. Output Signal

High Accuracy & Stability

Application Functional Schematic
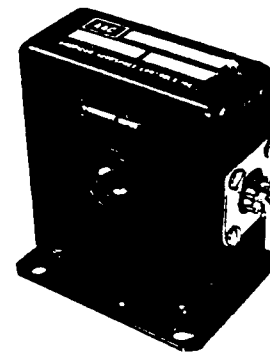
High Overload Capability

Reverse Polarity Protection

Short Circuit Protection

Rugged Construction

Fully Encapsulated

APPLICATIONS

The 903 Series Current Sensors while used extensively for low amperage D.C. current measurements also meet application needs for high voltage readings on lines that can not safely or conveniently be contacted with voltage leads. This type of measurement is accomplished with a non contact D.C. current sensor by measuring the current flow through a fixed resistor of known value. The multiplication of the current flow by the fixed ohmic resistance represents the non-intrusive voltage measurement.

The 903 type sensors are also suitable for use in process control and power control applications, current ground leakage detection on communication equipment, detection of relay coil actuation current and other switch gear parameters and measurement of fuel cell and battery current flow.

Unlike shunts there is no power dissipation or insertion loss associated with the 903 sensors whose output signal is moreover, compatable with computer or data logger equipment.

American Aerospace Controls, Inc.

AAC

570 SMITH STREET, FARMINGDALE, NEW YORK
(516) 694-5100

Figure 11-A.   Outline Drawing of Leakage Current Detector

SPECIFICATIONS

INPUT CURRENT RANGES	MILLIAMPS	AMPS
	0-5	0-1
	0-10	0-2
	0-20	0-5
	0-50	
	0-100	
	0-200	
	0-500	

*OUTPUT SIGNAL	0 TO 5 VOLTS D.C.
OUTPUT IMPEDANCE	1000 OHMS (5MA TO 1A RANGE)
	500 OHMS (2 AMP RANGE)
	200 OHMS (5 AMP RANGE)
OUTPUT RIPPLE	2% F.S. RMS MAX.

*THE 903 MAY BE OBTAINED WITH A CURRENT LEVEL OUTPUT OF
0 TO 5mA WITH A COMPLIANCE VOLTAGE OF 5 VOLTS.

EXCITATION VOLTAGE	+28 VOLTS D.C. ±4 VOLTS D.C.
	20 MA TO 50 MA DRAIN

PERFORMANCE SPECS	GRADE		
	B MIL	C IND	
ACCURACY	±1	±2	% FS
TEMP. COEF	±.04	±.10	%FS/°C
TEMP. RANGE	−55 +85	−20 +70	°C
RESPONSE	50	50	MILLISEC

OVER CURRENT	1000 AMPS STEADY STATE MAX. (NO DAMAGE)
ALLOWABLE di/dt	50 AMPS PER MICRO SEC. MAX.
INPUT CABLE VOLTAGE	10 KV MAX. (INSULATED LINE)
ALLOWABLE dv/dt	50 VOLTS PER MICRO SEC. MAX.
WEIGHT	12 OZ. TYPICAL

HOW TO ORDER

MODEL NO. [903] [B] [100] [ ]

TYPE ————

GRADE ————

CURRENT RANGE MILLIAMPS ————
INDICATE "A" AFTER CURRENT RANGE IN AMPS.

TERMINATION TYPE ————
HEADER — BLANK (NO DESIGNATION)
CONNECTOR — C

Example above shows model number for grade B sensor, 100 milliamps range with solder type terminals.

The sensor is normally supplied with a 6 pin solder type header. If a connector type terminal is required indicate the letter "C" at the end of the model number. The connector is a Bendix type PT02E-10-6P or equivalent. The mating receptacle PT06A-10-6S(SR) is not supplied with the sensor but may be ordered as a separate item.

OUTLINE DIMENSIONS
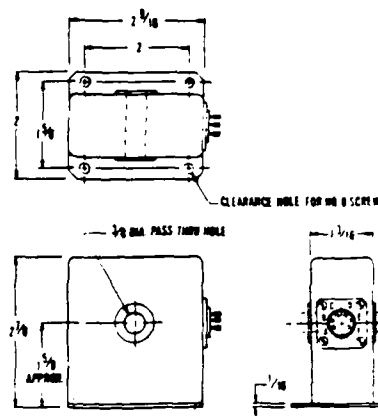
TERMINAL IDENTIFICATION

A. +28 Volts D.C. Excitation — D. Spare

B. Common (Excitation and — E. Spare
Signal Return)
— F. Case Ground

C. 0 to 5 VDC Output Signal
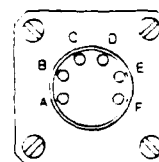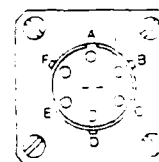
SOLDER HEADER   CONNECTOR

CHARACTERISTIC CURVE

American Aerospace Controls, Inc.

AAC

570 SMITH STREET FARMINGDALE NEW YORK
(516) 694-6100

Figure 11-B. Outline Drawing of Leakage Current Detector
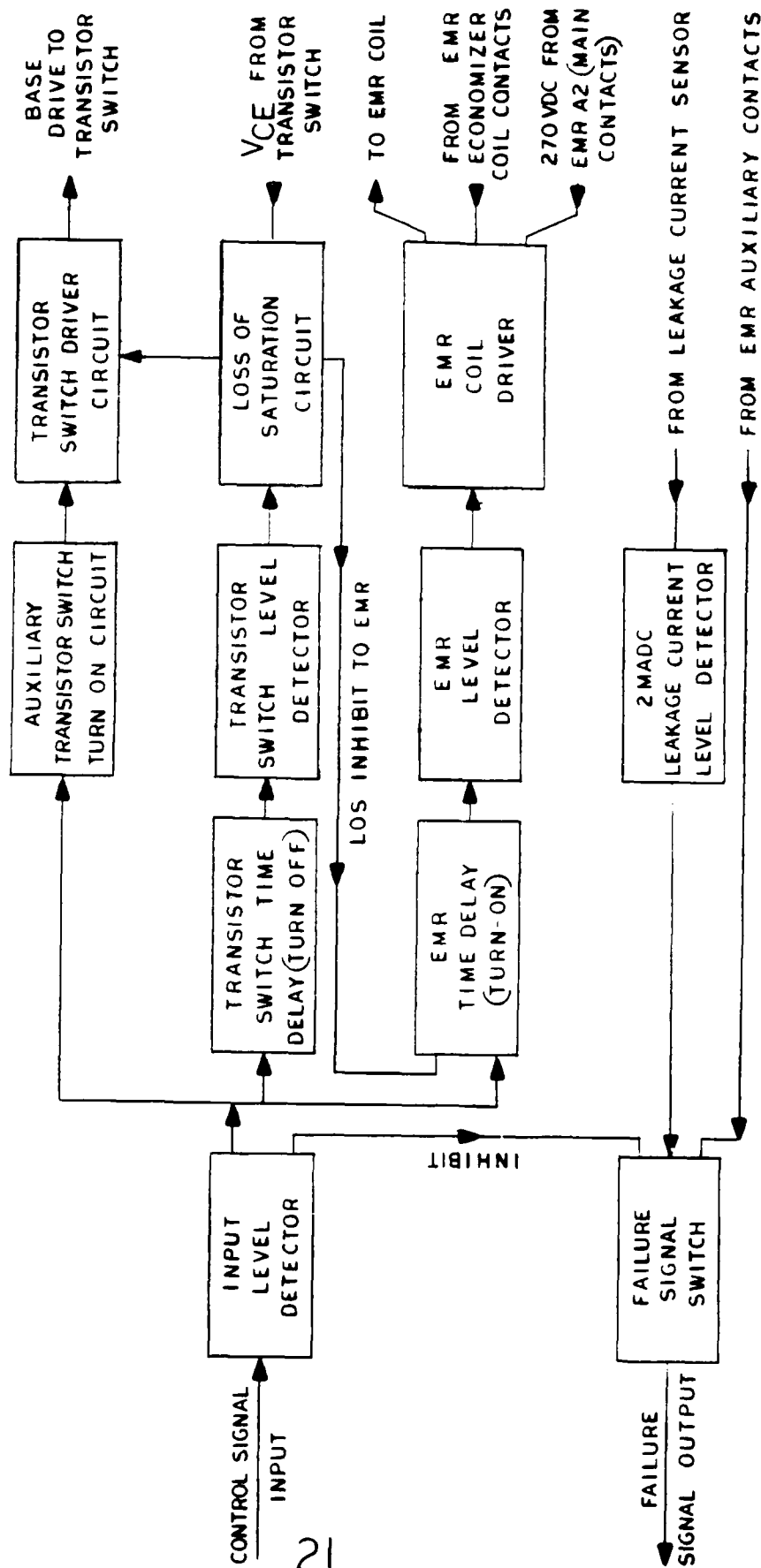
FIGURE 12. FUNCTIONAL BLOCK DIAGRAM OF CONTROL LOGIC.

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The load current transfers from the transistor power switch to the electromagnetic relay contacts:

(1) due to the lower resistance of the current path provided by the relay contacts and

(2) the transistor power switch is turned-off by the Baker Clamp circuit that reduced the base current drive to zero when it sensed the low voltage drop (e.g., 0.17 Vdc) across the electromagnetic relay contacts.

The turn-off sequence is to:

(1) open the relay contacts,

(2) which transfer load current from electromagnetic relay to transistor power switch; and

(3) turn-off the transistor power switch.

The load current transfers from the electromagnetic relay contacts to the transistor power switch:

(1) due to the higher path resistance of the relay contacts when they just begin to open and

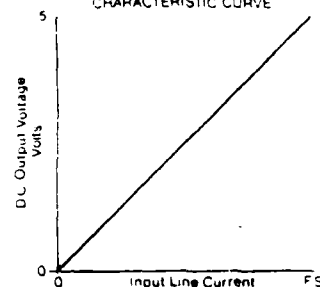(2) the transistor power switch is turned-on by the Baker Clamp circuit that sensed the higher voltage drop (e.g., 0.7 Vdc) across the electromagnetic relay contacts as they begin to open.

Figure 12 shows the block diagram of the control logic that was used to obtain the:

(1) turn-on and turn-off sequences described above;

(2) Auxiliary Transistor Switch Turn-on Circuit (which has been eliminated by the circuit simplification task);

(3) Loss-of-Saturation Circuit shutdown;

(4) 2 mAdc Leakage Current Failure Signal; and

(5) Welded Electromagnetic Relay Contact Failure Signal.

a. Turn-On Sequence.

(1) Input Level Detector. The Input Level Detector monitors the input current control signal and outputs a turn-on signal if the average input current control signal exceeds 8.1 mAdc.

The input circuit contains an R-C filter that does not respond to
the high frequency coding that may be on the input control
signal; it responds roughly to the average dc input. There is
approximately a 5 mS delay time between the input turn-on command
and the Level Detector output to turn-on.

The turn-on signal from the Input Level Detector is fed via a
single opto-isolator to the Transistor Switch Time Delay block,
the Electromagnetic Relay (EMR) Time Delay block, and the
Auxiliary Transistor Switch Turn-On Circuit (currently deleted).
The opto-isolator isolates the input control signal (and the
Failure Signal output circuitry) from the remaining ALC
circuitry.

        (2) Initial Transistor Power Switch Turn-On. The
turn-on signal propagates through the Transistor Switch Time
Delay (Turn-Off), Transistor Switch Level Detector, Loss of
Saturation Circuit, and Transistor Switch Driver Circuit blocks
with a minimum time delay (typically 98 microseconds) to turn-on
the Transistor Power Switch.

The Baker Clamp circuit in the Transistor Switch Driver Circuit
block adjusts the base current drive to the Transistor Power
Switch such that the collector-emitter voltage will not be less
than approximately one-diode drop (0.7 Vdc) over a wide range of
load currents. This ensures that the Transistor Power Switch
will not operate in "deep saturation," which aids uniform turn-
off switching.

        (3) Electromagnetic Relay (EMR) Turn-On. The turn-on
signal propagates through the EMR Time Delay (Turn-On), EMR Level
Detector, and EMR Driver blocks with a small time delay
(typically 290 microseconds). This time delay allows time to
inhibit the EMR turn-on in the event that the Loss-of-Saturation
Circuit senses an over-current condition and the need to shut-
down the ALC when the Transistor Power Switch was initially
turned-on.

The coil of the EMR is enabled by the turn-on of the main
Transistor Power Switch; it is energized by the EMR turn-on
signal to transistor switches Q20 and Q22 in the EMR coil Driver.
Initially, the pull-in coil is excited; then after 25 mS,
typically, the main contacts close and the normally closed
auxiliary contacts open and interrupt base drive current to
transistor switch Q20 in the EMR pull-in coil driver; which
permits transistor switch Q22 to excite the hold-in coil.

The Baker Clamp circuit in the Transistor Switch Driver Circuit
block then senses the low voltage drop (0.17 Vdc) across the EMR
contacts and reduces the base current drive to the Transistor
Power Switch to zero in an effort to maintain a minimum
collector-emitter voltage of one-diode drop (0.7 Vdc).

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b. Turn-Off Sequence.

(1) Input Level Detector. The Input Level Detector
monitors the input current control signal and outputs a turn-off
signal if the average input current control signal falls below
2.3 mAdc.

The input circuit contains an R-C filter that does not respond to
the high frequency coding that may be on the input control
signal; it responds roughly to the average dc input. There is
approximately a 10 mS delay time between the input turn-off
command and the Level Detector output to turn-off.

The turn-off signal from the Input Level Detector is fed via a
single opto-isolator to the Electromagnetic Relay (EMR) Time
Delay block, the Transistor Switch Time Delay block, and the
Auxiliary Transistor Switch Turn-On Circuit (currently deleted).

(2) Electromagnetic Relay (EMR) Turn-Off. The turn-
off signal propagates through the EMR Time Delay (Turn-On), EMR
Level Detector, and EMR Driver blocks with a minimum time delay
(typically 15 microseconds).

The hold-in coil of the EMR is de-energized by the turn-off of
transistor switch Q22 in the EMR coil Driver. After 35 mS,
typically, the main contacts open.

(3) Transistor Power Switch Turn-On and Turn-Off.
When the main contacts just begin to open, the Baker Clamp
circuit in the Transistor Switch Driver Circuit block senses
the higher voltage drop across the EMR contacts and increases the
base current drive to the Transistor Power Switch to the amount
required to maintain a minimum collector-emitter voltage of one-
diode drop (0.7 Vdc).

The turn-off signal propagates through the Transistor Switch Time
Delay (Turn-Off), Transistor Switch Level Detector, Loss of
Saturation Circuit, and Transistor Switch Driver Circuit blocks
with a maximum time delay (typically 58 mS) to turn-off the
Transistor Power Switch.

Thus, the Transistor Power Switch will turn-on as the EMR
contacts open and then turn-off 21 mS (typically) later.

c. Auxiliary Transistor Switch Turn-On Circuit. The
initial design of the ALC used an auxiliary turn-on circuit to
provide base drive current into the Transistor Power Switch
before the EMR contacts opened to ensure that load current
properly transferred from the EMR contacts to the main Transistor
Power Switch when the contacts opened. The Auxiliary Transistor
Switch Turn-On Circuit used the turn-off signal to by-pass the
Baker Clamp circuit to provide maximum base drive current to the
Transistor Power Switch during the period of load current

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transfer. Laboratory tests have shown that this circuitry is not
required for load currents of 600 Adc and below. Therefore, the
circuitry was removed.

        d. Loss-of-Saturation Circuit Shutdown. The Baker Clamp
circuit provides the proper base drive current to the Transistor
Power Switch to limit the minimum collector-to-emitter voltage to
no less than one-diode drop (0.7 Vdc) over a wide range of load
currents. The Transistor Power Switch is designed to carry a
certain maximum current. If this maximum current is exceeded,
the ALC circuitry is designed to shut-down the Transistor Power
Switch to prevent self damage. That is, if the load current
grows larger than the product of the Transistor Power Switch
current gain (Beta) times the maximum available base drive
current, the collector-to-emitter voltage will grow larger; which
will increase the power dissipation and can lead to destruction
of the Transistor Power Switch, if not shutdown quickly.

The Loss-of-Saturation (LOS) Circuit monitors the collector-to-
emitter voltage of the Transistor Power Switch. For example, if
the collector-to-emitter voltage exceeds 10 Vdc for approximately
85 microseconds, the LOS circuit will shut-down the Transistor
Power Switch and the Electromagnetic Relay.

The LOS shut-down of the Transistor Power Switch and
Electromagnet Relay can be reset by cycling Off and On the input
command signal.

        e. 2 mAdc Leakage Current Failure Signal. If the leakage
current between terminals A1 and A2 should increase to between 2
mAdc and 4.25 Adc, the 2 mAdc Leakage Current Level Detector will
provide an output signal to turn-on the Failure Signal Switch as
shown in Figure 12. However, an inhibit signal from the Input Level
Detector block is present when ever the ALC is in the "turn-on"
mode. Thus, a Failure Signal Output can only be obtained when
the ALC is in the "off" mode.

        f. Welded Electromagnetic Relay Contact Failure Signal.
If the main EMR contact(s) should become welded closed, a Failure
Signal Output will be obtained when the ALC is given the "turn-
off" command. The operation of this circuit assumes that the
auxiliary contacts are so coupled to the welded main contacts
that the auxiliary contacts can not change state when the EMR is
de-energized.

It is normal operation to see the Failure Light turn-on
momentarily upon energizing and switching the ALC.

6. LOW VOLTAGE POWER SUPPLY WITH MULTIPLE OUTPUTS. Figure 13
shows the functional block diagram of the low voltage power
supply with multiple outputs. The low voltage power supply
consists of the four following circuits: input switchmode buck
regulator power circuit, transistor bridge inverter, logic
circuit, and multiple isolated rectifier-filter output circuits.

     a. Input Switchmode Buck Regulator Circuit. The input
switchmode buck regulator circuit is composed of a dc input
filter and a switchmode buck regulator power circuit. The
function of the input switchmode buck regulator circuit is to
convert the 270 Vdc (nominal) input voltage to a regulated
voltage of 150 Vdc.

          (1) Dc Input Filter. The dc input filter is made up
of a small 25 microhenry inductor and a 54 microfarad (nominal)
bank of high temperature (125 degree C) aluminum electrolytic
capacitors. The function of the dc input filter is two fold:

               (a) The capacitor bank stores electric charge
                    from the 270 Vdc input when the switching
                    device in the buck regulator is open and
                    supplies electric charge to the buck
                    regulator when the switching device is
                    closed. Thus, the capacitor bank sees an
                    alternating current eventhough the voltage
                    across the capacitor bank is dc. The
                    capacitor bank tends to smooth the current
                    pulse demand from the switchmode buck
                    regulator such that the input current is a
                    continuous dc quantity.

                    The basic equation for the capacitor bank is:

$$i = C \times de/dt$$

                    where, i is the instantaneous current (Adc)
                         into the capacitor bank;

                         C is the capacitance (Farads) of the
                         capacitor bank; and

                         de/dt is the time rate of change of the
                         capacitor voltage (volts/second).

                    Thus, as the capacitor bank stores electric
                    charge (i x dt), the capacitor voltage
                    increases proportionally (i x dt/C);
                    similarly, as the capacitor bank supplies
                    electric charge (-i x dt) to the buck
                    regulator circuit, the capacitor voltage
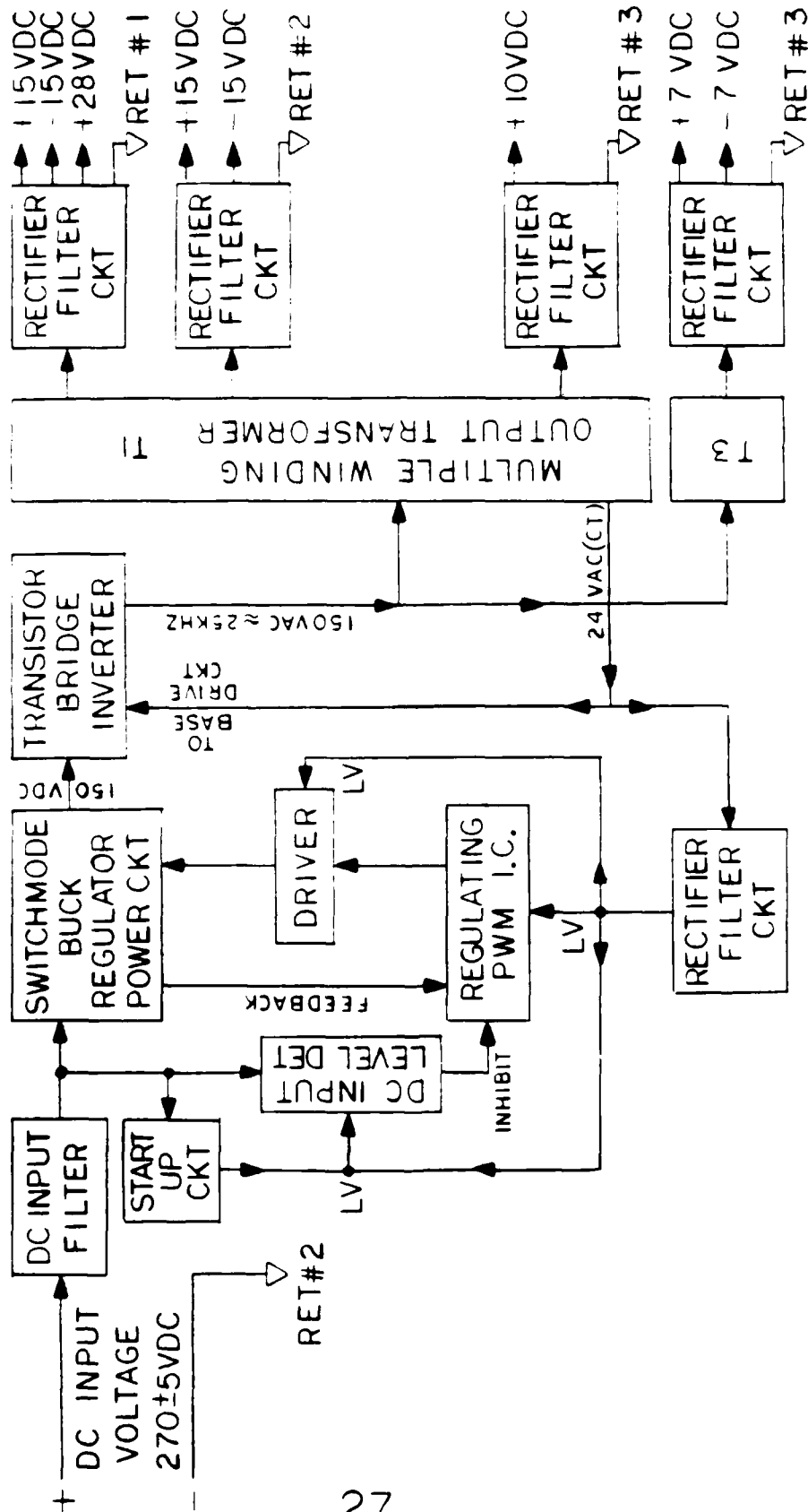   decreases proportionally (-i x dt/C).

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FIGURE 13. FUNCTIONAL BLOCK DIAGRAM OF LOW VOLTAGE POWER SUPPLY WITH MULTIPLE OUTPUTS.

(Note that the use of the symbol "i" for
charging current and "-i" for discharging
current does not mean that the magnitudes of
these currents are equal. In general they
will not be equal.) Thus, the capacitor bank
tends to maintain a constant input voltage to
the switching device in the switchmode buck
regulator power circuit.

It is most important that the actual ac
current (or ripple current) through the
capacitor bank does not exceed the ripple
current rating of the capacitors that make up
the capacitor bank:

(worst case is one-half of the maximum output
load current from the switchmode buck
regulator).

The input current has an average value that
equals the product of the output load current
(from the buck regulator) and the duty cycle
of the switchmode buck regulator, where:

duty cycle = on-time/(on-time + off-time).

(b)   The ac current through the capacitor bank
      will develop a voltage across the Equivalent
      Series Resistance (ESR) of the capacitor
      bank. This ac voltage, which is usually
      a few tenths of a volt, will be impressed on
      the 270 Vdc input line.

      The function of the 25 microhenry dc input
      inductor is to insert a high impedance (3
      ohms at the switching frequency of the
      switchmode buck regulator) between the
      capacitor bank (with its ESR ac voltage
      source) and the 270 Vdc input line. This
      inductor prevents large high frequency
      currents from flowing in the the 270 Vdc
      input lines, which may cause Electromagnetic
      Interference (EMI) to other services on the
      dc input line.

     (2)   Switchmode Buck Regulator Power Circuit. The
switchmode buck regulator power circuit consists of a Solitron
SDT 13305 transistor switch, a Motorola MR1378 free-wheeling
diode, a 2.4 millihenry dc "C" core inductor, and a 108
microfarad (nominal) output filter capacitor bank.

The switchmode buck regulator power circuit converts the 270 Vdc
(nominal) input voltage into a regulated output voltage of 150
Vdc. The regulator is capable of maintaining the 150 Vdc over an
input voltage range of from 175 to 350 Vdc.

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When the transistor switch is turned-on, the input current flows
from the +270 Vdc input line through the output load (which is
shunted by the 108 microfarad output filter capacitor bank),
through the 2.4 millihenry inductor, and through the NPN
transistor switch (collector to emitter) to the 270 Vdc return.

(Note: The output load is the transistor bridge inverter.)

The input current to the bulk regulator increases as follows:

$$di/dt = e/L = (V_{in} - V_{out})/L$$

where: di/dt is the time rate of change of the input current
          or the current through the 2.4 millihenry
          inductor;

       e is the voltage across the 2.4 millihenry
          inductor;

       L is the inductance of the 2.4 millihenry
          inductor;

     V_{in} is the 270 Vdc input voltage; and

     V_{out} is the 150 Vdc output voltage.

The current through the inductor will continue to increase until
the transistor switch is turned-off.

When the transistor switch is turned-off, the current through the
inductor will continue to flow in the same direction. The
current path is through the inductor, through the free-wheeling
diode, through the output load, and back to the inductor. (The
cathode of the free wheeling diode is connected the +270 Vdc
input line, and the anode is connected to the collector of the
NPN transistor switch.)

The energy stored in the inductor when the transistor switch was
turned-on, is now being used to maintain current through the load
while the transistor switch is turned-off. The energy stored
during the transistor on-time is:

$$W = (1/2) L \times (i_{peak})^2$$

where: W is energy stored in the 2.4 millihenry inductor
                in joules;

                L is the inductance of the 2.4 millihenry inductor;

                and

        i   is peak current (Adc) through the inductor.
          peak

The inductor current decreases as follows:

$$di/dt = e/L = (-V_d - V_{out})/L$$

where: di/dt is the time rate of change of the inductor
                current or the load current;

          e is the voltage across the 2.4 millihenry
                inductor;

          L is the inductance of the 2.4 mil henry
                inductor;

          V_d is the voltage across the free-wheeling diode;

                and

          V_{out} is the 150 Vdc output voltage.

The current through the inductor will continue to decrease until
the transistor switch is again turned-on.

With the assumption that the voltage across the free-wheeling
diode (1 Vdc) can be neglected, it can be shown from the above
that the output voltage is:

$$V_{out} = V_{in} \times T_{on}/(T_{on} + T_{off}),$$

which shows that the output voltage is proportional to the duty
cycle of the transistor switch.

    b. Transistor Bridge Inverter. The transistor bridge
inverter consists of two transformers, four Solitron SDT 13305
transistors, eleven resistors, four capacitors, twenty diodes,
and a bi-directional switch. The function of the transistor
bridge inverter is to convert the regulated 150 Vdc from the
switchmode buck regulator power circuit into an alternating
squarewave voltage. Thus, with alternating voltage available,

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the various voltage transformations required can be obtained
by using transformer techniques.

(1) Single "Totem Pole" Transistor Switch Circuit. A
single "totem pole" transistor switch is two NPN transistors
connected in series across the dc rail voltage (the regulated 150
Vdc). The collector of the upper transistor switch is connected
to the positive dc rail and the emitter is connected to the
collector of the lower transistor switch. This junction is
called the mid-point of the "totem pole" and is connected to one
end of the output load (two transformer primaries connected in
parallel). The emitter of the lower transistor is connected to
the negative dc rail. A fast recovery diode is also connected
across each transistor switch (cathode to collector and anode to
emitter) to provide an alternate current path when a transistor
switch is turned-off.

The upper and lower transistor switches are alternately turned-on
and off such that the midpoint of the "totem pole" is switched to
the positive or negative dc rail voltage. Each transistor
switch is turned-on slightly less than 50% of the period of
the switching frequency (20 kHz). However, both transistor
switches are never turned-on at the same instant of time, since
this would cause a short-circuit between the positive and
negative dc rail voltage.

(2) Bridge Inverter Circuit. The bridge inverter
circuit consists of two "totem pole" transistor switch
configurations with the output load connected between the mid-
points of the two "totem pole" transistor switch configurations.
The turn-on sequence for the transistor switches in the first
"totem pole" transistor switch configuration is exactly opposite
to the turn-on sequence for the second "totem pole" transistor
switch configuration. For example, the upper transistor switch
in the first "totem pole" and the lower transistor switch in the
second "totem pole" are turned-on, while the remaining transistor
switches are turned-off. Thus, current from the positive dc rail
can flow through the upper transistor switch (in the first "totem
pole"), through the output load, through the lower transistor
switch (in the second "totem pole") to the negative side of the
dc rail.

After the upper transistor switch in the first "totem pole" and
the lower transistor switch in the second "totem pole" are
turned-off; the lower transistor switch in the first "totem pole"
and the upper transistor switch in the second "totem pole" are
turned-on. Thus, current from the positive dc rail can flow
through the upper transistor switch (in the second "totem pole"),
through the output load (but in the opposite direction from the
former case), through the lower transistor switch 'in the first
"totem pole") to the negative side of the dc rail.

This switching sequence applies an alternating squarewave voltage
to the output load that is equal to the dc rail voltage (minus the
voltage drops across the transistor switches (1 to 3 v).

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For an inductive load, the load current can not instantaneously
reverse direction when the transistors change state. When the
transistors turn-off, the fast recovery diodes across each of the
transistor switches provides a current path for the load current
to flow back through the dc rail voltage source. This actually
returns energy that was stored in the load inductance back to the
dc rail voltage source to be reused. These fast recovery diodes
are called "free-wheeling," or "catch" diodes.

The output load is the primary windings of two transfomers
(denoted T1 and T3) connected in parallel. Thus, the output load
has an inductive component.

    (3) <u>Saturable Core Transistor Base Drive</u>
<u>Transformer</u>. The switching frequency of this inverter is
determined by the lenght of time it takes to saturate the core of
a small transformer, denoted T2. This transformer has four
isolated windings; each winding provides base current drive to
one of the four transistor switches. It is polarized such that
it provides positive base current drive to only two transistor
switches at a time (e.g., the upper transistor switch in the
first "totem pole" and the lower transistor switch in the second
"totem pole").

It will be shown later that the current drawn from the two
windings supplying positive base current drive will be
essentially constant, until the transistor switches are turned-
off. Similarly, the primary current of Transformer T2 will be
essentially constant, until the transistor switches are turned-
off.

Most transformers are designed not to saturate in the operation
intended; they are designed to support an alternating voltage
with a magnitude V and a half-period T. In general, a
transformer will not saturate if the V x T (volt-second) product
is not exceeded. The design of Transformer T2 is such that it
does saturate after a certain volt-second product has elapsed.

The primary of Transformer T2 is connected through a series
dropping resistor to a 30 Vac secondary winding of the Output
Transformer T1. Since the primary current of Transformer T2 is
essentially constant, the resultant voltage drop across the
primary of Transformer T2 is essentially contant. The design of
Transformer T2 is such that the time elapsed to saturate the core
is approximately one-half the period of a 20 kHz squarewave.

When the core of Transformer T2 saturates:

    (1) the transistor switches (that were turned-on) turn-off
      since they no longer receive positive base drive
      current;

    (2) the primary impedance ceases to reflect the secondary
      impedance, and essentially falls to the very low dc

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resistance of the primary winding. The series dropping
resistor now limits the current drawn from the 30 Vac
winding to a reasonable value.

When the transistor switches (that were turned-on) turn-off, the
partially inductive load current will continue to flow via the
free-wheeling diodes back to the dc rail voltage source. In so
doing, the voltage impressed on the primary of Output Transformer
T1 will be reversed. Subsequently, this reverse voltage will be
impressed on the primary of Transformer T2 and bring it out of
saturation. The reverse voltage will also turn-on the other set of
transistor switches which will reinforce the existing base
current drive. This state will continue until Transformer T2
again saturates (but in the opposite direction) a half-period
later.

The load on this inverter varies considerably. Most of the time,
the load is small, but when the ALC is turning-on or turning-off,
the load can be 400 W for 100 milliseconds. For fast and
efficient switching, the transistor switches should not be
operated into deep saturation; they need high base drive current
for high power output and low base drive current for low power
output. The Baker Clamp Circuit performs this service. It will
not permit the collector-emitter voltage of the transistor
switches to be less than two diode drops (1.4 V). The only draw
back is that Transformer T2 must provide the maximum base drive
current continuously. The Baker Clamp provides the proper base
drive current and deverts the remaining available current to the
collector-emitter path.

When the 270 Vdc is initially applied to the input of the
switchmode buck regulator, the regulator output voltage increases
in a cosinusoidal like fashion from zero to 150 Vdc. The
regulator then maintains the 150 Vdc output.

The inverter does not start to oscillate until the regulator
output voltage is 32 Vdc. A bi-directional switch is used to
breakover at 32 Vdc and discharge a 0.1 microfarad capacitor into
the base winding of the lower transistor switch in the first
"totem pole." By transformer action, this capacitor discharge
will also turn-on the upper transistor switch in the second
"totem pole," which will start the inverter to oscillate. (The
capacitor discharge also provides reverse bias to the two
remaining transistors.)

The inverter oscillates with a half-period that does not allow
the voltage across the 0.1 microfarad capacitor to reach 32 Vdc,
which effectively removes this starting circuit from futher
inverter operation.

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c.   Logic Circuit. The logic circuit for the low voltage
power supply provides the following functions:

(1)   base drive switching signals for the transistor switch
      in the switchmode buck regulator;

(2)   low voltage for the power supply logic circuitry during
      start-up and subsequent operation; and

(3)   self protection for the power supply.

These functions, and how they are implemented, are discussed in
broad detail in the following paragraphes.

(1)   Base Drive Switching Signals. The base drive
switching signal to the transistor switch in the switchmode buck
regulator has the following requirements:

(a)   a pulse width modulated (PWM) waveform that
      properly regulates the dc output of the
      switchmode buck regulator and

(b)   a specified minimum current capacity.

The pulse width modulated waveform is generated by a Silicon
General (SG 1524) integrated circuit (IC). The IC is associated
with approximately twelve resistors and six capacitors. These
components provide the following functions:

(i)   set switching frequency,

(ii)   set dead time,

(iii)   feedback voltage proportional to the
        output of the buck regulator,

(iv)   lead network for feedback stablization,

(v)   reference voltage,

(vi)   buck regulator output current
        monitoring and limiting, and

(vii)   output shutdown or inhibit.

The pulse width modulated output from the IC is amplified by a
multistage current amplifier (made up from two switching
transistors) and then fed into the base of the switching
transistor of the buck regulator. A third switching transistor
is used to speed-up the sweep-out of the majority current
carriers from the base region to improve the transistor switching
speed.

(2) Low Voltage for Logic Circuitry.

(a) Steady-State Operation. For steady-state
operation, low voltage for the power supply logic circuitry is
provided by a rectifier/filter circuit connected to a winding
from the inverter output transformer.

This supply voltage is proportional to the dc output from the
switchmode buck regulator (and any subsequent voltage drop(s) in
the inverter stage) and is used as feedback voltage to the IC
pulse width modulated regulator.

(b) Start-Up Operation. When the 270 Vdc input
voltage is initially applied to the low voltage power supply, a
12 Vdc zener diode, two power resistors, and an emitter follower
transistor stage form an interim 11 Vdc supply for:

(1) the driver of the transistor switch in the switchmode
     buck regulator circuit;

(2) the IC pulse width modulated regulator; and

(3) a voltage level detector circuit that senses when the
     dc input voltage is above 160 Vdc.

The IC pulse width modulated regulator is supplied a shutdown
signal while the dc input voltage is below 160 Vdc. (This is to
ensure proper operation of the Electromagnetic Relay with a pick-
up voltage of 150 Vdc.)

When the dc input voltage is initially applied (above 160 Vdc),
the switchmode buck regulator and inverter are not in operation;
and thus, there is no feedback voltage present. In this
condition, the IC pulse width modulated regulator turns on the
driver circuit to turn on the transistor switch in the switchmode
buck regulator circuit. The regulator output voltage increases
in a cosinusoidal fashion. When the regulator output voltage
reaches 32 Vdc, the inverter stage starts to oscillate and
produce output voltage. This produces an increasing feedback
voltage to the IC pulse width modulated regulator circuit. When
the feedback voltage reaches the set point, the IC regulator will
cut down the duty cycle of the pulse width modulation and
maintain a stable output voltage from the inverter stage.

The steady-state low voltage supply now back-biases the interim
11 Vdc supply, and effectively removes the components of the 11
Vdc supply from operation. The interim supply is designed for
only a short period of operation during the start-up sequence (1
or 2 seconds, maximum). If the unit does not start-up properly,
the interim supply can be damaged (unless the dc input voltage is
quickly removed).

(3) Self Protection. The low voltage power supply has two self protection circuits for the buck regulator output: current limiting and shutdown due to low dc input voltage.

(a) Current Limiting Circuit. The peak current of the buck regulator is monitored by sensing the voltage across a small resistance in the emitter of the switching transistor. This voltage is electronically coupled to a filter circuit and then to the current limiting port of the IC regulator. The filter circuit is a capacitor with a practically instantaneous charge time constant and a fairly long discharge time constant (150 microseconds).

If the peak current rises above the set point, the IC regulator will quickly reduce the buck regulator output voltage by decreasing the duty cycle of the pulse width modulator output. If the peak current falls below the set point, the voltage stored on the capacitor in the filter circuit will continue to maintain a reduced output voltage for approximately 500 microseconds (three-time constants). If the peak current continues to increase above the set point, the output will be completely cut-off.

(b) Low Dc Input Voltage Shutdown. The low voltage power supply is shutdown when the dc input voltage is below 160 Vdc. This is to ensure proper pick-up voltage for the Electromagnetic Relay (150 Vdc). If the relay is energized below this voltage, it may not be able to transfer from it momentary pull-in coil (2 Adc, maximum) to the steady-state operating coil (55 mAdc, maximum). Thus, the pull-in coil would be damaged after about 30 seconds or less.

However, if the input voltage should drop below 160 Vdc during an "on" period of operation, the low voltage power supply would shutdown and would cause the following serious problem: the main transistor switch would open before the Electromagnetic Relay and force the Relay to open the load current. The dc input voltage level detector circuit can be redesigned such that the drop-out voltage is below 32 Vdc.

d. Multiple Dc Output Voltages. The low voltage power supply has four groups of isolated voltages dedicated to ALC operation. Three of the isolated groups have secondary windings on Inverter Output Transformer T1, and the forth group has secondary windings on Inverter Output Transformer T2 (the primaries of T1 and T2 are connected in parallel). Each group has full-wave diode rectification and a capacitor input filter.

(1) First Group. The first group of isolated voltages is for the customer interface and consists of the following voltages: +28 Vdc, +15 Vdc, -15 Vdc and Common #1.

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(2) Second Group. The second group of isolated
voltages is for the ALC logic with the potential reference of the
input 270 Vdc return. The group provides the following voltages:
+15, -15 Vdc and Common #2.

(3) Third Group. The third group of isolated voltages
is for the ALC logic with the potential reference of the output
load (+270 Vdc). The group provides +10 Vdc and Common #3.

(4) Forth Group. The forth group of isolated voltages
has the same potential reference as the third group and is
dedicated to the base current driver that turns-on and off the
main transistor power switch. The group supplies +7 Vdc, -7 Vdc
and Common #3. For load currents of 400 to 600 Adc the group
must be able to supply from 60 to 80 A at +5 Vdc during the
switching period.

CAUTION:

270 VDC CAN EXIST BETWEEN GROUP 2 COMMON
AND GROUPS 3 AND 4 COMMON.

DO NOT CONNECT DIFFERENT COMMONS TOGETHER
WITH TEST EQUIPMENT, E.G.

GROUPS 3 AND 4 COMMON CAN BE AT +270 VDC POTENTIAL.

IV.   CIRCUIT SIMPLIFICATIONS

1.   ORIGINAL SCHEMATIC DIAGRAM.

The original schematic diagram for the ALC is shown in Figures
14-A through 14-D.

2.   PRESENT SCHEMATIC DIAGRAM.

The present schematic diagram for the ALC is shown in Figures 15-
A through 15-D.

3.   CIRCUIT REFINEMENTS.

a.   Auxiliary Transistor Switch Turn-On Circuit.   The
initial design of the ALC used an auxiliary turn-on circuit to
provide base drive current into the Transistor Power Switch
before the electromagnetic relay (EMR) contacts opened to ensure
that load current properly transferred from the EMR contacts to
the main Transistor Power Switch when the contacts opened.   The
Auxiliary Transistor Switch Turn-On Circuit used the turn-off
signal to by-pass the Baker Clamp circuit to provide maximum base
drive current to the Transistor Power Switch during the period of
load current transfer.   Laboratory tests have shown that this
circuitry is not required for load currents of 600 Adc and below.
Therefore this circuitry was removed.

b.   Double-Ended EMR Coil Driver Circuit.   The basic
operation of the electromagnetic relay (EMR) has been previously
discussed (III.   INTERNAL FUNCTIONS OF SUBSYSTEMS, 2.b.).

The 135 ohm pull-in coil (coil #1) of the electromagnetic relay
(EMR) is connected between terminals X1 and D; the 6200 ohm
econimizer coil (coil #2) is connected between terminals D and
X2. The initial design of the ALC used three 2 Adc transistor
power switches and three free wheeling diodes to turn-on and off
the EMR.   Transistor switch Q19 was connected between ALC
terminal A2 (load) and EMR terminal X1.   Thus, the turn-on of
transistor switch Q19 applies +270 Vdc to the EMR terminal X1
(assuming that the ALC main transistor switch is turned-on).
Transistor switch Q20 conected EMR terminal D to the 270 Vdc
return and controlled the on-time of the pull-in coil.
Transistor switch Q22 connected EMR terminal X2 to the 270 Vdc
return and controlled the on-time of the econimizer coil.   The
first free wheeling diode was connected between EMR terminals X1
and D (cathode to X1, anode to D, respectively); the second free
wheeling diode was connected from ALC terminal A1 (+270 Vdc) to
EMR terminal X2 (cathode to A1, anode to X2, respectively); and
the third free wheeling diode was connected from EMR terminal X1
to the 270 Vdc return (cathode to X1, anode to return,
respectively).

Figure 14-8.   Original Schematic Diagram
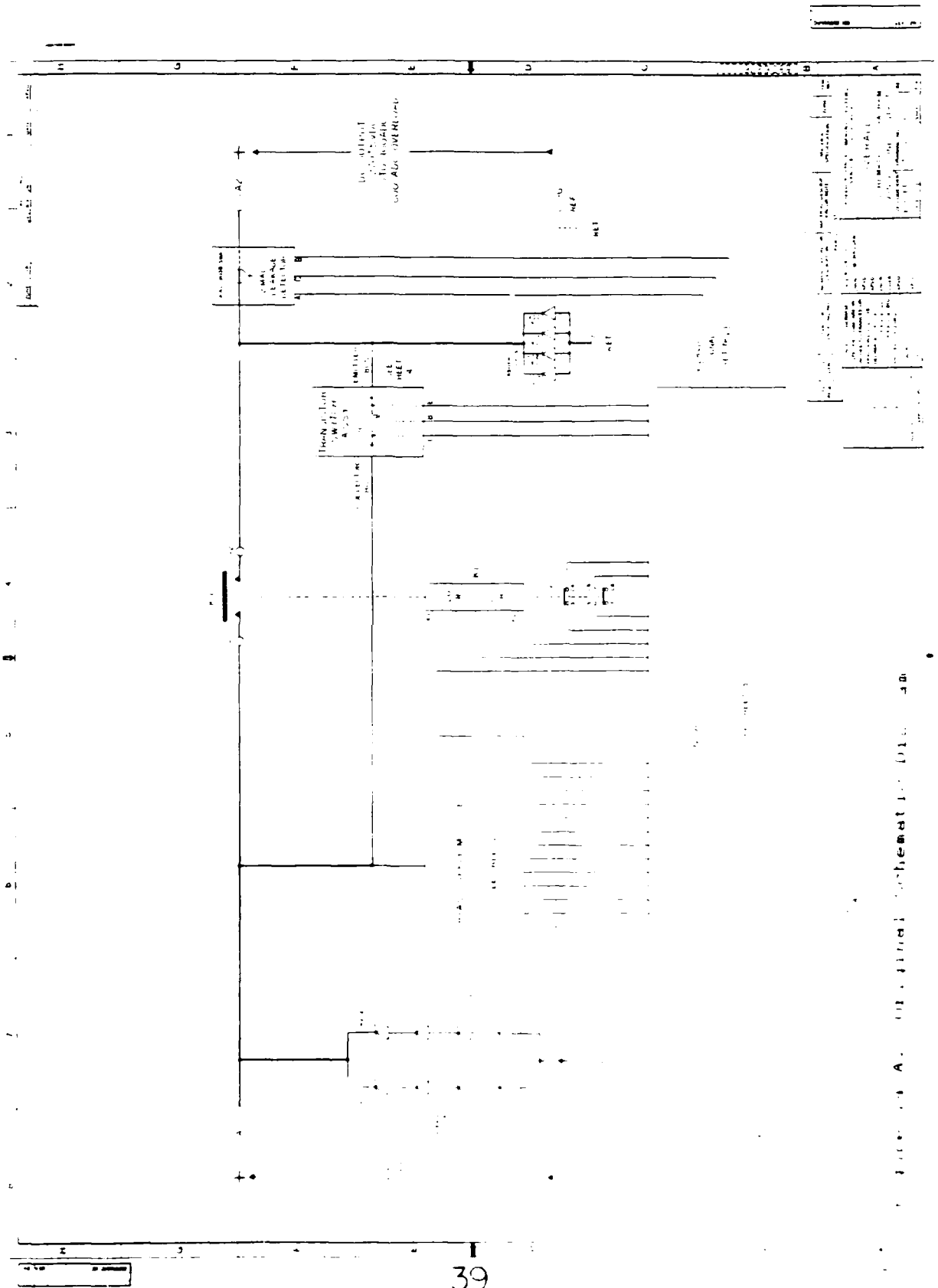
NOTES:

    ALL RESISTORS ARE 1 PERCENT AND 0.25 W,
    UNLESS NOTED OTHERWISE.
    ALL DIODES ARE 1N4148, UNLESS NOTED
    OTHERWISE.

Figure 14-C.   Original Schematic Diagram

TO
TRANSISTOR
SWITCH
ASSY

+5VDC

> COLLECTOR (A1)

> BASE

EMITTER (A2)

TRANSISTOR SWITCH DRIVER

RELAY DRIVER

FROM
CONTROL
LOGIC
SHEET
3

EMITTER
BUS
(FROM SHEET 1)

Figure 14-D.   Original Schematic Diagram
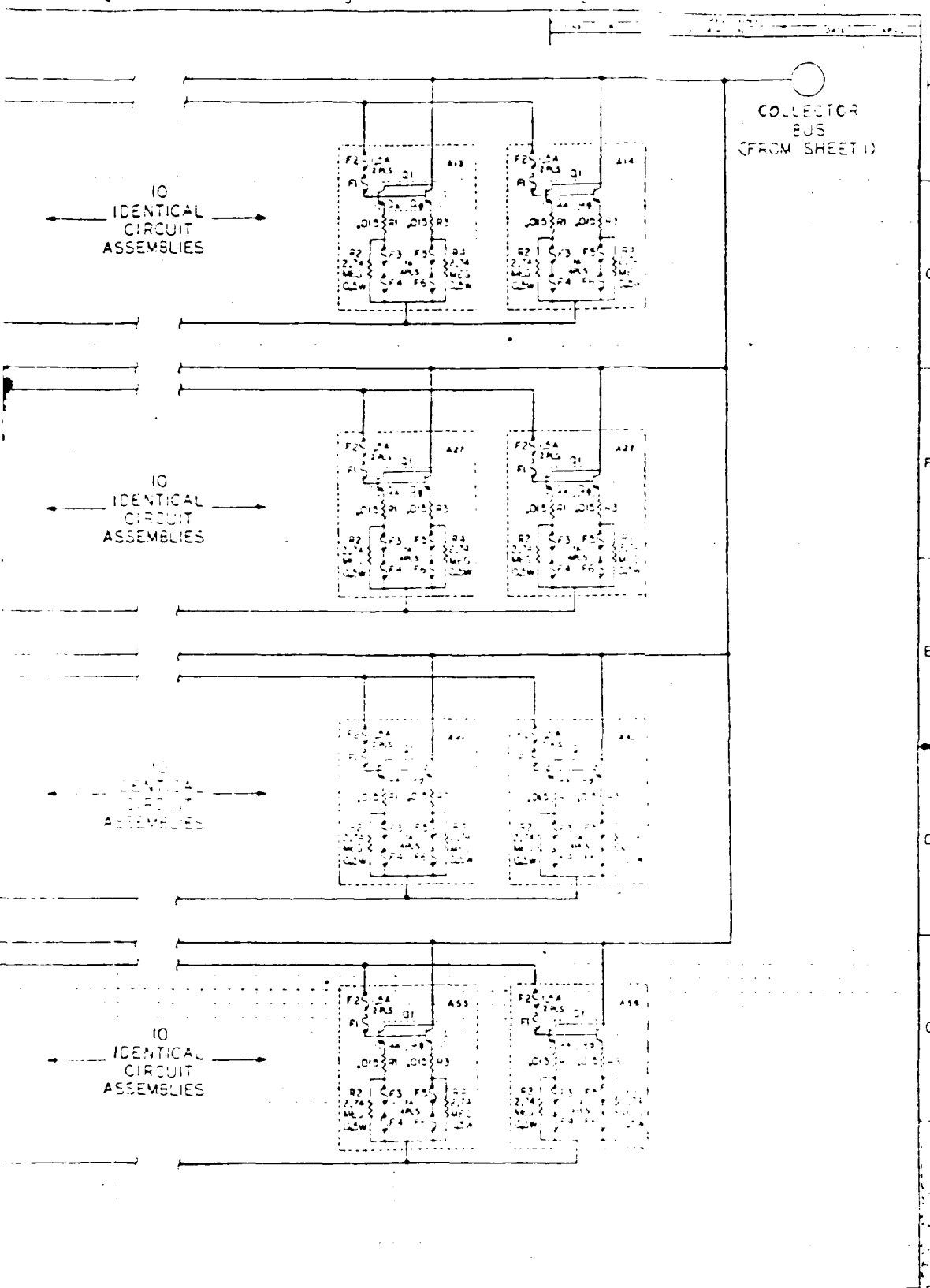
COLLECTOR
BUS
(FROM SHEET 1)

H

IO
IDENTICAL
CIRCUIT
ASSEMBLIES

G

IO
IDENTICAL
CIRCUIT
ASSEMBLIES

F

E

IDENTICAL
CIRCUIT
ASSEMBLIES

D

IO
IDENTICAL
CIRCUIT
ASSEMBLIES

C

B

TRANSISTOR SWITCH ASSEMBLY
SCHEMATIC DIAGRAM
ADVANCED LINE CONTACTOR

A
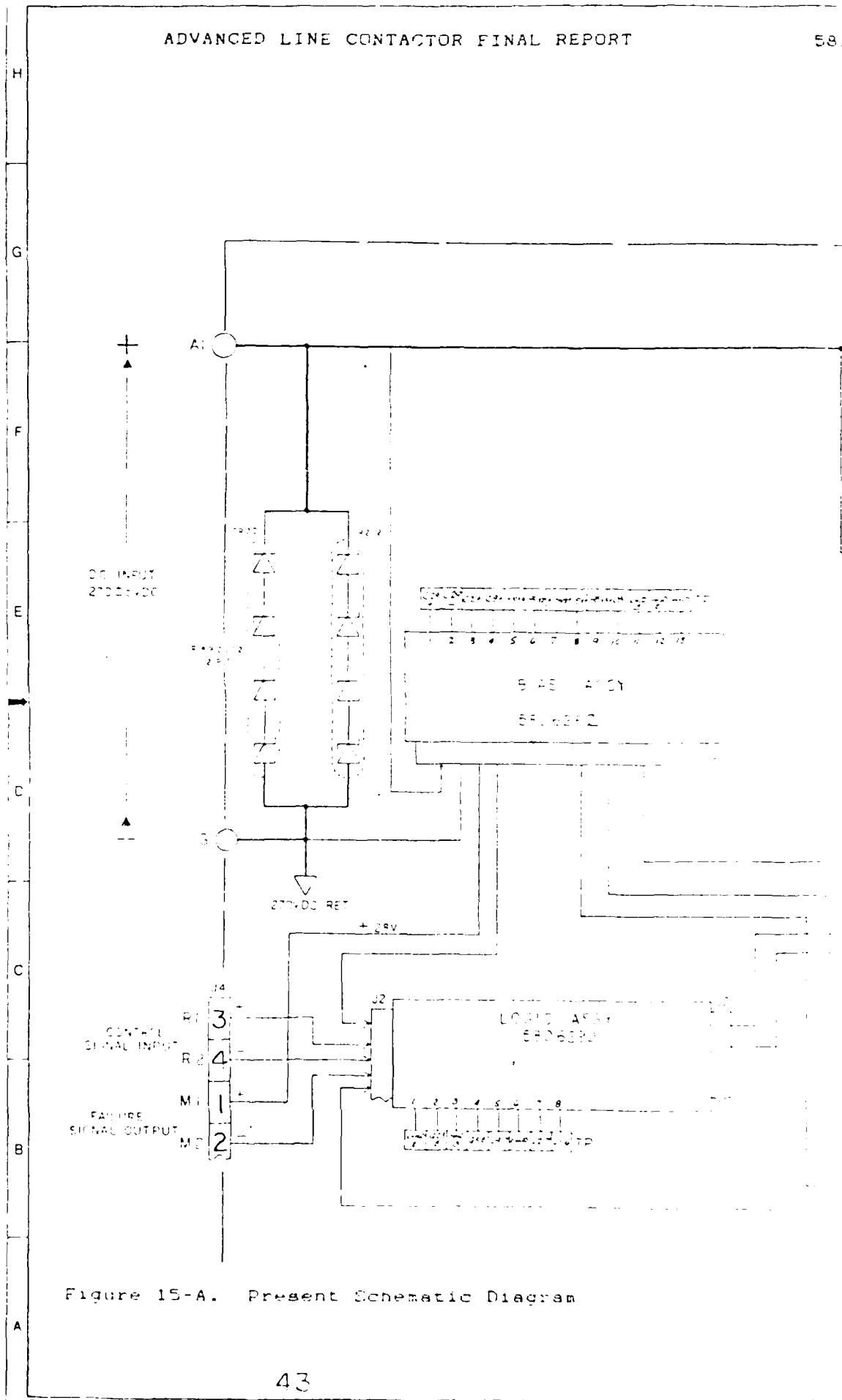
Figure 15-A.   Present Schematic Diagram

43

5814498

K I

A1   A2   A2   +

AAC 9038 5MA

2 MADC
LEAKAGE
DETECTOR

J5 A   B   C

COLLECTOR   EMITTER
B   BUS

DC OUTPUT
270±5VDC
0 TO 400 ADC
600 ADC OVERLOAD

X1

270.0   REF

270.0   REF

REF

J3

DRIVER ASSY
5806290

1 2 3 4 5 6 7

+28V DC
RET NO 1

WARNING
HIGH VOLTAGE

To KI-AI
+270VDC

TO 270VDC
RET

RET A

44

Figure

NOTES:
1. UNLESS OTHERWISE STATED —
   RESISTOR VALUES IN OHMS 1/4 W
   CAPACITOR VALUES IN MICROFARADS
   DIODES ARE IN4148
2. OBSERVE CIRCUIT GROUND ISOLATION.
3. RET 'A' AND RET 'B' SHALL BE CONNECTED AT RS AS SHOWN.
4. RS IS 2.5 IN. (TOTAL ℓ TO ℓ) MANGANIN WIRE, 22 AWG.
5. REF DESIG NOT USED:
   R14 R27 R28 R30 R31 R32 R33 R35
   R37 R38 R41 R42 R43 C1 C6
6. LAST REF. DESIG. USED:
   R64   C39   CR44 Q11 U2
7. ▽ DENOTES TEST POINTS ON BOARD
   USE 100K, 1/4W RESISTOR BETWEEN
   TEST POINT (TP) AND TERMINAL
   TO GET TERMINAL (EYELET)
8. TP1 TO TP2 NOMINAL 145VDC.
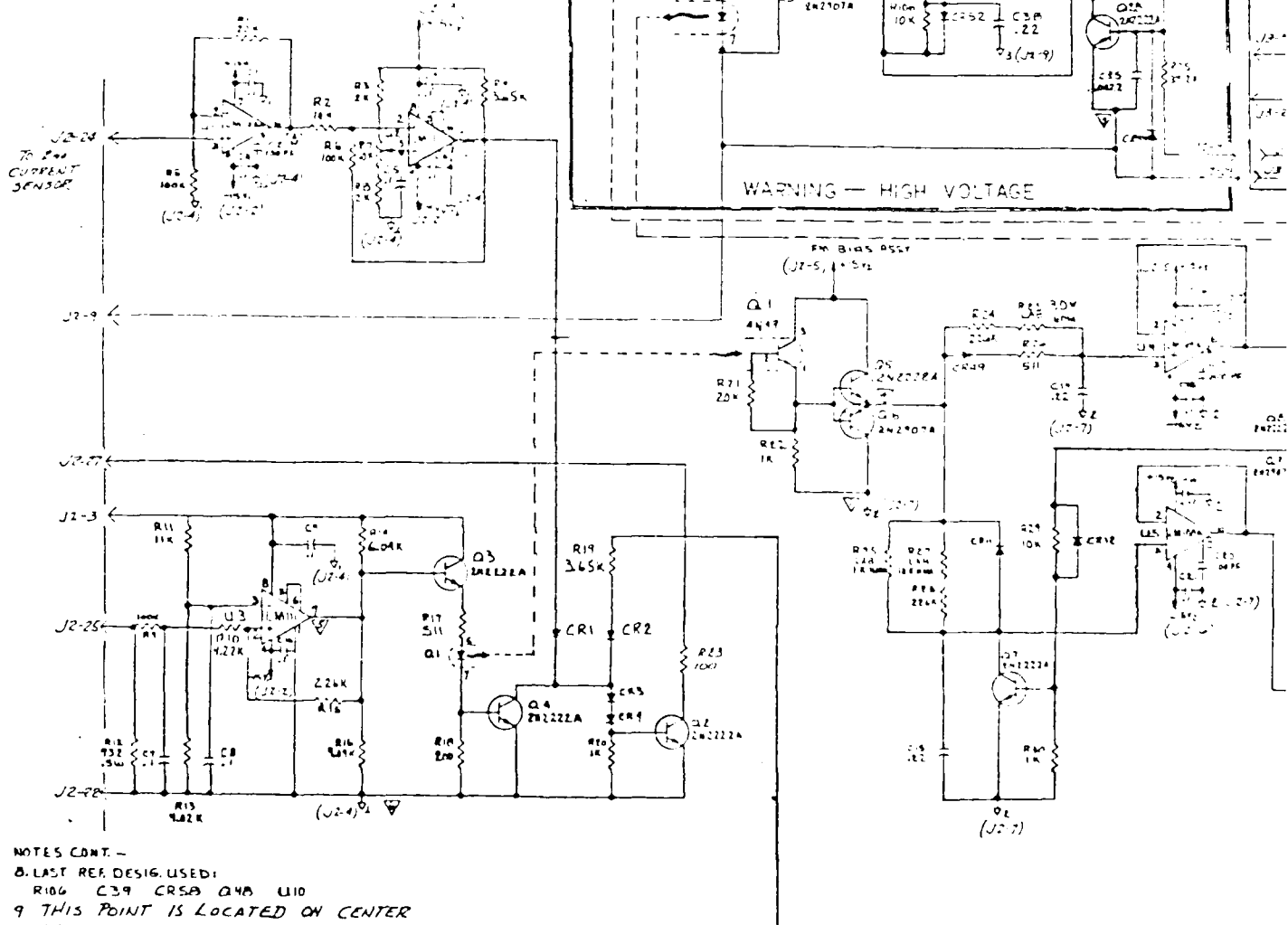
REV:

LOCKHEED Advanced Marine Systems
BIAS SUPPLY MODULE
270 VDC INPUT, 150V REG OUTPUT
SCHEMATIC DIAGRAM
E57128   5806282

Figure 15-B.   Present Schematic Diagram

Figure 15-C. Present Schematic Diagram
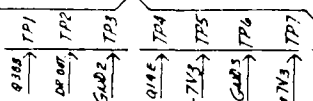
System Schematic — Advanced Line Contactor (Drawing No. 5814498 / 5806290)

Figure 15-D. Present Schematic Diagram

COLLECTOR
BUS
(FROM SHEET 1)

10
IDENTICAL
CIRCUIT
ASSEMBLIES

10
IDENTICAL
CIRCUIT
ASSEMBLIES

10
IDENTICAL
CIRCUIT
ASSEMBLIES

10
IDENTICAL
CIRCUIT
ASSEMBLIES

TRANSISTOR SWITCH ASSEMBLY
SCHEMATIC DIAGRAM

5806287
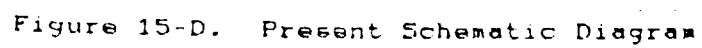
The EMR was energized by turning-on all three transistor switches, Q19, Q20, and Q22. When the main contacts pulled-in, the EMR econimizer switch would turn-off transistor Q20 which would: (1) force the first free wheeling diode to conduct current around the pull-in coil until its value decayed from 2 Adc to 50 mAdc and (2) allow the econimizer coil to be energized.

The EMR was turned-off by turning-off both transistor switches Q19 and Q22, and forces the second and third free wheeling diodes to free wheel the econimizer coil current through the 270 Vdc source. The econimizer coil current rapidly decays and allows the EMR main contacts to open.

In an effort to reduce the parts count, the present design eliminated the transistor switch Q19 (in line with EMR terminal X1); the associated driver, opto-isolator, and isolated low voltage supply; and the second and third free wheeling diodes. In return, the present design added a direct connection between EMR terminal X1 and ALC terminal A2 and a free wheeling diode between EMR terminals X2 and X1 (cathode to X2, anode to X1, respectively).

This change caused the EMR release time to increase, but laboratory tests with the first Hartman EMR prototype showed that operation with the increased release time was acceptable.

However, recent tests on three Hartman EMR prototypes have shown that they had a wide range of release times and suggested that the original turn-off scheme might be more beneficial. To reduce the release times, a 10,000 ohm resistor was inserted in series with the free wheeling diode connected between EMR terminals X2 and X1; and a 0.033 microfarad capacitor was connected from EMR terminal X2 to the 270 Vdc return (to absorb the voltage spike across the collector-emitter of transistor switch Q22).

MORE RECENT TESTS HAVE SHOWN THAT THE OPERATION OF THE EMRs IS MORE DEPENDENT UPON A NUMBER OF EXTREMELY CRITICAL MECHANICAL ADJUSTMENTS (WHICH MAY VARY WITH EMR USE) THAN IT IS ON THE DECAY OF CURRENT IN THE ECONIMIZER COIL.

c. Transistor Switch Sweep-Out Circuit. The initial design of the ALC used a base current sweep-out circuit with the same current capacity as the present base current driver (80 Adc) to obtain fast turn-off of the main transistor switch. In the ALC application, fast turn-off of the main transistor switch is not required, nor desired, since fast turn-offs produce high voltage spikes on the dc input voltage. Laboratory tests showed that satisfactory switching of 400 Adc and 600 Adc were obtained with the present design, which eliminated the use of five TO-3 power transistors and the need for a high current -7 Vdc supply.

d. Reduction Of -7 Vdc Current Capacity. See the discussion above.

e. Deletion Of Various Speed-Up And Baker Clamp Diodes.
Much of the electronic experience of AMS is with fast switching,
high frequency, power switching transistor applications. The
initial design of the ALC was done over a very short period of
time and much of the AMS standard circuits went into the initial
design. In the packaging phase, it was necessary to review the
entire design and reduce the parts count where ever possible. In
a number of places speed-up diodes and Baker Clamps were not
actually required for ALC application and were, therefore,
eliminated.

V. BASIC LIMITATIONS

1. SAFETY NOTE.

The leakage current detector monitors the dc load current from
the ALC output without any direct electrical connection. This is
a proprietary item and is purchased from American Aerospace
Controls, Inc. It is designed to sense current over the range of
0.2 to 5 mAdc with an accuracy of +/- 4% over a temperature range
of +/- 75 degrees C. It has a linear output of 1 Vdc/mAdc to 8
mAdc. The maximum output voltage is 10 Vdc and is obtained from
10 mAdc to 4.25 Adc. Above 4.25 Adc the sensor output drops to
zero.

THUS, IF THE TRANSISTOR SWITCH SHOULD FAIL TO TURN-OFF (OR IF ANY
TYPE OF A SHORT-CIRCUIT EXISTS BETWEEN TERMINALS A1 AND A2) THE
FAILURE ALARM LIGHT WILL NOT SHOW THIS DANGEROUS CONDITION,
UNLESS THE LOAD CURRENT IS BELOW 4.25 ADC.

If the main relay contacts weld close, the failure alarm light
will function properly only if the auxiliary contacts follow the
main contacts and do not change state.

2. INTRODUCTION.

This section and the following section (BASIC FAILURE MODES)
allowed the designers of the ALC to review the ALC system and
component design concepts that were conceived by AMS in May of
1983. At that time, there was little laboratory data to confirm
one design concept over another. Funding limitations required a
very short design period, yet the design had to be "bullet-
proof," straight forward, and consistent with AMS technology
(high power, fast switching transistor applications). The review
was based on the experience gained by fabricating and testing a
breadboard and two prototype Advanced Line Contactors (ALCs).
During the review, the following statement was frequently voiced:
"In the next design, we should do it this other way, rather than
that way, because . . ."

3. BASIC LIMITATIONS:

a. Function. The function of the Advanced Line Contactor
(ALC) is to turn-on and turn-off currents of 400 Adc and below in
a dc circuit. This function should not be confused with the

protective function of a circuit breaker to open large overload currents. The ALC is simply a switch with a finite time (75 milliseconds, maximum) to turn-on or turn-off a load current of 400 Adc (maximum). In an overload condition, the ALC is capable of turning-on and off 600 Adc three times in a two (2) minute period; it is not designed to open load currents above 600 Adc.

b. Input/Output Suppressor Limitations. In any direct current switching application the stored energy, associated with the dc input circuit inductance and the output load circuit inductance plays a major role in the success or failure of the switching device. In the ALC design, input and output suppressors have been incorporated to control the release of this energy.

The input and output suppressors have limited dissipation abilities; but in the case of the input suppressor the allowable dissipation is not well defined. Thus, if the input/output circuit inductance is increased sufficiently, either suppressor can be made to fail. Although the circuit parameters of the input/output circuit inductances have not been contractually defined, a paper design estimate indicated that the ALC should be able to function satisfactory with 1.5 mH, maximum, in the dc input circuit, and 1.2 mH, maximum, in the output load circuit. This estimate has not been confirmed in laboratory testing.

c. Loss-of-Saturation Circuit Operation.

(1) If the ALC turns-on into a shorted or too heavy of a load, the Loss-Of-Saturation (LOS) circuitry will:

(a) turn-off the transistor switch in less than 100 microseconds and

(b) prevent the relay from closing into the fault current.

The result is that there will be no damage to the unit.

(2) HOWEVER, IF THE ALC (IN THE "ON" CONDITION) IS ASKED TO SWITCH-OFF A LOAD CURRENT ABOVE 600 ADC, THE LOS (IF ACTIVATED) WILL TURN-OFF THE POWER TRANSISTOR SWITCH IN LESS THAN 100 MICROSECONDS, WHICH WILL DE-ENERGIZE THE RELAY. IN THE ATTEMPT TO OPEN THIS EXCESSIVE CURRENT, THE RELAY WILL BE DAMAGED.

The elimination of the LOS circuit might allow the unit to survive over current excursions at the expense of some transistor failures.

d. Transistor Power Switch Limitation. If the relay main contacts fail to close, the transistor power switch will be

forced to carry the load current continuously. Since there is no
transistor heat sinking for continuous operation, the transistor
junction temperature will continue to rise until it reaches 200
degrees C, where the silicon will melt and cause the transistors
to fail (short-circuit). The shorted transistor switch will
continue to carry load current, but will be unable to turn-off
the load. Therefore, future designs should include fail safe
contact closure.

        e. Electromagnetic Relay Limitations. Tests have shown
that the operation of the EMR is dependent upon a number of
extremely critical mechanical adjustments (which may vary with
EMR use). If the energizer switch is adjusted to open too soon,
the main contacts may not seat properly, or may cause the EMR to
chatter. If the energizer switch is adjusted to open too late,
the pull-in coil may be continuously excited and will burn-up.
Similarly, if the EMR "throw" adjustment is too short the main
contacts will not seat properly; if too long, the soleroid may
not seat properly and the force generated by the solenoid may not
be enough to properly seat the contacts.

Future designs will use a energizer switch (with a non-critical
adjustment) and time delay circuits to electronically transfer
from the energizer coil to the econimizer coil.

        f. Low Voltage Power Supply Shutdown Circuit. The present
design has a protection circuit that will shutdown the low
voltage power supply if the dc input voltage falls below 160 Vdc.
The original purpose was to protect the EMR from attempting to
turn-on, if the dc input voltage was below the EMR pick-up
voltage of 150 Vdc.

If the ALC has been turned-on and then the dc input voltage falls
below 160 Vdc, all low voltage will be shutdown until the dc
input again rises above approximately 170 Vdc. When the low
voltage is shutdown, the main transistor switch will not
function, the EMR coil driver transistor will turn-off, and the
EMR will be left to open the load current.

In future designs, a feature should be implemented such that
the start-up voltage is 160 Vdc, or greater, and the drop-out
voltage is below 32 Vdc.

VI.   BASIC FAILURE MODES

1.   INTRODUCTION.   This section details basic failure modes for
the major ALC subsystems.

2.   ALC SUBSYSTEMS.   The ALC can be divided into the six
following subsystems:

      (1)   Main Transistor Power Switch,
      (2)   Electromagnetic Relay (EMR),
      (3)   Transistor Switch Driver and Logic,
      (4)   EMR Driver and Logic,
      (5)   Customer Interface Logic, and
      (6)   Low Voltage Power Supply.

3.   FAILURE SYMPTOMS.   The ALC has only two meaningful normal
states:

      a.   energized and not carrying load current (off) and
      b.   energized and carrying load current (on).

(The third state, i.e., not energized and not carrying load
current, is superfluous.)

The ALC can have the following failure symptoms (as well as
others not listed):

      a.   will not turn-on;

      b.   will not turn-off;

      c.   will not turn-on with proper transistor switch/EMR
           timing sequence;

      d.   will not turn-off with proper transistor switch/EMR
           timing sequence;

      e.   will turn-on, but voltage across ALC terminals A1-A2 is
           too high:

           (1)   EMR contact voltage,
           (2)   transistor switch saturation voltage;

      f.   will turn-on, but voltage across ALC terminals A1-A2 is
           erratic:

           (1)   EMR contact voltage,
           (2)   transistor switch saturation voltage;

    g.   will turn-on, but timing of voltages across ALC
        terminals A1-A2 is erratic:

        (1)   EMR contact voltage,
        (2)   transistor switch saturation voltage;

    h.   the dc input current exceeds 150 mAdc (at 270 Vdc) with
        the ALC turned-off; and

    i.   excessive heat from the ALC enclosure (50 degrees C, hot
        to the touch).

The likelyhood of each ALC subsystem causing a particular failure
sysmptom is evaluated in TABLE II as follows:

                 NA   Not Applicable

                 X   Probable Subsystem Failure

                 O   Possible Subsystem Failure

If one looks deeply enough, each subsystem could cause
practically all of the failure symptoms listed. This table only
gives the primary (probable) and secondary (possible) subsystem
failures that could give the particular failure symptom in
question. Thus, "Not Applicable" (NA) may not rule out a
subsystem from being a problem area.

TABLE II.   FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM
FAILURES

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
a. will not turn-on	X	O	X	O	X	X
b. will not turn-off	X	X	X	X	X	X
c. will not turn-on with proper transistor switch/EMR timing sequence	O	X	O	X	NA	O
d. will not turn-off with proper transistor switch/EMR timing sequence	O	X	O	X	NA	O
e. will turn-on, but voltage across ALC terminals A1-A2 is too high:						
(1) EMR contact voltage	O	X	O	X	NA	O
(2) transistor switch saturation voltage	X	O	X	O	NA	X

TABLE II.   FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM
FAILURES (CONTINUED)

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
f. will turn-on, but voltage across ALC terminals A1-A2 is erratic						
(1) EMR contact voltage	O	X	O	X	NA	O
(2) transistor switch saturation voltage	X	O	X	O	NA	X
g. will turn-on, but timing of voltages across ALC terminals A1-A2 is erratic						
(1) EMR contact voltage	O	X	O	X	NA	O
(2) transistor switch saturation voltage	X	O	X	O	NA	X

TABLE II.   FAILURE SYMPTOMS VS. PROBABLE/POSSIBLE SUBSYSTEM
FAILURES (CONTINUED)

FAILURE SYMPTOMS	MAIN TRANSISTOR POWER SWITCH	ELECTROMAGNETIC RELAY (EMR)	TRANSISTOR SWITCH DRIVER AND LOGIC	EMR DRIVER AND LOGIC	CUSTOMER INTERFACE LOGIC	LOW VOLTAGE POWER SUPPLY
h. the dc input current exceeds 150 mAdc (at 270 Vdc) with the ALC turned-off	NA	NA	O	O	O	X
i. excessive heat from the ALC enclosure (50 degrees C, hot to the touch)	X	X	X	X	NA	X

KEY TO SYMBOLS:

    NA   NOT APPLICABLE

    X   PROBABLE SUBSYSTEM FAILURE

    O   POSSIBLE SUBSYSTEM FAILURE

VII. LABORATORY TEST RESULTS

1. SUMMARY OF TEST SET-UP AND PROCEDURE

      a. List of Test Equipment. A list of test equipment is shown in Table III.

TABLE III

#1. Dc Power Supply #1: Rapid Electric Co. Inc., 0 to 400 Vdc @ 800 Adc (maximum), Shop Order B7221, S/N 1282427

#2. Dc Power Supply #2: Kepco Inc., 0 to 40 Vdc @ 300 mAdc (maximum), Model ABC 30-3M

#3. Circuit Breaker CB1: General Electric Co., POWER BREAK, 600 A @ 250 Vdc, TPY2606, S/N 157200

#4. Current Shunt SH1: 500 Adc @ 50 mVdc, PRO500-2

#5. Load: Simplex Inc., 180 kW (maximum) in 1 kW steps @ 270 Vdc, Dwg 47D31349, S/N 9375

#6. Dc millivoltmeter, milliammeter, and voltmeter: Fluke, 8020A multimeter(s)

#7. Command Control Box:

        Toggle Switch (2PST)
        100 ohm 10T Potentiometer
        Milliammeter: Simpson, 0 to 25 mAdc
        28 Vdc Light

#8. Oscilloscope: Hewlett-Packard Storage Scope (10 MHz), Model 1741A

#9. Scope Camera: Hewlett-Packard, Model 197B

#10. Isolator: Tektronix Inc., Model A6902A

#11. Isolation Transformer: Stancor

#12. Miscellaneous

      b. Test Circuit. The circuit for testing the ALC is shown in Figure 16.

FIGURE 16. TEST CIRCUIT SCHEMATIC DIAGRAM
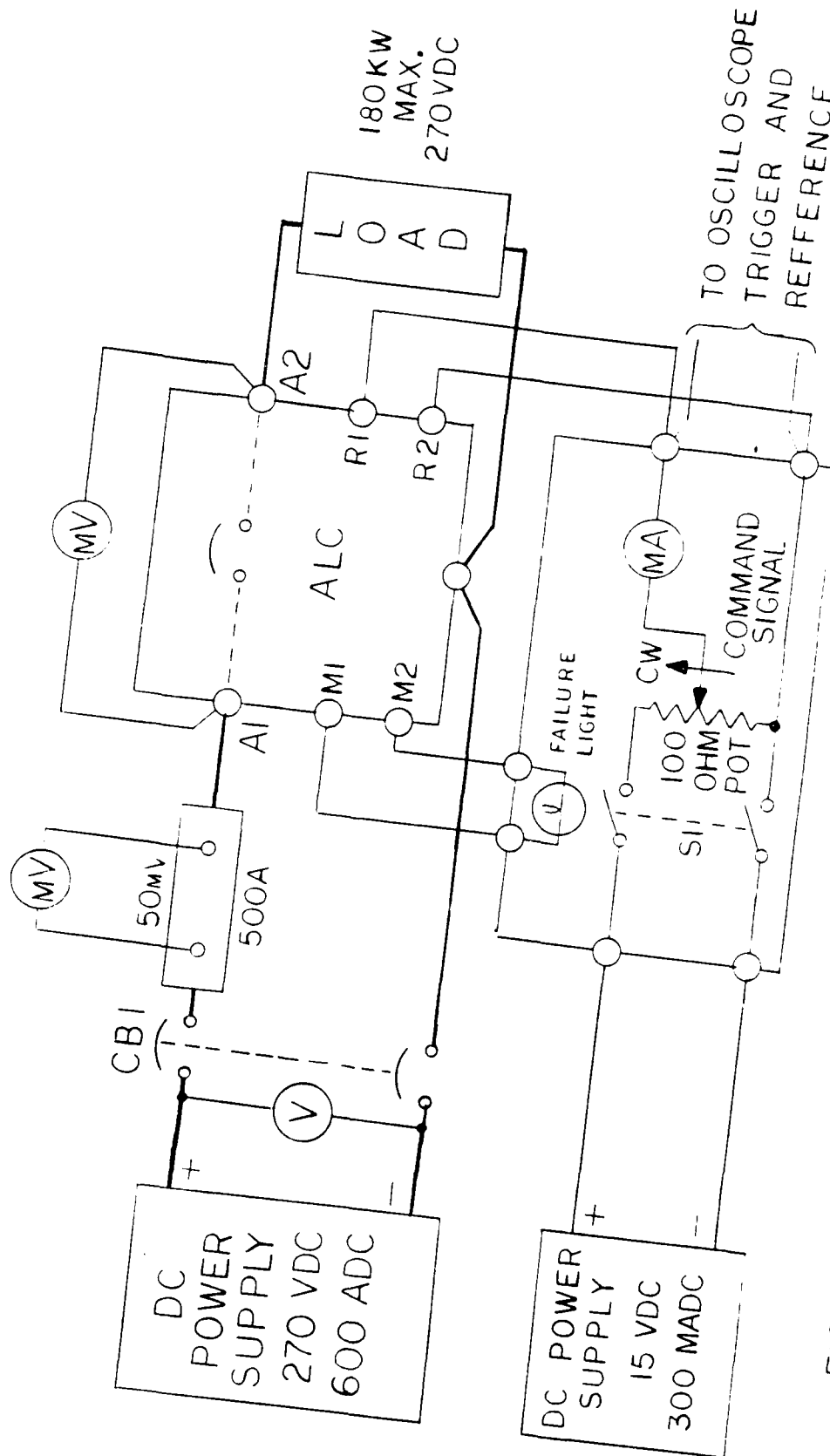
c. Test Procedure.

(1) Connect the ALC unit as shown in Figure 16.

(2) With the output load open circuited and the
millivoltmeter removed from across the ALC terminals A1 and A2;
insert a dc milliammeter in series with the +dc input line to ALC
terminal A1. Adjust the dc input voltage to 265 Vdc and read the
no-load input current to the ALC for the off condition. Repeat
at 280 Vdc.

(3) Re-connect the load and the millivoltmeter as shown
in Figure 16. Select a 1 kW load (@ 270 Vdc).

(a) Slowly turn the 100 ohm input command signal
potentiometer CW from zero until the ALC unit initially turns on.
Record the milliamperes required on the data sheet.

(b) Similarly, slowly turn the 100 ohm input
command signal potentiometer CCW until the ALC unit turns off.
Record the milliamperes required on the data sheet. (Note: Reset
input command for 10 mAdc "on" signal.)

(4) For each of the following load currents: 4.5, 100,
200, 300, 400, 500, and 600 Adc; record the voltage drop across
ALC terminals A1-A2 (using zener diode clamp circuit shown in
Figure 17) during the ALC turn-on and turn-off periods. Use the
input command signal to the ALC as a trigger and reference. Also
record the actual load current and the steady-state and transient
voltage drops across ALC terminals A1 and A2.

(5) For 600 Adc load currents, turn-on and off the unit
a minimum of three times within a two minute period. (Note:
Turn-on ALC only long enough to take data readings.)

(6) For a load current of 400 Adc (except as noted),
record the following waveforms during the ALC turn-on and turn-
off periods (using the input command signal as a trigger and
reference):

(a) the voltage drop across ALC terminals A1-A2
(using the zener clamp circuit shown in Figure 17);

(b) the dc input voltage to ALC (across terminal
A1 to the 270 Vdc return), the dc output voltage from the ALC
(terminal A2 to the 270 Vdc return), and the voltage drop across
ALC terminals A1-A2 (not using the zener clamp circuit);

(c) the dc input current to ALC terminal A1 (100
Adc, maximum); and

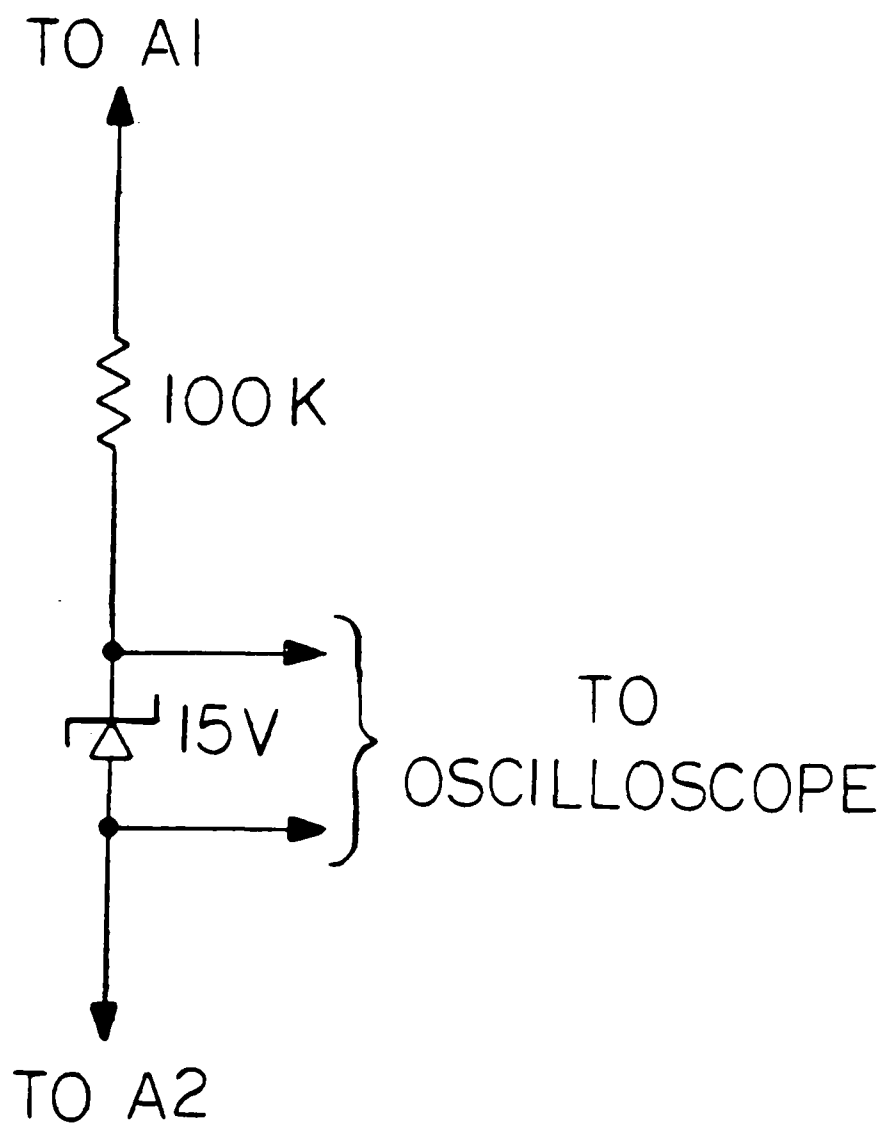(d) the dc output current from ALC terminal A2
(100 Adc, maximum).

Figure 17. Voltage Clamp Circuit for Observing Transistor
Switch and Relay Contact Voltage Drops.

2. SUMMARY OF FINAL TEST RESULTS

UNIT #1 TESTED ON 29 MAY 1986::

No-Load Input Current at 265 Vdc: 113 mAdc

                          at 280 Vdc: 110 mAdc

At 4.5 +/- 0.5 Adc Load Current:

Turn-On Command Current: > 7.58 mAdc

Turn-Off Command Current: < 2.32 mAdc

Turn-On Time (from turn-on
current command to relay
contact closure):   32 mS

Turn-Off Time (from turn-off
current command to transistor
switch turn-off)   75 mS

Dc Input Voltage: 280 Vdc:

LOAD CURRENT IN ADC	ACTUAL LOAD CURRENT IN ADC	STEADY-STATE VOTAGE DROP ACROSS A1-A2 IN mV	MAXIMUM FORWARD VOLTAGE DROP ACROSS TRANSISTOR SWITCH IN mV
4.5	4.5	3.1	200
100	105	35.2	600
200	207	63.5	800
300	315	89	1100
400	410	112.5	1400
500	500	133.9	1800
600 *	620	175.8	4000
600 *	620	175.8	4000
600 *	620	175.8	4000

* Three runs conducted within a two minute period.

2. SUMMARY OF FINAL TEST RESULTS (CONTINUED)

UNIT #2 TESTED ON 29 MAY 1986:

No-Load Input Current at 265 Vdc:	115 mAdc
at 280 Vdc:	112 mAdc

At 4.5 +/- 0.5 Adc Load Current:

Turn-On Command Current:	> 7.5 mAdc
Turn-Off Command Current:	< 2.4 mAdc
Turn-On Time (from turn-on current command to relay contact closure):	33 mS
Turn-Off Time (from turn-off current command to transistor switch turn-off)	74 mS

Dc Input Voltage: 280 Vdc:

LOAD CURRENT IN ADC	ACTUAL LOAD CURRENT IN ADC	STEADY-STATE VOTAGE DROP ACROSS A1-A2 IN mV	MAXIMUM FORWARD VOLTAGE DROP ACROSS TRANSISTOR SWITCH IN mV
4.5	4.5	7.9	200
100	102	116	600
200	202	180	800
300	308	210	1100
400	403	250	1300
500	523	306	1800
600 *	610	316	2600
600 *	610	316	2600
600 *	610	316	2600

* Three runs conducted within a two minute period.

3.   WAVEFORMS OF ALC OPERATION.

The following pages contain operational waveforms of ALC
units #1 and #2. Table IV contains notes and abbreviations
associated with the waveforms.

TABLE IV.   WAVEFORM NOTES AND ABBREVIATIONS

NOTES:

a.   A voltage clamp is required to observe transistor and
     contact voltage drops in a 270 Vdc circuit. Such a clamp
     is shown schematically in Figure 17.

b.   Waveforms will be triggered by the turn-on/turn-off input
     command voltage signal across ALC terminals R1 and R2.

c.   The upper trace zero line is four (4) divisions from the
     bottom line. The lower trace zero line is one (1)
     division from the bottom line.

ABBREVIATIONS   MEANINGS

A1-A2 VOLTAGE   Voltage across ALC terminals A1 and A2
   (CLAMPED)   is clamped (see Note a., above) and has a
_____ V/DIV   vertical sensitivity of _____ V/Div.

COMMAND   Input command voltage signal across ALC
VOLTAGE   terminals R1 and R2 (J4-3 and J4-4,
_____ V/DIV   respectively) and has a vertical
                              sensitivity of _____ V/Div.

LOAD: The load current is _____ Adc.
_____ADC

3. WAVEFORMS OF ALC OPERATION: UNIT #1:
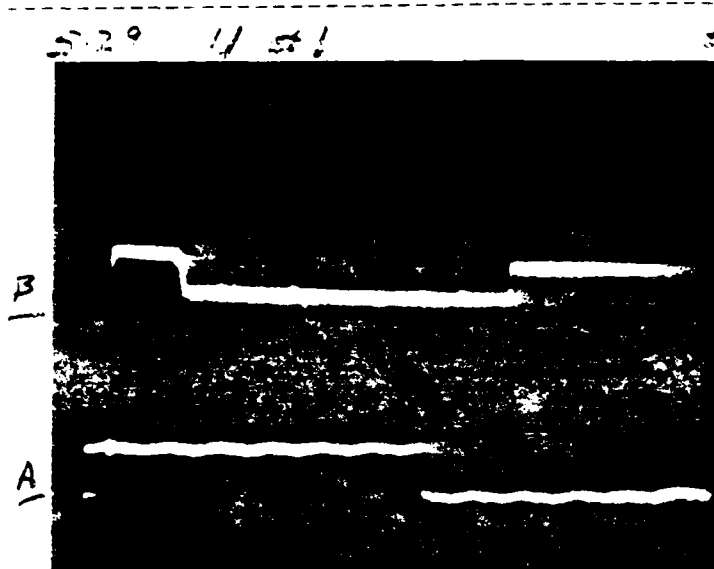
LOAD:
4.5 ADC

A1-A2 VOLTAGE
(CLAMPED):
200 mV/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
20 mS/DIV
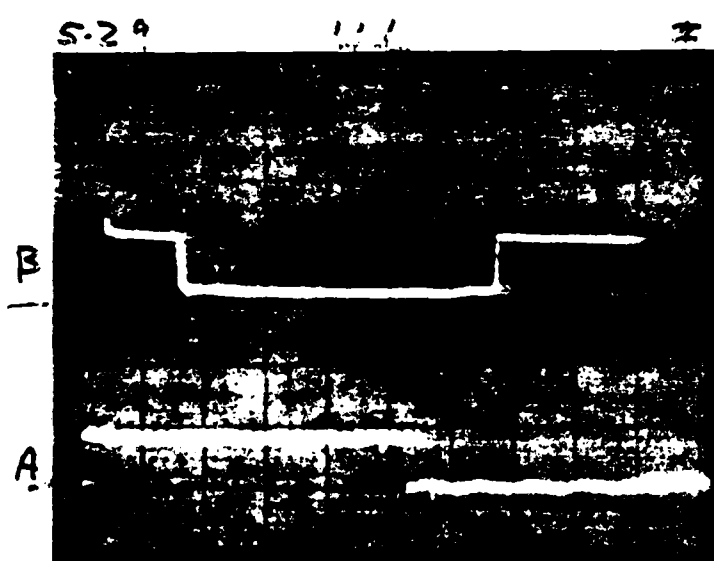
LOAD:
105 ADC

A1-A2 VOLTAGE
(CLAMPED):
500 mV/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
20 mS/DIV

ADVANCED LINE CONTACTOR FINAL REPORT   5814498
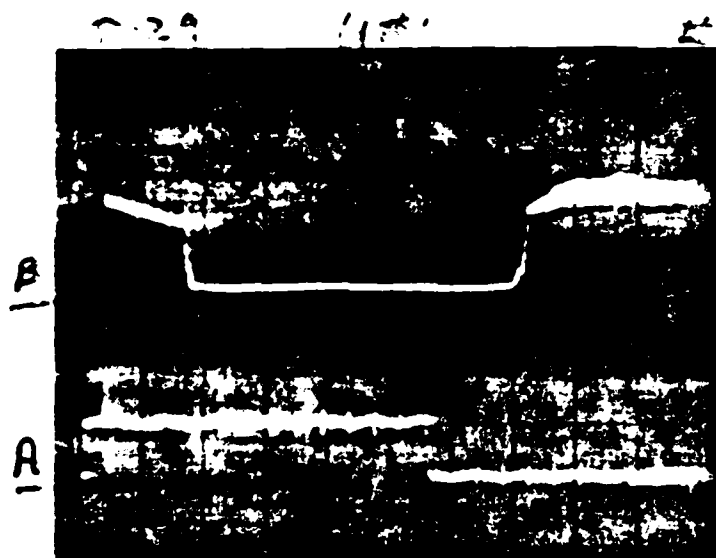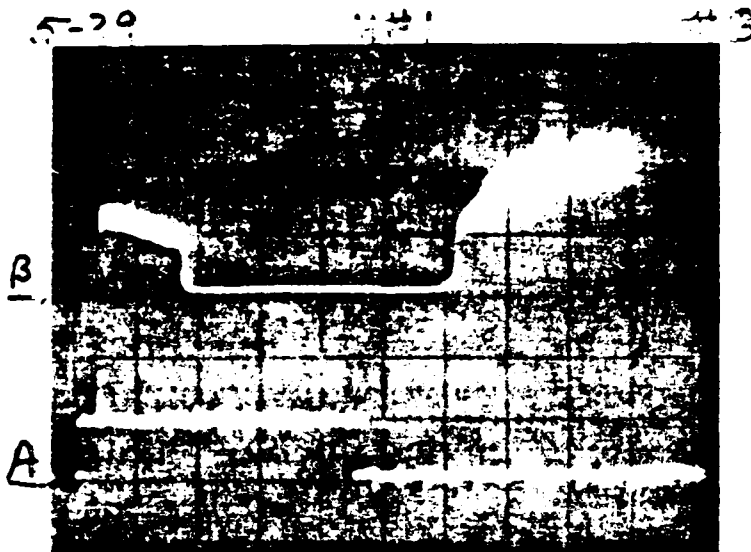
3.   WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):
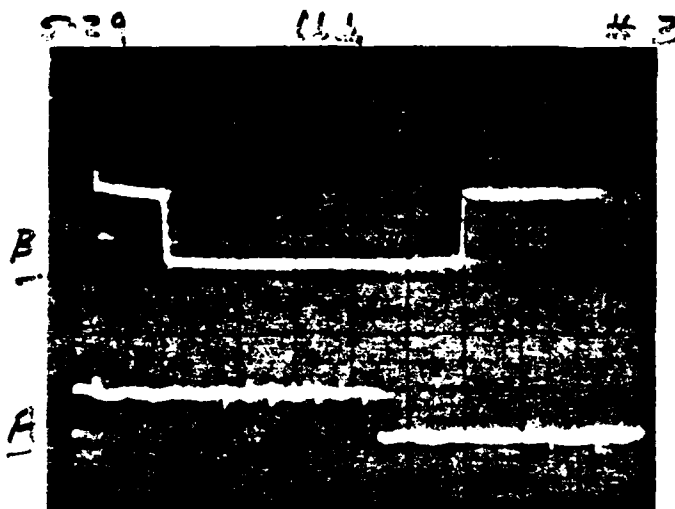
LOAD:
207 ADC

A1-A2 VOLTAGE
  (CLAMPED):
  500 mV/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV
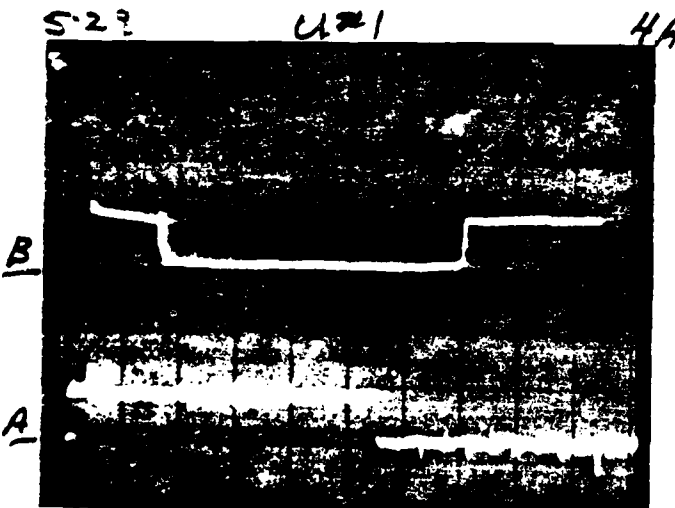
LOAD:
315 ADC

A1-A2 VOLTAGE
  (CLAMPED):
  1.0 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):
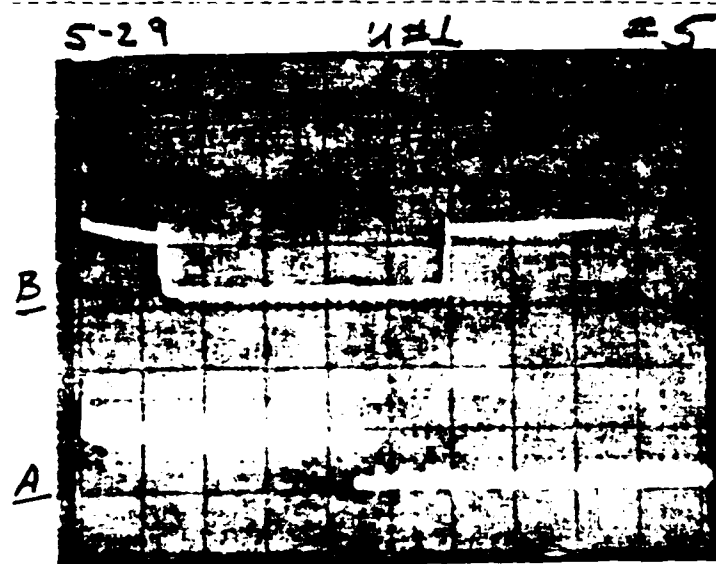
LOAD:
410 ADC

A1-A2 VOLTAGE
 (CLAMPED):
 1.0 V/DIV

COMMAND
VOLTAGE:
 10 V/DIV

HORIZONTAL
 SCALE:
 10 mS/DIV

LOAD:
500 ADC

A1-A2 VOLTAGE
 (CLAMPED):
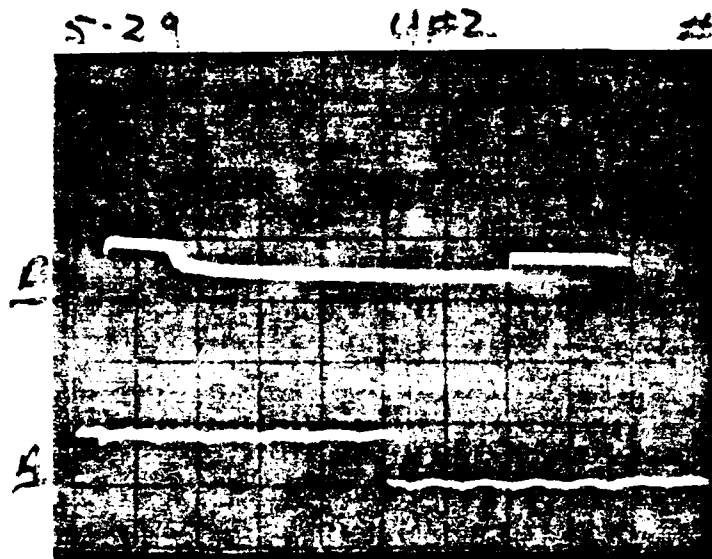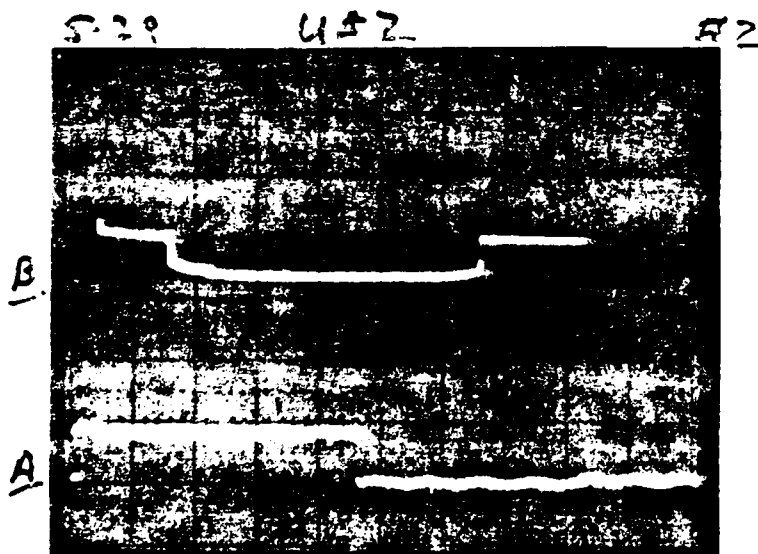 1.0 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
 SCALE:
10 mS/DIV

3.   WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):

LOAD:
620 ADC

A1-A2 VOLTAGE
(CLAMPED):
2.0 V/DIV

COMMAND
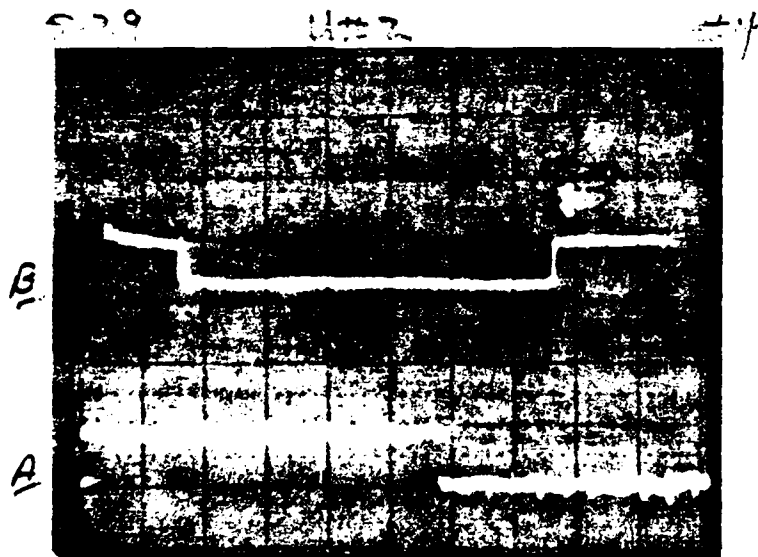VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
20 mS/DIV

NOTE: ALC UNIT #1 WAS SUCCESSFULLY OPERATED AT 620 ADC THREE
TIMES WITHIN A TWO MINUTE PERIOD.
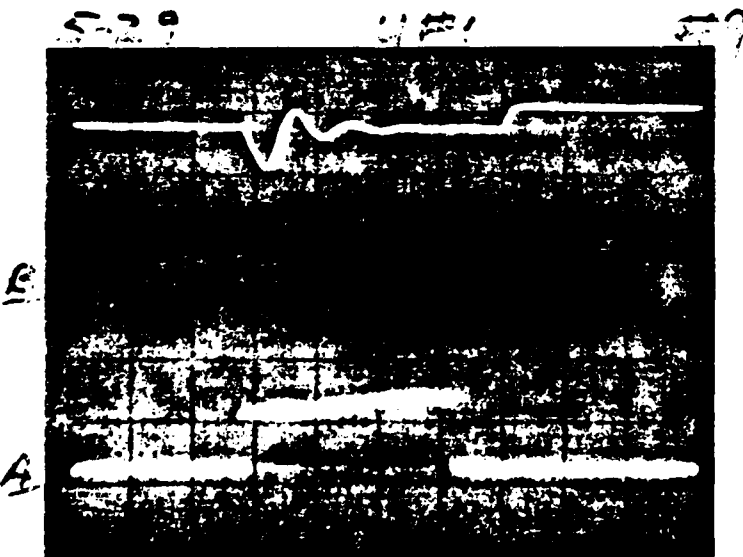
LOAD:
400 ADC

DC INPUT
VOLTAGE:
100 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

3.   WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):

LOAD:
400 ADC

OUTPUT
VOLTAGE:
100 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
100 mS/DIV

LOAD:
400 ADC

A1-A2
VOLTAGE:
100 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
100 mS/DIV
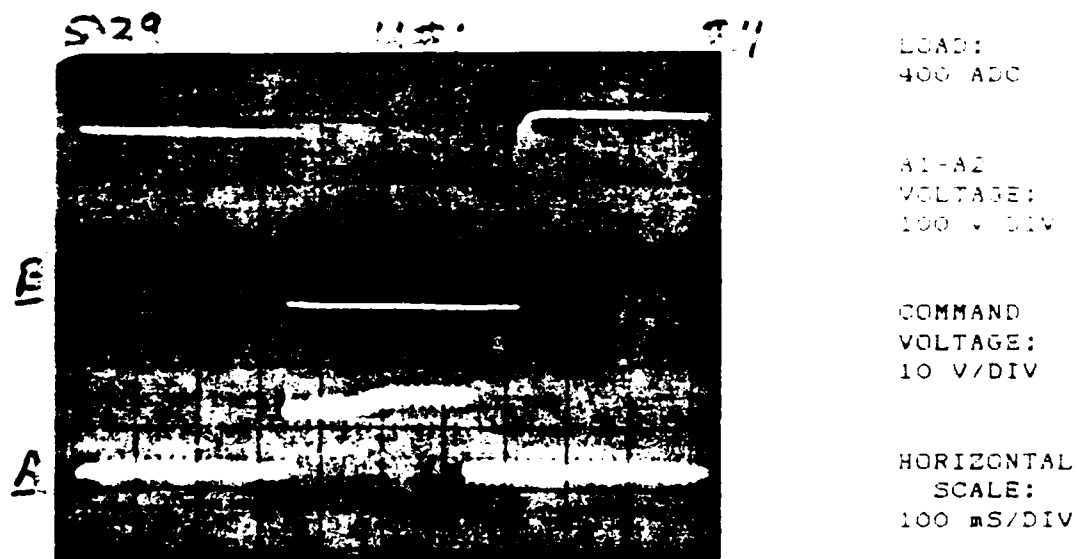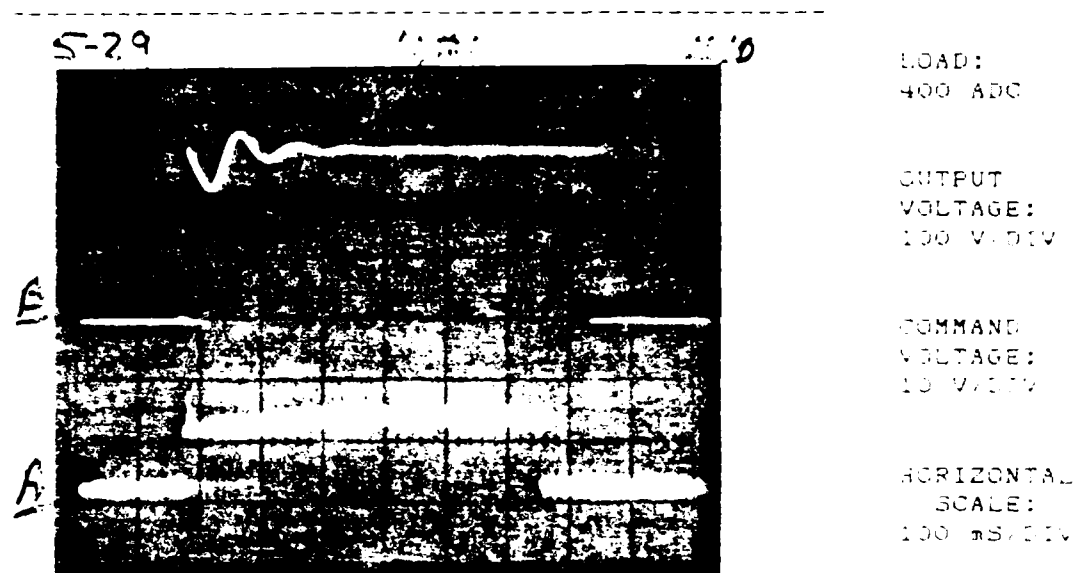
3. WAVEFORMS OF ALC OPERATION: UNIT #1: (CONTINUED):
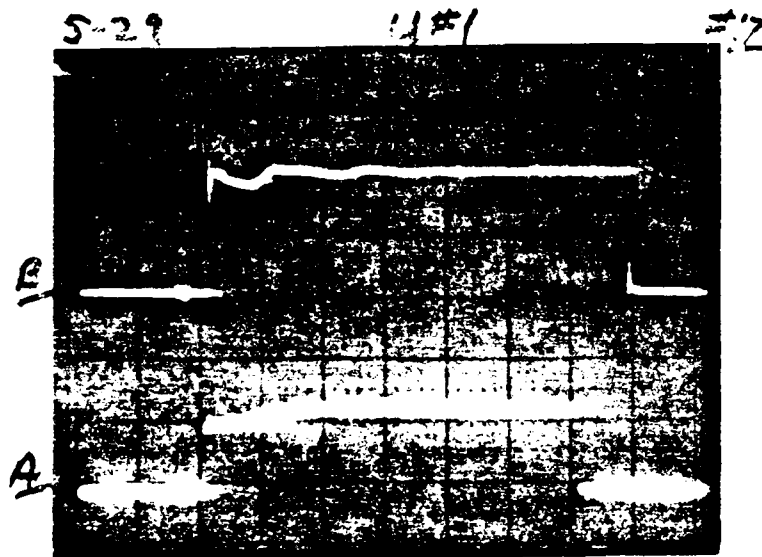
LOAD:
100 ADC

INPUT
CURRENT:
50 A/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV
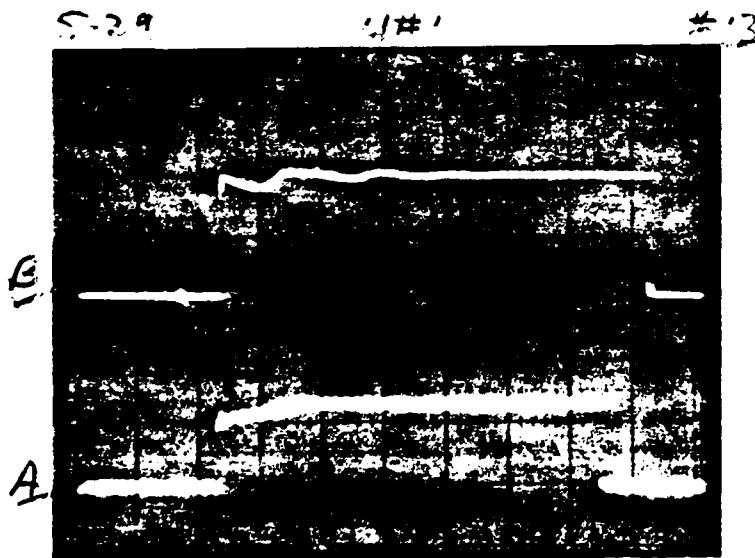
LOAD:
100 ADC

OUTPUT
CURRENT:
50 A/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

3.   WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

LOAD:
4.5 ADC

A1-A2 VOLTAGE
  (CLAMPED):
  200 mV/DIV
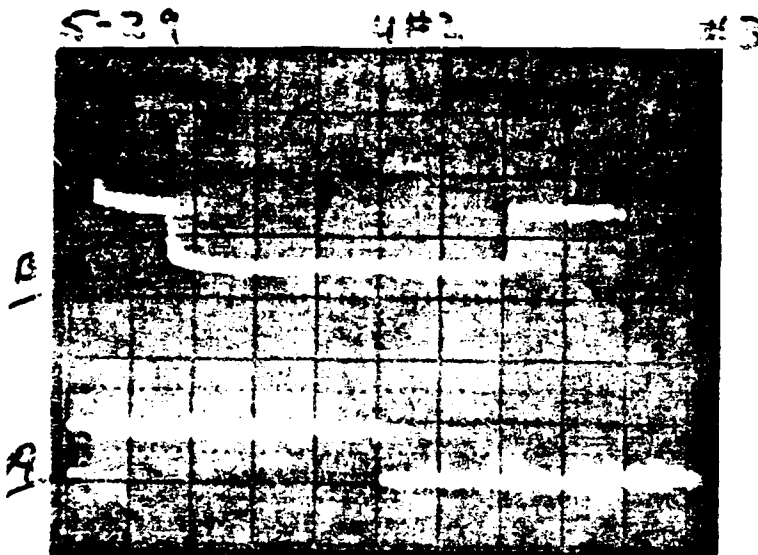
COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV

LOAD:
102 ADC

A1-A2 VOLTAGE
  (CLAMPED):
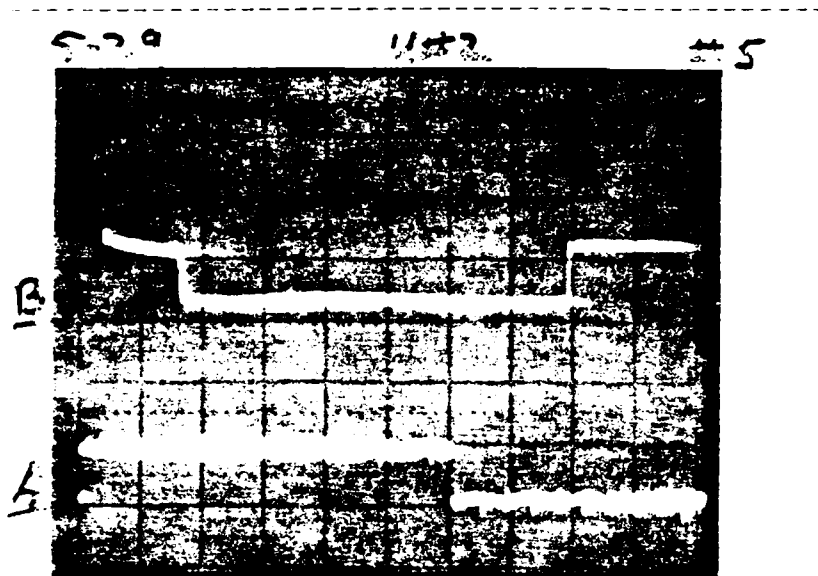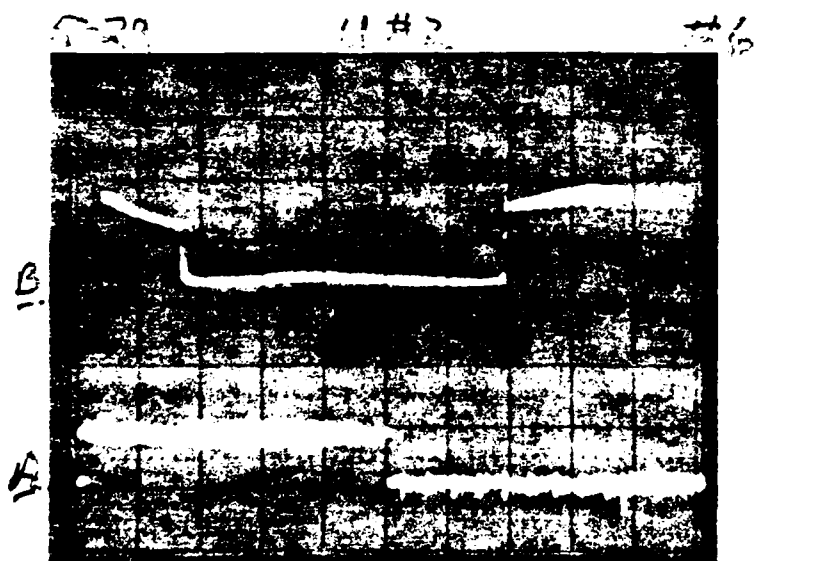 500 mV/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

LOAD:
202 ADC

A1-A2 VOLTAGE
(CLAMPED):
500 mV/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
20 mS/DIV

LOAD:
308 ADC

A1-A2 VOLTAGE
(CLAMPED):
1.0 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
20 mS/DIV

* Flaw in Photo

3. WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

LOAD:
403 ADC

A1-A2 VOLTAGE
  (CLAMPED):
  1.0 V/DIV

COMMAND
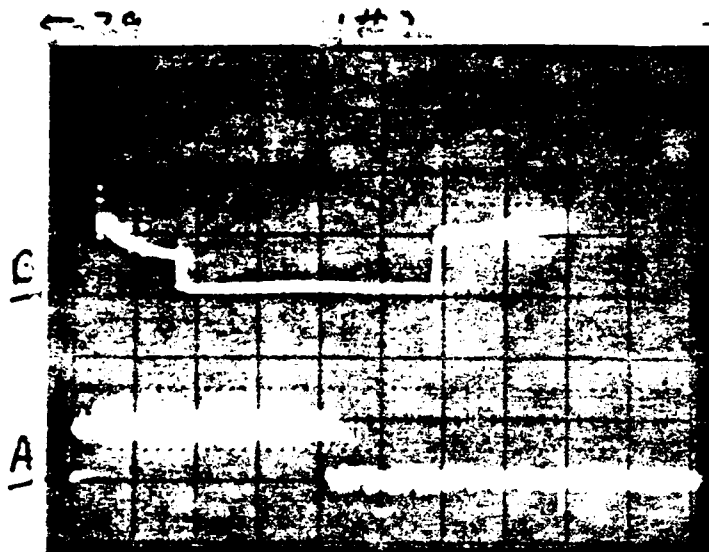VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV

LOAD:
523 ADC

A1-A2 VOLTAGE
  (CLAMPED):
  1.0 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
  SCALE:
20 mS/DIV
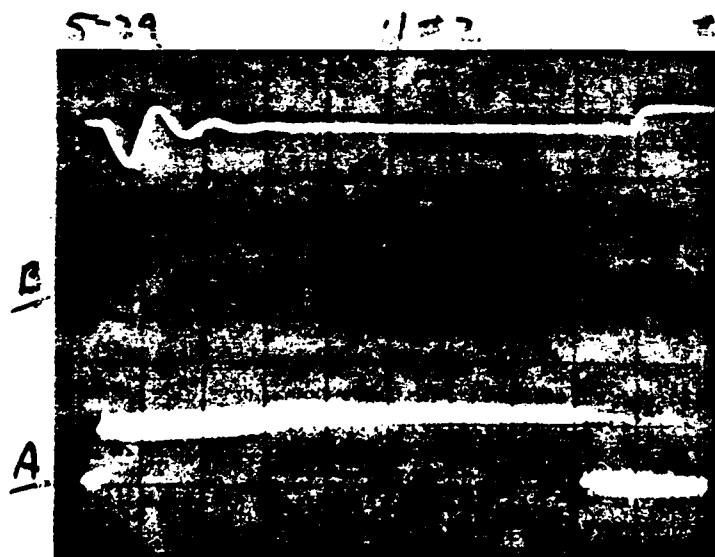
3.   WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

LOAD:
610 ADC

A1-A2 VOLTAGE
   (CLAMPED):
   2.0 V/DIV

COMMAND
VOLTAGE:
_._ V/DIV

HORIZONTAL
   SCALE:
_._ mS/DIV

NOTE: ALC UNIT #2 WAS SUCCESSFULLY OPERATED AT 610 ADC THREE
TIMES WITHIN A TWO MINUTE PERIOD.

LOAD:
400 ADC

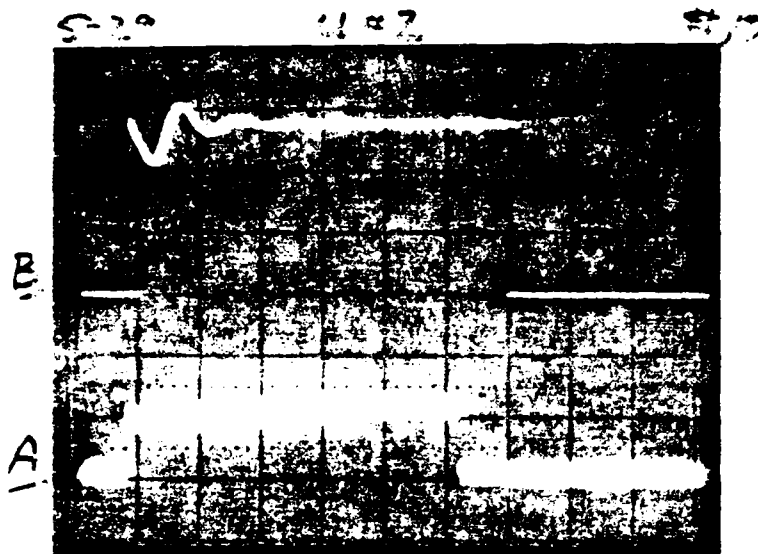DC INPUT
VOLTAGE:
100 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
   SCALE:
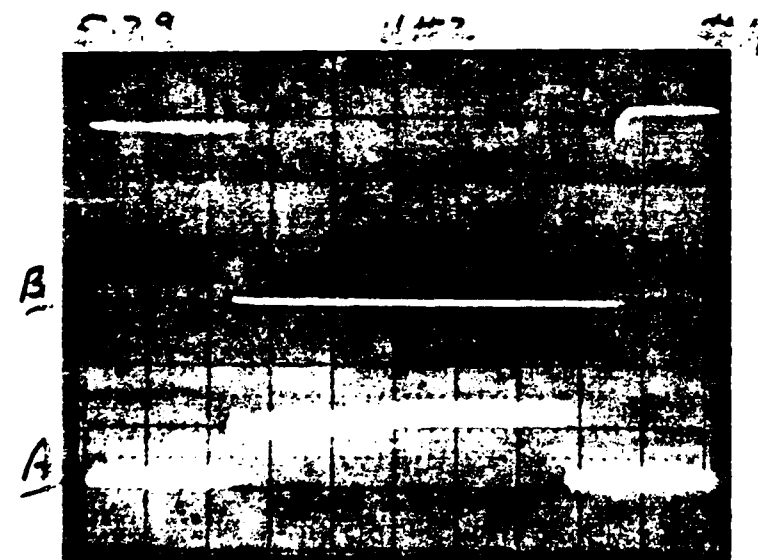100 mS/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):

LOAD:
400 ADC

OUTPUT
VOLTAGE:
100 V/DIV
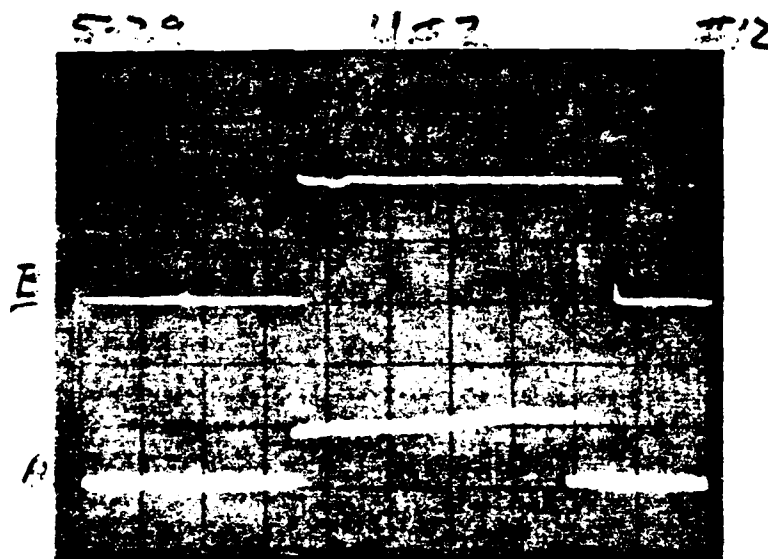
COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

LOAD:
400 ADC

A1-A2
VOLTAGE:
100 V/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

3. WAVEFORMS OF ALC OPERATION: UNIT #2:(CONTINUED):
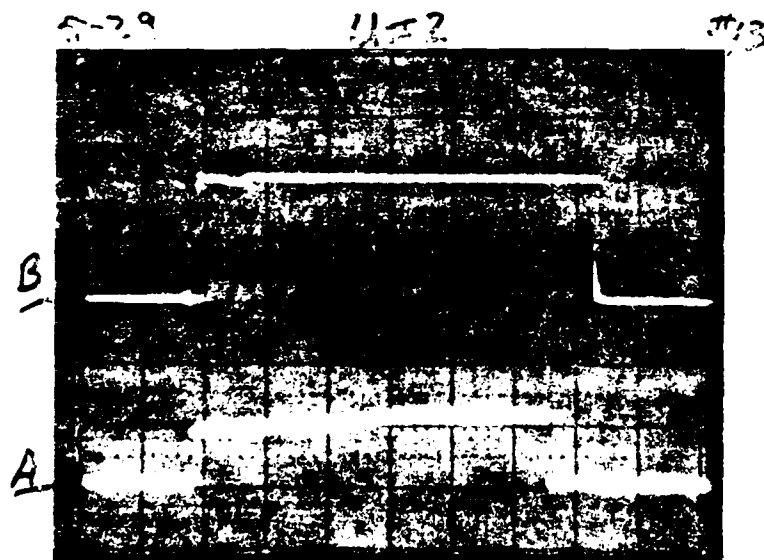

LOAD:
100 ADC

INPUT
CURRENT:
50 A/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

LOAD:
100 ADC

OUTPUT
CURRENT:
50 A/DIV

COMMAND
VOLTAGE:
10 V/DIV

HORIZONTAL
SCALE:
100 mS/DIV

IIX. TEST VERIFICATION

A breadboard and two prototype Advanced Line Contactors (ALCs)
have been fabricated and successfully tested to contract
requirements.

The people listed below have witnessed that the ALCs are able to
turn-on and turn-off continuous load currents between zero and
400 Adc; and non-continuous overload currents of 600 Adc can be
turned-on and off three times in two minutes. In addition they
verify, to the best of their knowledge, that all waveforms and
test data are true.

1. Herbert Schamp, Test Conductor and Responsible for ALC
    Prototype Fabrication:

2. Charles B. Hassan, Circuit Designer:

    C. B. Hassan   06-03-86

3. James E. Honeycutt, Supervisor:

    J. E. Honeycutt 06-04-86

TELCON:

TO: Ed White (Code 6012) of Naval Air Development Center
Warminster, PA

From: Jim Honeycutt of Lockheed Advance Marine Systems
San Diego, Ca

Date: 29 May 1986   Time: 11:30 AM

1.   Jim Honeycutt informed Ed White that AMS had successfully
tested two Functionally Equivalent Prototype Advanced Line
Contactors.

2.   The test was conducted with load currents from 4.5 Adc to
600 Adc, and included turning-on and off 600 Adc three times
within two minutes.

3.   Mr. Honeycutt pointed out to Mr. White that:

    a.   ALC Unit #1 had a total turn-off time of 90 milliseconds
          at 620 Adc (transistor on-time could be shortened and
          reduce the total turn-off time by to 20 milliseconds):

    b.   ALC Unit #2 had a total turn-off time of 72 milliseconds
          at 610 Adc (transistor on-time could be shortened and
          reduce the total turn-off time by 20 milliseconds);

    c.   ALC Unit #2 contains the rebuilt contactor that was
          previously damaged by opening a 634 Adc load (the
          transistor power switch turned-off before the contactor
          opened). As a result, the contact voltage drop is
          higher than anticipated. It is 250 millivolts at 400
          Adc, 306 at 500 Adc, and 316 at 610 Adc.

    d.   Near the end of testing, the 2 mAdc leakage current
          failure light came on in ALC Unit #2. After the unit
          was shutdown to measure the actual leakage current
          (which was only 0.25 mAdc) the failure light did not
          reappear. Subsequent trouble shooting did not reveal
          the cause.

Mr. Honeycutt asked Mr. White for direction. Mr. White indicated
that he was pleased with the results and wanted ALC Units #1 and
#2 shipped to NARDC with out any additional work. Mr. Honeycutt
said that he would comply.

Mr. Honeycutt also mentioned that the transistor switch voltage
drop at 610-620 Adc was only 2.6 Vdc in ALC Unit #2, but was 4.00
Vdc in ALC Unit #1 (5 Vdc is spec max.).

J.E. Honeycutt: _____   06-04-86

C.B. Hassan: _____   06-03-86

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