PROTECTION OF MEDICAL EQUIPMENT AGAINST ELECTROMAGENTIC PULSE (EMP): PHASE I

Final Report

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J. Klebers

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The purpose of Phase I was to examine EMP vulnerabilities of medical equipment and to form a technical basis for definition of hardening options. To accomplish this, 1.) site surveys were conducted of the deployable MUST and MASH field hospitals, 2.) equipment manuals were obtained, 3.) shielding effectiveness of shelters was examined, 4.) EMP vulnerability screens were carried out on critical equipment, 5.) summaries of vulnerabilities were documented, and 6.) feasible hardening options were identified. Findings of this study are that many units of medical equipment are vulnerable to EMP. All vulnerable equipment does not need to be hardened, if it is to be deployed in hardened shelters. Of the 145 units considered for deployment by the Army, it is likely that many will require hardening. This work has demonstrated a cost-effective approach to future assessments and EMP mitigation techniques.

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ACKNOWLEDGEMENT

Equipment data has been provided by Maj. Vandre, USAMBRDL, Maj. Boyle, 10th MASH, Maj. Barnwell, 8th Evacuation Hospital, Capt. Byrne, Medical Service Corps, T. Bock, Harry Diamond Laboratories, A. Kasten, National Maintenance Point, and T. Godfrey, U.S. Army Natick Research and Development Center. Their contributions are greatly appreciated. The following IRT personnel also made significant contributions to this project: D. Cameron, T. Styer and W. Clark.

EXECUTIVE SUMMARY

This report documents the results of Phase I of the Small Business Innovation Research (SBIR) Program to study methods of EMP mitigation or hardening options for medical equipment. The purpose of Phase I was to examine EMP vulnerabilities of medical equipment and to form a technical basis for definition of hardening options. To accomplish this, 1.) site surveys were conducted of the deployable MUST (Medical Unit Self-contained Transportable) and MASH (Mobile Army Surgical Hospital) field hospitals, 2.) equipment manuals were obtained, 3.) shielding effectiveness of shelters was examined, 4.) EMP vulnerability screens were carried out on critical equipment, 5.) summaries of vulnerabilities were documented, and 6.) feasible hardening options were identified.

The information collected and analyses completed during Phase I of this SBIR program provides a good database for use in achieving the Army's goal of protecting critical medical equipment against EMP.

Critical equipments have been identified and are listed in this report. Seventeen of these equipments were assessed for EMP vulnerability. Of these, eleven were found to be vulnerable to EMP. The results indicate the probable vulnerability of many types of medical equipment. Actual tests of equipment at Harry Diamond Laboratories have served to support this conclusion.

Observations made from the site surveys indicate that, in the present unprotected state, equipment in Temper tents would probably be damaged during an exposure to EMP. With an unprotected power grid, even equipment in the ISO-shelters (International Organization for Standardization) presently in use would have a high probability of damage.

All the equipment surveyed in this program will not be hardened to EMP. One reason for this is that a large part of the equipment in present use will be replaced. Another reason is that about 60% of the equipment will be located in ISO-shelters, and thus, be at least partially protected from EMP. This equipment will be fully protected when hardened ISO-shelters come into use, and when protection has been deployed in the power grid.

Techniques for protecting individual equipments are presented and discussed. There will be some units which are critical and which can be deployed in unprotected areas. These units must be identified and hardened individually. One candidate is the Hi-Cap X-ray unit presently in the procurement process. Standardized layouts developed by the Defense Medical Standardization Board (DMSB) will facilitate identification of other equipments to be hardened.

Most of the new units are off-the-shelf items. Units selected for individual hardening will then require a form of a product improvement program (PIP) to implement and maintain the hardening.

The PIP will involve screening and testing to determine which equipment doesn't survive and must be retrofitted with hardening. Cost-effective test methods will have to be utilized. This will call for use of small simulators or pin-injection testing, which are fast and relatively inexpensive. IRT has such facilities in-house.

In its Phase I SBIR program, IRT has demonstrated a methodology for preliminary EMP vulnerability screening of medical equipment. An approach has been demonstrated whereby seventeen equipments have been screened in a short time period under a cost-effective program.

Phase II of this work should develop a sound EMP protection program for medical equipment, where selected equipments will be screened, tested, and retrofitted. Some important elements and issues for this program have been discussed above. Details for this program will be discussed in IRT's Phase II proposal.

1. INTRODUCTION

The high altitude nuclear burst presents a potential threat to sensitive ground-based electronic equipment from its radiated electromagnetic pulse (EMP). This study, sponsored under the Small Business Innovation Research (SBIR) program,* was undertaken to establish vulnerabilities and to identify feasible EMP mitigation or hardening options for medical equipment.

Initial steps in this study were to compile equipment lists, and to identify the equipments considered most critical to maintaining acceptable patient handling capability in a deployable military hospital. Sources of data include USAMBRDL, Fort Detrick, the Harry Diamond Laboratories Woodbridge Research Facility (HDL WRF), US Army Natick Research and Development Center, Site Surveys, and the National Maintenance Point, Fort Detrick. Two site surveys were conducted to gain first-hand knowledge about existing equipment and its deployment. The first was at the 10th MASH unit at Fort G.G. Meade, MD, and the second was at the 8th Evacuation Hosptial, deployed in the field at Camp Roberts, CA.

Once critical equipments were identified, service manuals were obtained to evaluate likely modes of EMP susceptibility. This susceptibility screening was limited to interface and input/output (I/O) circuits. Hence, power and sensor or control lines were treated as the primary collectors of EMP. Vulnerability assessments were based on application of a damped sinusoid pulse for the EMP threat. The pulse parameters were derived from response data measured for an Electrosurgical Apparatus at the AESOP facility, HDL WRF.

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2. CRITICAL EQUIPMENT SELECTION

Units addressed in this study were selected from medical equipment inventory lists and site surveys. Interviews with commanding officers and maintenance and supply personnel served to identify equipments considered most critical in the military hospital. The units which were consistently referenced are tabulated below, along with location of use (Ref. 10, 11).

a. Emergency Room
   1. Electrocardiograph
   2. Defibrillator and Cardioscope
   3. Field Suction Unit

b. Operating Room
   1. Electrosurgical Apparatus
   2. Defibrillator
   3. Surgical Lights

c. Laboratory
   1. Flame Photometer
   2. pH Blood Gas Analyzer

d. X-Ray Room
   1. X-Ray Apparatus and Fluoroscope

e. Intensive Care Ward
   1. Field Suction Unit
   2. Respirator

Additional guidance on the selection of equipment was gained from interviews with seven surgeons conducted by Maj. Vandre (Ref 3). The survey group consisted of four generals, two orthopedic surgeons, and one thoracic surgeon. All but one had either war experience or heavy trauma experience. A category and ranking was assigned as an aid to judging the relative importance of the various types of equipment. A listing of the survey results is given below.

Table 2.1 Critical Equipment Ranking (Maj. Vandre) (Ref 8)

Category 1 - CRITICAL, many lives would be lost if this item were destroyed.

Category 2 - IMPORTANT, some lives would be lost.

Category 3 - UNIMPORTANT, could get along without it but with reduced capacity.

* - Indicates data obtained on item by IRT.

ITEM	CATEGORY/RANKING
1. Surgical Lights	1.14
2. X-Ray Apparatus without Flouroscope	1.33*
3. Resuscitator	1.43*
4. Electrosurgical Apparatus	1.57*
4. Respirator, Positive Pressure	1.57*
6. Electrical Generator	1.67
7. X-Ray Apparatus with Flouroscope	1.83
8. Physiological Functions Monitor: ECG, Temp, BP	2.00*
8. Respirator, Intermittent Positive Pressure	2.00
10. Defibrillator and Cardioscope	2.14*
11. Blood Gas Apparatus	2.50*
12. Hematology with Platelets Analyzer	2.67
12. X-Ray Mobile Image Intensifier	2.67
14. Electronic Ultransonic Sphygmomanometer	2.71
14. Angiographic Injection System	2.71
14. Automatic Digital Blood Cell Counter	2.71
17. Electrolytic Solution Analyzer	2.83
17. Chemistry Analyzer	2.83
17. Ultrasonic Unit	2.83
20. Electroencephalograph	3.00

Table 2.1 (Continued)

ITEM	CATEGORY/RANKING
20. 2-Channel Electroneptagmograph recorder	3.00
20. Audiometer	3.00
20. Hemodialysis Apparatus	3.00
20. Automatic Hypodermic Injection Apparatus	3.00
20. Densitometer-Fluorometer Electrophoresis	3.00
20. Automatic Flame Photometer	3.00*
20. Ultraviolet Spectrophotometer	3.00
20. Electrophoretic Scanner	3.00
20. Co-Oximeter	3.00
20. Digital Chloride Meter	3.00
20. CAT Scanner	3.00

Circuit diagrams, parts lists, or complete service manuals were collected for the equipments listed below. The majority of the literature available, but not all, contained sufficient identification of parts to construct EMP susceptibility models.

Table 2.2 Manuals/Data Collected By IRT

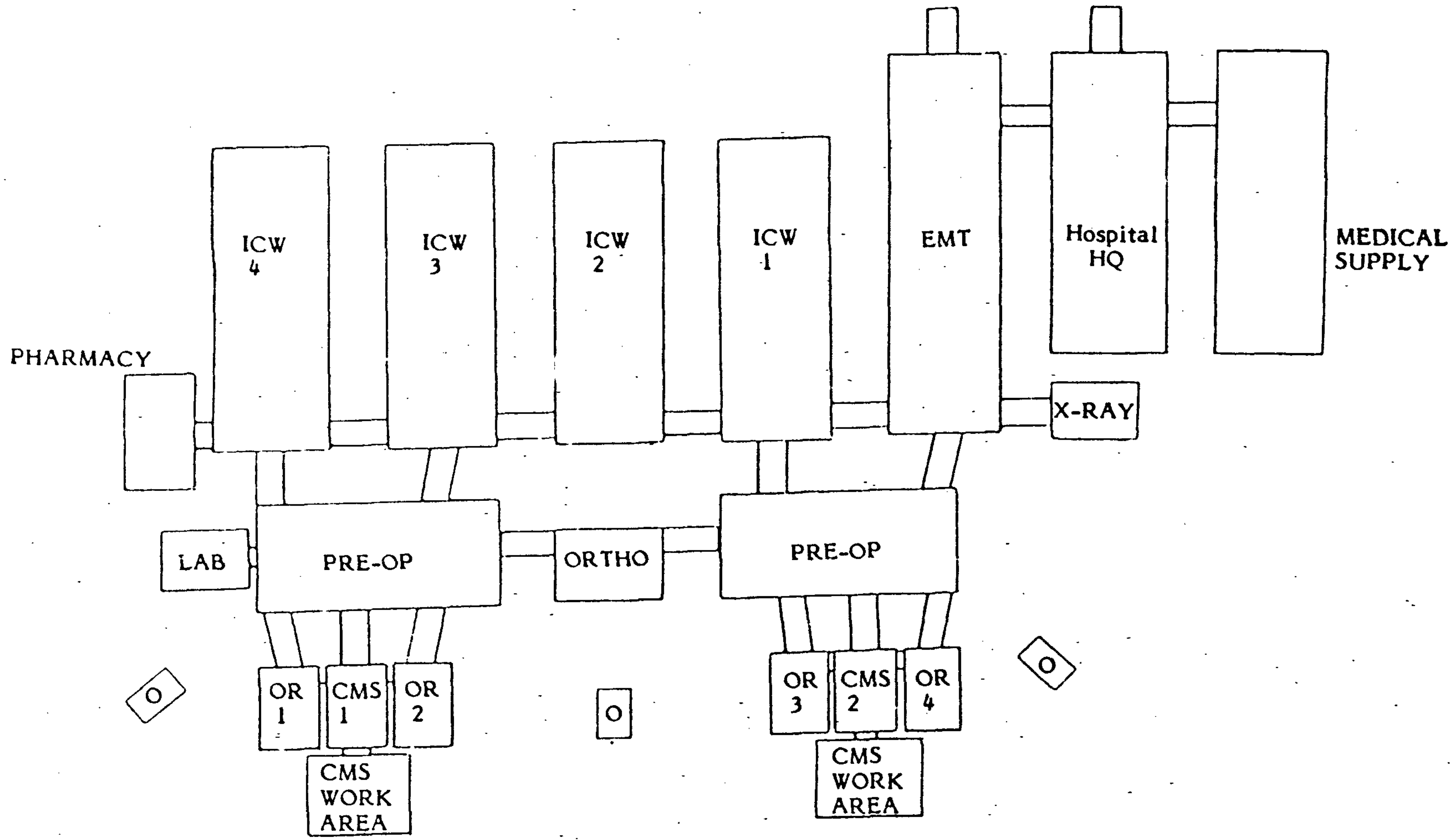
1. X-Ray Apparatus 2MA, 120KVP
2. X-Ray 100MA-100KVP Transp
3. Portaray Dental X-Ray
4. Oxygen monitor
5. Resuscitator, Field-Globe
6. ECG - HP 1500B
7. ECG - Birtcher 339
8. ECG - Burdick EK/5A 673
9. Defibrillator Lifepak 33
10. ESA Neomed 3000
11. ESA Birtcher 771
12. Respirator - Bennett MA-1
13. Flame Photometer 343(IL)
14. Blood Gas Analyzer IL113
15. Xenon Endoscopic Light Source
16. Vari MIX III Amalgomator
17. Volumetric Infusion Pump
18. Opthalmic Diathermy TR 3000
19. RICH-MAR Ultrasonic Unit
20. Spectrophotometer - Stasar

3. FIELD HOSPITAL LAYOUT

The 10th MASH and the 8th Evacuation Hospital units were visited to survey equipment and its deployment. The 10th MASH was not deployed in the field at the time of the visit, but critical equipments were identified from interviews with key personnel. A diagram of the MASH unit is shown in Figure 3.1. This hospital is a sixty-bed unit, sheltered in Temper tents and International Standards Organization (ISO) shelters.

The 8th Evacuation Hospital was visited in the field at Camp Roberts, CA. This hospital was sheltered in the MUST configuration shown in Figure 3.2. The MUST utilizes inflatable shelters. The inflatable shelter is being phased out because of excessive fuel requirements to operate the air compressors. Hence, equipment locations and shelter configurations will change as obsolete material is replaced.

Hospital layout and prescribed equipments are undergoing a program of standardization (under charter of the Defense Medical Standarization Board). Standardized medical equipment sets are being developed for Level III Corps and Level IV COMMZ Hosptial functions (Ref 7). These sets consist of complete functional modules including the appropriate shelter, if required. To date, these include the operating room, central material service, x-ray, pharmacy, laboratory, blood bank, triage/emergency/pre-op, wards, physical therapy, optometry, and general dentistry. The impact of this standardization program may be to reduce the number of different EMP protective measures required for medical equipment (i.e., equipment relocation and selection of appropriate shelter type, where feasible, may provide adequate protection, and reduce the need for protection at the box level). The next section discusses the types of shelters available for deployable medical systems, and summarizes data on shielding effectiveness against EMP.



78 TEMPER 8' SECTIONS
21 VESTIBULES
15 DOOR SECTIONS

APPROX. DIMENSIONS 237' x 150'
TOTAL HOSPIAL AREA

Figure 3.1 10th MASH Hospital layout.

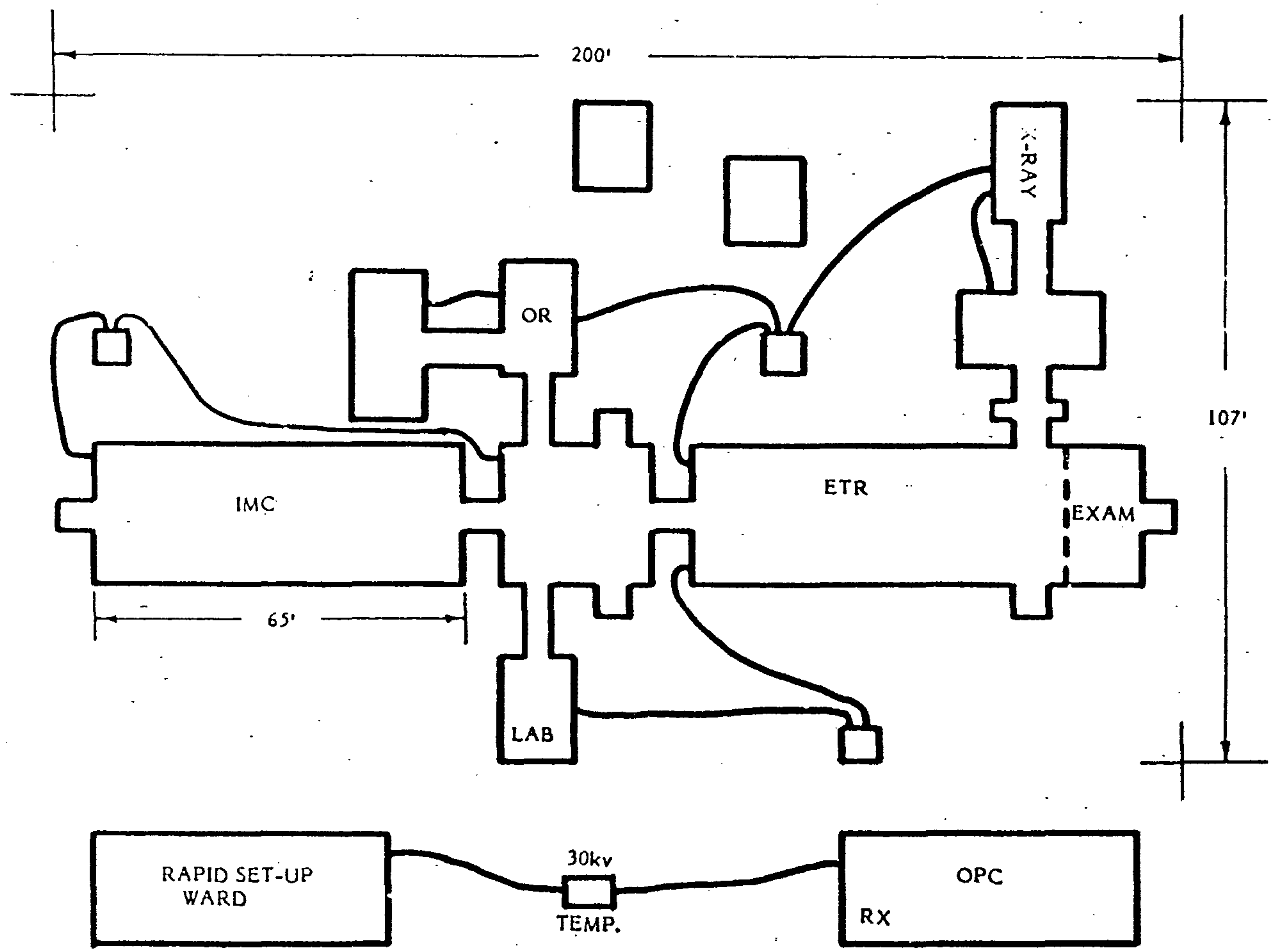


Figure 3.2 8th Evacuation Hospital (MUST) shelter and power layout.

4. SHELTER TYPES

The basic shelter types used for the deployable medical hospital are the TEMPER and the ISO shelter. The TEMPER provides no shielding against EMP. The ISO shelter provides some residual shielding (less than 20dB) against EMP due to its metalic skin, and can be upgraded for significant EMP protection. Description of these shelter types follow in sections 4.1 and 4.2. Section 4.3 summarizes EMP shielding effectiveness data for mobile tactical shelters.

4.1 TEMPER

The Temper features an aluminum frame and a cotton, wind resistant sateen, outer skin. Minimum dimensions of the extendable tent are as follows:

Length:	8 feet
Width:	20 feet
Ridge Height:	10 feet
Eave Height:	6 feet, 9 inches

Included with the basic tent are a 16-foot fly or an 8-foot long fly, with metal eave and ridge extenders, and a vestibule; covers are provided for each tent section; tent is procurable in varied lengths and can be assembled in different configurations depending on the arrangement and number of window or door sections utilized; large screened openings in the walls and roof of the tent make it suitable for tropical or desert operations, particularly when the flies are installed; tent sections without roof openings are available for temperate climate uses.

Provisions are made in these tent sections for heating, i.e., heater duct sleeves in the endwalls of the tent, or stovepipe shields in the roof; a matching sectionalized liner with a sectionalized single ply-coated fabric or insulated floor are also available.

The estimated weight and cube for a TEMPER shelter 32 feet long consisting of tent, frame, liner, and fly are as follows:
20 feet wide x 32 feet long; weight: 802 lbs. cube: 75 cu feet.

4.2 ISO SHELTERS

Engineers at the US Army Natick R&D Center are responsible for the design of the Army Standard Family of Rigid Wall Tactical ISO Shelters (Ref 6). The shelters are for use in situations requiring a highly mobile, environmentally controlled, work-in/live-in space. The initial general purpose family of shelters consists of three models:

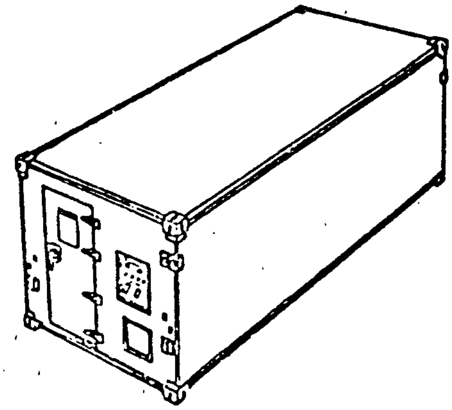
MODEL	USEABLE FLOOR SPACE
Non-Expandable	150 sq ft
One-Side Expandable	275 sq ft 2:1
Two-Side Expandable	400 sq ft 3:1

All three models conform to the container standards of the International Organization for Standardization (ISO) and have exterior dimensions of 8'x8'x20' when in their transporation mode. They are compatable with the Army as well as commercial material handling equipment and can be transported by all modes of transportation including cargo container ships. The three types of ISO shelters are shown in Figure 4.1.

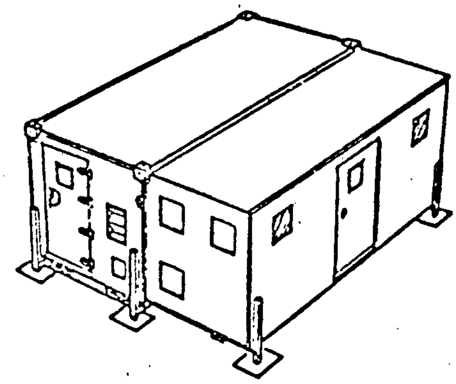
These shelters are designed to replace the large number of special purpose non-standard (non-supportable) shelters currently in the Army inventory as well as to provide a general purpose field shelter capability that was previously unavailable for areas such as field hospital operating rooms, diagnostic test centers, maintenance shops, computer centers, C^3I operations, field kitchens, etc.

Integrated Logistics Systems (ILS) principles have been incorporated throughout the design of these shelters. Standardization of components has been maximized. In the event a piece of equipment becomes obsolete, or a particular function is no longer required, this standard shelter can be re-cycled for an entirely different purpose. The standardization of the shelters greatly simplifies maintenance and support requirements.

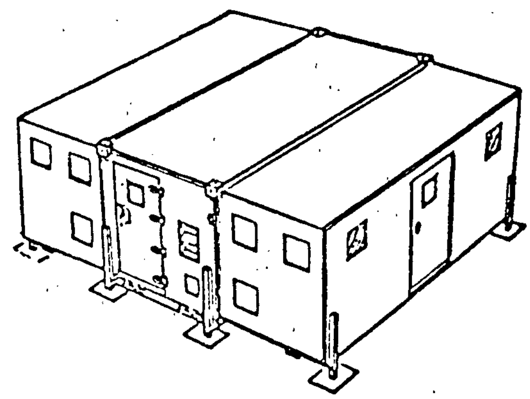
The shelters are constructed of nonmetallic honeycomb core thermally bonded to aluminum skins which allow the users to mount hardware or equipment anywhere on the panels. Each shelter has built-in systems for three phase electrical distribution, internal fluorescent lignts, and external area light and interface for external environmental control units. Each is equipped with leveling jacks and can be erected in the field without special tools. The shelter, with payload, has a gross weight capacity of 15,000 lbs.



ISO RIGID 8' X 20'



ISO 2:1 EXPANDABLE



ISO 3:1 EXPANDABLE

Figure 4.1 Army Family ISO shelter

Natick Research & Development Center is presently developing kits for upgrading the shelter to counter threats and enhance capabilities for specific users. These kits include chemical protection, electromagnetic interference (EMI) protection, electromagnetic pulse (EMP) protection, ballistic protection, blast and thermal protection and the capability to provide additional functional space in the field by complexing the shelters or attaching knockdown hardwall extendible kits to the basic configurations.

The EMI Shielding Kit installed in an Expandable ISO Shelter will provide 60 dB of attenuation to Electromagnetic Fields over a frequency range of 150 KHz to 10 GHz. A unique use of flexible shielding material will be made to shield expanding portions of the shelter. These flexible shields will fold with folding panels allowing erection of the shelter without any special effort required to establish the shield over the folding joints. Latching panel joints will utilize flexible shields with quick fastening attachments. A Two-Side Expandable Shelter with the shielding kit would provide 400 square feet of shielded floor space, easily transportable as a single ISO container.

A feasibility prototype was built in FY83 to prove the possibility of EMI shielding an expandable shelter. This prototype successfully provided 60 dB of attenuation, however, the approach taken required an unacceptable degree of effort in erecting and striking the shielded shelter. A contract should be awarded in first quater FY86 to build an improved prototype.

4.3 HEMP SHIELDING EFFECTIVENESS OF TACTICAL MOBILE SHELTERS

Four ISO shelters were subjected to the AESOP high altitude EMP (HEMP) environment at tests conducted at HDL WRF (Ref 2). Shelters tested were: 1.) the Natick rigid shelter, 2.) the Marine Corps general-purpose shelter, 3.) the Navy Basic Mobile Facility (BMF), and 4.) the Natick one-side expandable shelter.

The shelters were tested with doors closed. All apertures and entrance ports were sealed or gasketed to prevent field penetration. Special wave-guide-below-cutoff entrance ports were fabricated and installed to accommodate data channels. Shelters were not electrically grounded, except for on-ground contact.

HEMP effect on the S280C shelter was measured with the door open versus the door closed. The S280C is smaller than the ISO shelter, however, the results demonstrate the large reduction on shielding effectiveness when doors are left open during an exposure to EMP. The HDL results are listed in Table 4.1.

Table 4.1 Penetrated Field Reduction on S280C Shelter with Door Closed VS Open (Ref 2)

Location	Measured Field	Field Reduction (dB) With Door Closed
Door Center	E	80 to 100
Shelter Center	E	81 to 95
Door Center	H	36 to 54
Shelter Center	H	43 to 52

To illustrate the importance of keeping shelter doors closed in a hostile environment, 100dB represents a field reduction by a factor of 99,000, and 36dB represents a field reduction by a factor of 63 with door closed during exposure to EMP.

The lowest measured values for ISO shelter shielding effectiveness based on peak amplitude for the HDL tests are given in Table 4.2

Table 4.2 HEMP Shielding Effectiveness (Lowest Values) for ISO Shelters Based on Peak Amplitude (Ref 2)

	Shielding Effectiveness	
Shelter	H field (dB)	E Field (dB)
Natick Rigid	50	92
Marine Corps	56	103
Navy BMF	44	91
Natick Expandable	47	81

5. EMP THREAT CHARACTERIZATION

EMP fields incident on electronic systems interact with enclosures, cabling, and other extended conductors producting transient voltages and currents at system interface pins and in interior circuits. The induced EMP transients may cause two types of detrimental responses - either upset or damage.

Upset is the generation of false signals which can cause a system to take undesired actions. Damage refers to the degradation of a component to the point where it can no longer meet its design function criteria. Only damage criteria were considered in this study.

The EMP voltages and currents (and their associated time behavior) must be known at the circuit level in order to perform circuit analysis. Often the EMP specification is given in what is called a pin specification, which is the worst-case EMP voltages and currents that may appear at any input/output (I/O) pin. The pin specification usually is defined in terms of a Thevenin equivalent source with a specified frequency and time behavior applied between each I/O pin and the lowest impedance return.

The EMP threat specification often includes a surface current threat for system components (boxes). The effect of this current on the interval circuitry must be determined via a penetration and coupling analysis. Types of EMP penetrations through box (chassis) walls include penetrations through apertures, panel joint seams, connector gaps, and wall diffusion. Box coupling due to surface current was not considered in this study. A more detailed assessment should also include the surface current coupling. However, the coupled energies to buried circuits are small when the chassis or box deminisions are small. For example, maximum energies calculated at buried circuit pins in the interior of a 6"x8"x12" aluminum box with a 1mm wall thickness (assuming a 50 kV/M exterior field) are in the order of: 3×10^{-9} joules from panel joint seams, 5×10^{-13} joules from connector gaps, and 5×10^{-13} joules from diffusion. Suceptibility thresholds for low power transistors and linear ICs are greater than 10^{-6} joules, so the above energies present no threat of damage.

Thevenin equivalent I/O pin sources used for the analysis in this report were derived from EMP tests conducted by Maj. Vandre at the AESOP and REPS simulators (Ref 8). Maj. Vandre tested several equipments. The most complete data set available to IRT was for the Electrosurgical Apparatus (ESA) Neomed 3000. Although the pin threats derived from this limited data may not be the worst-case for all possible medical equipment configurations, they do represent a good example based on the following considerations:

1. The ESA configuration is a typical medical equipment set-up. It has a chassis box, and has external power and sensor connection with extended conductors.
2. The EMP coupling levels measured are reasonable, both with respect to amplitude and wave shape.
3. Actual component damage occurred to the ESA at threat-level exposure. Several parts burned out at more than one I/O interface.
4. It would be relatively easy to apply a different pin threat to the I/O susceptibility circuits identified in this report. Options for other pin threats include: 1.) coupling results of HDL tests on the medical system power grid; 2.) detailed coupling predictions for specific system configurations; 3.) MIL-STD-2169.

5.1 HEMP TEST OF THE ELECTROSURGICAL APPARATUS

The AESOP free field strength at the ESA test point was 42.4 kV/m and the REPS field strength was 10 kV/m.

The cables connected to the ESA were oriented for worst-case coupling to the primary E and H fields associated with horizontally polarized EMP. A vertical E field was also part of the test environment due to the off-centerline location of the test. Figure 5.1 shows the components of the ESA with power and sensor and control cables attached. The ESA, patient plate and active probe were placed on a wooden table 30" above the ground. Peak amplitudes and relative polarities of the first peak are indicated in the figure. The REPS coupling data were scaled to AESOP levels, and are designated with an asterisk for the scaled value.

Bulk current responses were measured on ESA cables at location A, B, C, D and E marked in Figure 5.1. Figures 5.2 through 5.4 show the test data. Responses are plotted for two time scales at each test point. The longer time scale traces exhibit the general damped sine characteristic associated with a typical EMP pin threat. This pin threat can be specified either as a damped sine wave or a rectangular pulse having a short circuit current and an open circuit voltage or a source resistance. The next section discusses the damped sine model for the ESA data.

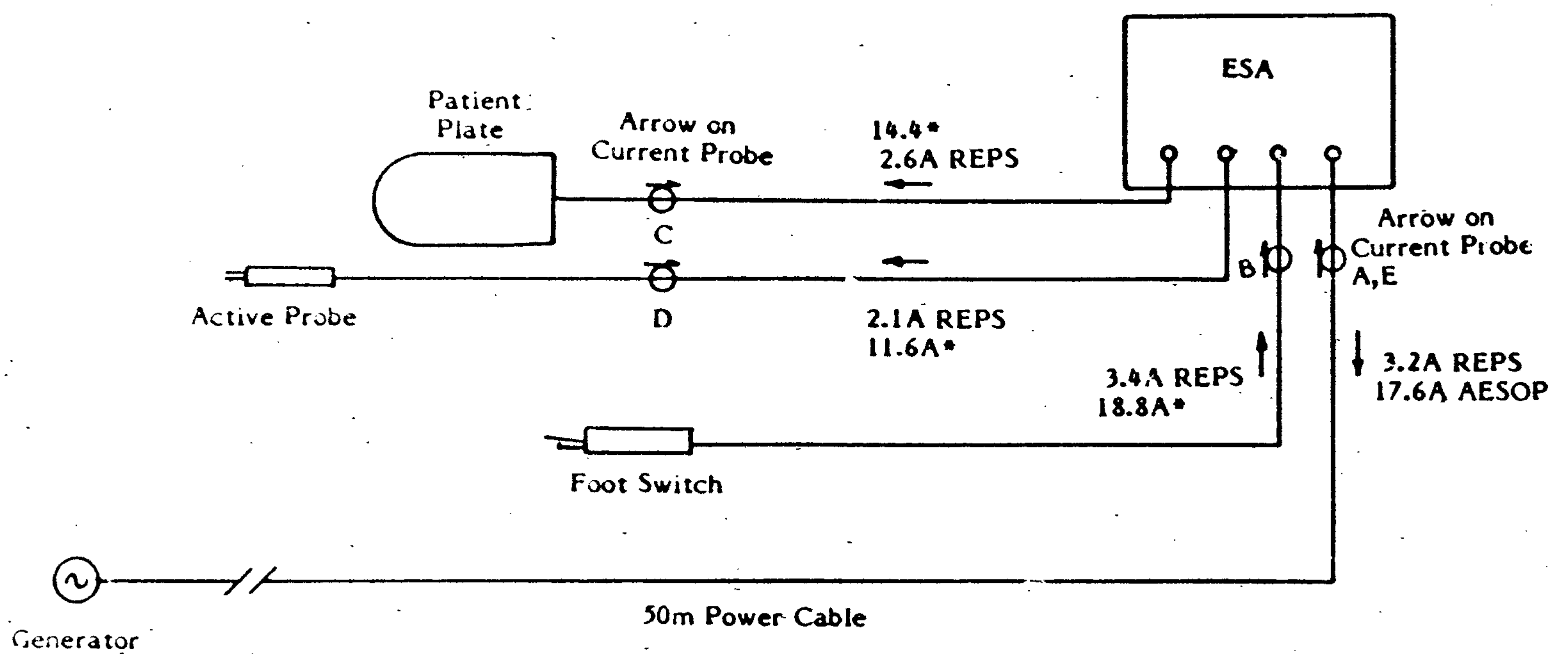
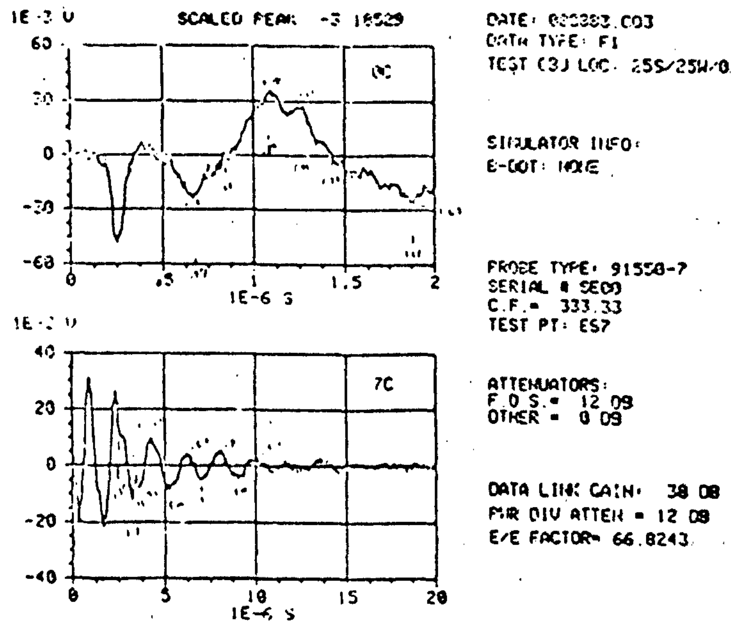
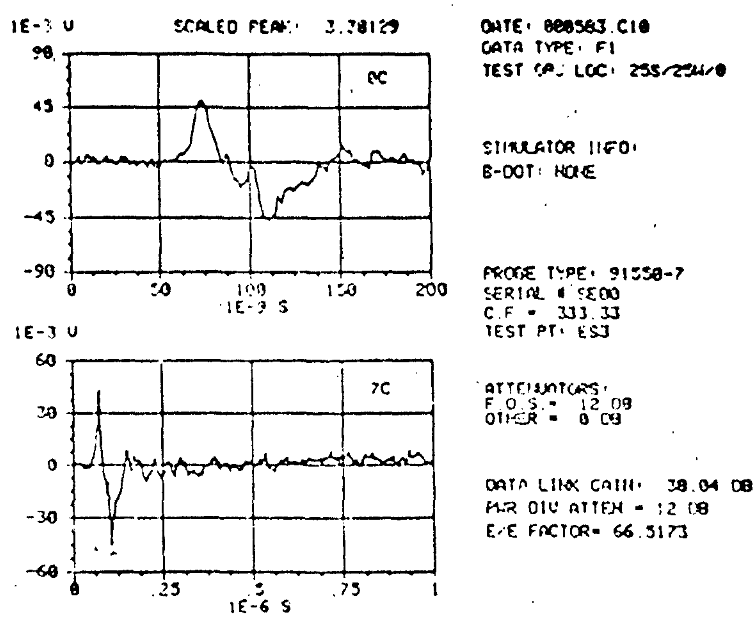


Figure 5.1 Electrosurgical Apparatus response to REPS and AESOP illumination (From Maj. Vandre data)

* Scaled to AESOP Level.
Arrow shows polarity of first peak.

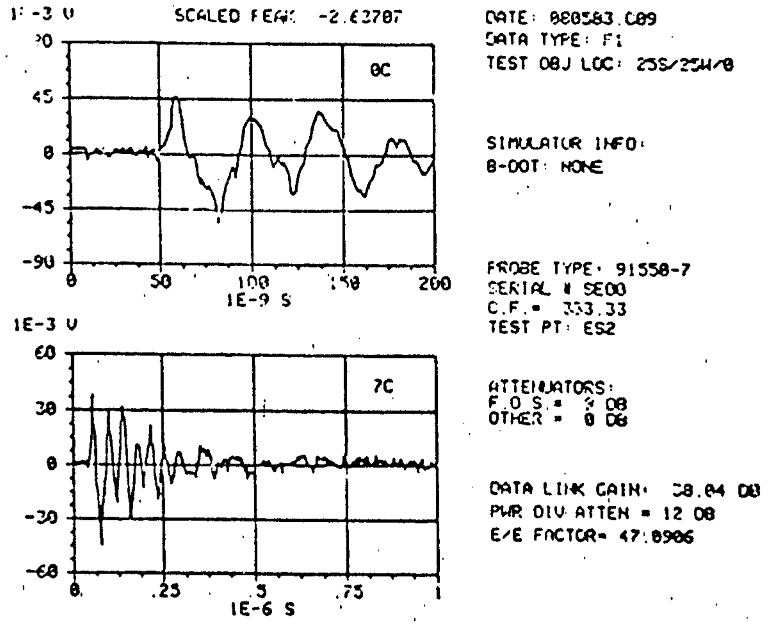


(a) Test Point A. Power Cable

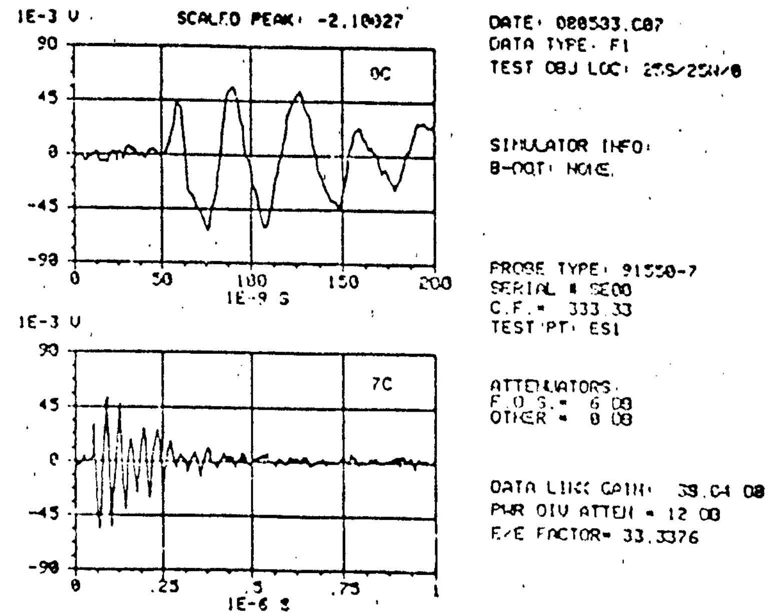


(b) Test Point B. Foot Switch

Figure 5.2 Bulk current measured on power cable and foot switch in REPS



(a) Test Point C. Patient Plate



(b) Test Point D. Active Probe

Figure 5.3 Bulk current measured on patient plate and active probe in REPS

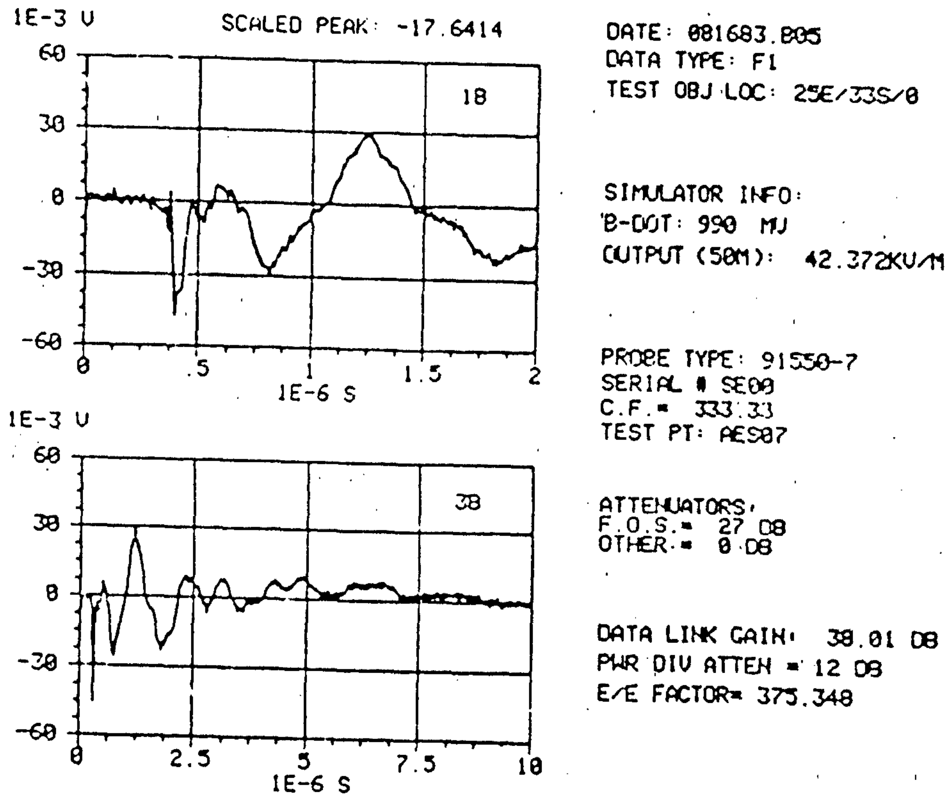


Figure 5.4 Bulk current measured on power cable in AESOP

5.2 DAMPED SINE MODEL FOR THE ESA HEMP RESPONSE

The best approximation for the ESA data is the damped sine model. The equation for the current is given below.

$$I(t) = I_0(f)e^{-at} \sin(2\pi ft) \quad (5.1)$$

where $a = \pi f/Q$, f is the appearent ringing frequency of the pulse, and Q is the ratio of stored to dissipated energy in the pulse. $I_0(f)$ is the bulk current characteristic as a function of frequency of the pulse.

Five data points were available from the ESA data to characterize the damped sine parameters. The approximate ringing frequency, f_0, was read from the measured signals. The exponential decay factor, a, was selected for a Q = 10 to model all data. A nominal Q for observed EMP responses can vary from this value to a value of 20. A summary of the damped sine fit to the ESA data is given in Table 5.1.

Table 5.1 Electrosurgical Apparatus (Neomed 3000)
REPS and AESOP Test Results (From Maj. Vandre Data)

Simulator	Test Point	Measured Sc.Pk.	Sc.Pk. Scaled to AESOP	Probe	f_0	Q*	Cable Type
REPS	A	-3.19	-17.6	ES7	6.6E5	10	Power
REPS	B	3.38	18.8	ES3	8.0E6	10	Signal
REPS	C	-2.64	-14.4	ES2	2.6E7	10	Signal
REPS	D	-2.1	-11.6	ES1	2.8E7	10	Power
AESOP	E	-17.6	-17.6	AES07	8.0E5	10	Power

Peak Fields: REPS = 10Kv/m AESOP = 42.37Kv/m

* Nominal value assumed for all coupling responses.

6. I/O SUSCEPTIBILITY MODELS

Characterization data used in the susceptibility analysis for medical equipment are summarized in this section. Also, assumptions made with the data are explained.

6.1 PARTS CHARACTERIZATION TECHNIQUES

EMP pin threats can cause both transient upset and permanent damage. Semiconductor devices are the most sensitive electronic components to burnout (see Figure 6.1).

6.1.1 Diodes and Transistors

Semiconductor junctions are vulnerable to thermal damage and electrical breakdown when stressed by EMP transients. The most common failure is local thermal runaway, which generally produces a resolidified melt channel across the junction whose equivalent form is a resistive short circuit. Junction damage is most likely to occur when the EMP transient reverse-biases the junction and drives it into secondary breakdown. Forward stressed junctions also fail, but typically have damage thresholds which are three to ten times higher than reverse stressed junctions due to the low voltage and impedance levels present in forward conduction (see Figure 6.2).

The large scatter in the empirical data requires the determination of a mean value for application to systems. Least squares fits to the data are plotted in Figure 6.2. The following pulsed power failure relationships are typically found for diodes and transistors.

$$\text{forward pulsing } P_F = \frac{K_1}{t},\ 0 \leq t \leq t_1 \qquad (6.1)$$

$$\text{reverse pulsing } P_F = K_2 t^{-1/2},\ 0 \leq t \leq t_2 \qquad (6.2)$$

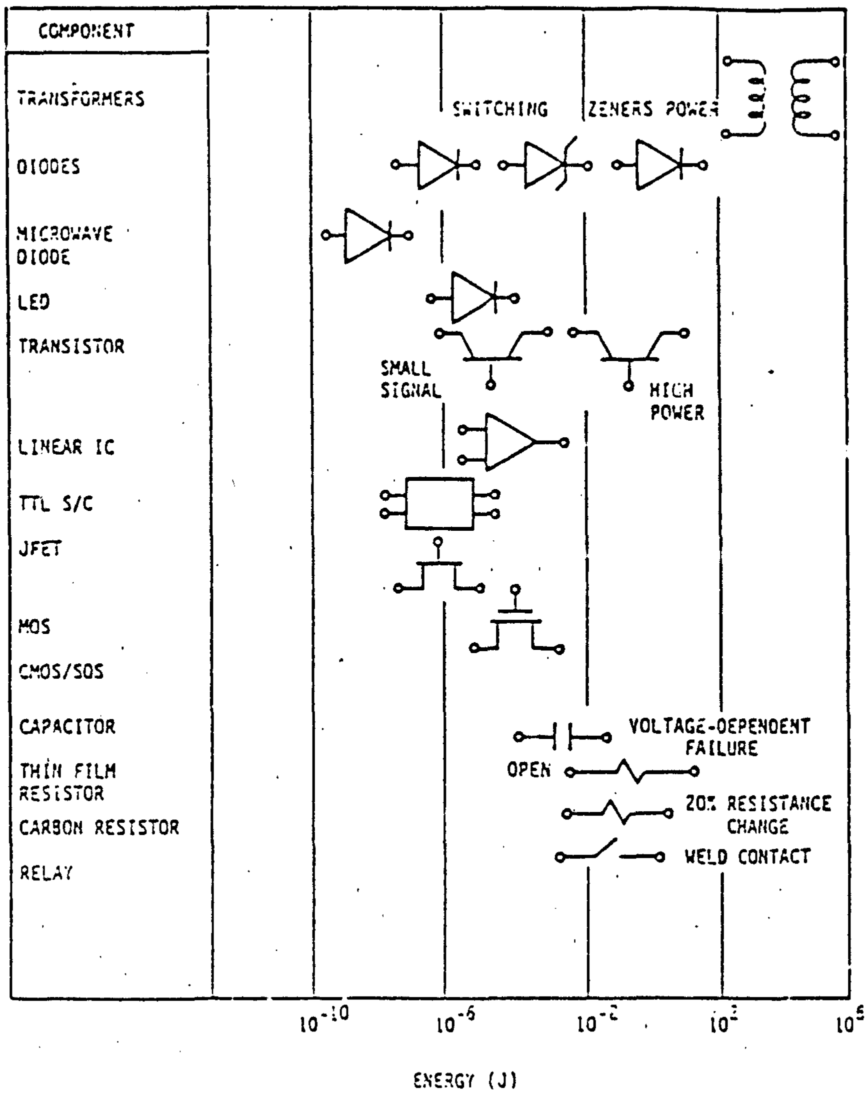


Figure 6.1 Parts permanent damage threshold energy for 100 ns square pulses

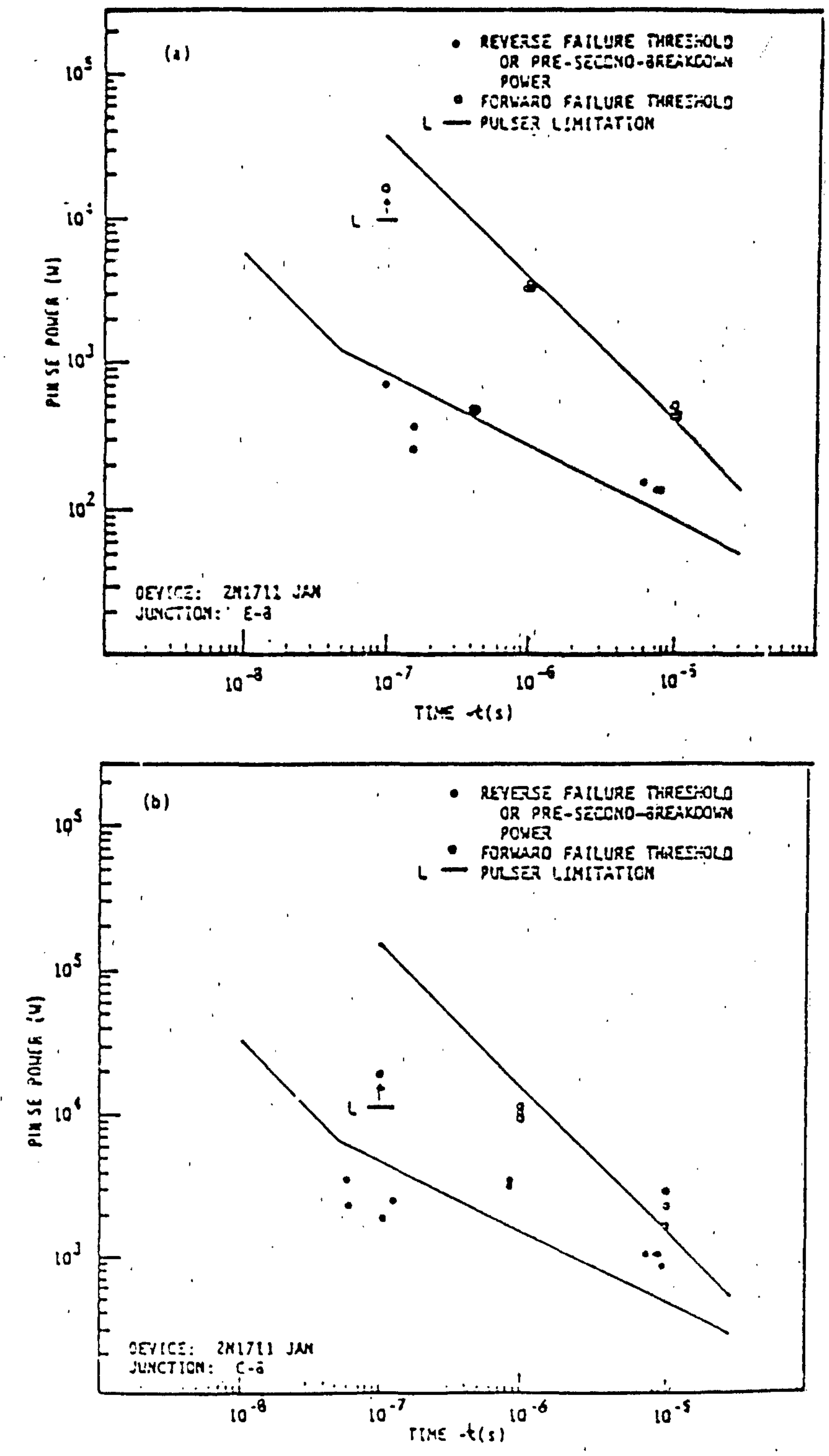


Figure 6.2 Damage characteristics of 2N1711 JAN: (a)E-B junction and (b)C-B junction (Ref 13)

where

K_1 = forward damage constant in Ws
K_2 = reverse damage constant in Ws or $Ws^{1/2}$
Q = quality factor
t_1 = device forward thermal time constant
t_2 = device reverse thermal time constant

The equivalent square pulse time factor, $t^{-1/2}$ is converted for damped sine pulses of frequency f_o by using Equation 6.3 (Ref 15).

$$t^{-1/2} = \frac{2.45}{(2Q)^{.347}} (2\pi f_o)^{1/2} \tag{6.3}$$

Usually, only the K_2 value is reported in the literature and it is represented simply as K. This convention is adopted here. The damage constant is not, however, sufficient for characterizing a diode. One also needs to know the junction breakdown voltage, V_{BD}, and the surge resistance, R_B. These three quantities can then be used to determine the threshold failure current, I_F, using Equation 6.4.

$$I_F = \frac{-V_{BD} + (V_{BD}^2 + 4R_BP_F)^{1/2}}{2R_B} \tag{6.4}$$

where

V_{BD} = breakdown voltage in V,
R_B = junction surge resistance in ohms
P_F = power required to cause the device to fail in watts

The junction breakdown voltage, V_{BD}, is found from test data or generic values.

The surge resistance, R_B, of a forward biased junction is given as the resistance of the bulk material. In the reverse-biased case, R_B is made up of two terms, the bulk resistance and a resistance due to space charge limiting, the vicinity of the junction depletion region under high current conditions. Surge resistance based on the class of parts and the bias conditions are shown in Table 6.1. If empirical K values are not available, the damage constants that are used come from tables of data for similar devices, or from generic values determined for the part type (see Table 6.2). Damage constants can also be derived from estimation formulas. The latter method was not applied in this study.

Table 6.1 Surge Resistance of Devices

Device Category	Reverse Bias (ohms)	Forward Bias (ohms)
Zener Diode	1	0.1
Signal Diode	25	0.25
Rectifier Diode	25+	0.25
Low Power Transistor (E-B)	10	1
High Power Transistor (E-B)	2	0.2

The failure threshold voltage, V_F, can be found by using the junction breakdown voltage, V_{BD}, the threshold failure current, I_F, and the surge resistance, R_B, as shown in equation 6.5.

$$V_F = V_{BD} + I_F R_B \tag{6.5}$$

A limited number of devices have been characterized for pulsed power burnout in the forward direction. For those cases where data is not available, it will be assumed that the forward K factor is three times the reverse K factor (Ref 14).

Transistors are characterized in the same manner. Both the emitter-base and the collector-base junctions are characterized. In general, the individual junctions in transistors behave much the same as diodes. Damage constants are usually somewhat lower for reverse-biased pulsing than for forward. In most instances, the E-B (Emitter-Base) junction has a lower damage constant than does the C-B (Collector-Base) junction. This may be partly due to the fact that E-B junctions are much smaller than C-B junctions in typical planar devices. As with diodes, there are exceptions to these general rules, so caution is required. For conservation, it is common practice to assume that the lowest value of damage constant applies to both junctions in both directions.

Table 6.2 Damage Constant Estimation Based on Device Category (Ref 12)

Category	K_{Min} ($Ws^{1/2}$)	K_{Max} ($Ws^{1/2}$)	K_{Mean} ($Ws^{1/2}$)	Lower 95% ($Ws^{1/2}$)	Upper 95% ($Ws^{1/2}$)	Sample Size
Diodes						
Zener	0.73	87.9	10.1	1.05	96.5	52
Reference	0.02	27.9	4.9	0.12	199	4
Hi-Voltage Rectifier	0.30	40	2.94	0.19	46.5	56
General Purpose Signal (Si)	0.02	5.2	0.67	0.11	4.18	13
Microwave Mixer	0.00029	0.026	0.00194	0.00028	0.0138	22
Switching	0.00717	0.92	0.13	0.0088	1.83	21
Transistors						
NPN Low Power (Si)	0.0075	1.14	0.11	0.01	1.96	47
NPN Med Power (Si)	0.2	2.1	0.63	0.12	3.3	7
NPN High Power (Si)	0.25	3.43	2.13	1.11	4.06	5
PNP Low Power (Si)	0.005	0.65	0.15	0.01	1.8	25
PNP Med Power (Si)	0.442	1.0	---	---	---	2

6.1.2 Integrated Circuits

The pulsed power failure data for ICs are represented in a slightly different form. The relationship for the failure power, P_F, is shown in Equation 6.6.

$$P_F = A_T^{-B} W \tag{6.6}$$

where

$t = 1/2.4f$ = pulse width in seconds (f = frequency of pulse width)
A and B are constants (from Table 6.3).

Composite A and B values for ICs are listed in Table 6.3. The constants provide the average failure power. The breakdown voltage and surge resistance for each IC terminal are also listed in Table 6.3.

Table 6.3 Integrated Circuit Damage Model Parameters by Category (Ref 1)

Category					R_B	Lower 95%
Family	Terminal	A	B	V_{BD}(V)	(ohms)	A
TTL	Input	0.00216	0.689	7	16	0.00052
	Output	0.00359	0.722	15	2.4	0.00098
RTL	Input	0.554	0.384	6	40	0.12
	Output	0.0594	0.508	5	18.9	0.0096
	Power	0.0875	0.555	5	20.8	0.026
DTL	Input	0.0137	0.580	7	25.2	0.0046
	Output	0.0040	0.706	1	15.8	0.012
	Power	0.0393	0.576	1	30.6	0.009
ECL	Input	0.152	0.441	20	15.7	0.045
	Output	0.0348	0.558	0.7	7.8	0.0031
	Power	0.456	0.493	0.7	8.9	0.22
MOS	Input	0.0546	0.483	30	9.2	0.0063
	Output	0.0014	0.819	0.6	11.6	0.00042
	Power	0.105	0.543	3	10.4	0.038
Linear	Input	0.0743	0.509	7	13.2	0.0054
	Output	0.0139	0.714	7	5.5	0.0045

Table 6.4 EMP Burnout Analysis Component Lumped Equivalent Models (LEM)

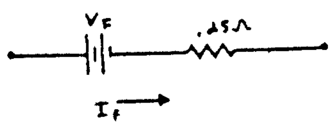
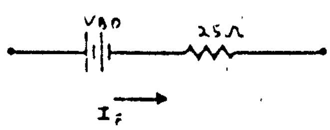
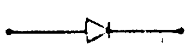
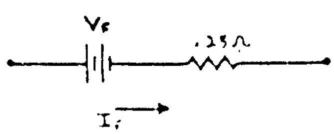
Part Type	Lumped Element Model
Signal Diode 	Forward Bias  V_F is manufacturer's specified forward voltage drop. Use 0.7V if unknown. I_F is the reverse failure threshold current. Reverse Bias:  V_{BD} is manufacturer's specified reverse breakdown voltage. I_F is the failure threshold current.
Rectifier Diode 	Forward Bias:  V_F is manufacturer's specified forward voltage drop. Use 1V if unknown. I_F is the reverse failure threshold current.

Table 6.4 (Continued)

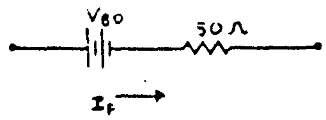
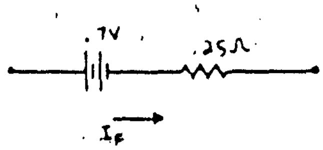
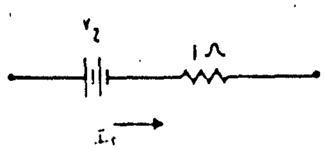
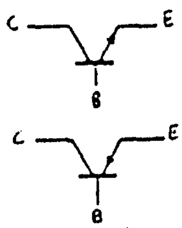
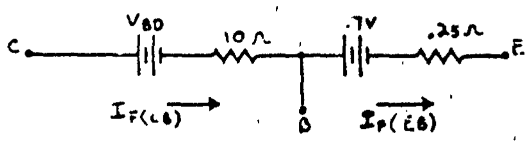
Part Type	Lumped Element Model
	Reverse Bias:  V_{BD} is manufacturer's specified reverse breakdown voltage. I_F is the failure threshold current.
Zener & Reference Diodes 	Forward Bias:  I_F is the reverse failure threshold current (as worst case)
	Reverse Bias:  V_Z is manufacturer's specified typical zener voltage. I_F is the failure threshold current.

Table 6.4 (Continued)

Part Type	Lumped Element Model
Transistor-Low Power	Forward Bias (NPN), Reverse Bias (PNP):

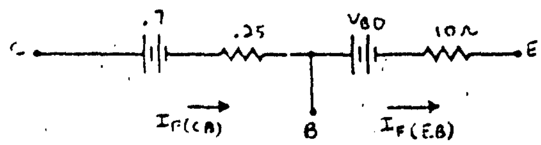




V_{BD} is manufacturer's specified breakdown voltage for the CB junction.

$I_{F(CB)}$ and $I_{F(EB)}$ are the failure threshold currents for the respective junctions. Currents are for reverse-biased junction as worst case.

Reverse Bias (NPN), Forward Bias (PNP)

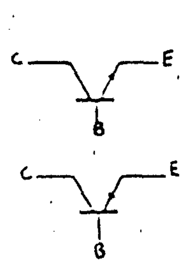


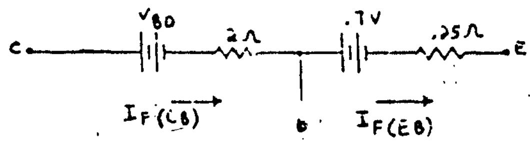
V_{BD} is manufacturer's specified breakdown voltage for the EB junction.

$I_{F(CB)}$ and $I_{F(EB)}$ are the failure threshold currents for the respective junctions. Currents are for reverse-biased junction as worst case.

Table 6.4 (Continued)

Part Type	Lumped Element Model
Transistors-High Power	Forward Bias (NPN), Reverse Bias (PNP):

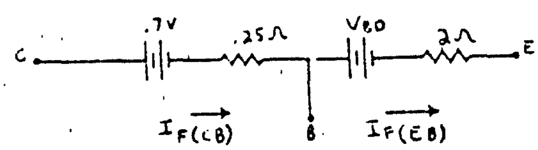




V_{BD} is manufacturer's specified breakdown voltage for the CB junction.

$I_{F(CB)}$ and $I_{F(EB)}$ are the failure threshold currents for the respective junctions. Currents are for reverse-biased junction as worst case.

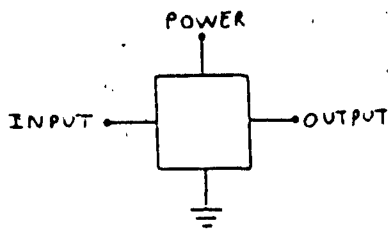
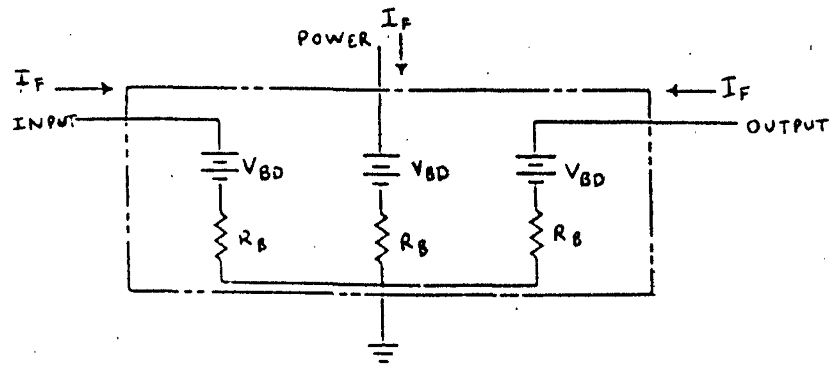
Reverse Bias (NPN), Forward Bias (PNP):



V_{BD} is manufacturer's specified breakdown voltage for the EB junction.

$I_{F(CB)}$ and $I_{F(EB)}$ are the failure threshold currents for the respective junctions. Currents are for reverse-biased junction as worst case.

Table 6.4 (Continued)

Part Type	Lumped Element Model
ICs Linear, TTL, ECL & MOS 	Forward and Reverse Bias:  I_F, V_{BD} and R_B are variables, depending on the IC technology. Values are presented in Table 6.3. If test data exists on the device under analysis, the test data model should be used.

6.2 Parts Characterization Data

Table 6.5 depicts the EMP parts burnout characterization for semiconductors used in the various interface circuits of the units that were studied. The table defines a generic part number, type of part, Wunsch damage constant, reverse bias break-down voltage, surge resistance, source of data (REF), threshold failure current I(F), threshold failure voltage V(F), and threshold failure power P(F). The data reference used is Reference 1, designated by 1 in the tables, or generic data, designated by G in the tables. The failure parameters are defined at 5 differenct frequencies ranging from 6.6 x 10^5Hz to 2.8 x 10^7Hz. These frequencies were observed in the HDL tests of the Electrosurgical Apparatus. Tables similar to Table 6.5 are included in Section 7 for each unit addressed.

Table 6.5 Sample Table for Parts Burnout Characterization

ELECTROSURGICAL APPARATUS NEOMED 3000

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4003	DIODE	2.2000	200	1.0	1	6.6E+05	17.82	217.82	3.9E+03
						8.0E+05	19.47	219.47	4.3E+03
						8.0E+06	53.34	253.34	1.4E+04
						2.6E+07	85.37	285.37	2.4E+04
						2.8E+07	87.83	287.83	2.5E+04

7. EMP SUSCEPTIBILITY SCREEN: COMPUTED EMP CURRENTS AND FAILURE THRESHOLDS FOR INTERFACE CIRCUITS

Results of an EMP susceptibility screen for equipments with sufficient circuit data are presented in this section.

Circuit schematics were examined to identify paths where EMP surges from outside conductors could penetrate and cause failure. In the worst case, the bulk EMP current from an outside cable bundle can enter at a single pin and follow a path of lowest resistance to ground. Semiconductors in the path are susceptible to damage if failure thresholds are exceeded. A path to ground can be a normal circuit loop to a ground node, or by capacitive coupling to the chassis at places where wires are located near the chassis wall. Where appropriate, a stray capacitance of 100pf is added to the circuit model.

Figure 7.1 shows a representative chassis for medical equipment. External cables, such as power and signal or sensor, enter unprotected inside the chassis, and branch to circuit board or component connections. These interfaces can be easily identified on circuit schematics, and provide a quick and relatively inexpensive methodology for assessing vulnerabilities for medical equipment.

A detailed description of the susceptibility models and equations is given for the first few equipments assessed to demonstrate the methodology. Results for the remaining equipments were obtained by analogous means, and are summarized in a shorter format. References to schematics and piece parts are made to identify the possible EMP coupling paths studied.

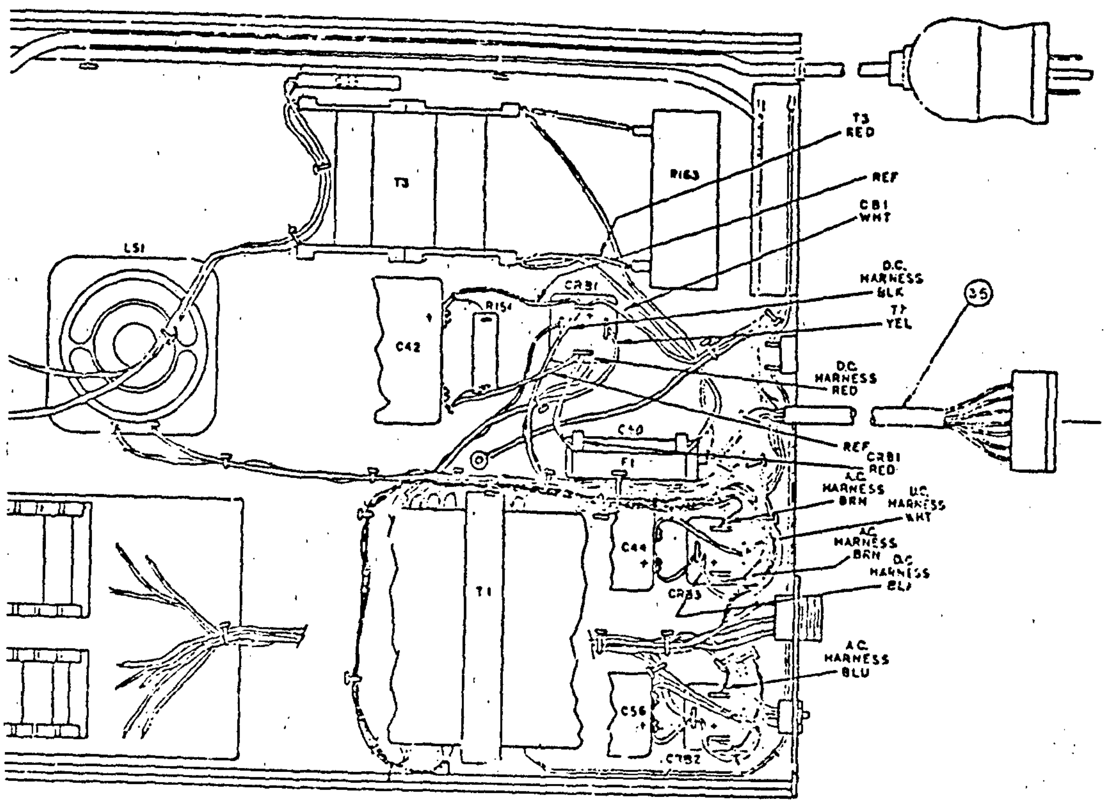


Figure 7.1 Typical chassis and outside cables for medical equipment

7.1 ELECTROSURGICAL APPARATUS, NEOMED 3000

Circuit diagrams for the Neomed 3000 ESA are shown in Figures 7.2 and 7.3. The interface circuits identified in the EMP I/O screen are the 1.) power input, 2.) patient monitor, and 3.) the foot switch. The piece parts in the above circuits, and respective damage failure data are given in Table 7.1.

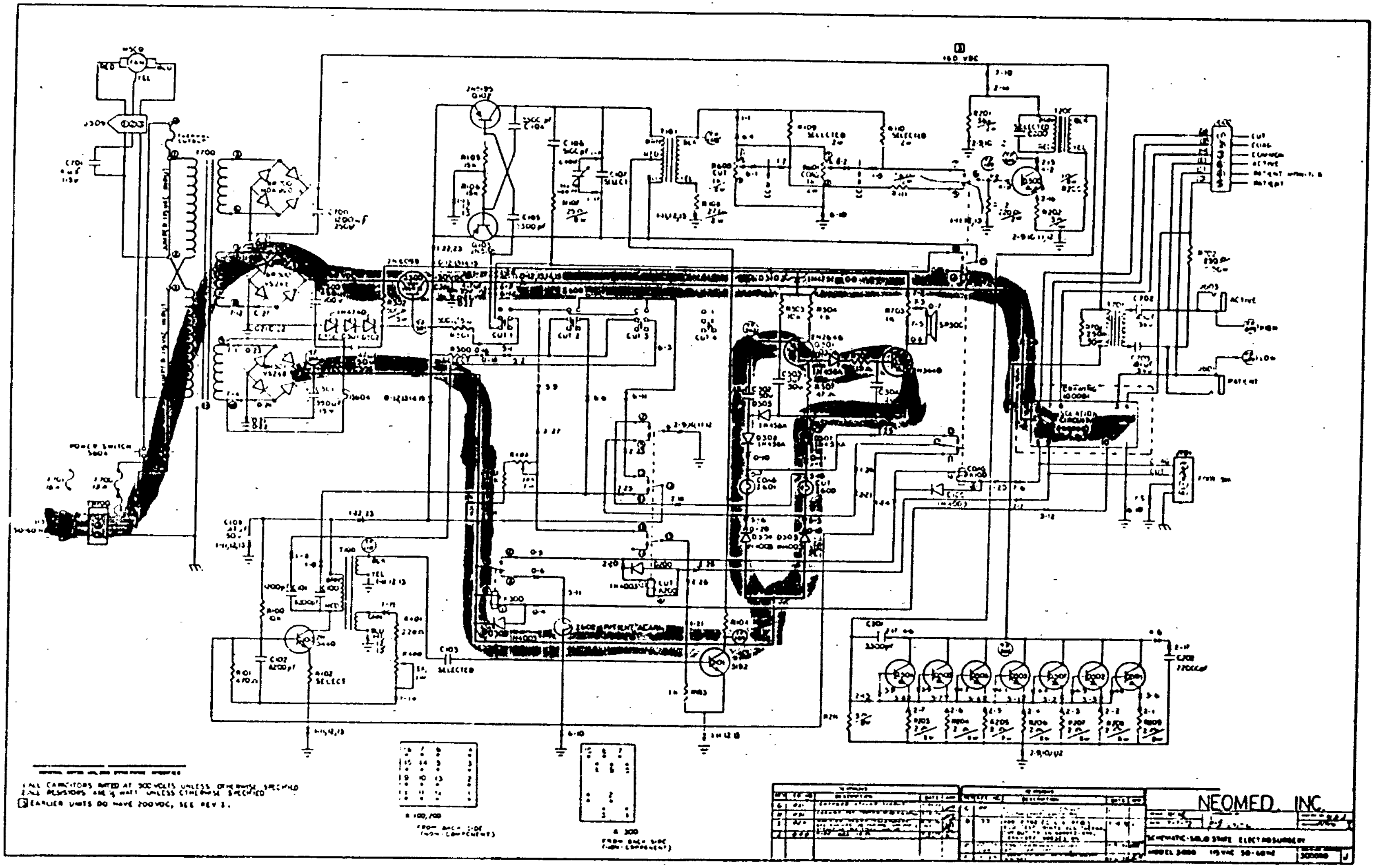


Figure 7.2 Electrosurgical Apparatus schematic

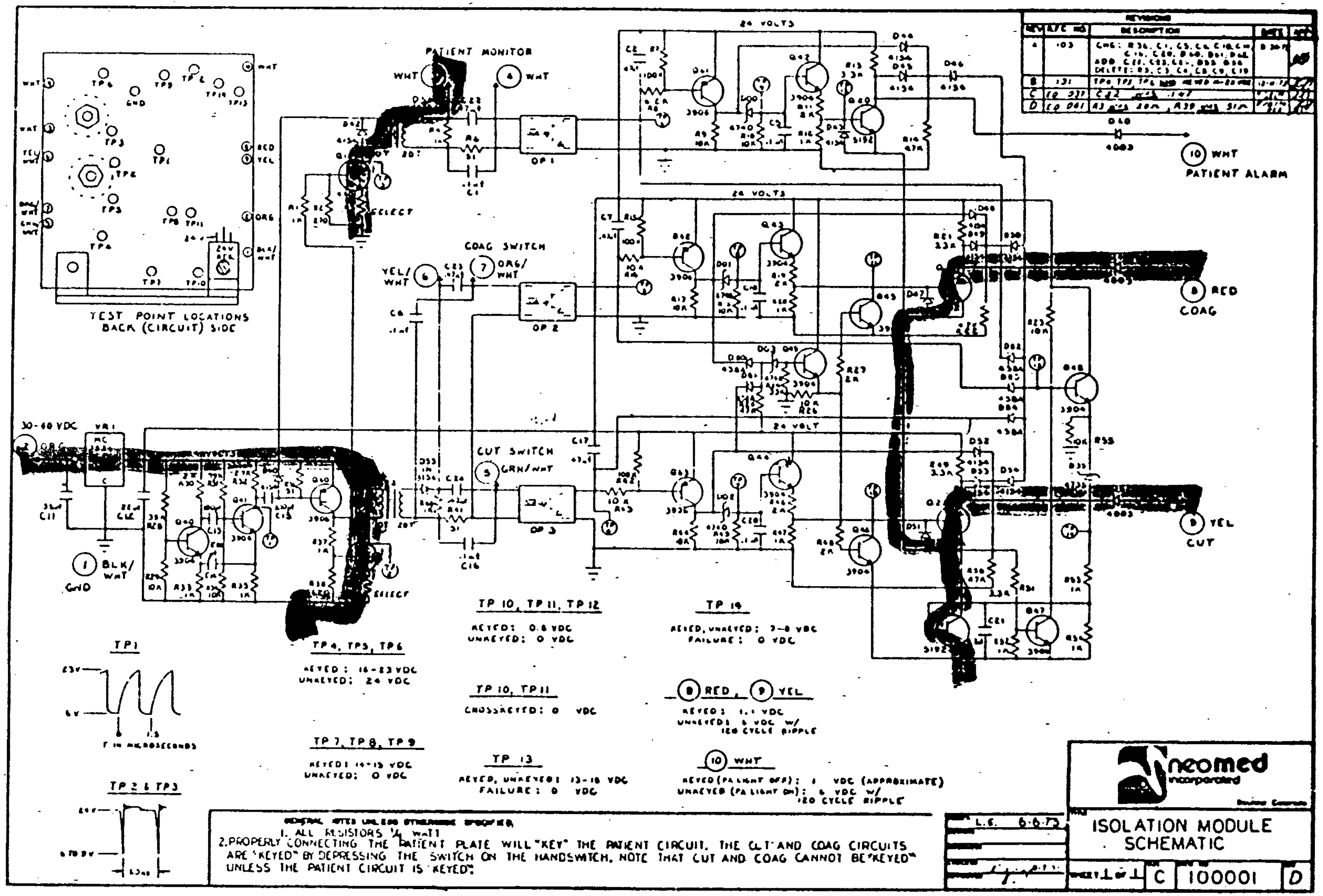


Figure 7.3 Electrosurgical Apparatus Isolation Module schematic

Table 7.1 Failure Thresholds for the Electrosurgical Apparatus

ELECTROSURGICAL APPARATUS NEOMED 3000

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4003	DIODE	2.2000	200	1.0	1	6.6E+05	17.82	217.82	3.9E+03
						8.0E+05	19.47	219.47	4.3E+03
						8.0E+06	53.34	253.34	1.4E+04
						2.6E+07	85.37	285.37	2.4E+04
						2.8E+07	87.83	287.83	2.5E+04
1N458A	DIODE	0.9600	200	1.0	1	6.6E+05	8.14	208.14	1.7E+03
						8.0E+05	8.93	208.93	1.9E+03
						8.0E+06	26.08	226.08	5.9E+03
						2.6E+07	43.63	243.63	1.1E+04
						2.8E+07	45.02	245.02	1.1E+04
2N2646	TRANS	0.7200	30	1.0	1	6.6E+05	23.67	53.67	1.3E+03
						8.0E+05	25.29	55.29	1.4E+03
						8.0E+06	53.17	83.17	4.4E+03
						2.6E+07	75.54	105.54	8.0E+03
						2.8E+07	77.19	107.19	8.3E+03
2N3440	TRANS	1.1000	7	1.7	1	6.6E+05	31.79	61.05	1.9E+03
						8.0E+05	33.45	63.87	2.1E+03
						8.0E+06	61.02	110.73	6.8E+03
						2.6E+07	82.61	147.44	1.2E+04
						2.8E+07	84.20	150.13	1.3E+04
2N5192	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
2N4401	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
1N4154	DIODE	0.0609	111	0.5	1	6.6E+05	0.96	111.48	1.1E+02
						8.0E+05	1.06	111.53	1.2E+02
						8.0E+06	3.32	112.66	3.7E+02
						2.6E+07	5.92	113.96	6.7E+02
						2.8E+07	6.14	114.07	7.0E+02
VS 248	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.1.1 Power Cord

The EMP surge couples to the power cord and is transferred through the transformer into the rectifiers, and beyond. A possible path to ground follows through Q301 and Q302. Failures of Q301 and Q302 occurred during one phase of the HDL/Vandre tests at AESOP. The equivalent circuit for this damage path is shown in Figure 7.4. The transformer was assumed 1:1 ratio with no internal losses for the EMP spectrum to assume worst case condition.

The current in the power cord path due to the EMP pin threat is computed from:

$$
\begin{aligned}
V_{EMP} = {} & I(R_S + R_{B1} + R_{B2} + R_L + R_{B3} + Z_C + R_{B4} + R + RB5 \\
& R + R_{B6} + R_{B7}) + V_{BD1} + V_{BD2} + V_{BD3} + V_{BD4} + V_{BD5} \\
& + V_{VBD6} + V_{BD7}
\end{aligned} \qquad (7.1)
$$

where R_{Bi} and V_{BDi} represent the surge resistance and breakdown voltage, respectively, for each device. R_L represents the impedance by the light bulb and Z_C represents the impedance from the capacitor. Diodes are usually modeled with the voltage source reverse biasing the diode. However, in the case of EMP analysis the diode is always modeled with the positive terminal of the voltage source going against the failure current. Thus, the polarity of the voltage sources will all be the same in a one loop problem, but the value of the sources and resistances will be dependent on whether the diode is forward biased or reverse biased. Data for R_B and V_{BD} in the reverse bias condition are given in Table 7.1. In the forward bias condition $R_B = .25$ ohms and $V_{BD} = 0.7$ volts. Substituting appropriate values into equation 7.1:

$$
\begin{aligned}
1800 = {} & I(100 + .25 + .25 + 70 + 1 + 5 + .25 + 15 + .25 + .25) \\
& + .7 + .7 + 200 + .7 + .7 + .7 + .7
\end{aligned} \qquad (7.2)
$$

Hence, the EMP induced current I in the circuit is 8.3A.

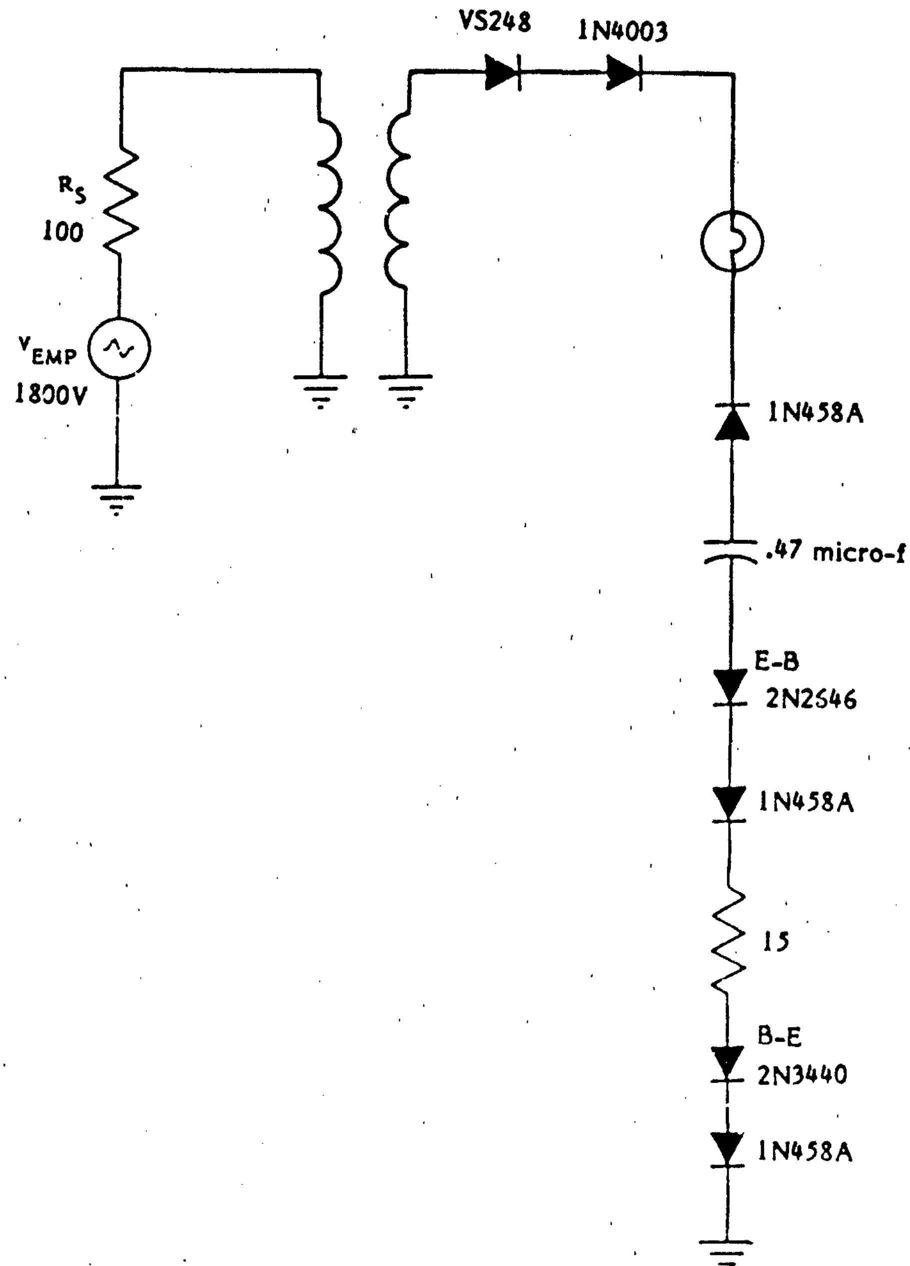


Figure 7.4 ESA: Power cord path to ground.

According to data from Table 7.1, the VS248 diode will fail at a current of 3.71A for $f = 0.66$MHz. This piece part has the lowest predicted failure current in the electrical path. Damage is most likely when the current affects a device in the reversed bias condition. This will always occur, since the initial peaks of the damped sine pulse are bipolar. In addition, the 1N458A diode will also fail since its failure current of 8.14A is less than 8.3A.

The 2N2646 and the 2N3440 failed in the HDL/Vandre EMP test. This damage most likely occurred due to the failure of the diodes to limit the voltage between the 2N2646 and the base-emitter junction of the 2N3440.

7.1.2 Patient Monitor

The EMP surge couples to the patient monitor cable and is transferred through the transformer to the Q10 circuit (Figure 7.3). Failures of D56, Q10, R2, and R3 occurred during one phase of the HDL/Vandre tests at AESOP. The equivalent circuit for this damage path is shown in Figure 7.5. The transformer is out of band in the EMP range and is assumed to couple the EMP directly in the worst case to the diode and transistor circuit.

$$V_{EMP} = I(R_S + R_{B1} + R_{B2} + R_{B3} + R_{B4} + R) + V_{BD1} + V_{BD2} + V_{BD3} + V_{BD4} \qquad (7.3)$$

where, as in the previous case, R_{Bi} and V_{BDi} represent the surge resistance and breakdown voltage, respectively, for each device in the circuit. Substituting appropriate values from Table 7.1:

$$1800 = I(100 + .5 + .5 + 10 + 25 + 270) + 111 + 111 + 5 + .7 \qquad (7.4)$$

The EMP inducted current I in the circuit is 4.1A.

From data in Table 7.1, the 1N4154 diode will fail at 0.96A for $f = 0.66$MHz. The failure of this diode most likely resulted in excess current at the 2N4401 base-collector and base-emitter, causing damage.

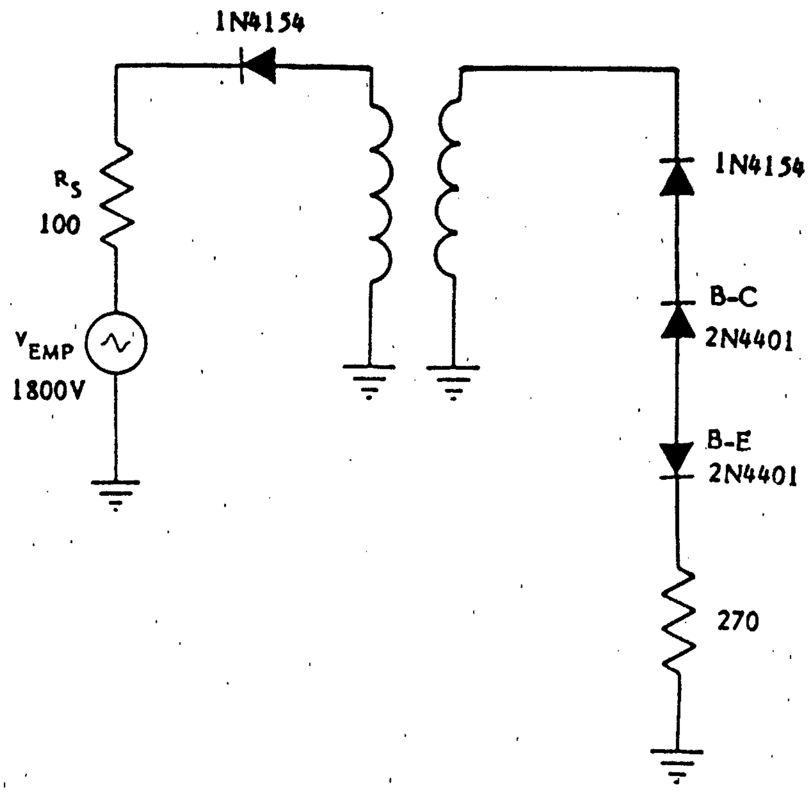


Figure 7.5 ESA: Patient monitor path to ground.

7.1.3 Foot Switch

EMP coupled to the foot switch cable poses a threat to the 2N5192 transistors and the 1N4154 diodes, (Q21, Q22, Q23) and D47, D571), respectively. The EMP induced current through the path shown in Figure 7.6 is 8.25. This current will cause failure in the 1N4154 diode (D51). A failure in the diode to limit the current can cause damage in the collector-emitter junctions of the 2N5192 transistor.

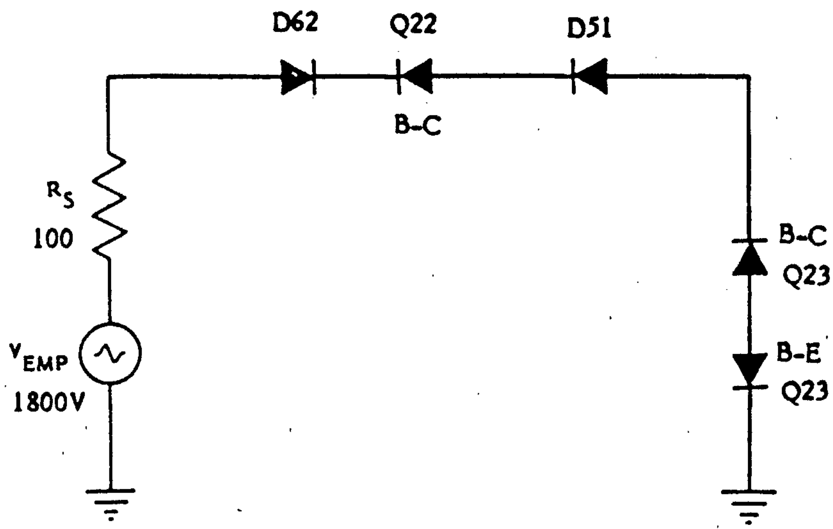
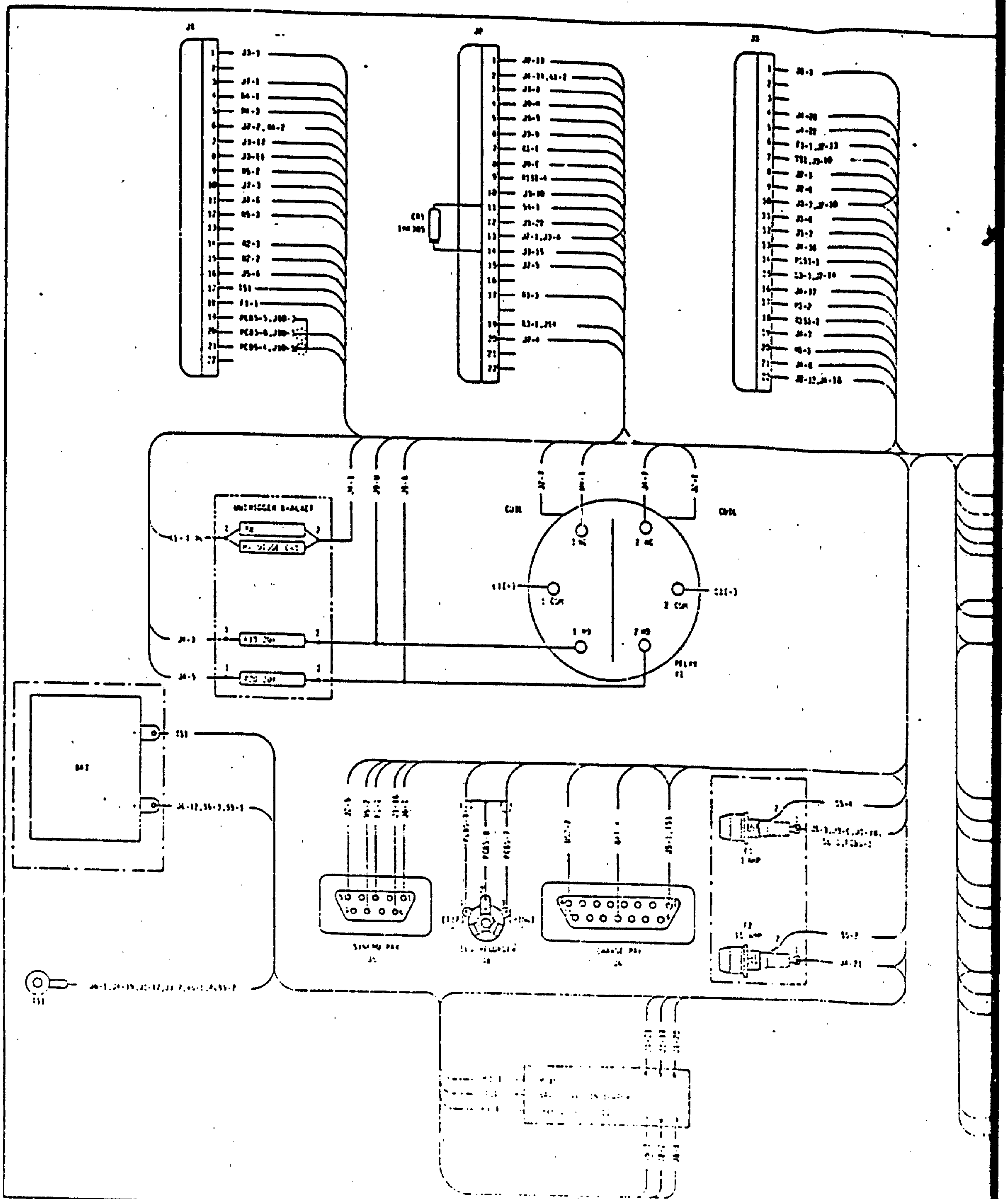


Figure 7.6 Foot Switch

7.2 DEFIBRILLATOR AND CARDIOSCOPE, LIFEPAK/33

Circuit diagrams for the Defibrillator and Cardioscope unit are given in Figures 7.7 through 7.9. Potential coupling paths can be identified from Figure 7.7 for the paddle connections, and from Figure 7.9 for the power interface. The interface circuits identified in the EMP I/O screen are the 1.) battery charger (Figure 7.9), 2.) paddle connections J2-4 and J2-8 (Figure 7.8), and 3.) paddle connection, relay (Figure 7.7). The piece parts list, and respective damage failure data are given in Table 7.2.



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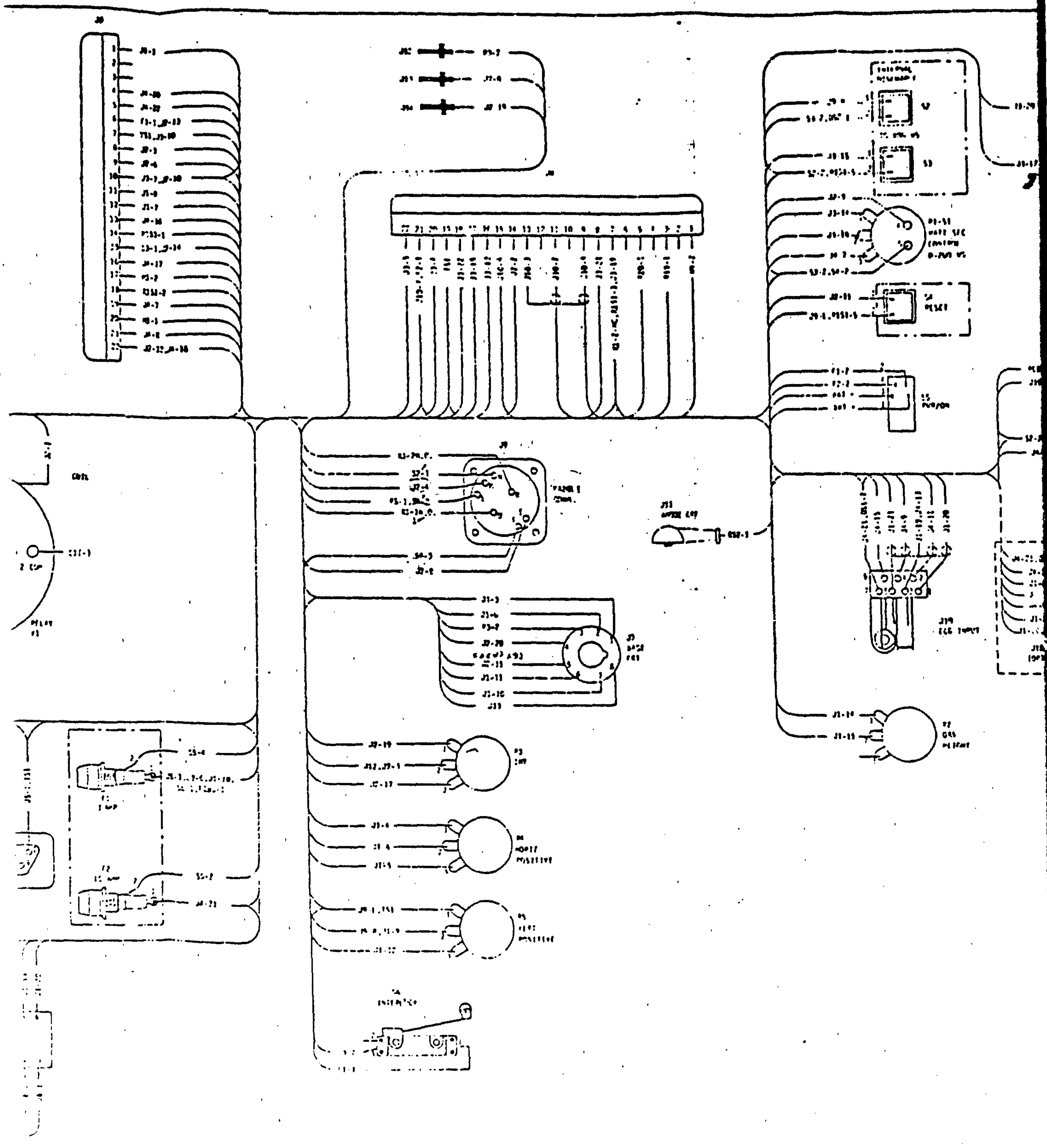


Figure 7.7 Wiring diagram, LIFEPAK/33

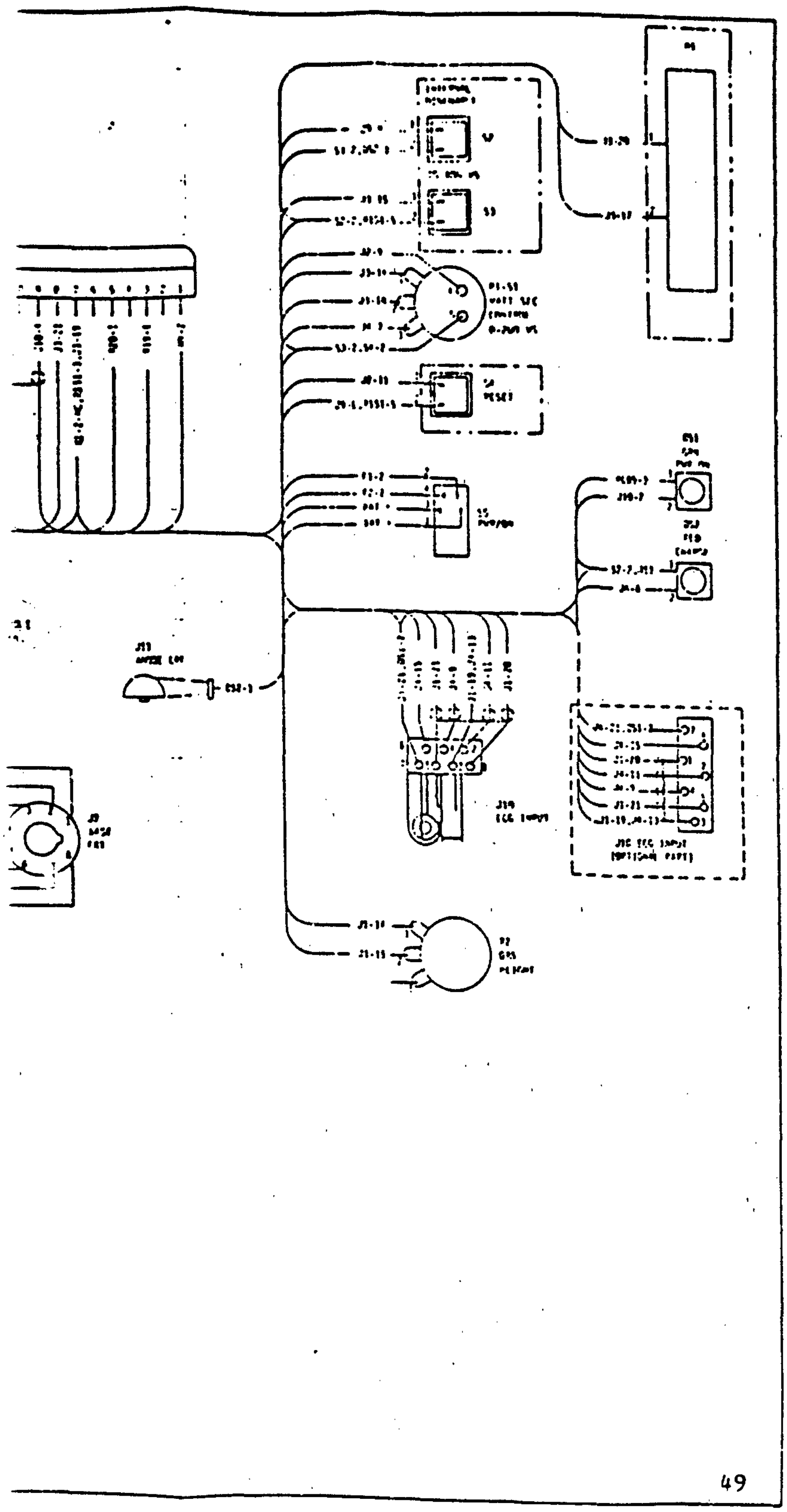


Figure 7.7 Wiring diagram, LIFEPAK/33

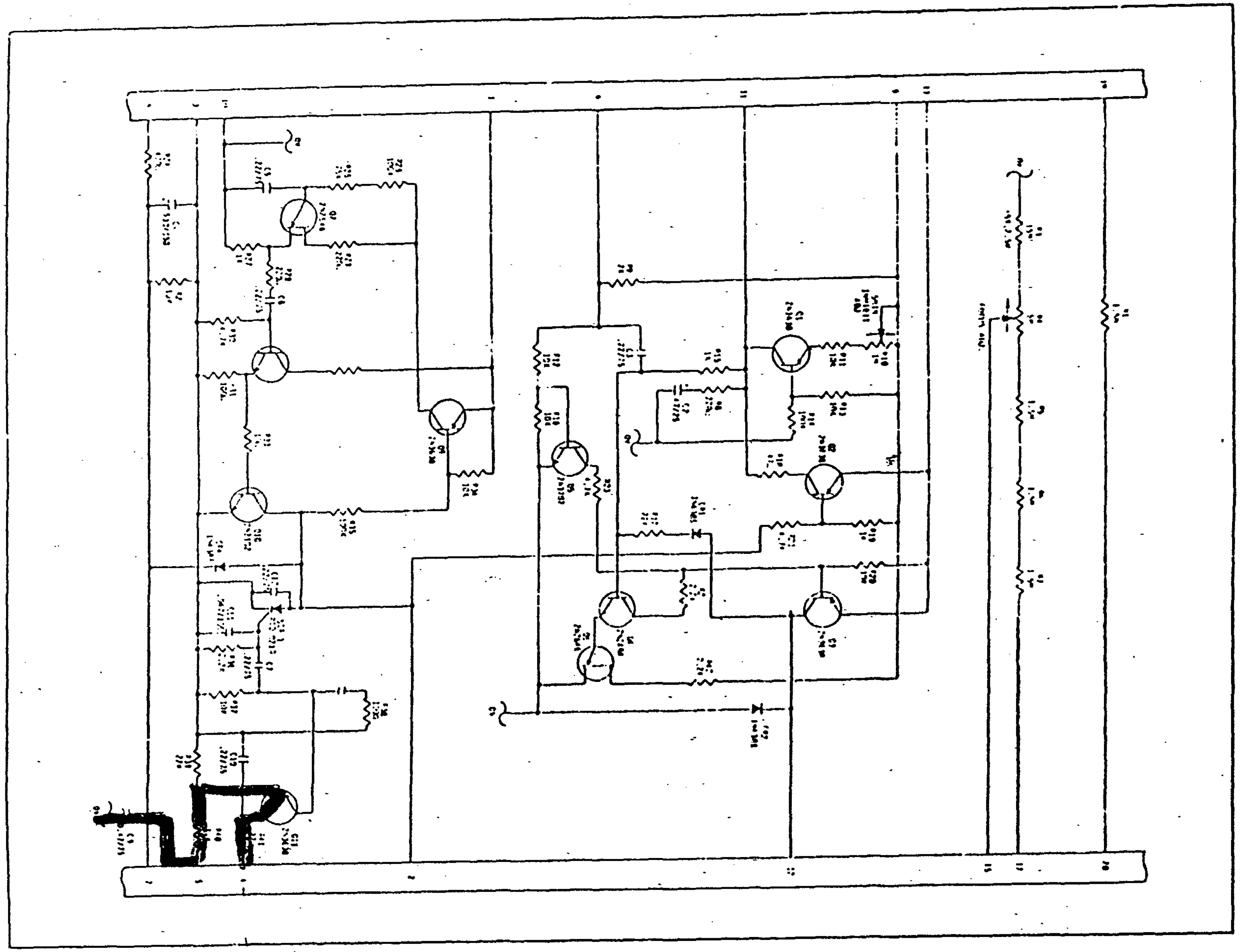


Figure 7.8 Schematic diagram. Discharge control PCB2

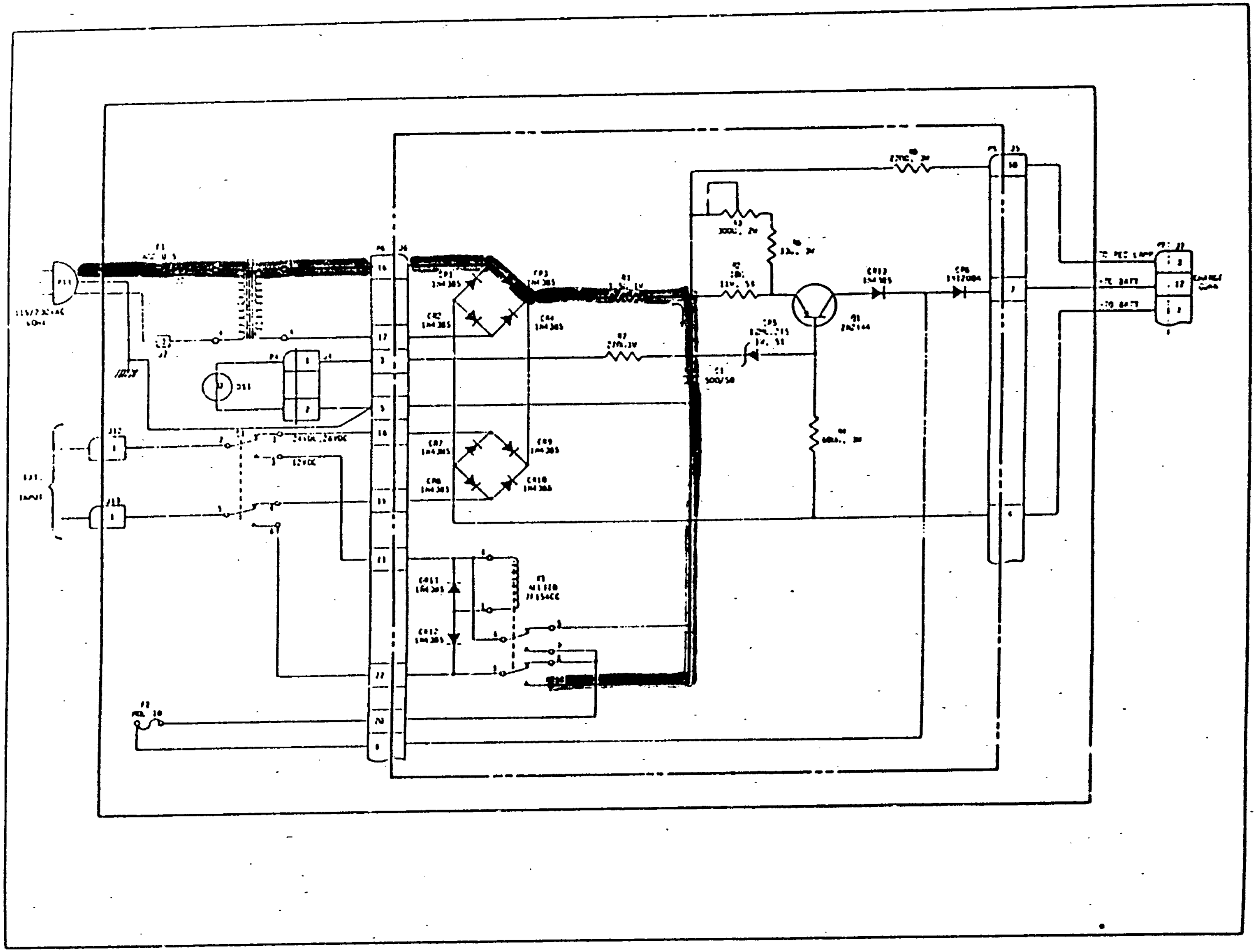


Figure 7.9 Schematic diagram. Battery charger PCB6

Table 7.2 Failure Thresholds for the Defibrillator and Cardioscope

DEFIBRILATOR AND CARDIOSCOPE LIFEPAK/33

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4385	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
2N2144	TRANS	0.2500	100	2.0	G	6.6E+05	4.08	108.16	4.4E+02
						8.0E+05	4.46	108.92	4.9E+02
						8.0E+06	12.32	124.64	1.5E+03
						2.6E+07	19.82	139.65	2.8E+03
						2.8E+07	20.40	140.81	2.9E+03
1N753A	DIODE	14.8000	6	0.5	1	6.6E+05	222.60	117.30	2.6E+04
						8.0E+05	233.86	122.93	2.9E+04
						8.0E+06	420.44	216.22	9.1E+04
						2.6E+07	566.55	289.27	1.6E+05
						2.8E+07	577.25	294.63	1.7E+05
2N3638	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
2N3707	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
2N2646	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
TF154CC	RELAY	0.3500	700	46.0	G	6.6E+05	0.84	738.47	6.2E+02
						8.0E+05	0.92	742.14	6.8E+02
						8.0E+06	2.62	820.53	2.1E+03
						2.6E+07	4.31	898.44	3.9E+03
						2.8E+07	4.45	904.54	4.0E+03

7.2.1 Battery Charger

The EMP coupled to the power cord will pass through the transformer and can flow to ground through the rectifier, R1, and C1 shown in Figure 7.9. The computer EMP current is 3.44A. The minimum failure threshold for the 1N4385 diode is 3.71A at f = 0.66MHz. Hence, this interface is hard to the assumed EMP threat.

7.2.2 Paddle Connection J2-4

The EMP coupled to the paddle cord can flow through R41, emitter-base of Q11, R40, and C9 shown in Figure 7.8. The computed EMP current for this path is 0.77A. This is well below the minimum 3.01A threshold for the 2N3638 transistor, therefore, this interface is hard to the assumed EMP threat.

7.2.4 Paddle Connection, Relay

The principle threat to the relay is from arcing across its contacts. By inspection, it appears that sufficient current limiting will be provided at the outrigger bracket to prevent damage to the relay. The current induced is less than 0.06A.

7.3 OXYGEN MONITOR, MODEL 5100 OHMEDA

The Oxygen Monitor is battery operated and has a short coiled sensor cable. The sensor cable is shielded which will provide reduction to induced EMP. The schematic for this unit is shown in Figure 7.10. Interface parts susceptible to the coupled EMP are the two op-amps, U5 and U3A. Generic failure data is given in Table 7.3. The worst case current at U5 will be 2.9A and at U3A will be 0.6A. These are well below the generic failure thresholds for the interface circuits. Also, coupling to the sensor cable will be small, due to its short length. Therefore, this unit is expected to be hard to EMP.

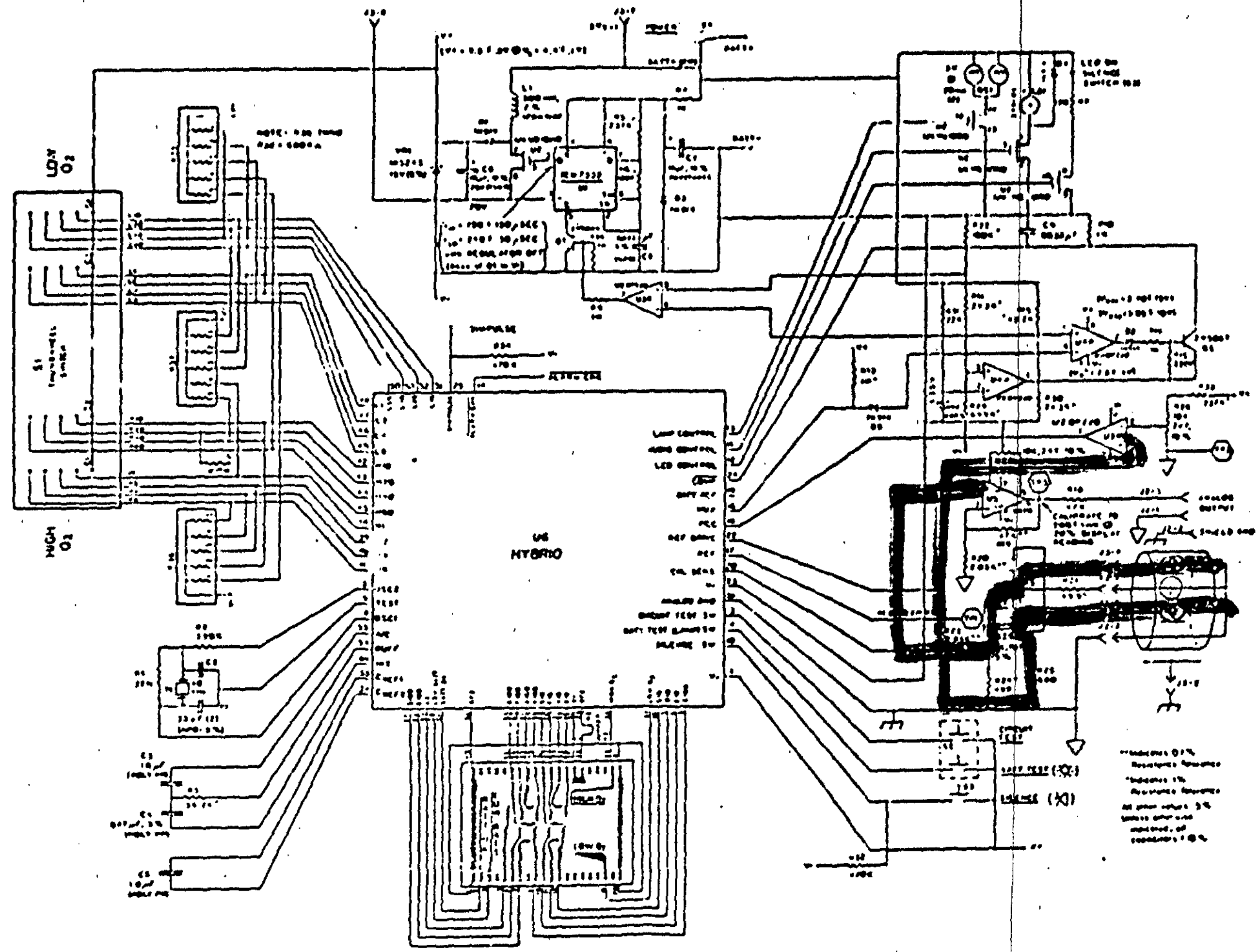


Figure 7.10 Oxygen Monitor, Model 5100 Ohmeda

Table 7.3 Failure Thresholds for the Oxygen Monitor

Part No.	Part Type	A	B	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
OP20	OP AMP	.0045	.714	7	5.5	G	6.6E+05	4.12	29.64	121.96
OP220							8.0E+05	4.45	31.46	139.92
							8.0E+06	10.86	66.71	724.24
							2.6E+07	16.85	99.70	1680.22
							2.8E+07	17.32	102.27	1771.52

7.4 RESUSCITATOR, GLOBE SAFETY PRODUCTS, INC.

The circuit diagram for the Globe Resuscitator is shown in Figure 7.11. The susceptible part is CR-4. Since the part type is not given in the manual, a typical rectifier diode (1N385) was selected. The damage data for this diode is listed in Table 7.4.

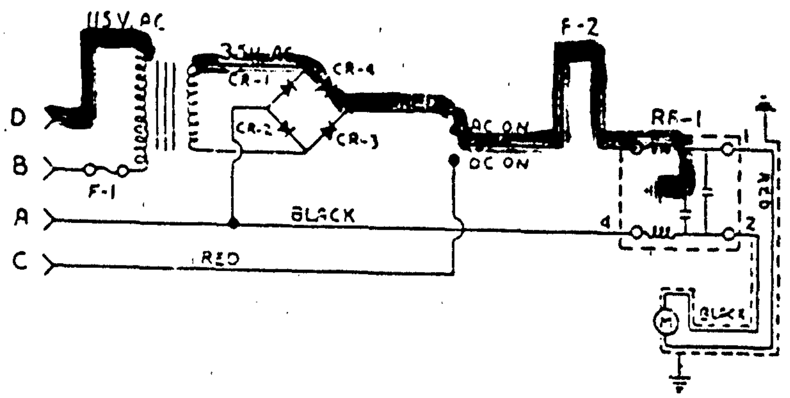


Figure 7.11 Resuscitator Schematic

Table 7.4 Failure Thresholds for the Globe Resuscitator with Assumed Diode Type

RESUSCITATOR; FIELD. GLOBE SAFETY PROD.

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4385	DIODE	0.2900	50	25.0	1G	6.6E+05	3.69	142.34	5.3E+02
						8.0E+05	3.91	147.87	5.8E+02
						8.0E+06	7.62	240.38	1.8E+03
						2.6E+07	10.53	313.31	3.3E+03
						2.8E+07	10.75	318.66	3.4E+03

Coupling through the transformer is assumed 1:1 with no losses for the worst case. The EMP induced current is computed from:

$$V_{EMP} = I(R_s + R_B) + V_{VBD} \qquad (7.5)$$

$$1800 = I(100 + 25) + 50 \qquad (7.6)$$

The resulting threat current is 14A. The rectifier diode threshold is 3.7A at f = 0.66 MHz and failure is likely due to EMP coupling to the power cord.

Vulnerability is indicated with the assumed part type. A conclusive assessment of this unit would, however, require identification of the actual part type used in the rectifier. When operated in the DC mode with batteries, this unit would probably not be vulnerable to EMP, since the power cord coupling path would be eliminated.

7.5 ULTRASONIC GENERATOR, RICH-MAR IV

EMP coupled to the power cord can be transmitted through the transformer and line filter to the rectifier circuit, CR2. A possible path to ground is through C8. The schematic is shown in Figure 7.12. Failure threshold data for the rectifier diode type is given in Table 7.5.

The computed EMP current is 7.1A through the diode at f = 0.66MHz, therefore, this unit is vulnerable to the assumed EMP threat.

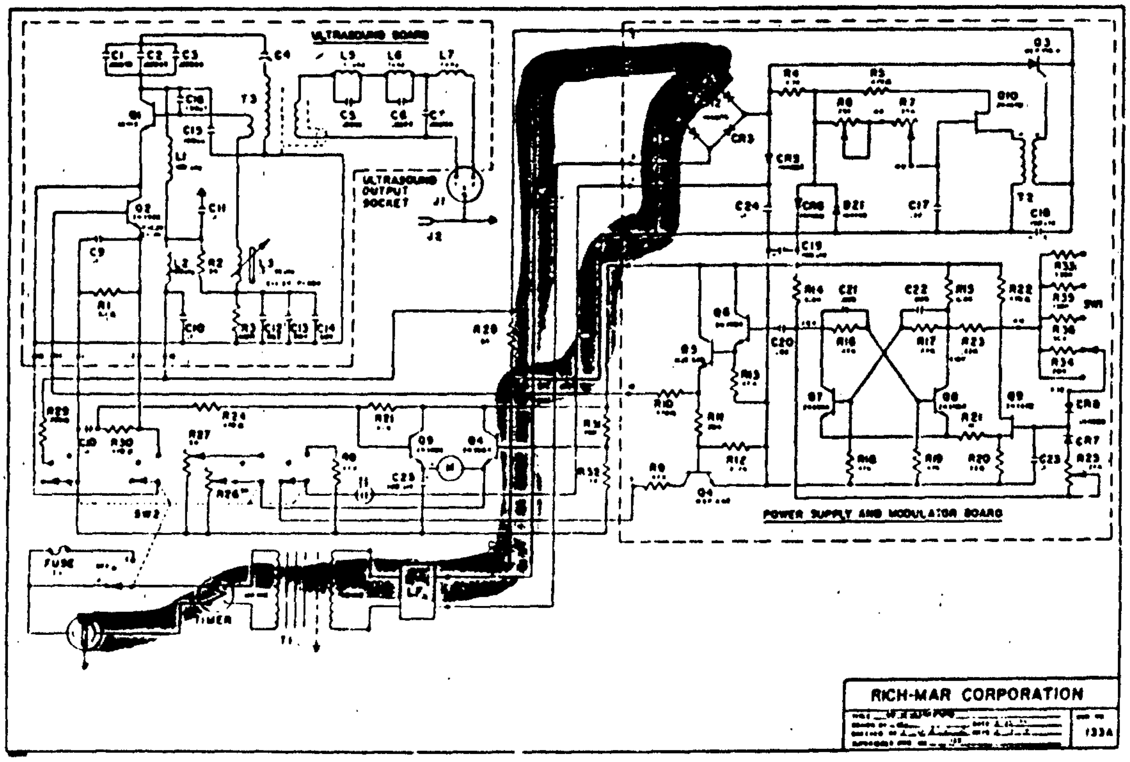


Figure 7.12 Ultrasonic Generator, Rich-Mar IV.

Table 7.5 Failure Thresholds for the Ultrasonic Generator

ULTRASONIC GENERATOR RICH-MAR IV

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4005	DIODE	0.3467	600	116.0	1	6.6E+05	0.87	701.19	6.1E+02
						8.0E+05	0.95	710.02	6.7E+02
						8.0E+06	2.42	880.55	2.1E+03
						2.6E+07	3.72	1031.67	3.8E+03
						2.8E+07	3.82	1043.07	4.0E+03
LINE	FILTER	0.0001	500	15.0	8	6.6E+05	0.00	500.01	1.8E-01
						8.0E+05	0.00	500.01	1.9E-01
						8.0E+06	0.00	500.02	6.1E-01
						2.6E+07	0.00	500.03	1.1E+00
						2.8E+07	0.00	500.03	1.1E+00

7.6 X-RAY APPARATUS, 2mA, 120PKV

The 2mA, 120 PKV X-ray Apparatus I/O circuits susceptible to EMP are the 1.) exposure timer, 2.) the emitter follower, and 3.) the M.A. regulator. Failure thresholds for parts identified are given in Table 7.6.

7.6.1 Exposure Timer

The exposure timer schematic is shown in Figure 7.13. The unit is connected with a cable to provide for remote firing. Two possible EMP coupling paths were investigated. One is through CR401, and the other is through Q401 and Q402. Neither case is vulnerable to the assumed EMP pulse. The maximum predicted current at CR 401 is 5.8A. The generic failure threshold for this type of diode is 27.9A at f = 0.66 MHz. The maximum predicted current at Q401 and Q402 is 0.6A. The generic failure threshold for the 2N404A is 12.56A at f = 0.66 MHz.

Table 7.6 Failure Thresholds for the X-Ray Apparatus, 2mA 120PKV

X-RAY APPARATUS 2mA 120PKV

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N1763	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
VR18A	DIODE	0.6000	10	1.0	G	6.6E+05	27.92	37.92	1.1E+03
						8.0E+05	29.50	39.50	1.2E+03
						8.0E+06	55.91	65.91	3.7E+03
						2.6E+07	76.66	86.66	6.6E+03
						2.8E+07	78.19	88.19	6.9E+03
2N441	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
2N414	TRANS	0.0600	50	10.0	G	6.6E+05	1.60	66.03	1.1E+02
						8.0E+05	1.73	67.31	1.2E+02
						8.0E+06	4.07	90.65	3.7E+02
						2.6E+07	6.03	110.26	6.6E+02
						2.8E+07	6.17	111.72	6.9E+02
VR85A	DIODE	0.6000	10	1.0	G	6.6E+05	27.92	37.92	1.1E+03
						8.0E+05	29.50	39.50	1.2E+03
						8.0E+06	55.91	65.91	3.7E+03
						2.6E+07	76.66	86.66	6.6E+03
						2.8E+07	78.19	88.19	6.9E+03
CER68	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
2N404A	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
VR10A	DIODE	0.6000	10	1.0	G	6.6E+05	27.92	37.92	1.1E+03
						8.0E+05	29.50	39.50	1.2E+03
						8.0E+06	55.91	65.91	3.7E+03
						2.6E+07	76.66	86.66	6.6E+03
						2.8E+07	78.19	88.19	6.9E+03
2N526	TRANS	0.3900	10	2.0	1G	6.6E+05	16.22	42.43	6.9E+02
						8.0E+05	17.12	44.24	7.6E+02
						8.0E+06	32.20	74.40	2.4E+03
						2.6E+07	44.04	98.07	4.3E+03
						2.8E+07	44.90	99.81	4.5E+03

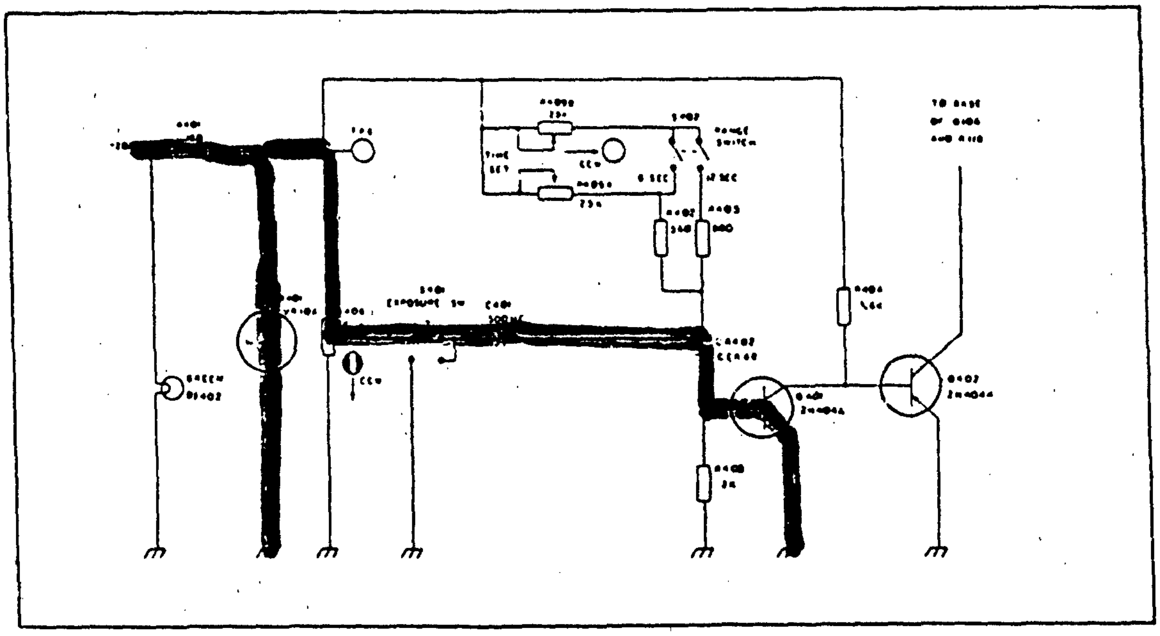


Figure 7.13 Exposure Timer

7.6.2 Emitter Follower

The Emitter Follower schematic is shown in Figure 7.14 EMP coupled to the remote control cable can cause failure in the base-emitter junction of the 2N526 (Q106) transistor. The computed current is 17.6A. The failure threshold for this device is 16.22A, therefore, this junction is vulnerable.

7.6.3 M. A. Regulator

The M.A. Regulator schematic is shown in Figure 7.15. For this analysis, it is assumed that the tube and the circuit are separated by cable. If this is the case, then EMP will couple to the cable and can present a threat at the collector-base junction of the 2N441 (Q304) transistor. The computed current at this junction is 14.7A. The generic threshold is 12.56A at f = 0.66 MHz, therefore, a vulnerability is indicated. In this case, however, the exact configuration should be confirmed with the manufacturer if a more detailed assessment of this unit is desired.

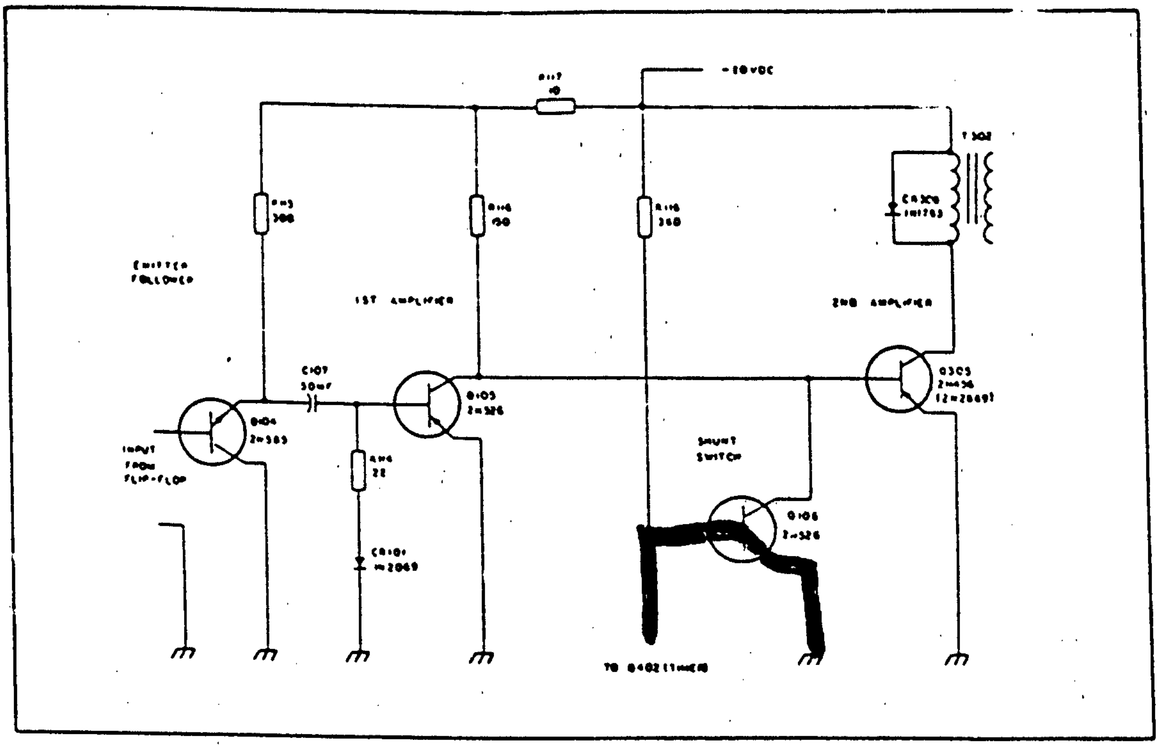


Figure 7.14 Emitter Follower, 1st and 2nd Amplifiers, and Shunt Switch

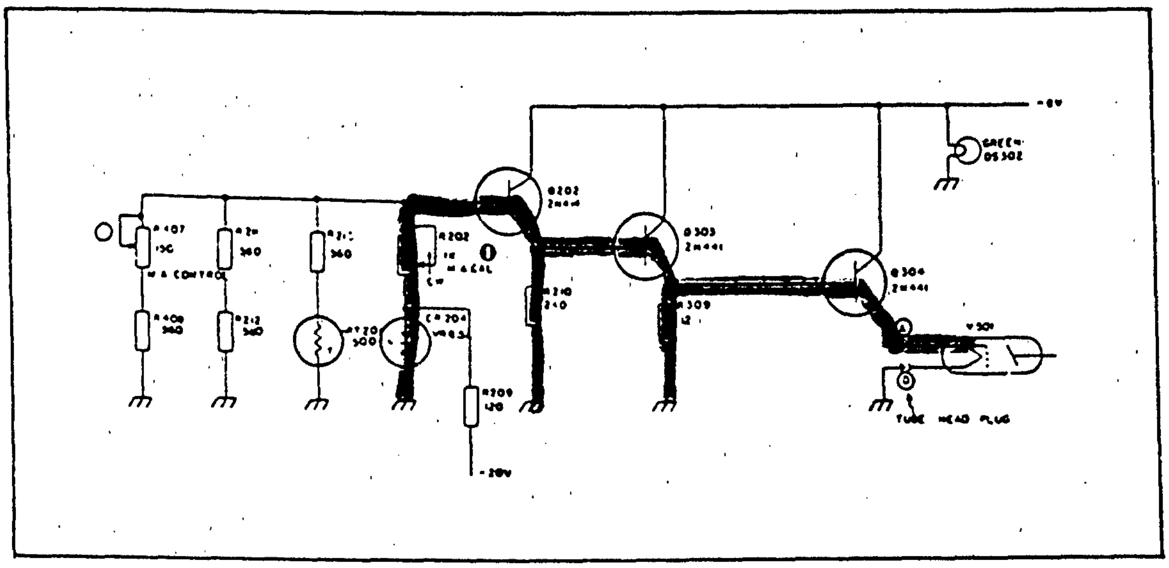


Figure 7.15 M. A. Regulator

7.7 EK/5A ELECTROCARDIOGRAPH, BURDICK CORP.

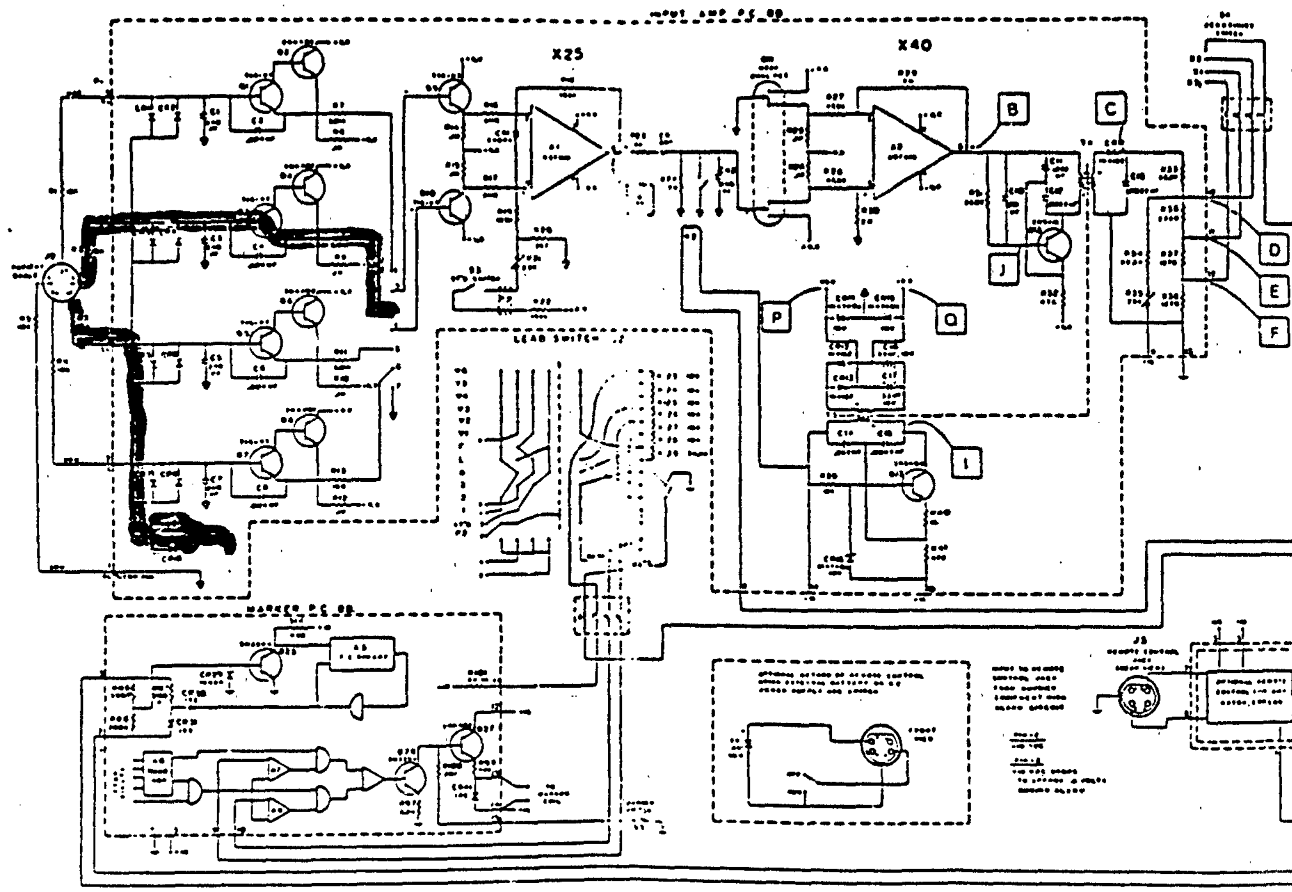
The patient cable interface and the power cable interface were examined for this unit. The schematic is shown in Figure 7.16. Generic part data was used for this unit. The failure thresholds are given in Table 7.7.

7.7.1 Patient Cable C

A likely EMP path to ground on patient cable C is through CR9 and CR10. The current in this path will be 14A due to the assumed EMP threat. In the reverse bias condition, this current can cause failure in the diode limiter circuit. The generic failure threshold is 3.71A. A more detailed analysis would be required to establish the effect of this failure to the patient monitor circuits.

7.7.2 Power Cable

A likely path to ground for EMP coupled to the power cable is through CR21 and C32 (see Figure 7.16). The EMP current in this path can be 14A. Assuming the generic failure threshold of 3.71A, the diode will fail due to the EMP pin threat.



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1.

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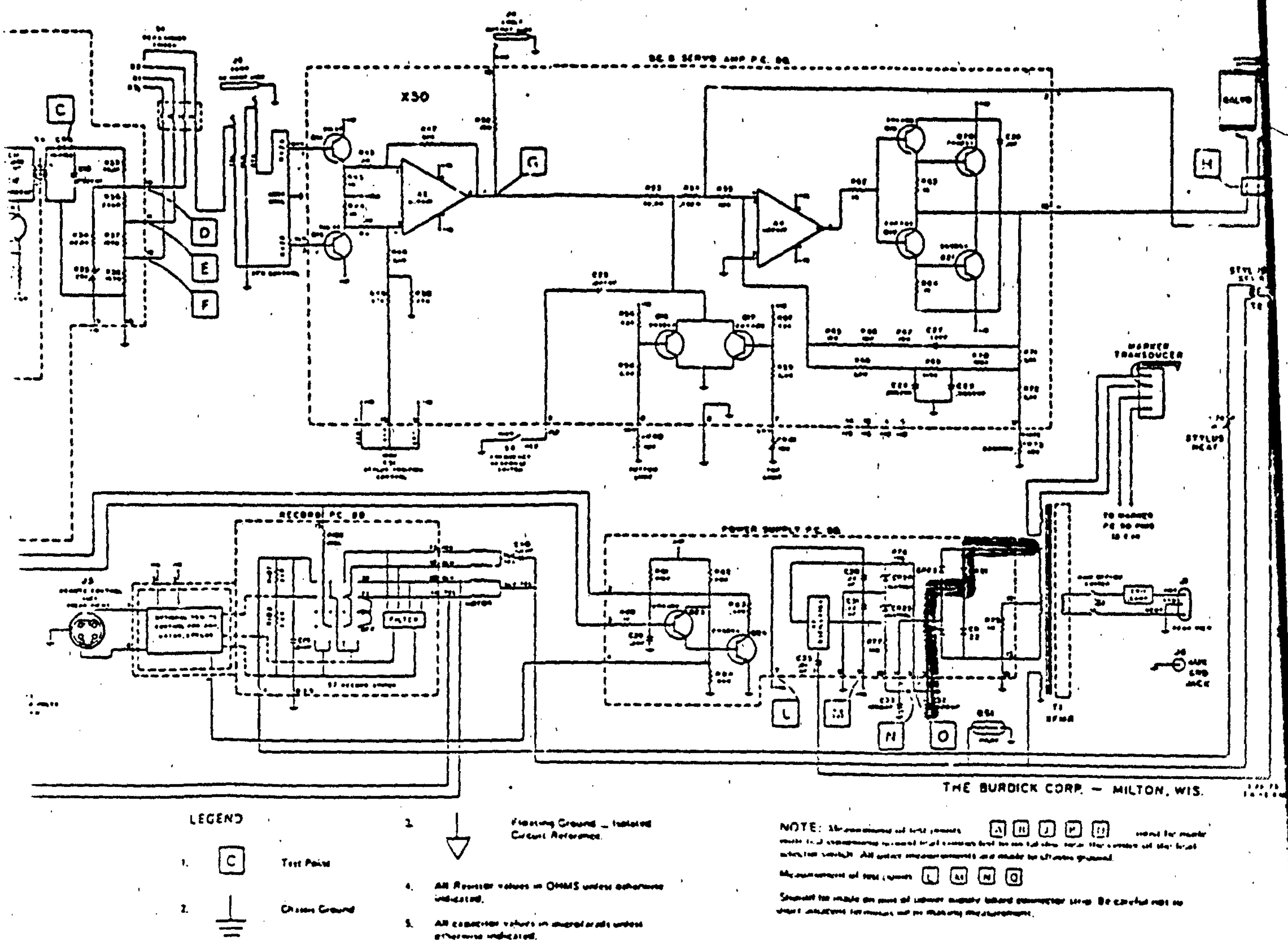
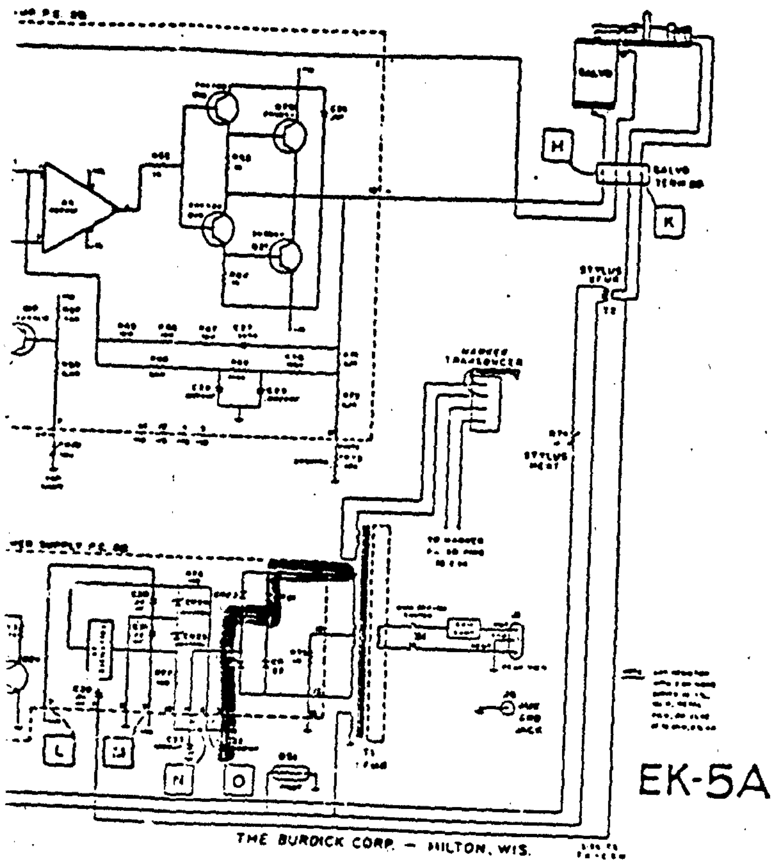


Figure 7.16 EK/5A Electrocardiograph, Burdick Corp., Schematic



NOTE: [illegible]

ctrocardiograph, Burdick Corp., Schematic 66

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Table 7.7 Failure Thresholds for the EK/5A Electrocardiograph

EK/5A ELECTROCARDIOGRAPH BURDICK CORP.

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
TIS-97	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
CR9;10	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
CR21	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.8 Volumetric Infusion Pump, IMED Model 922

The power cable interface was examined for this unit. The schematic for this unit is shown in Figure 7.17. A possible path for EMP to ground is through the rectifier and to the 2N4401 transistor, Q7. This path, and others, in the bridge circuit contain 5.6K resistors which limit the current to less than 1 amp. This is below the generic failure threshold for all parts. Therefore, this unit will survive the assumed EMP threat.

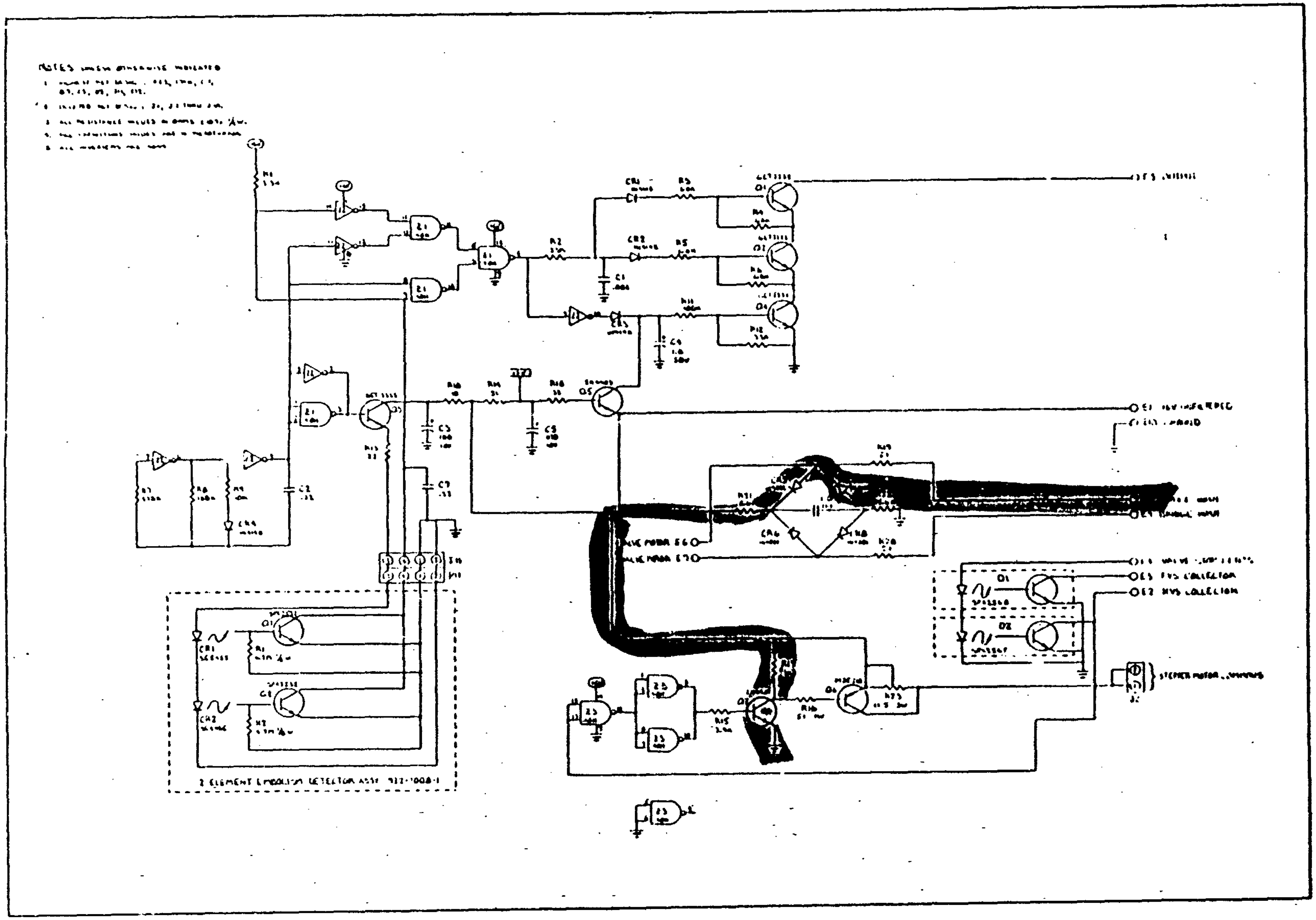


Figure 7.17 IMED Model 922 Volumetric Infusion Pump

Table 7.8 Failure Thresholds for the IMED Volumetric Infusion Pump

VOLUMETRIC INFUSION PUMP IMED MODEL 922

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
2N4403	TRANS	0.0600	50	25.0	G	6.6E+05	1.29	82.20	1.1E+02
						8.0E+05	1.38	84.49	1.2E+02
						8.0E+06	2.97	124.19	3.7E+02
						2.6E+07	4.25	156.2C	6.6E+02
						2.8E+07	4.35	158.65	6.9E+02
1N4001	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
2N4401	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02

7.9 BLOOD GAS ANALYZER, I. L. INC., MODEL 113

The schematic for the Blood Gas Analyzer is shown in Figure 7.18. The only long external conductor to this unit is the power cord. A possible EMP path to ground is from the transformer through the emitter-base junction of transistor Q13. Failure thresholds are given in Table 7.9. The computed EMP current for the transistor junction is 12.95A. This exceeds the failure thresholds for all the piece parts at f = 0.66 MHz. Therefore, this unit is likely to fail if the power circuit is left unprotected.

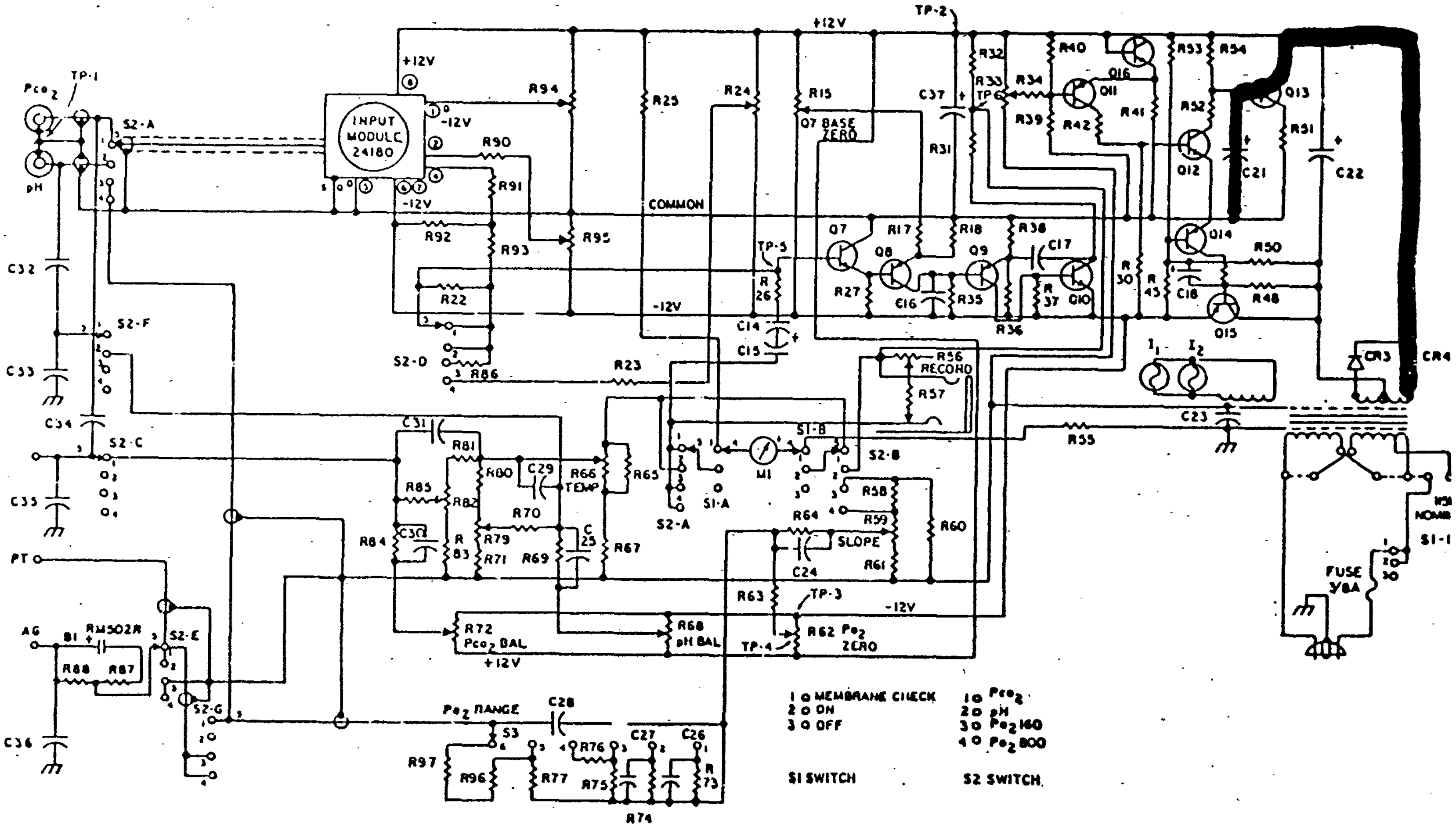


Figure 7.18 Blood Gas Analyzer, L. L. Inc. Model 113

Table 7.9 Failure Thresholds for the Blood Gas Analyzer, I.L. Inc. Model 113

BLOOD GAS ANALYZER I.L. INC. MODEL 113

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
61540	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
70100	TRANS	0.2500	10	2.0	B	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
Q13	TRANS	0.2500	10	2.0	B	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03

7.10 Xenon Endoscopic Light Source, Model L12

The schematic for this unit is shown in Figure 7.19. The only long external conductor is the power cord. A possible EMP path to ground is through the rectifier circuit and the collector-emitter junction of the transistor Q120. The failure thresholds are given in Table 7.10. The computed EMP current is 12.9A. This current exceeds the failure thresholds at f = 0.66 MHz. Therefore, the unit is vulnerable to EMP if the power input is left unprotected.

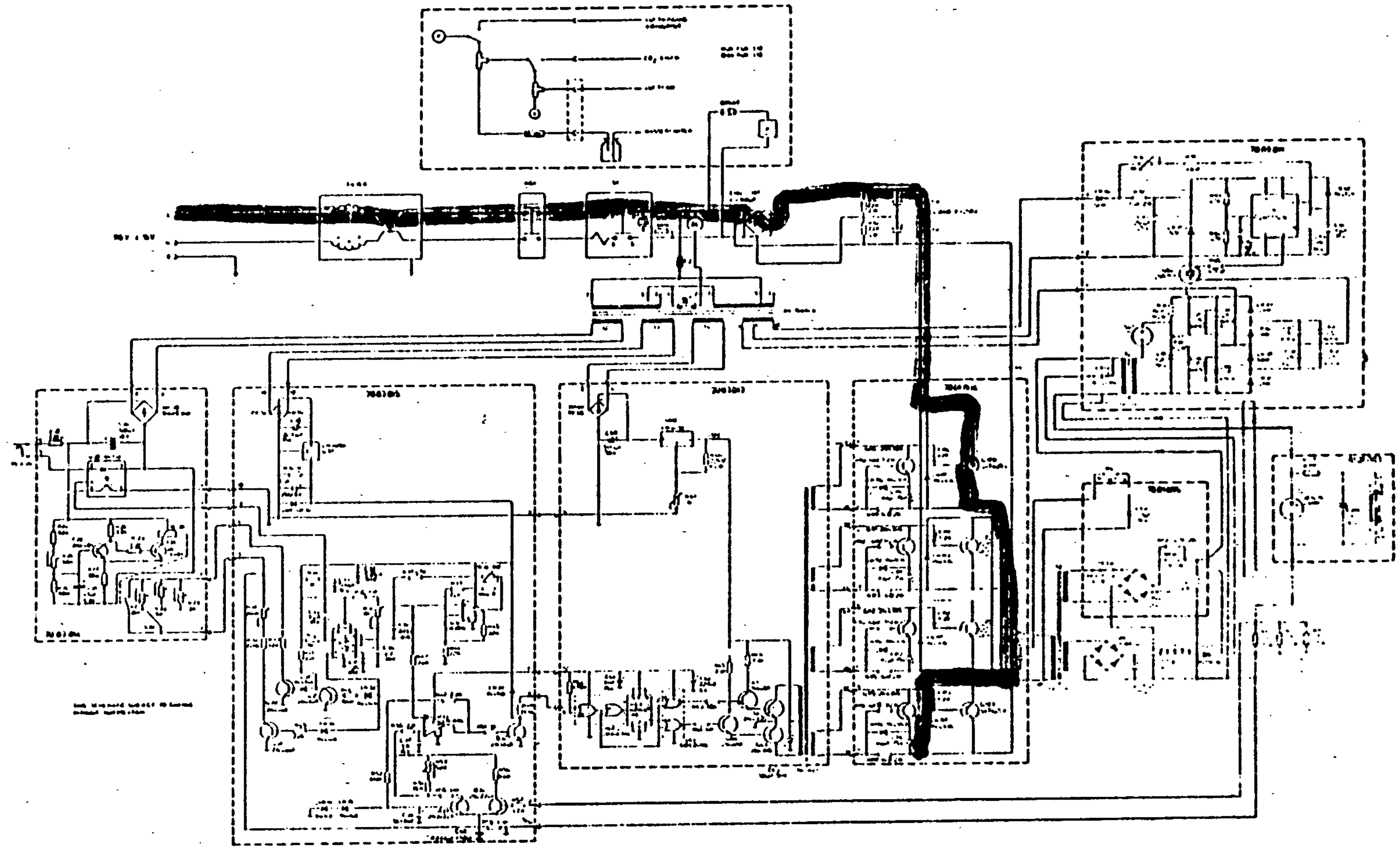


Figure 7.19 L12 Xenon Endoscopic Light Source

Table 7.10 Failure Thresholds for the Xenon Endoscopic Light Source

XENON ENDOSCOPIC LIGHT SOURCE MODEL L12

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N4385	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
SVT6253	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
1N4936	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.11 Spectrophotometer, Stasar

The schematic for this unit is shown in Figure 7.20. Possible EMP coupling can occur through the 12.6 volt input from the main power, and through the 11 volt input from the main power. The computed currents for these paths are less than 2.6A. This is below all failure thresholds of the affected parts. Therefore, this unit will survive the assumed EMP threat.

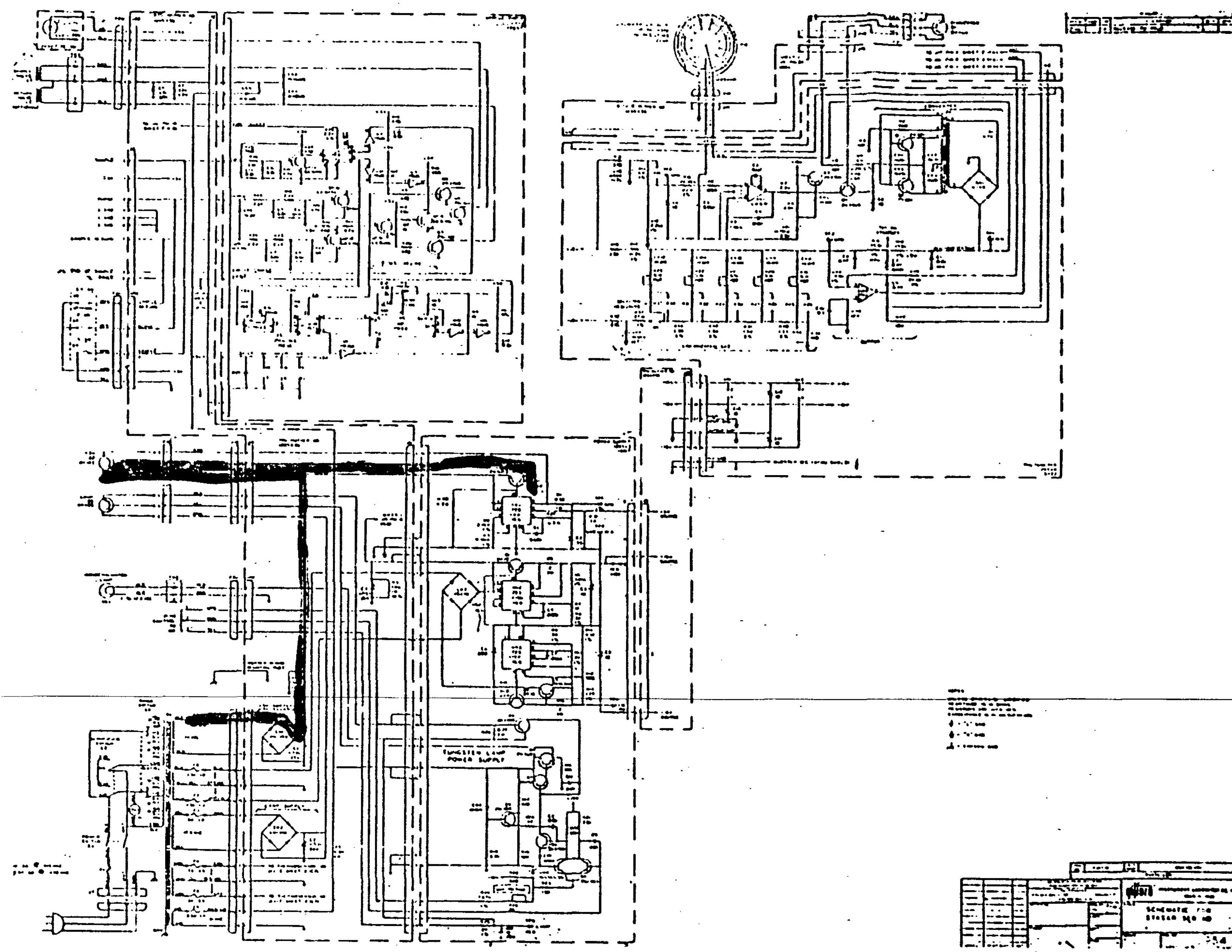


Figure 7.20 Stasar Spectrophotometer

Table 7.11 Failure Thresholds for the Stasar Spectrophotometer

SPECTROPHOTOMETER STASAR

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
2N3054	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
2N3053	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
VR723	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
1N914	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
2N1303	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
VM148	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.12 Opthalmic Diathermy, TR 3000

The schematic for this unit is shown in Figure 7.21. The footswitch and handle controls and the power interface were examined. Of these, the power interface may contain vulnerable components. As in previous equipments, the power interface contains a transformer and rectifier with possible paths to semiconductor junctions. Tables 7.12a and 7.12b give the failure thresholds. EMP induced currents above 3.71A will cause failure. The coupled EMP currents can be up to 10A for the power interface. An added threat to the 2N3645 transistor Q5 comes from possible EMP coupling from both the handle control, and the power cord. Therefore, this unit is vulnerable to EMP without added protection.

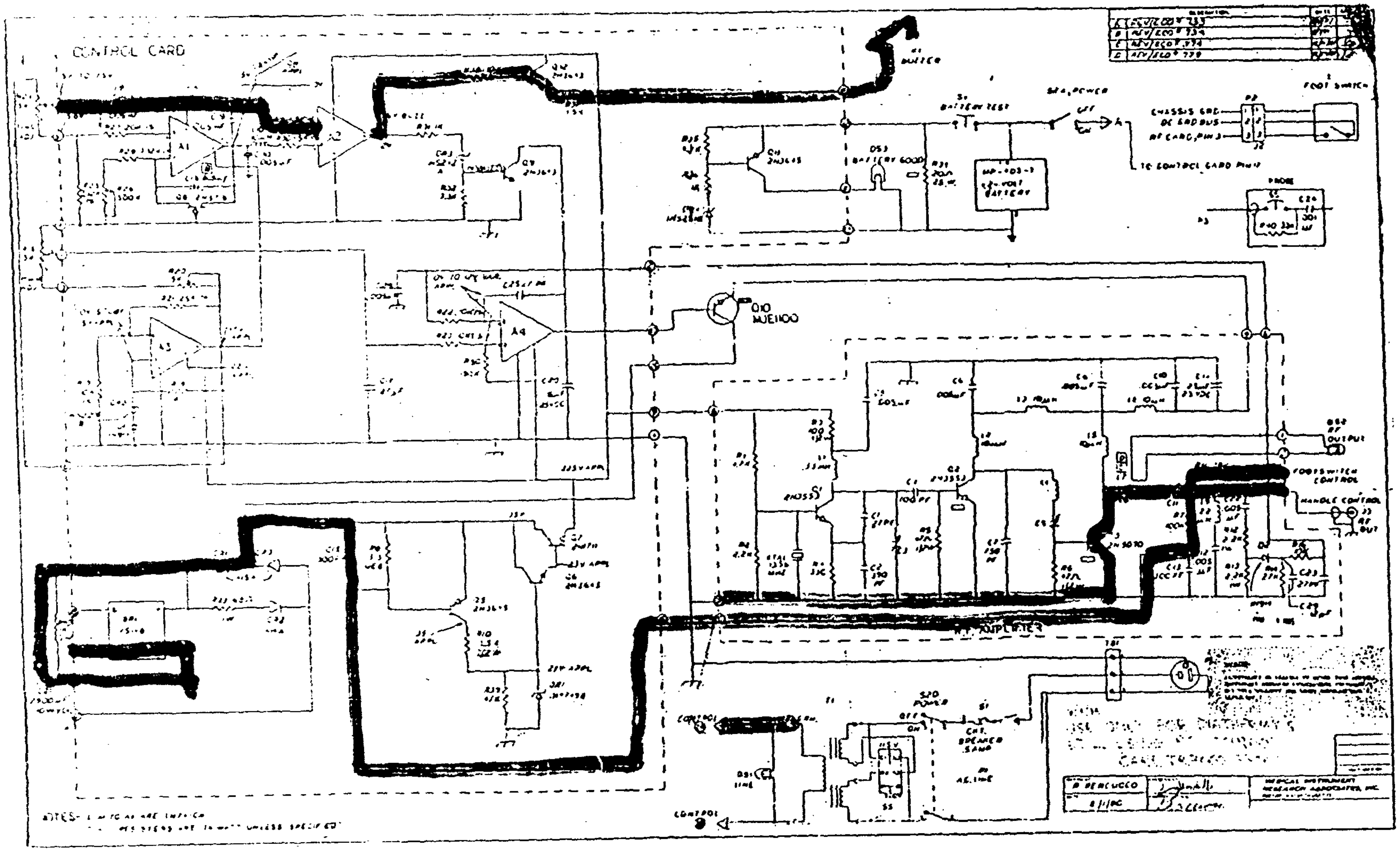


Figure 7.21 Opthalmic Diathermy, TR 3000

Table 7.12a Failure Thresholds for the Opthalmic Diath~ermy TR 3000

OPTHALMIC DIATHERMY TR 3000

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
VS148	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
A15A	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
2N5070	TRANS	0.2500	100	2.0	G	6.6E+05	4.08	108.16	4.4E+02
						8.0E+05	4.46	108.92	4.9E+02
						8.0E+06	12.32	124.64	1.5E+03
						2.6E+07	19.82	139.65	2.8E+03
						2.8E+07	20.40	140.81	2.9E+03

Table 7.12b Opthalmic Diathermy TR 3000

Part No.	Part Type	A	B	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
LM741CM	OP AMP	.0045	.714	7	5.5	G	6.6E+05	4.12	29.64	121.96
							8.0E+05	4.45	31.46	139.92
							8.0E+06	10.86	66.71	724.24
							2.6E+07	16.85	99.70	1680.22
							2.8E+07	17.32	102.27	1771.52

7.13 Birtcher 771 Micro Bipolar Coagulator

The schematic for this unit is shown in Figure 7.22. The interface circuits studied were the power interface and the foot switch interface. The failure thresholds for the diode type used in these circuits are given in table 7.13. The maximum EMP currents computed for these circuits did not exceed 0.1A. Therefore, this unit is hard to the assumed EMP threat.

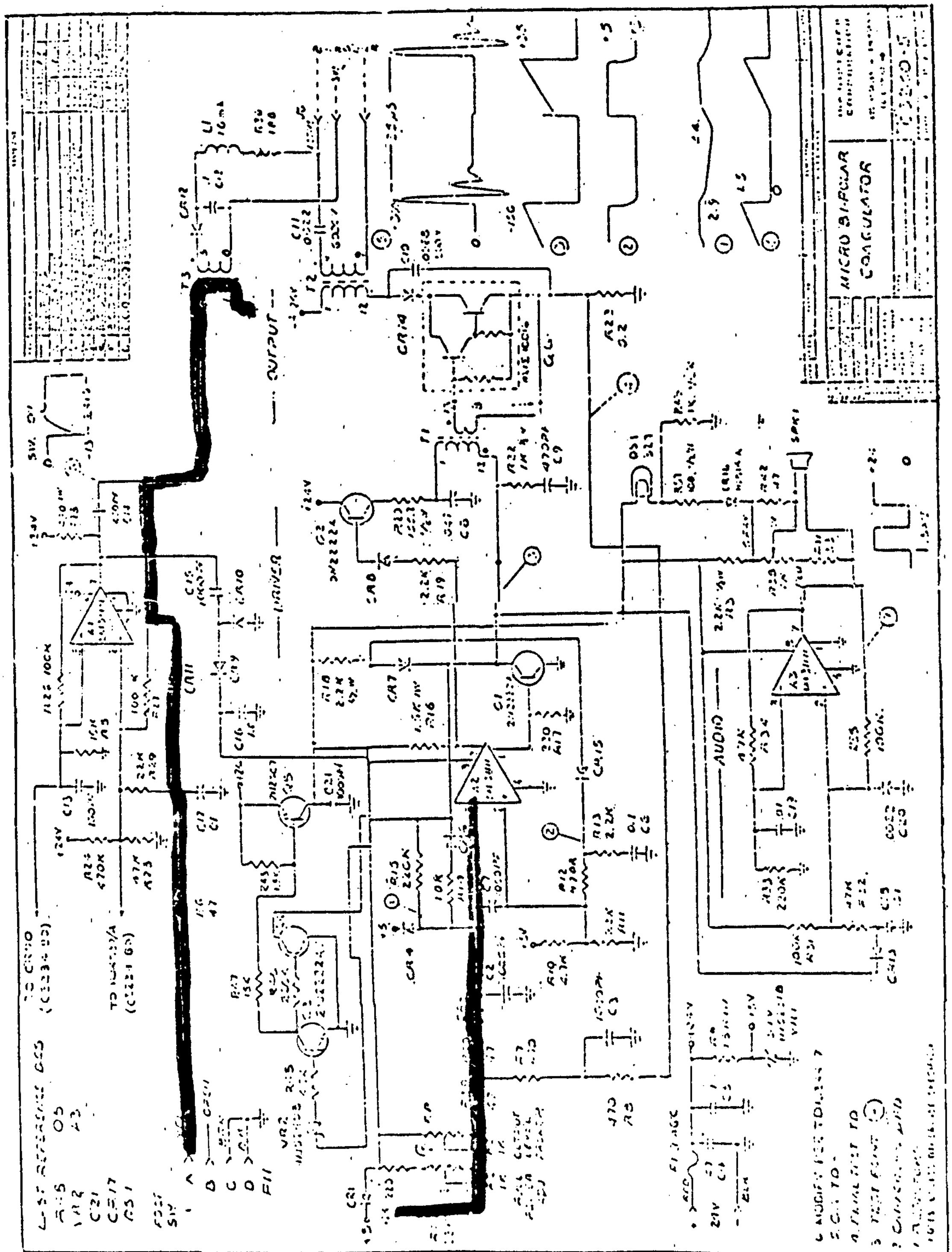


Figure 7.22 Birtcher 771 Micro Bipolar Coagulator

Table 7.13 Failure Thresholds for the Micro Bipolar Coagulator, Birtcher 771

MICRO BIPOLAR COAGULATOR BIRTCHER 771

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
1N514B	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.14 Portaray Heliodent 70, Siemens D3152

The schematics for this unit are shown in Figures 7.23 and 7.24. The vulnerability identified for the Portaray is, as in many previous cases discussed, in the power interface. More data would be required from the manufacturer to search for other possible EMP coupling paths. The failure threshold data is given in Table 7.14. A possible EMP path is from the transformer through to V2, V3, and V4, and C3. Assuming generic part parameters; the computed current in this path is 6.8A. This exceeds the failure thresholds at f = 0.66 MHz. Therefore, the power interface is vulnerable, if left unprotected.

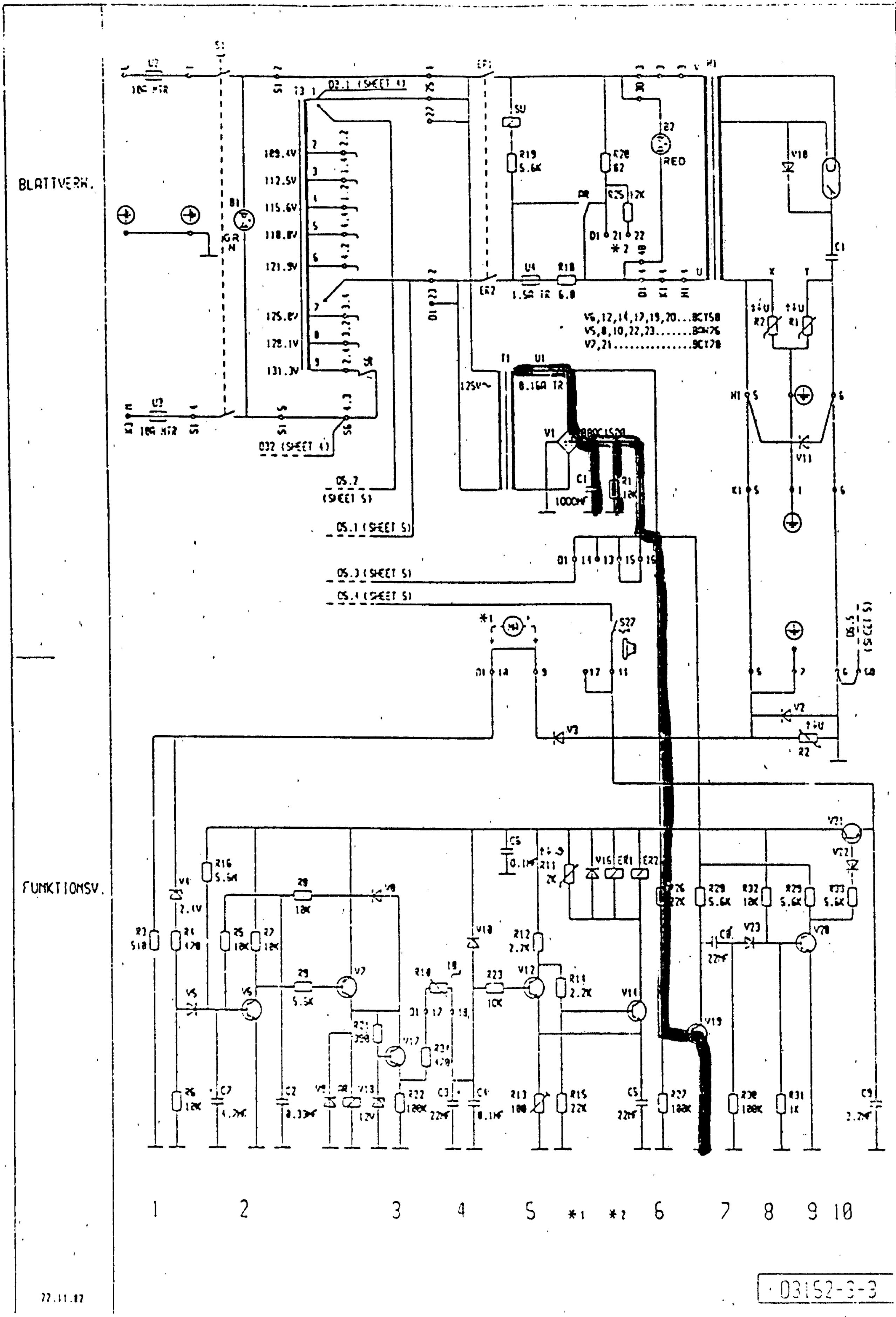


Figure 7.23 Siemens D3152 Portaray Heliodent 70

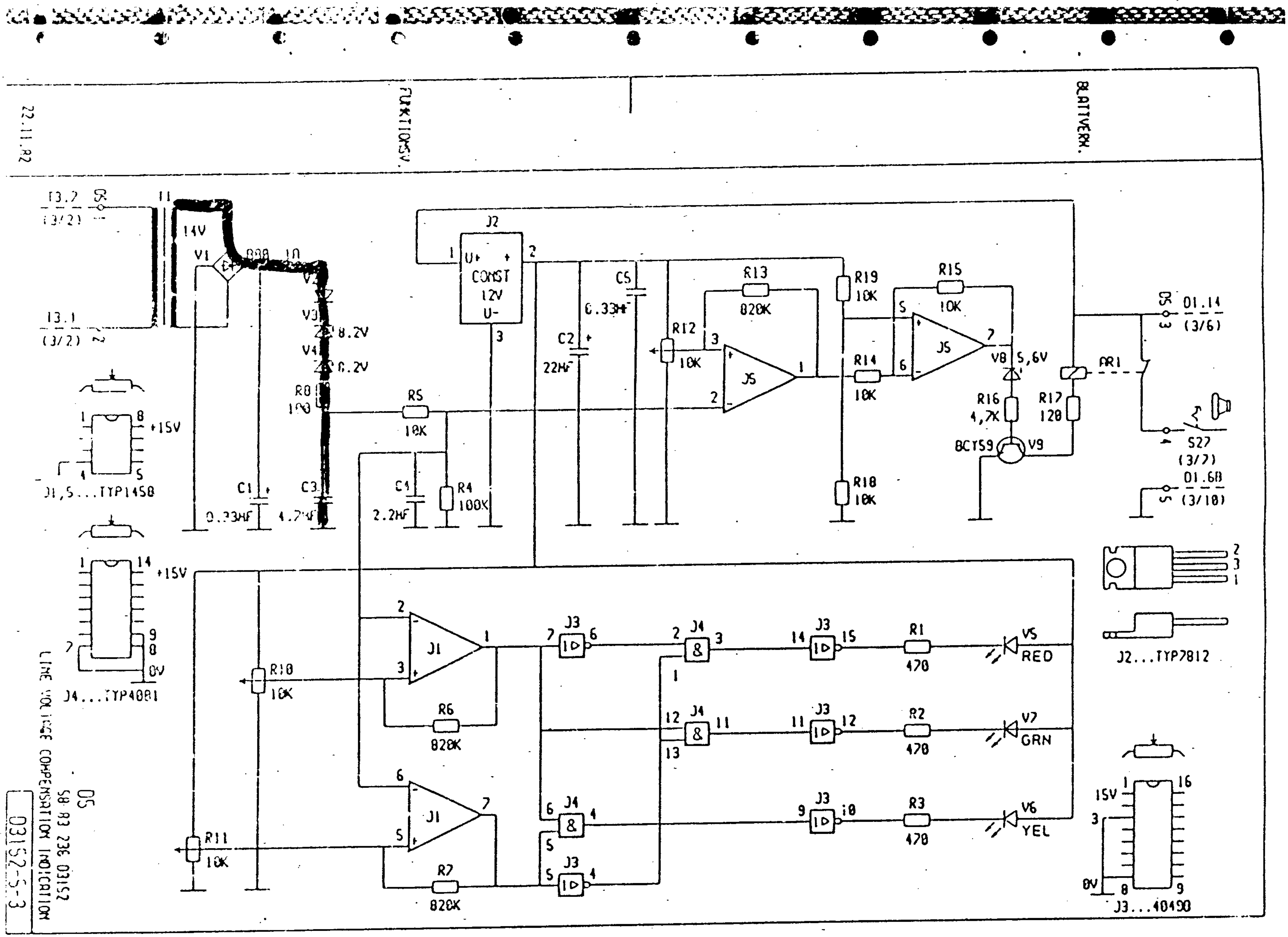


Figure 7.24 Siemens D3152 Portaray Heliodent 70

Table 7.14 Failure Thresholds for the Portaray Heliodent 70 X-Ray Unit

PORTARAY HELIODENT 70 SIEMENS D3152

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
U1	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
V1	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
V19	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
V2	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
V3	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
V4	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

7.15 Birtcher Model 339 Electrocardiograph

The schematic for this unit shown in Figure 7.25. Only the sensor interfaces are shown. Insufficient detail was available to assess the power supply interface. Failure thresholds are given in table 7.15. The sensor leads on this unit contain 20K resistors, which will limit the current. Therefore, these interfaces are not vulnerable to the assumed EMP threat.

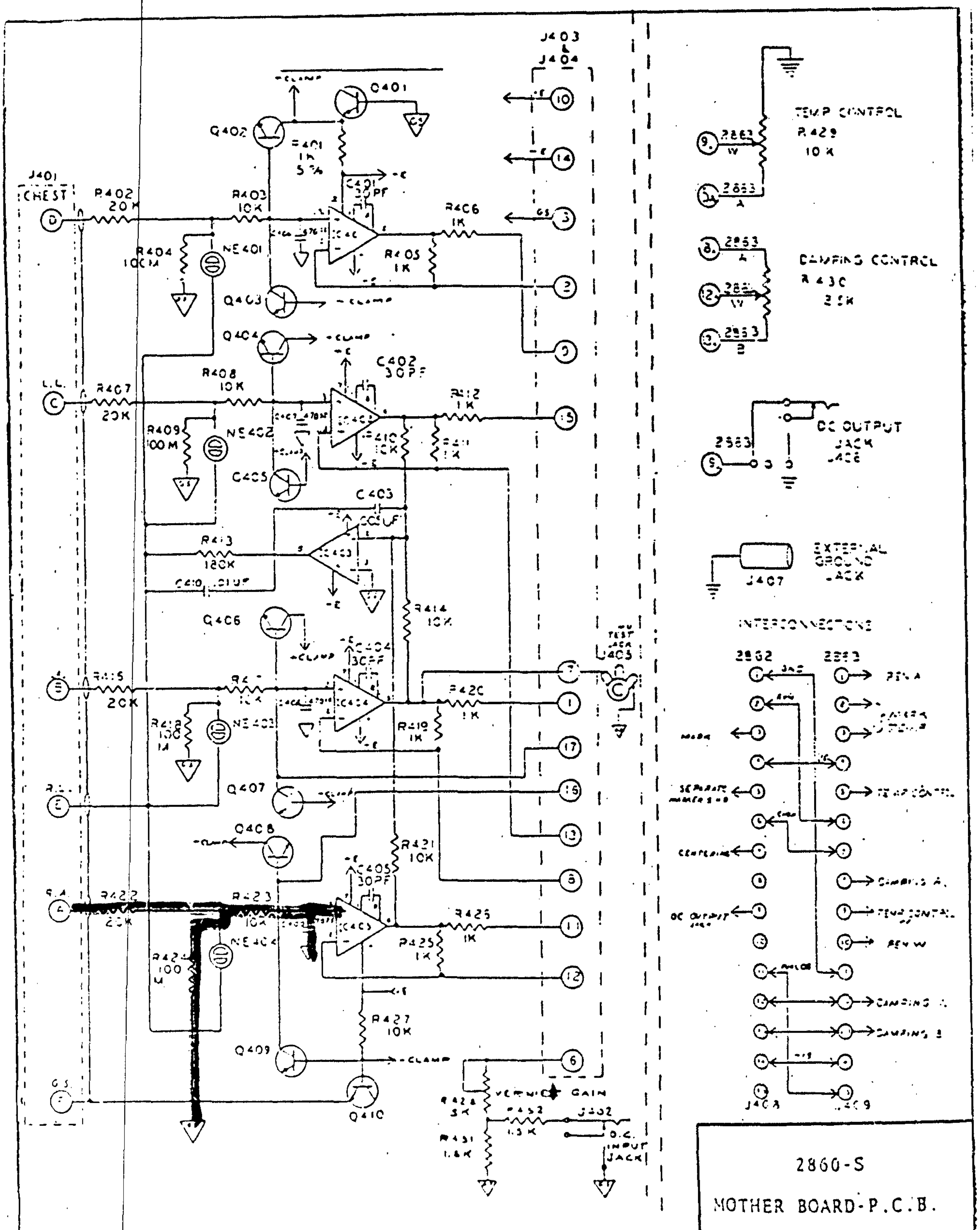


Figure 7.25 Birtcher Model 339 Electrocardiograph

Table 7.15a Failure Thresholds for the Birtcher Model 339

ELECTROCARDIOGRAPH BIRTCHER MODEL 339

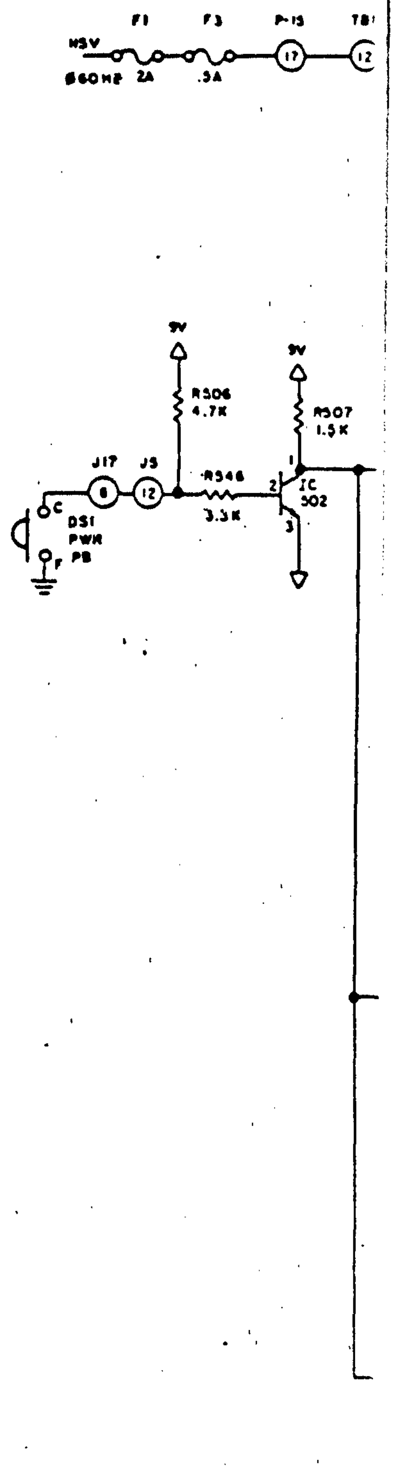
PART NO.	PART TYPE	K	VBD	RS	REF	F(Hz)	I(F)	V(F)	P(F)
MR751	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
MJE720	TRANS	0.2500	100	2.0	G	6.6E+05	4.08	108.16	4.4E+02
						8.0E+05	4.46	108.92	4.9E+02
						8.0E+06	12.32	124.64	1.5E+03
						2.6E+07	19.82	139.65	2.8E+03
						2.8E+07	20.40	140.81	2.9E+03
CR309	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
MJE710	TRANS	0.2500	100	2.0	G	6.6E+05	4.08	108.16	4.4E+02
						8.0E+05	4.46	108.92	4.9E+02
						8.0E+06	12.32	124.64	1.5E+03
						2.6E+07	19.82	139.65	2.8E+03
						2.8E+07	20.40	140.81	2.9E+03
SG4501N	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03

Table 7.15b Failure Thresholds for the Electrocardiograph, Birtcher Model 339

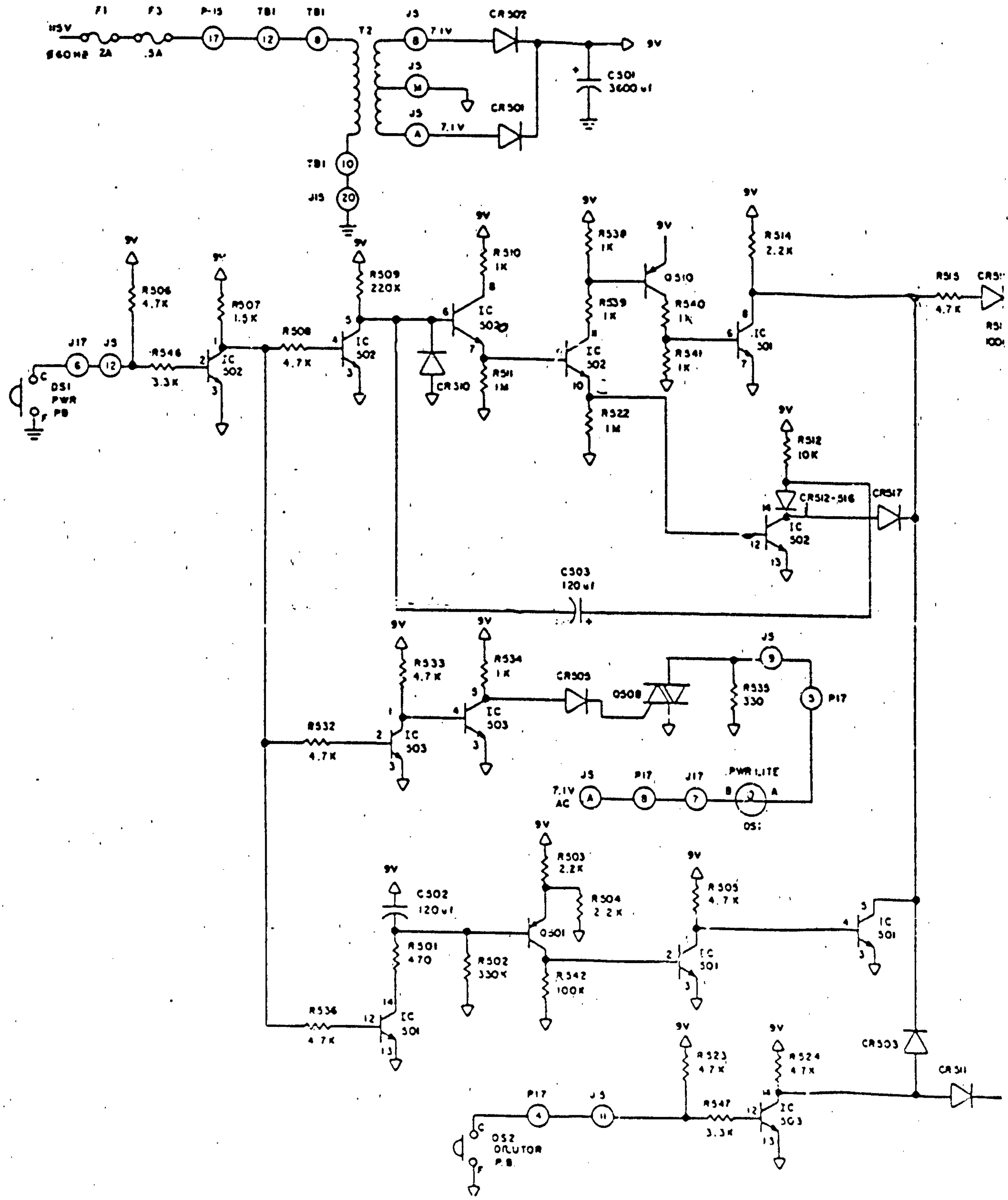
Part No.	Part Type	A	B	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
LM741CM	OP AMP	.0045	.714	7	5.5	G	6.6E+05	4.12	29.64	121.96
SG 4501N	Regulator						8.0E+05	4.45	31.46	139.92
LM 308	OP AMP						8.0E+06	10.86	66.71	724.24
							2.6E+07	16.85	99.70	1680.22
							2.8E+07	17.32	102.27	1771.52

7.16 Flame Photometer, I.L. Inc. Model 343

The schematic for this unit is in Figure 7.26. The power and the transient inhibitor interfaces were examined. The failure thresholds are given in Table 7.16. The EMP induced currents in the transient inhibitor will be less than 1A, therefore, this circuit will survive. The EMP induced current in the power interface is 13.9A. This exceeds all failure thresholds. Therefore, EMP protection is required.


F1
F3
P-15
2A
.5A
17
12
9V
R506
4.7K
J17
J5
R546
3.3K
R507
1.5K
IC
502
DS1
PWR
PB

POWER (



POWER CONTROL CIRCUIT

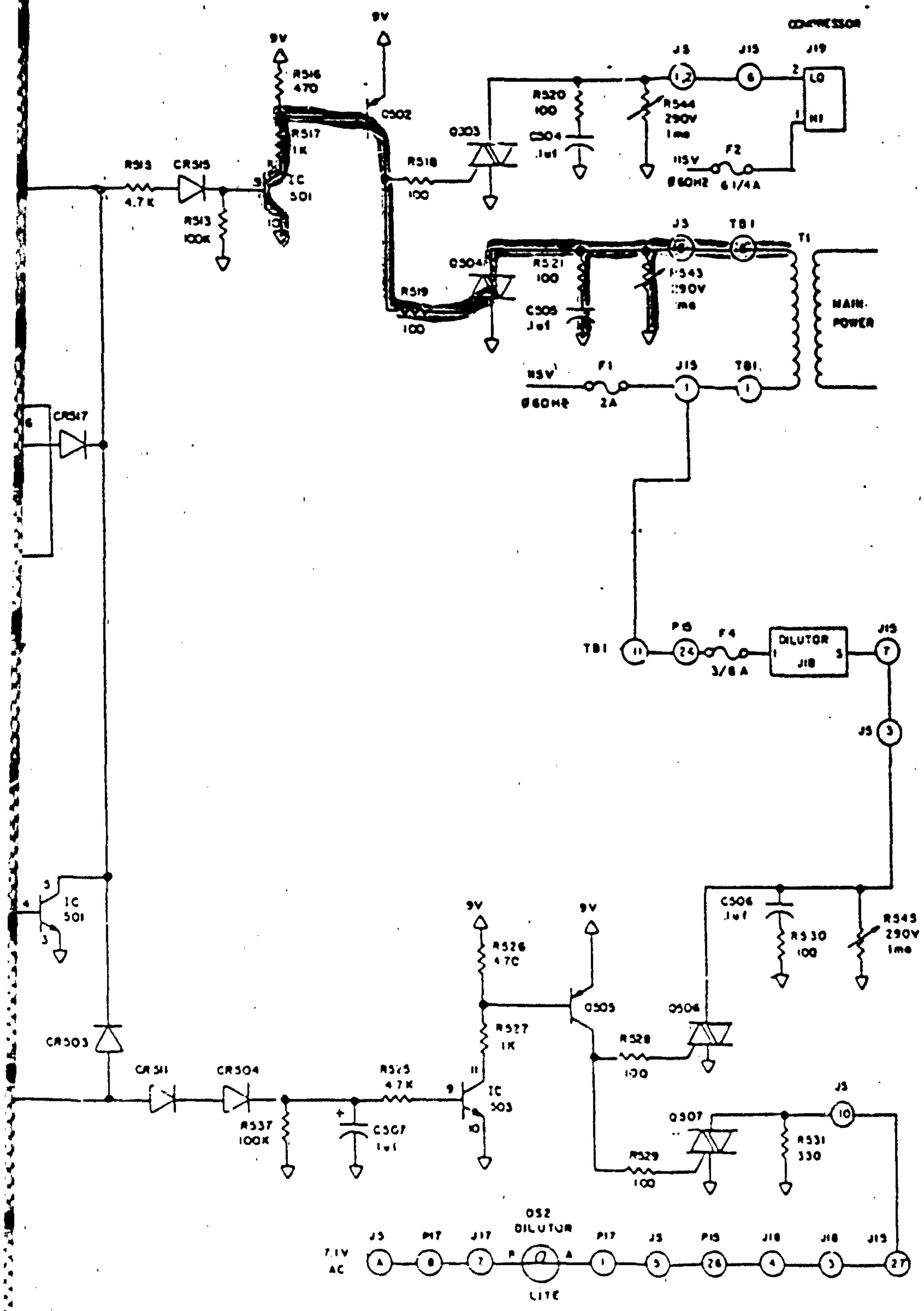


Figure 7.26 Flame Photometer Power Control Circuit

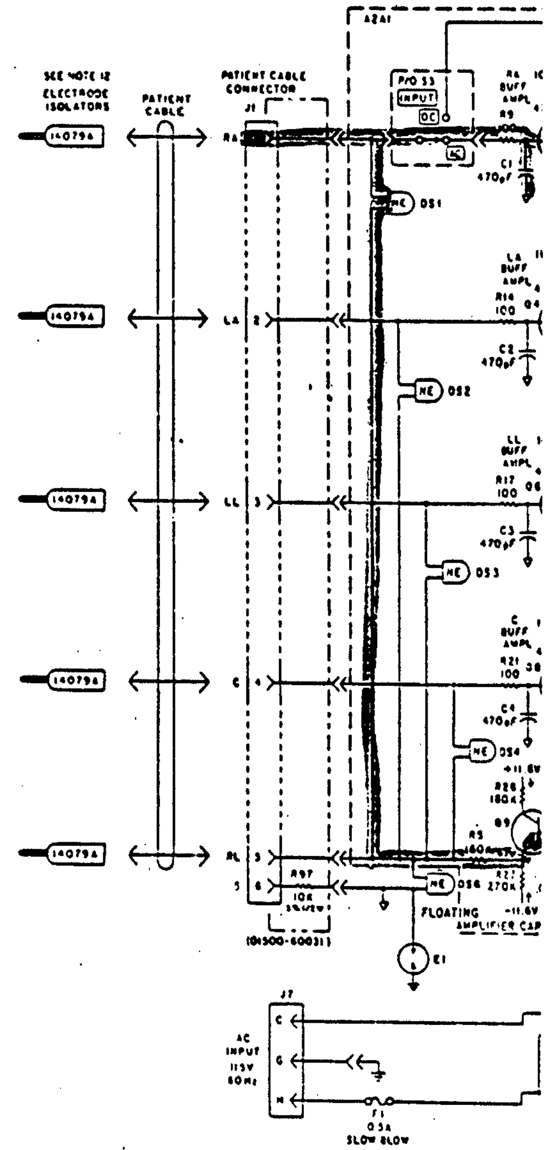
Table 7.16 Failure Thresholds for the Flame Photometer, I.L. Inc. Model 343

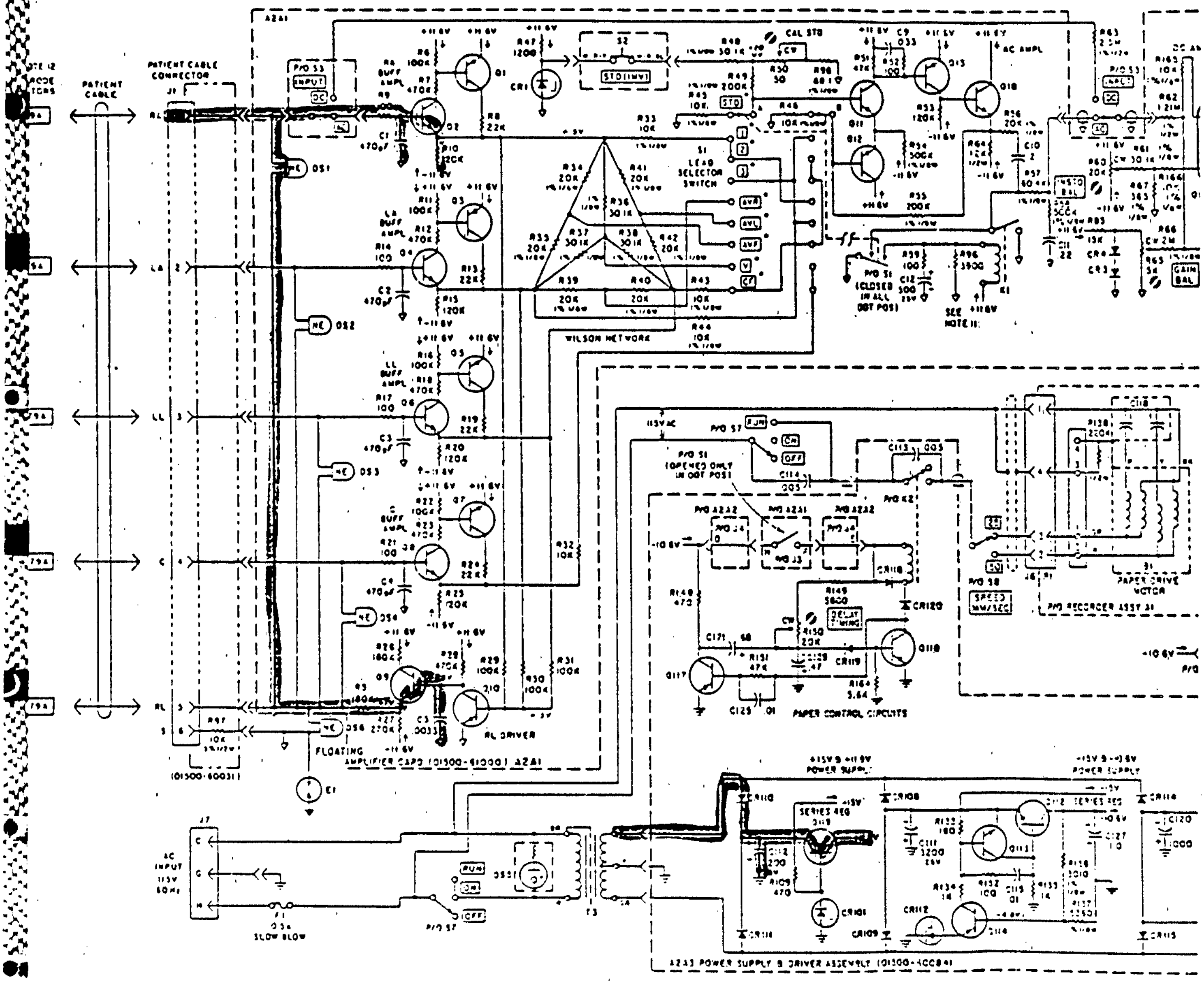
FLAME PHOTOMETER I.L. INC. MODEL 343

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
57425	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
CA3045	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
60183	THYRIS	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
1N4997	DIODE	0.3000	50	25.0	G	6.6E+05	3.71	142.72	5.3E+02
						8.0E+05	3.93	148.26	5.8E+02
						8.0E+06	7.64	241.09	1.8E+03
						2.6E+07	10.57	314.27	3.3E+03
						2.8E+07	10.79	319.64	3.4E+03
56574	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
20203	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
56490	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02

7.17 Electrocardiograph, HP 1500 B

The schematic for this unit is shown in Figure 7.27. The failure thresholds are given in Table 7.17. As with other similar units, the sensor leads have high resistance (10K) limiters at the interface. Therefore, these interfaces are not vulnerable. Possible failure can occur to CR110 in the AC power interface. Assuming no losses in the transformer for the worst case, the current at this diode can be 17A. Therefore, the power interface is vulnerable to the assumed EMP threat.


SEE NOTE 12
ELECTRODE ISOLATORS
PATIENT CABLE
PATIENT CABLE CONNECTOR
J1
A2A1
140794
RA
LA
LL
C
RL
DS1
DS2
DS3
DS4
DS6
470pF
FLOATING
AMPLIFIER
E1
J7
AC INPUT 115V 60Hz
F1
0.5A SLOW BLOW



PATIENT CABLE
WILSON NETWORK
LEAD SELECTOR SWITCH
CAL STD
FLOATING
RL DRIVER
SLOW BLOW
PAPER CONTROL CIRCUITS

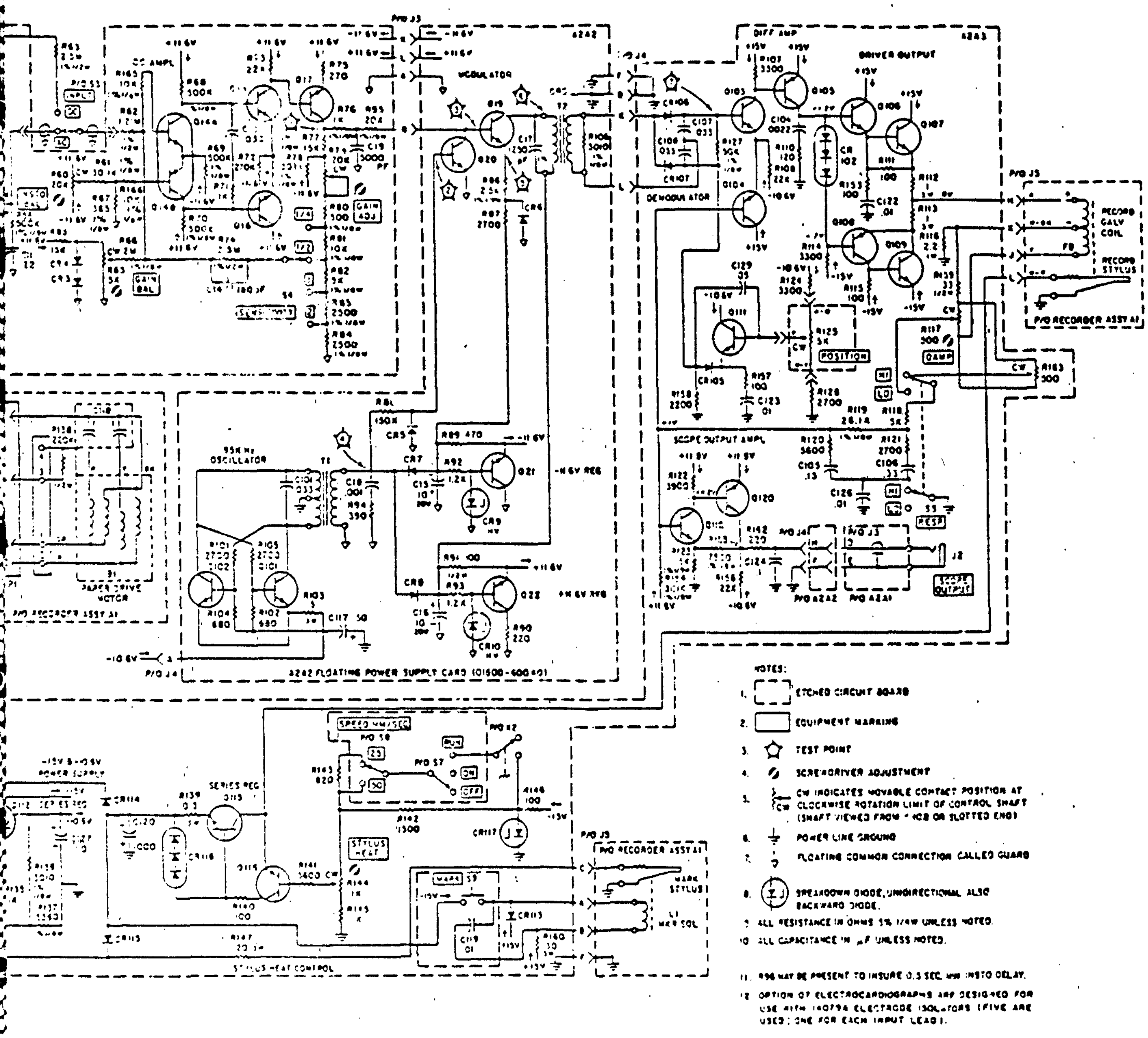


Figure 7.27 HP 1500 B Electrocardiograph Schematic

Table 7.17 Failure Thresholds for HP 1500 B Electrocardiograph

ELECTROCARDIOGRAPH HP 1500B

PART NO.	PART TYPE	K	VBD	RB	REF	F(Hz)	I(F)	V(F)	P(F)
2N2484	TRANS	0.0650	74	0.5	1	6.6E+05	1.21	94.61	1.1E+02
						8.0E+05	1.33	94.67	1.3E+02
						8.0E+06	4.16	96.08	4.0E+02
						2.6E+07	7.37	97.68	7.2E+02
						2.8E+07	7.64	97.82	7.5E+02
2N3704	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
1N4713	DIODE	0.7800	8	1.0	1G	6.6E+05	33.18	41.48	1.4E+03
						8.0E+05	34.99	43.29	1.5E+03
						8.0E+06	65.19	73.49	4.8E+03
						2.6E+07	88.88	97.18	8.6E+03
						2.8E+07	90.62	98.92	9.0E+03
2N4249	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02
FDG1088	DIODE	0.6000	10	1.0	G	6.6E+05	27.92	37.92	1.1E+03
						8.0E+05	29.50	39.50	1.2E+03
						8.0E+06	55.91	65.91	3.7E+03
						2.6E+07	76.66	86.66	6.6E+03
						2.8E+07	78.19	88.19	6.9E+03
2N3054	TRANS	0.2500	10	2.0	G	6.6E+05	12.56	35.12	4.4E+02
						8.0E+05	13.28	36.56	4.9E+02
						8.0E+06	25.32	60.64	1.5E+03
						2.6E+07	34.79	79.58	2.8E+03
						2.8E+07	35.48	80.97	2.9E+03
2N3704	TRANS	0.0600	5	10.0	G	6.6E+05	3.01	35.13	1.1E+02
						8.0E+05	3.17	36.73	1.2E+02
						8.0E+06	5.83	63.26	3.7E+02
						2.6E+07	7.90	84.05	6.6E+02
						2.8E+07	8.06	85.57	6.9E+02

7.18 Summary of Assessments

Seventeen units of medical equipment were assessed. Of these, six units do not require EMP hardening. The screen of the remaining eleven units has indicated possible vulnerabilities at the interface level. Table 7.18 contains a summary of the assessment results.

The results obtained should be treated as preliminary in that in many instances generic failure data was used. The indication is clear, however, that many power and sensor interfaces for medical equipments would be damaged by EMP. Damage observed in the AESOP tests provides supporting evidence. The next step in this assessment procedure would be to perform a more detailed circuit (but not excessive) analysis to confirm the flagged vulnerabilities. Specific part failure data should be researched. Once the vulnerability is reconfirmed, proceeding with EMP mitigation measures would be justified. The next chapter discusses hardening measures applicable to medical equipment.

Table 7.18 Summary of Assessments

Unit	Power Vulnerable	Power EMP Current	Sensor Vulnerable	Sensor EMP Current	Is Hardening Required?
Neomed 3000 ESA	Yes	8.3A	Yes	7.9A	Yes
Defibrillator & Cardioscope Lifepak/33	No	3.44A	No	.77A	No
Oxygen Monitor Ohmeda Model 5100	No	n/a	No	.6A	No
Resuscitator, Globe Safety Products, Inc.	Yes	14A	No	n/a	Yes
Ultransonic Generator, Rich-Mar IV	Yes	7.1A	No	n/a	Yes
X-Ray Apparatus, 2mA, 120KVP	Yes	17.6A	n/a	n/a	Yes
EK/5A Electrocardiograph, Burdick Corp.	Yes	14A	Yes	14A	Yes
Volumetric Infusion Pump, IMED Model 922	No	1A	n/a	n/a	No
Blood Gas Analyzer, I.L. Inc., Model 113	Yes	12.59A	n/a	n/a	Yes
Xenon Endoscopic Light Source, Model L12	Yes	12.9A	n/a	n/a	Yes
Spectrophotometer Stasar	No	2.6A	n/a	n/a	No
Opthalmic Diathermy TR 3000	Yes	10A	No	.12A	Yes
Birtcher Micro Bipolar Coagulator	No	.1A	No	.1A	No

Table 7.18 - (Continued)

Unit	Power Vulnerable	Power EMP Current	Sensor Vulnerable	Sensor EMP Current	Is Hardening Required?
Portaray Heliodent 70, Siemens D3152	Yes	6.8A	n/a	n/a	Yes
Birtcher Model 339 Electrocardiograph	n/a	n/a	No	1A	No
Flame Photometer, I.L. Inc., Model 343	Yes	13.9A	n/a	n/a	Yes
Electrocardiograph HP 1500B	Yes	17A	No	1A	Yes

8. EMP MITIGATION OPTIONS AND PROTECTION DEVICES

Protection of medical equipment against EMP need not be as extensive and costly as, for instance, would be required for hardening a missile against in-flight exposure. When EMP hardened ISO-shelters become available, use of these shelters, with protected penetrations, will provide adequate protection for units located inside. As discussed earlier, the hardened ISO-shelters provide approximately 60dB of shielding against EMP. All equipment, however, will not be located in these shelters. There will be times when the equipment is deployed in Temper tents. The final identification of equipment locations and shelter types will be possible when the standardized unit definition is completed by the Defense Medical Standardization Board.

Power protection is the primary requirement for the medical equipment surveyed. Vulnerable sensor and control leads must also be protected on units deployed in other than hardened ISO-shelters. A wide variety of protection devices exist which would be applicable for use in medical equipment. Some representative devices are discussed in the following sections.

8.1 SPARK GAPS

8.1.1 Operation

One of the types of spark gaps used for EMP protection are voltage threshold switching devices which consist of two or more metal electrodes hermetically sealed in a gas-filled insulated housing. Some spark gaps contain minute quantities of radioactive isotopes to stabilize the firing point and to give fast response. Other types use shaped electrodes in a contact with dielectric to accomplish the same purpose.

For many applications, it is necessary to use a current limiting resistor in series with the spark gap. The transient current flowing through the resistor-gap combination causes an IR drop across the resistor which adds to the arc voltage of the gap. The sum of the IR drop and arc voltage is called the discharge voltage.

Spark gaps have a finite discharge life due to the physical deterioration of the device when it is in the discharge mode at high current levels.

8.1.2 Applications

8.1.2.1 AC Power - The first step for spark gap selection for ac power is that the gaps static firing voltage must be 25% greater than the peak ac circuit voltage. The next step is to select a spark gap that is able to handle the input transient current and any follow-current. Follow-current is current through the gap from the ac circuit sources following the transient and prior to gap extinction at the next zero of the frequency half cycle. For a 50 Hz system the power follow-current may have a duration of 10 msec. This follow-current's long duration can cause deterioration of the spark gap electrodes.

The next step is to consider gap extinction; however, this is usually not a problem since the circuit voltage goes through zero each half cycle.

Lastly, the gaps response to the transient input must be considered to assure that the loads damage level is not exceeded.

8.1.2.2 Control Circuits - For these circuits, extinction due to dc power on the line and ac follow-current is generally not a problem. In many cases where a dc voltage source is present the available dc short circuit current is sufficiently low to allow the gap to extinguish without additional series resistance. The usual considerations in spark gap selection are static breakdown, transient current capability and spark gap transient voltage response.

8.1.3 Spark Gap Features

8.1.3.1 Advantages

a. Low cost

b. Small size

c. High current and energy capacity

d. Bipolar operation

e. Three terminal gaps available

f. Low capacitance

g. Coaxial package available

h. Fast response

i. Low leakage currents

j. Can be used to treat power, communications, transmission line, and control cable penetrations.

8.1.3.2 Disadvantages

a. Poor dV/dt turn-on characteristics (i.e., large clamping factor)

b. Usually requires use of secondary protection elements

c. Spark gap may not extinguish for dc applications

d. Power follow-current can damage spark gap in ac circuits

e. Finite surge life

8.1.3.3 Application for medical equipment. When used together with filters, spark gaps will provide good EMP protection for power at hardened shelter inputs. A typical device, applicable to medical equipment, is shown in Figure 8.1.

8.2 METAL OXIDE VARISTORS

8.2.1 Operation

Metal oxide varistors are voltage dependent, nonlinear resistors which have an electrical behavior similar to back-to-back zener diodes. Their symmetrical, sharp breakdown characteristics enable the varistor to provide excellent transient suppression performance. When exposed to high level EMP transients the varistor impedance changes many orders of magnitude in nanoseconds from a near open circuit to a highly conductive level, thus clamping the transient voltage to a safe level. The potentially destructive energy of the incoming transient is diverted to ground by the varistor.

Metal oxide varistors are available with ac operating voltages from 10V to 1000V. Higher voltages are limited only by packaging ability. Peak current handling for single surges exceeds 25,000A and energy capability extends beyond 600J for the larger units. Package styles include the axial device series for automatic insertion and progress in size up to rugged high energy devices.

MSP® Miniature Gas-tube Surge Protectors

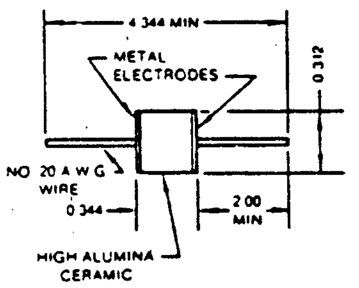


Figure A

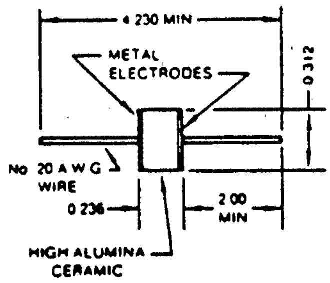
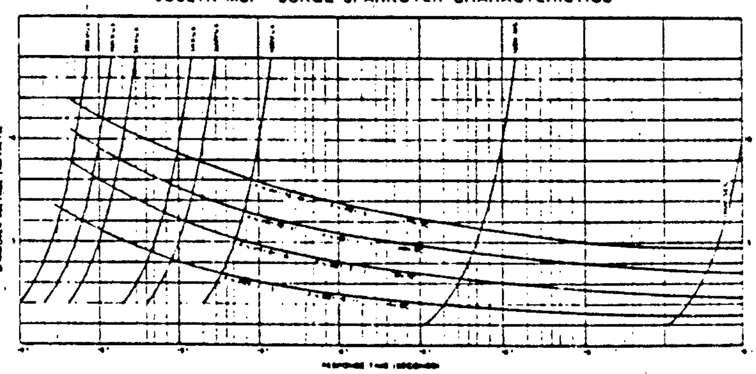


Figure B

JOSLYN MSP® TECHNICAL DATA

P/N	Leads	Dimensions (see Figure)	DC Sparkover Voltage	Nominal Impulse Sparkover Voltage at 5kV/μsec Rate of Rise	Surge Discharge Current on 10x20 μsec Waveshape	Maximum Holdover Voltage at 1 amp	Insulation Resistance at 100Vdc (ohms)	Capacitance (pF)	Maximum Power Follow Current at 120V rms 60 Hz Peak Amperes
2001-01 2001-06	no yes	A	230 ± 15%	700	10kA	115	>10^9	< 0 6 < 1.15	50
2001-02 2001-07	no yes	A	350 ± 15%	850	10kA	175	>10^9	< 0 6 < 1 15	50
2001-03 2001-08	no yes	A	470 ± 15%	1000	10kA	235	>10^9	< 0 6 < 1 15	50
2021-10 2021-11	yes no	B	145 ± 20%	500	5kA	100	>10^9	< 1 5 < 1 0	30 at 60V
2021-12 2021-13	yes no	B	230 ± 15%	700	5kA	115	>10^9	< 1 25 < 0 8	30
2021-14 2021-15	yes no	B	350 ± 15%	850	5kA	175	>10^9	< 1 25 < 0 8	30
2021-16 2021-17	yes no	B	470 ± 15%	1000	5kA	235	>10^9	< 1.25 < 0 8	30
2022-12 2022-13	yes no	B	150 + 30% -20%	500	5kA	100	>10^9	< 1 5 < 1 0	25 at 60V

JOSLYN MSP® SURGE SPARKOVER CHARACTERISTICS



ELECTRONIC SYSTEMS

6868 CORTONA DRIVE
SANTA BARBARA RESEARCH PARK
POST OFFICE BOX 817
GOLETA CALIFORNIA 93017
TELEPHONE AREA (805) 968-3551
TELEGRAM JOSLEC-RON GOLETA

Figure 8.1 Typical data sheet for a spark gap.

8.2.2 Applications

Varistors have two characteristics that limit their application and make silicon transient-voltage suppressors more applicable for many cases. To begin with, Varistors have a higher clamping factor (C_F = clamping voltage/breakdown voltage) at high currents than silicon transient voltage suppressors. In addition, they have a finite pulse life as described earlier. These two varistor characteristics limit their application for threating most penetrations. They are generally only recommended for treating ac power penetrations since components in power equipment can usually withstand the higher clamping voltages of varistors as well as the change in device characteristics caused by multiple transients.

8.2.3 Classes of Varistors

Varistors come in a variety of sizes and ratings. They are available in axial, radial, cylindrical and rectangular packages having leads or terminals. The varistors are classed into low current, medium current, and high current devices as described below.

8.2.3.1 Low Current - Class 1 - Class 1 varistors have a peak surge current rating of 200A or less for a 20 micro-sec surge and can survive 10^4 surge repititions. These MOV's are contained in a molded axial or radial lead package and have a disc diameter of 3 to 14 mm. The steady power dissipation is less than 1 watt for Class 1 varistors.

8.2.3.2 Medium Current - Class 2 - The Class 2 varistors have a peak surge current rating of 300A for a 20 micro-sec surge and can survive 10^4 surge repititions. The MOV's are packaged in axial type, disc type or rectangular packages and have a disc diameter of 20 to 32 mm. The steady-state power dissipation is less than 15 watts.

8.2.3.3 High Current - Class 3 - Class 3 varistors have a peak surge current rating of 400A for a 20 micro-sec surge and can survive 10^4 surge repititions. The MOV's are contained in rectangular and cylindrical packages and have a disc diameter of 32 mm or greater.

8.2.4 Varistor Features

8.2.4.1 Advantages

a. High transient current and energy handling capability

b. Bipolar operation

c. Well defined surge characteristics

d Low cost

e. Wide range of operating voltages

8.2.4.2 Disadvantages

a. High capacity

b. Finite pulse lifetime

c. Primarily limited to treating ac penetrations

d. High leakage current

e. Wide range of operating voltages

8.2.5 Application for Medical Equipment

When used together with a filter, will provide effective power line protection. A typical data sheet is shown in Figure 8.2.

Z-MOV Transient Voltage Suppressors

Z7, Z10, Z15, Z21 and Z33 Series, Data Sheet No. PD-5.006A

ELECTRICAL CHARACTERISTICS

Part Number	Applied Voltage AC (RMS) Max (V)	Applied Voltage DC (V)	Max. Operating Conditions P_{AV} (W) ①	Energy Joules @ 10 ms ②	I_{peak} Surge Current Capacity 8 x 20 μsec (A) (nonrepetitive)	Peak Voltage (Clamping) @ 1 mA (V_1) Min. (V)	Max. (V)	③ Clamping Ratio ±20%	At Amps	Capacitance Reference Value (pF)
Z15L390	20	27	0.1	30	1000	33	45	2.20	10	8000
Z15L470	25	33	0.1	24	1000	39	54	1.83	10	5000
Z15L560	30	40	0.1	24	1000	47	64	1.83	10	4000
Z15L680	36	48	0.1	24	1000	57	78	1.83	10	3100
Z15L820	44	58	0.1	30	1000	68	94	1.83	10	2500
Z15L101	54	72	0.1	30	1000	85	115	1.83	10	1800
Z15L121	65	86	0.1	38	1000	102	138	1.83	10	1600
Z15L151	80	120	0.6	30	2000	135	165	1.83	100	1600
Z15L181	110	140	0.6	36	2000	162	198	1.75	100	1400
Z15L201	120	160	0.6	36	2000	180	220	1.67	100	1200
Z15L221	130	170	0.6	45	2000	198	242	1.67	100	1100
Z15L271	160	210	0.6	45	2000	243	297	1.67	100	870
Z15L331	200	260	0.6	51	2000	297	363	1.67	100	820
Z15L391	230	310	0.6	60	2000	351	429	1.67	100	700
Z15L411	250	330	0.6	60	2000	373	456	1.67	100	680
Z15L441	260	350	0.6	60	2000	396	484	1.67	100	640
Z15L471	280	380	0.6	60	2000	423	517	1.67	100	600
Z15L561	340	450	0.6	60	2000	504	616	1.67	100	520
Z15L681	410	550	0.6	75	2000	612	748	1.67	100	440
Z15L751	450	610	0.6	75	2000	675	825	1.67	100	400
Z15L821	490	660	0.6	80	2000	738	902	1.58	100	380
Z15L102	600	810	0.6	80	2000	900	1100	1.58	100	330
Z21L470	25	33	0.15	33	2000	39	54	1.80	10	7800
Z21L560	30	40	0.15	33	2000	47	64	1.80	10	6200
Z21L680	36	48	0.15	38	2000	57	78	1.80	10	5000
Z21L820	44	58	0.15	45	2000	68	94	1.80	10	4000
Z21L101	54	72	0.15	45	2000	86	115	1.80	10	3000
Z21L121	65	86	0.15	45	2000	102	138	1.80	10	2300
Z21L151	80	120	0.8	45	4000	135	165	1.87	100	2300
Z21L181	110	140	0.8	54	4000	162	198	1.58	100	2000
Z21L201	120	160	0.8	54	4000	180	220	1.58	100	1800
Z21L221	130	170	0.8	66	4000	198	242	1.58	100	1700
Z21L271	160	210	0.8	66	4000	243	297	1.58	100	1400
Z21L331	200	260	0.8	75	4000	297	363	1.58	100	1200
Z21L391	230	310	0.8	90	4000	351	429	1.58	100	1050
Z21L441	260	350	0.8	90	4000	396	484	1.58	100	860
Z21L471	280	380	0.8	90	4000	423	517	1.58	100	800
Z21L561	340	450	0.8	70	4000	504	616	1.58	100	800
Z21L681	410	550	0.8	70	4000	612	748	1.58	100	680
Z21L821	490	660	0.8	70	4000	738	902	1.58	100	580
Z21L102	600	810	0.8	80	4000	900	1100	1.58	100	500
Z33M221	130	170	2.4	150	20000	198	242	1.58	100	5000
Z33M271	160	210	2.4	150	20000	243	297	1.58	100	4000
Z33M331	200	260	2.4	180	20000	297	363	1.58	100	3200
Z33M391	230	310	2.4	225	20000	357	429	1.58	100	2700
Z33M441	260	350	2.4	225	20000	396	484	1.58	100	2400
Z33M471	280	380	2.4	225	20000	423	517	1.58	100	2200
Z33M561	340	450	2.4	255	20000	504	616	1.58	100	1800
Z33M681	410	550	2.4	255	20000	612	748	1.58	100	1500
Z33M821	490	660	2.4	300	20000	738	902	1.50	100	1200
Z33M102	600	810	2.4	300	20000	900	1100	1.50	100	1000

① Derating above 80°C. ② Applied 1000 times. ③ Ratio of voltage at specified amps to voltage at 1 mA.

Reliability Test and Criteria

Test	Method
1. Ipeak Maximum allowable current	V_1 is measured, the rated current value with the waveform of Figure 2 is applied twice in the same direction at a 2 min. interval. V_1 is measured 30 min. later
2. Surge life expectancy	V_1 is measured, the tabulated current with the waveform of Figure 2 is applied 10 000 times in the same direction. V_1 is measured 30 min. later
	Type: Z7, Z10, Z15, Z21, Z33; I(peak): 25A, 50A, 100A, 200A, 500A
3. Maximum storage temperature	Measure V_1 at T = 25°C. Store the device at 110°C for 1000 hr., allow to cool to T = 25°C, measure V_1 30 min. later
4. Humidity tolerance	Measure V_1 at T = 25°C. Store the device at 40°C in a 90-95% relative humidity and apply the rated AC voltage for 1000 hr. Allow to cool to T = 25°C, measure V_1 30 min. later
5. Temperature cycling	Measure V_1 at T = 25°C. Perform 5 cycles of T = -25°C for t = 30 min., T = 25°C for t = 15 min., T = 85°C for t = 30 min., T = 25°C for t = 15 min. Measure V_1
6. Boiling water	Measure V_1 at T = 25°C. Perform 6 cycles of immerse in boiling water for t = 8 hr., leave under ambient conditions for t = 16 hr. Measure V_1

Type	Z7	Z10	Z15	Z21	Z33
I(peak)	25A	50A	100A	200A	500A

The criteria for all these tests is that the change of V_1 is to be less than 10%, and additionally for test 5, that the outside surface appearance should not be affected.

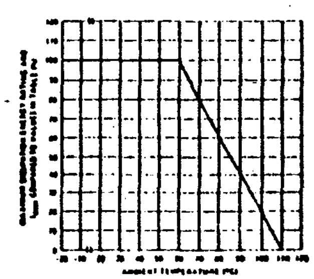


Fig. 1 – Energy Dissipation Rating Vs. Ambient Temperature

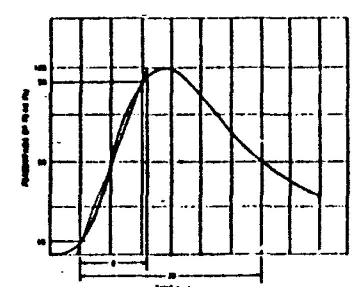


Fig. 2 – Test Current Waveform

Figure 8.2 Typical data sheet for Metal Oxide Varistors.

8.3 SILICON TRANSIENT VOLTAGE SUPPRESSOR

8.3.1 Operation

Silicon transient voltage suppressors (TVS) are PN silicon junction diodes that are designed, manufactured, specified and tested for transient suppression. Their special design allows the device tc have extremely fast operation (approx. 10^{-12} sec), and to carry high peak currents and handle high peak powers for short periods of time. Transient suppression is obtained by ensuring that transient pulses take the device into avalanche breakdown. The avalanche breakdown, combined with low bulk resistance produces a very sharp knee in the I-V characteristrics of the TVS.

Silicon transient voltage suppressors range in clamping thresholds from 1.3 to 700 volts, have surge energy capability at 10 sec of 1 joule and a capacitance between 100 to 15000 pf.

8.3.2 Applications

TVS's have low clamping factors and are available in both unipolar and bi-polar configuration. TVS's generally do not have an adequate surge handling capacity to serve as a primary treatment for penetrations. Hence, they are usually employed as a secondary treatment and are often used in conjuction with spark gaps which is the primary penetration treatment.

TVS's are useful for secondary penetration treatment of power, signal, and control cables.

8.3.2.1 Reverse Standoff - The reverse standoff voltage of the TVS should be equal to or greater than the peak operating voltage for the penetration.

8.3.2.2 Peak Pulse Power - The peak pulse power for the incoming transient should be less than the rated peak pulse power for the TVS. The rated peak pulse power is usually given in graphical form.

8.3.2.3 Peak Pulse Current - The rated peak pulse current of the TVS should be greater than the peak current of the input transient.

8.3.2.4 Clamping voltage - The TVS clamping voltage at the peak transient current should be less than the damage level of the load.

8.3.3 Silicon Transient Voltage Suppressor Features

8.3.3.1 Advantages

a. Fast Response

b. Small size

c. Low cost

d. Bipolar units available

e. Long surge life

f. Low clamping factor

g. Useful for treating power, communication, transmission line and control cable penetration.

8.3.3.2 Disadvantages

a. High capacitance

b. Lower surge handling capability than MOV's or spark gaps at high clamping voltage.

c. Not usually employed for primary penetration treatment

8.3.4 Applications for Medical Equipment

The PN diodes can be used very effectively to protect sensor and control cables on medical equipment. A typical data sheet is given in Figure 8.3

POWER ZENERS
5 Watt, Military

1N4954-1N4995
JAN, JANTX & JANTXV
1N4996

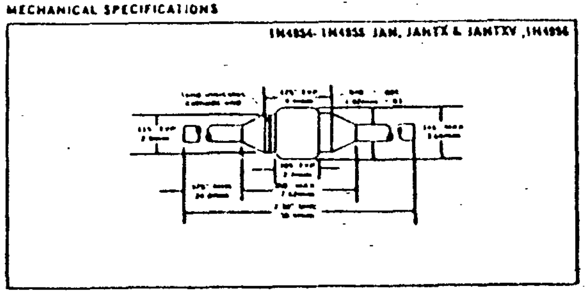
FEATURES
- 2 Times Greater Surge Rating than Conventional 10 Watt Zeners
- Small Physical Size

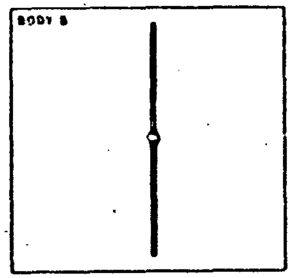
DESCRIPTION
Fused in glass, metallurgically bonded 5 watt zeners, qualified to MIL-S-19500/356.

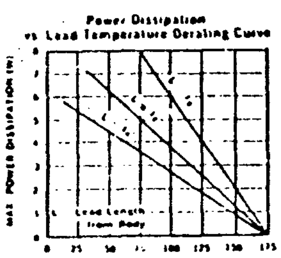
ABSOLUTE MAXIMUM RATINGS

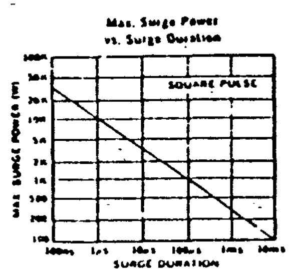
Zener Voltage, V_Z	6.8 to 390V
Continuous Current	See Table
Surge Current (8.3ms)	See Table
Surge Power	See Graph
Power	See Lead Temperature Derating Curve
Storage and Operating Temperature	−65°C to +175°C

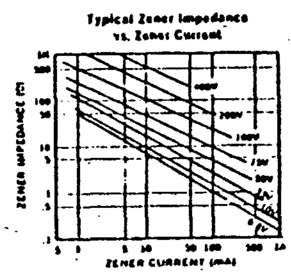
MECHANICAL SPECIFICATIONS











Type	Nominal Zener Voltage† V_Z @ I_{ZT}	Test Current I_{ZT}	Maximum Zener Impedance§ Z_Z @ I_{ZT}	Maximum Zener Impedance§ Z_{ZK}†† @ I_K = 1mA	Voltage Regulation ΔV §§	Maximum Reverse Leakage Current I_R††	Maximum Reverse Leakage Current I_R	Maximum Reverse Leakage Current V_R	Maximum Temperature Coeff. T_C @ I_{ZT}	Maximum Continuous Current ¤ I_{ZM}	Maximum Surge Current‡ I_S
±5% Tolerance	Volts	mA	Ohms	Ohms	Volts	µA	µA	Volts	%/°C	mA	Amps
1N4954*	6.8	175	1.0	1000	.07	150	300	5.2	.05	700	40
1N4955*	7.5	175	1.5	800	.07	100	200	5.7	.06	630	32
1N4956*	8.2	150	1.5	600	.07	50	100	6.2	.06	580	24
1N4957*	9.1	150	2.0	400	.07	25	50	6.9	.06	520	22
1N4958*	10.0	125	2.0	125	.08	25	25	7.6	.07	475	20
1N4959*	11	125	2.5	130	.08	10	15	8.4	.07	430	19
1N4960*	12	100	2.5	140	.08	10	10	9.1	.07	395	18
1N4961*	13	100	3.0	145	.08	10	10	9.9	.08	365	16
1N4962*	15	75	3.5	150	1.0	5	5	11.4	.08	315	12
1N4963*	16	75	3.5	155	1.1	5	5	12.2	.08	294	10
1N4964*	18	65	4.0	160	1.2	5	5	13.7	.085	264	9.0
1N4965*	20	65	4.5	165	1.5	2	2	15.2	.085	237	8.0
1N4966*	22	50	5.0	170	1.8	2	2	16.7	.085	216	7.0
1N4967*	24	50	5.0	175	2.0	2	2	18.2	.090	198	6.5
1N4968*	27	50	6.0	180	2.0	2	2	20.6	.090	176	6.0
1N4969*	30	40	8	190	2.5	2	2	22.8	.090	158	5.5
1N4970*	33	40	10	200	2.8	2	2	25.1	.095	144	5.0
1N4971*	36	30	11	220	3.0	2	2	27.4	.095	132	4.5
1N4972*	39	30	14	230	3.0	2	2	29.7	.095	122	4.0
1N4973*	43	30	20	240	3.3	2	2	32.7	.095	110	3.5
1N4974*	47	25	25	250	3.5	2	2	35.8	.095	100	3.2
1N4975*	51	25	27	270	4.0	2	2	38.8	.095	92	3.0
1N4976*	56	20	35	320	4.4	2	2	42.6	.095	84	2.8
1N4977*	62	20	42	400	5.0	2	2	47.1	.100	76	2.5
1N4978*	68	20	50	500	5.5	2	2	51.7	.100	70	2.2
1N4979*	75	20	55	620	6.0	2	2	56.0	.100	63.0	2.0
1N4980*	82	15	80	720	6.6	2	2	62.2	.100	58.0	1.8
1N4981*	91	15	90	760	7.5	2	2	69.2	.100	52.5	1.6
1N4982*	100	12	110	800	8.0	2	2	76.0	.100	47.5	1.4
1N4983*	110	12	12*	1000	9.0	2	2	83.6	.100	43.0	1.2
1N4984*	120	10	170	1150	10	2	2	91.2	.100	39.5	1.00
1N4985*	130	10	190	1250	11	2	2	98.8	.105	36.6	0.80
1N4986*	150	8	330	1500	13	2	2	114.0	.105	31.6	0.75
1N4987*	160	8	350	1650	14	2	2	121.6	.105	29.4	0.70
1N4988*	180	5	450	1750	16	2	2	136.8	.110	26.4	0.60
1N4989*	200	5	500	1850	18	2	2	152	.110	23.6	0.50
1N4990*	220	5	550	2000	19	2	2	167	.115	21.6	0.50
1N4991*	240	5	650	2050	22	2	2	182	.115	19.8	0.40
1N4992*	270	5	800	2100	25	2	2	206	.120	17.5	0.35
1N4993*	300	4	950	2150	28	2	2	228	.120	15.6	0.30
1N4994*	330	4	1175	2200	32	2	2	251	.120	14.4	0.25
1N4995*	360	3	1400	2300	35	2	2	274	.120	13.0	0.22
1N4996	390	3	1800	2500	40	2	2	297	.120	12.0	0.20

* Available as JAN, JANTX & JANTXV.
† All zener voltages are measured with an automated test set using a 25 msec test time. Longer or shorter test times will have a corresponding effect on the measured value due to heating effects.
§ Zener impedance is derived from the 60-cycle voltage created when AC current with RMS value of 10% of DC zener test current is superimposed on the test current.
§§ ΔV is obtained by measuring the voltage change when the test current is changed from 10% to 50% of Iz max under DC conditions. During this measurement the leads are heat sunk .375 inch from the body and maintained at 25°C.
¤ Maximum current based on 5 Watt Rating. See lead temperature derating curves for proper mounting methods.
‡ Figures shown are for peak sinusoidal surge current of 8.3 msec duration, non-repetitive. The 8.3 ms square pulse rating is 75% of the value shown.
†† These specifications apply only to JAN and JANTX.

UNITRODE

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TWX (710) 326-6509 • TELEX 95-1064

Figure 8.3 Typical data sheet for Silicon Transient Voltage Suppressors.

8.4 FILTERS

8.4.1 Operation

Filters suppress EMP energy in two ways. Their shunt capacitor elements present a low impedance to ground for frequencies above the bandpass of the filter whereas series inductors present a high line impedance for frequencies below the bandpass of the filter.

The four common types of filters are low pass, high pass, bandpass and band reject. Low pass filters allow frequency components from dc up to the cutoff frequency to pass with low attenuation while greatly attenuating frequency components above the cutoff frequency. High pass filters allow frequency components above cutoff to pass while rejecting those frequencies below cutoff. Bandpass filters pass frequency components within a defined frequency band and reject it outside this band. Band reject filters reject frequency components within a specified frequency band and pass the frequency components outside the band.

8.4.2 Applications

Filters are usually employed as secondary penetration treatments since they have transient damage ratings which are usually much lower than EMP induced transient which have not been limited.

Filters respond to frequency components regardless of amplitude and hence can be used to suppress frequencies that are not strong enough to activate clamping devices. Filters are useful as penetration treatments as long as the frequency spectrum of the EMP transient is well within the operating frequency range of the filter. EMI filters are useful for treating power, and control cable penetrations.

Filters usually require primary protection because they contain components that can fail or be damaged by arcing. Filters generally have a transient damage threshold which is less than 10X which is their maximum rated operating voltage.

8.4.3 Filter Features

8.4.3.1 Advantages

a. Frequency selective

b. Can protect against upset

c. Low cost

d. Reliable

e. Provide EMI protection

8.4.3.2 <u>Disadvantages</u>

a. Normally requires primary protection

b. Large size

c. EMP threshold is not specified

e. Attenuation characteristics are unknown for most penetration treatment applications.

f. Reflected EMP energy must be dissipated elsewhere in the system.

8.4.4 Applications for Medical Equipment

Filters can be used effectively for power line protection, when used together with spark gaps or varistors. A typical data sheet is given in Figure 8.4.

Operating Temperature:
-55°C to +125°C

Operating Voltage (See table below)
-55°C to +125°C

Peak Transient Voltage:
(10 µsec) @ 25°C (See table below)

Dielectric Strength:
Twice DC Operating Voltage @ +25°C , 50 mA maximum charging current

Insulation Resistance:
Measured with 100VDC, 50 mA maximum charging current, @ +25°C after two minutes (See Test 5 on page 24.)

Insertion Loss:
Per MIL-STD 220 (full load)

Military Specifications:
Meets or exceeds the applicable parameters of MIL-F-15733 (See page 24 for more detailed information.)

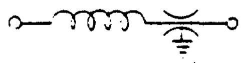
Housing (Hermetically Sealed):
Tin plated. Can be supplied with silver or gold plating. (See pages 2 & 24 for details.)

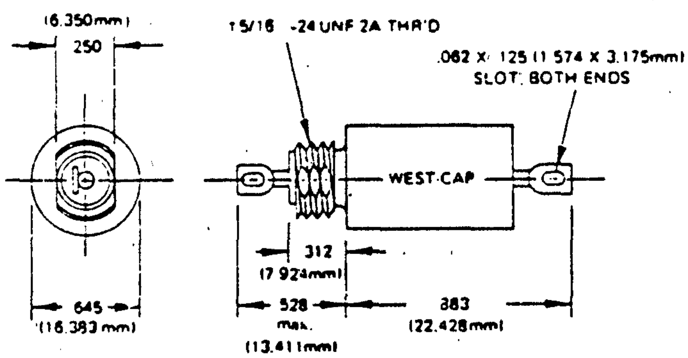
Torque:
48 inch oz. maximum

Marking:
West-Cap. part number and Federal Code identification, voltage, current, circuitry, and date code

Power Line Filters

100, 200VDC, 125VAC 400 Hz L Type Network .645 Diameter





Tolerance ± .015(± .381mm) unless otherwise specified.
†All units supplied with internal tooth lockwasher and hex nut.
See page 3 for further details.

PART NUMBER	CURRENT D C Max (A)	RESISTANCE D C Max (Ω)	WORKING VOLTAGE		INSULATION RESISTANCE (M Ω Min)	PEAK TRANSIENT VOLTAGE (10 µsec)	MIN INSERTION LOSS (dB) FULL LOAD -55°C TO +125°C *						
			D C	400 Hz			30 KHz	150 KHz	300 KHz	1 MHz	10 MHz	100 MHz	1 GHz
CF SA188 FEA 1AA	5	30	100	-	1000	300	21	48	60	70	70	70	70
CF SA188 GEA 1AA	1 0	21	100	-	1000	300	16	40	52	70	70	70	70
CF SA188 JEA 1AA	3 0	03	100	-	1000	300	14	29	37	55	70	70	70
CF SA188 KEA 1AA	5 0	007	100	-	1000	300	14	29	34	47	70	70	70
CF SA1CB FEA 1AA	5	30	200	125	700	500	9	38	50	70	70	70	70
CF SA1CB GEA 1AA	1 0	21	200	125	700	500	4	30	41	60	70	70	70
CF SA1CB JEA 1AA	3 0	03	200	125	700	500	-	19	27	45	70	70	70
CF SA1CB KEA 1AA	5 0	007	200	125	700	500	-	19	25	37	70	70	70

Figure 8.4 Data Sheet for a typical lumped element filter.

8.5 HYBRID TRANSIENT PROTECTION

8.5.1 Operation

All devices previously described have major limitations connected with their protection function. Spark gaps have excessive clamping voltage overshoot which could damage protected circuits. Varistors have a finite pulse life and a large clamping factor which makes them only useful for ac applications. Silicon transient voltage suppressors and filters do not have adequate transient power handling capability to serve as a primary protection device. Hence, adequate penetration treatments for medical equipment will require a hybrid circuit made up of two or more types of penetration treatments.

Hybrids can be self-designed or purchased as commercial units. The hybrids considered here are the commercially available units which can be obtained from transient protection device manufacturers.

8.5.2 Applications

HTP's are normally employed as primary penetration treatments. Units are available for treating power cables, communication cables, RF transmission lines and control cables.

Factors to consider in selecting HTP's are described below.

8.5.2.1 Rated Voltage - The rated voltage should equal or exceed the penetrations peak operating voltage.

8.5.2.2 Rated Current - The rated current should equal or exceed the penetrations peak operating current.

8.5.2.3 Clamping Voltage - The clamping voltage should be greater than the penetrations peak operating voltage and below that required to damage the protected circuit.

8.5.2.4 Surge Current - The rated surge current should be greater than the peak EMP transient current for the transient pulse width.

8.5.2.5 Response Time - The response time should be several nanoseconds or less.

8.5.2.6 Cutoff Frequency - The cutoff frequency should be equal to or greater than the bandwidth of operating signals present on the penetrations.

8.5.2.7 Form Factor, Connectors and Size - These should be consistent with application requirements.

8.5.3 Hybrid Transient Protection Features

8.5.3.1 Advantages

a. Packaged unit requiring routine installation

b. Some HTP's provide both primary and secondary penetration treatment

c. Bipolar units available

d. Units available for treating balanced line and multiple conductor penetrations.

8.5.3.2 Disadvantages

a. Surge capability of some units are not well defined

b. The selection of HTP's is limited

c. A specific application often requires modification of standard unit

d. Available standard voltages are limited.

8.5.4 Applications for Medical Equipment

Hybrid combinations, as stated in previous sections, are required for protection of power cables. Typical data sheets are given in Figures 8.5 through 8.7.

SPECIFICATIONS

Line Surge Absorber (LSA®)

Method of Protection Type F Failsafe The LSA® forms a short circuit across the protected input if it fails
Type M Mostly failsafe There is a narrow range of overvoltages which could in theory make this type fail open circuit It is highly probable that this type also fails safe

Configurations Type B Balanced Protection is both common mode (each lead with respect to earth) and difference mode (across leads)
Type U Unbalanced Protection is with respect to earth only

Max. Surge Current 20,000 Amps Test waveform overdamped bipolar sine wave with 10 microsec. period lasting 5 periods

Surge Life at 500 Amps 500 surges min

Surge Life at 20,000 Amps 50 surges min

Max. Continuous Overvoltage No limit.

Max. Surge Voltage No limit.

External Signal Wires 1.5mm diameter max.

Resetting Automatic after the overvoltage ceased

Nominal Clamping Voltage (Vc) 7V to 200V, single polarity or bi-polarity, as required.

Max. Clamping Voltage 1.4Vc at max. surge current.

Max. Signal Amplitude 0.8Vc

Max. Signal Current Type F 50mA RMS or DC
Type M 2Amps. RMS or DC

Series Resistance Type F less than 50 ohm
Type M less than 0.5 ohm

Response Time Less than 1×10^{-12} sec (1 picosecond)

3dB Cutoff Frequency 100kHz (load and source = 600 ohm)
300kHz (load and source = 50 ohm)

Operating Temperature + 5°C to + 50°C

Storage Temperature - 20°C to +85°C

Shock 30 g-s max. half sine, 11msec duration

Standard Connectors Screw terminal blocks

Enclosures Available Standalone shockproof plastic box (standard version), or rack mount modules, or circuit board plug-in modules

Dimensions (Standalone LSAv-2W L 105mm (4.1"), W 85mm (3.3"), H 50mm (2")
LSAv-4W L 120mm (4.7"), W 85mm (3.3"), H 50mm (2")

Mounting Standalone boxes can be mounted on a rail side by side

Net weight LSAv-2W 0.45kg (1 lb)
LSAv-4W 0.9kg (2 lb)

Model Designation LSAv - xWyz, where
v = nominal clamping voltage
x = number of wires
y = B: Balanced, U: unbalanced
z = F: failsafe, M: mostly failsafe

Ordering Information Number of lines to be protected, max. signal current, peak or peak-to-peak signal voltage, is 0V line grounded or floating, is the signal AC or DC, max. signal frequency, type of connector required, max signal attenuation allowed, type of enclosure required. A brief description of the application or a technical manual containing the circuit of the equipment to be protected should be supplied. Specify any special electrical or mechanical requirements.

KAPUSI LABORATORIES Phone: (415) 573-5475
2121 So. El Camino Real, San Mateo, CA 94403, TWX: 910 374 3004

Figure 8.5 Data Sheet for a typical class C2 Communication/Control hybrid Transient Protector.

MEDIUM-DUTY
AC POWER LINE PROTECTION

SELECTION GUIDE

1. For 1φ-use Chart 1, for 3φ 4W use Chart 2, for 3φ,3W Delta use Chart 3.
2. Select the proper voltage range from the chart. Model No. is directly below the voltage.
3. Models can be used on lines having currents up to 100A/per line.

CHART 1: SINGLE PHASE

Line Voltage	120 VAC	240 VAC	277 VAC	380 VAC	480 VAC
Model	1201	2401	2701	3801	4801
Clamp V (1 ma)	235V pk	413V pk	430V pk	690V pk	300V pk
Joule (watt-sec)	240j	480j	480j	480j	480j

CHART 2: 3φ, 4 WIRE, WYE

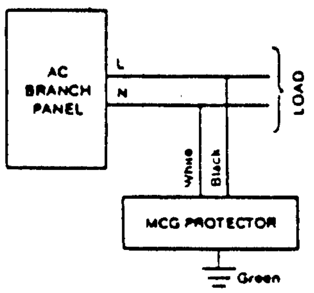
Line Voltage	120/208 VAC	220/380 VAC	277/480 VAC
Service	WYE 4 W	WYE, 4 W	WYE 4W
Model	2403Y	3803Y	4803Y
Clamp V (1 ma)	235V (L-N)	430 (L-N)	430V (L-N)
Joule (watt-sec)	240j	480j	480j

CHART 3: 3φ, 3 WIRE, DELTA

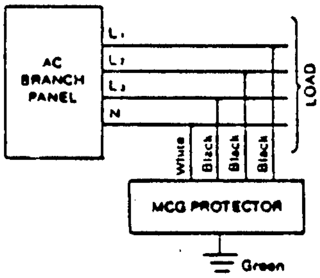
Line Voltage	120 VAC	240 VAC	380 VAC	480 VAC
Service	Delta 3 W	Delta 3 W	Delta 3 W	Delta 3 W
Model	12030	24030	38030	48030
Clamp V (1 ma)	235V (L-L)	430V (L-L)	690V L-L	900V L-L
Joule (watt-sec)	240j	480j	480j	480j

CONNECTION INSTRUCTIONS

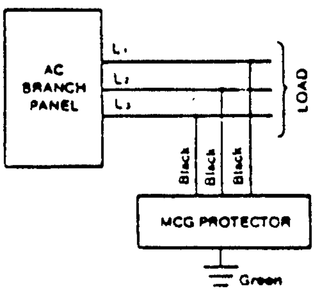
Single Phase: See Chart 1



3φ, 4 WIRE, WYE: See Chart 2

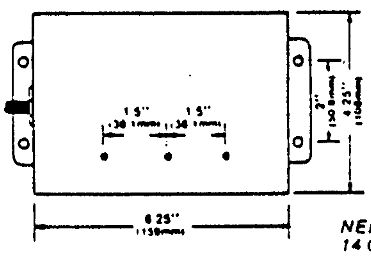


3 φ Delta 3 wire: See Chart 3



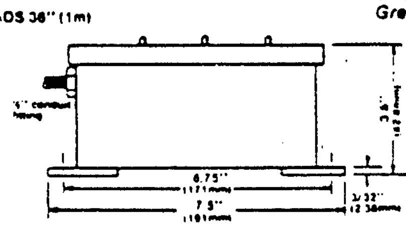
NOTE: The protectors should be operated on "Load" side of branch service panel.

MOUNTING INFORMATION



NEMA 12
14 Gauge Steel
Grey Finish

*3-5 LEADS 36" (1m)



MCG ELECTRONICS INC.
160 BROOK AVE., DEER PARK, N.Y. 11729 (516) 586-5125 TELEX 645518

Figure 8.6 Data Sheet for a typical class P2 Power hybrid Transient Protector

FISCHER CUSTOM COMMUNICATIONS

BOX 581 • MANHATTAN BEACH, CA. 90266
AREA CODE 213 545-4617

The FCC 450 series Spikeguards have been designed to provide transient protection for receivers and transmitters up to 100 watts of output power. They have also been designed to provide transient protection for sensitive semiconductor components and integrated circuits.

The 450 series are constructed from proven silicon components, that are in turn encased in epoxy.

They can be provided with clamping voltages varying from 6 to 200 volts. The 6 to 20 volt units are capable of sustaining 70 amperes of peak current for a triangular pulse having a 4 microsecond pulse width. From 20 volts and up the units have a decreasing current capability, with the 200 volt unit capable of sustaining 5 amperes of peak current for 15 microseconds.

The dc impedance in the nonconducting mode is equal to or greater than 5 megohms.

The clamping voltages are achieved in approximately 1 nanosecond for transients having a risetime gradient of 1 megavolt/microsecond. Of particular importance is the fact that these units exhibit a capacitance of approximately 2 picofarads.

Since these units operate extremely fast and have such low capacitance, they will provide transient protection for sensitive semiconductor components, particularly, integrated circuits, such as TTL, ECL, DTL, MOS, and MSI. Due to the fact that they have low capacitance these units can protect not only power supplies, but input and output data lines, without degrading the data transmission operating characteristics, by excessive capacitive loading.

Typical dimensions of these units are 0.75" long by 0.5" wide by 0.5" high.

The FCC 450 series are also packaged in coaxial connectors to protect receivers and transmitters from transients. They exhibit fast response through the UHF region by clamping in approximately 1 nanosecond when subjected to transients exhibiting risetime gradients of the order of 1 megavolt/microsecond. These units also have a distributed capacitance of approximately 2 picofarads.

For example, the FCC-450-10-(connector type) is used to protect receivers and clamps fast transients at 10 volts peak.

Typical VSWR characteristics for type N, C, and UHF coaxial connector versions of the FCC-450-( )-( ) are as follows:

Frequency (MHz)	VSWR
50	1.1:1
100	1.3:1
200	1.4:1
300	1.5:1
400	2.0:1
500	2.5:1

The 450 series when clamping a transient will not permit the energy levels to exceed the microjoule level even for transients lasting 20 microseconds. The VSWR values permit normal receiver operation with little or no degradation in performance to frequencies of 500 MHz.

The 450 series that clamp up to 200 volts are capable of protecting transmitters up to 100 watts.

It must be cautioned that, since the 450 series can only sustain a limited transient pulse, they should be used in combination with a 250 series. The 450 series must be placed as close to the transmitter or receiver as possible, and the 250 series must be placed as close to the antenna as possible. The 250 series will intercept the transient first and will limit the overall energy to the low millijoule level thus not permitting the transient energy to exceed the safe level of the 450 series.

In order to obtain optimum transient protection the two units must be separated via the coaxial cable by at least 50 feet for a slow transient having a risetime gradient of 20 kilovolts/microsecond; and by 3 feet for a fast transient having a risetime gradient of 1 megavolt/microsecond.

The above hybrid combination provides optimum protection of both transmitters and receivers.

Even though the 250 series will have some overshoot, those units used for transmitters up to 100 watts will still clamp at 1800 volts or lower, for a transient having a risetime gradient of 1 megavolt/microsecond, and 1000 volts or lower for a transient having a risetime gradient of 20 kilovolts/microsecond.

In most instances these overshoot voltages will not cause failure of an antenna or transmission line since they will only last for 2 nanoseconds for the 1 megavolt/microsecond risetime gradient, and 50 nanoseconds for the 20 kilovolt/microsecond gradient.

The energy levels finally permitted to arrive at a transmitter or receiver during a transient will be well within the safe levels of 450 series normal operation.

Figure 8.7 Data Sheet for a typical class T1 RF Transmission Line hybrid Transient Protector.

8.6 SELECTED EMP HARDENING DEVICES FOR MEDICAL EQUIPMENT

Two specific types of protection designs applicable to medical equipment are presented in this section. The first example is for protecting ac power. The second example is for sensor and control interface protection.

8.6.1 AC Power Protection

AC power lines will need EMP protection. The example given here is most suitable for mounting in an EMP vault at the wall of an ISO-shelter. The EMP vault is constructed such that the EMP surge conducted through the surge arresters is diverted entirely to the outside skin of the shelter. The protection device configuration for a three phase power line is shown in Figure 8.8. Device types are 1.) MOV: General Electric V150LA10A, and 2.) filters: RFI RF741, or RFI RF 9710-18, or MTK Electronics MTK 835. Equivalent types by other manufacturers are also acceptable. This configuration will reduce a 2000V, 20A Thevenin equivalent source damped sine pulse to a safe level of several hundred mV.

8.6.2 Sensor and Control Protection

The network for sensor and control interface protection is shown in Figure 8.9. A pair of high current low capacitance diodes such as the Unitrode UM 7101 pin diode, or equivalent is recommended. This protection network will have a clamping voltage of 1.5 volts or less.

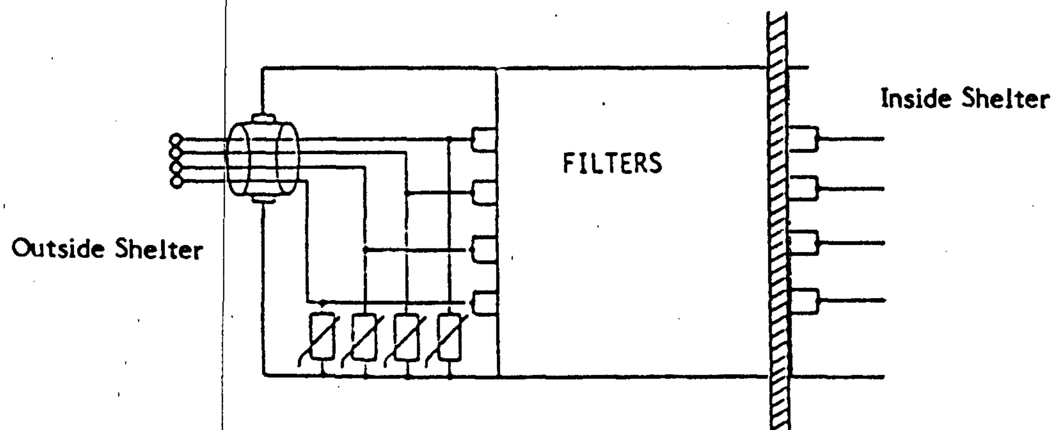


Figure 8.8 EMP Protection for AC power at ISO-shelter wall

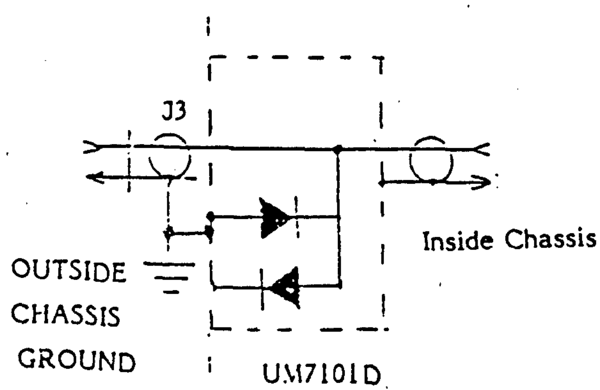


Figure 8.9 EMP Protection for sensor and control interfaces.

9. CONCLUSIONS AND RECOMMENDATIONS

The information collected and analyses completed during Phase I of this SBIR program provides a good database for use in achieving the Army's goal of protecting critical medical equipment against EMP.

Critical equipments have been identified from Maj. Vandre's survey and are listed in this report. Seventeen of these equipments were assessed for EMP vulnerability. Of these, eleven were found to be vulnerable to EMP. Since circuit designs are fairly similar, it is probable that many types of other medical equipment are also vulnerable. Actual tests of equipment at HDL have served to support this conclusion.

Observations made from the site surveys indicate that, in the present unprotected state, equipment in Temper tents would probably be damaged during an exposure to EMP. With an unprotected power grid, even equipment in the ISO-shelters presently in use would have a high probability of damage.

All the equipment surveyed in this program will not be hardened to EMP. One reason for this is that a large part of the equipment in present use will be replaced. The Defense Medical Standardization Board (DMSB) is asssessing 145 different equipment types. Equipment lists are included in Appendix A for reference. Groups from each type may be from several manufacturers. Another reason is that about 60% of the equipment will be located in ISO-shelters, and will therefore be at least partially protected from EMP. This equipment will be fully protected when hardened ISO-shelters come into use, and when protection has been deployed in the power grid.

Techniques for protecting individual equipments have been considered and discussed in the previous chapter. There will be some units which are critical and which can be deployed in unprotected areas. These units must be identified and hardened individually. One candidate is the Hi-Cap X-ray unit presently in the procurement process. Standardized layouts developed by DMSB will facilitate identification of other equipments to be hardened.

Most of the new units are off-the-shelf items. Units selected for individual hardening will then require a form of a product improvement program (PIP) to implement and maintain the hardening.

A cost-effective methodology must be implemented to the product improvement program. Most standard "rigorous" approaches to EMP hardening and testing would be too expensive. Detailed circuit code analyses would be too expensive to apply to a large number of equipment from numerous manufacturers.

Medical equipment does not need 100% confidence of survivability. A survivability of 80% would probably be sufficient. This means looking into the statistics of survivability. For example, one must determine the number of units to be tested for each equipment type to maintain a desired confidence level.

The PIP will involve screening and testing to determine which equipment doesn't survive and must be retrofitted with hardening. Cost-effective test methods will have to be utilized. This will call for use of small simulators or pin-injection testing, which is fast and relatively inexpensive. IRT has such facilities in-house.

In its Phase I SBIR program, IRT has demonstrated a methodology for preliminary EMP vulnerability screening of medical equipment. An approach has been demonstrated whereby seventeen equipments have been screened in a short time period under a cost-effective program. Proven hardening devices are available, and were discussed along with specific examples in the previous chapter.

Phase II of this work should develop a sound EMP protection program for medical equipment, whereby selected equipments are screened, tested, and retrofitted. Some important elements and issues for this program have been discussed above. Details for this program will be discussed in IRT's Phase II proposal.

10. REFERENCES

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Handbook, July 5, 1979.

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APPENDIX A

MEDICAL EQUIPMENT LISTS

OBTAINED FROM HDL AND MAJ. VANDRE

MEDICAL EQUIPMENT DATABASE
(PART I)

ITEM	CONTROL NUMBER	NSN	MODEL NUMBER	MANUFACTURER
Micro pH/Bloodgas Analyzer	med001	6630-01-120-8419	IL 113-02	Instrumentation Labs
[illegible] Endoscopic Light Source	med002	6515-01-100-0458	L 12	American Cystoscope Maker
Peri-Pro X-Ray Film Processor	med003	6525-01-154-9925	Peri-ProII	Air Techniques Inc
Cast Cutter	med004	6515-00-323-4510	840,848	Stryker
Oil-Less Compressor Dnt	med005	6520-00-139-1246	V4-1	Air Techniques Inc
Hanau Junior Curing Unit	med006	6520-00-597-7749	L-1	Teledyne Hanau
Vari-Mix III Amalgamator	med007	6520-00-149-0123	VariMixIII	The LD Caulk Division
Electrosurgery Unit	med008	6515-01-130-1386	771	Birtcher Corp
Electric Power System	med009	6515-01-165-3508	Storz Ergo	Storz Ergo Instruments
Volumetric Infusion Pump	med010	6515-01-025-8839	922	IMED Corporation
Intra-Articular Surgical Syst I	med011	6515-01-166-2603	System II	Dyonics Inc
Demineralizer	med012	4610-01-175-2334	CL-5	Crystalab Inc
Ophthalmic Diathermy	med013	6530-01-172-1176	IR 3000	Medical Inst Research
Warming Cabinet	med014	6530-01-098-5827	5510	Sybron Corporation
Mobile Hydrotherapy Unit	med015	6530-01-128-2442	HM 295	Ferno Ille
Rich Mar IV	med016	6530-01-119-7602	IV	Rich-Mar Corporation
Footswitch	med017	6515-01-165-6715	SE200-112	Storz Ergo Instruments
Console	med010	6515-01-185-2620	SE750-104	Storz Ergo Instruments
Bright Spot Illuminator	med019	6525-01-167-6678	240137	Picker International Inc
Air Drill	med020	6515-01-160-2597	100,000RPM	Codman & Shurtleff Inc
Isotemp Dry Bath	med021	6640-01-139-9488	145	Fisher Scientific Co
Spectrophotometer Stasar	med022	6650-01-117-3904	25066 X 42	Gilford Instrument Labs
Filling Laminator	med023	6515-01-181-8711	52-1211-S	Filling
Lifespan 100th Dual Monitors	med024	6515-01-169-5925	4020	Biochem International Inc
Blood Bank W/ Temp Monitor	med025	4110-01-117-3902	882	Jewett Refrigerator
Portable Heliodent 70 (Dental)	med026	6520-01-139-2530	D3152	Siemens Medical Systems
Blood Bank Ref W/ Temp Monitor	med027	4110-01-179-0124	CT1	Jewett Refrigerator

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....NSN....	........NOMEN........	UI	.......UP	MUAG	AAC	RIC	ASICE
3530012045393	SEALING MACHINES-230V9	EA	953.74	Z	W	0	
1510011811418	PRNTG PRES LABL PHARM	EA	1082.72	Z	W	0	
4110011587992	REFRIG MECH BLD BANK	EA	6161.16	3	W	0	
4110011631799	FRZR MECH PLASMA UPRI	EA	5420.00	3	A	0	*
4110011750126	REFRIGERATOR MECHANIC	EA	2289.40	Z	W	0	
4610011752334	DEMINERALIZER WATER	EA	133.26	Z	W	0	
4940011803217	CLEANER ULTRSONIC	EA	2732.35	3	A	0	*
6515001048080	ESOPHA 10MMX16MMX50CM	EA	318.90	Z	D	0	
6515001049318	BRONCHOSCOPE 7MMX40CM	EA	231.63	Z	L	0	
6515001069205	BUFFER CONN RUST RE90	EA	277.25	Z	D	0	
6515001152203	CASE BRONCH STER-STOR	EA	441.15	Z	D	0	
6515010985787	FORCEPS EYE SUTUREGCM	EA	308.00	Z	L	0	
6515011005560	RETRACTOR HOLDER SET	SE	3000.00	Z	L	0	
6515011005560	RETRACTOR HOLDER SET	SE	3000.00	Z	L	0	
6515011101382	CURETTE SET ANTRUM 6S	PG	336.0C	Z	L	0	
6515011145483	FRAME HEAD ORAL	EA	657.00	Z	L	0	
6515011150413	FIXATION KIT ORAL	EA	578.00	Z	L	0	
6515011301386	ELECTROSUR APPARAT AC ✓	EA	1750.73	3	J	0	*
6515011357642	RETRACTOR STERNAL	EA	404.30	Z	D	0	
6515011397679	FORCEPS BRONCHO 50CM	EA	184.46	Z	D	0	
6515011357797	RESPIROMETER MECHANCL	EA	395.00	Z	L	0	
6515011397943	FORCEPS COAGULATION	EA	202.65	Z	L	0	
6515011357944	FORCEPS COAGULATION6"	EA	224.90	Z	L	0	
6515011398115	RONGEUR SAUERBRU 17MM	EA	310.05	Z	L	0	
6515011398238	SHEARS RIB SS 25GP	EA	303.07	Z	C	0	
6515011358150	FORCEPS SEPTUM SMALL	EA	202.65	Z	D	0	
6515011358354	PUNCH NASAL MAJEK-ADF	EA	296.93	Z	D	0	
6515011358355	RETRACT ANTRAL6X11.5M	EA	395.35	Z	D	0	
6515011356980	RONGEUR KERRISON SZ#1	EA	203.55	Z	D	0	
6515011398981	RONGEUR KERRISON SZ 2	EA	203.55	Z	D	0	
6515011398905	SPREADER RIB TUFFIER	EA	218.00	Z	L	0	
6515011405233	SPREADER RIB ALUMINUM	EA	335.00	Z	L	0	
6515011405432	INSTRUMENT SE ORTHOPD	SE	1486.15	Z	D	0	
6515011531676	TRACTION-APP HEAD S24	EA	546.40	Z	D	0	
6515011531682	PROCTOSIGMOIDSCOPE SE ✓	SE	691.53	Z	W	0	
6515011569786	BLOOD RECOV DELIV SYS ✓	EA	27547.51	3	W	0	*
6515011656744	FORCEPS BONE MED SZ 2	EA	197.22	Z	D	0	
6515011665068	APPLICATOR CRANIAL RG	EA	900.00	Z	L	0	
6515011665068	APPLICATOR CRANIAL RG	EA	900.00	Z	L	0	
6515011665068	APPLICATOR CRANIAL RG	EA	900.00	Z	L	0	
6515011667777	PUMP AIR-CO2-WATER	EA	360.36	Z	W	0	
6515011667777	PUMP AIR-CO2-WATER	EA	360.36	Z	W	0	
6515011667777	PUMP AIR-CO2-WATER	EA	360.36	Z	W	0	
6515011667825	FORCEPS BONE HOLDING	EA	197.22	Z	D	0	
6515011676642	VACUUM CLEANR120-230V ✓	EA	306.69	Z	W	0	
6515011677287	SUCTION APP 120-230V ✓	EA	1981.25	Z	W	0	
6515011683752	TOURNIQUET PNEUMAT24"	EA	266.38	Z	D	0	
6515011690282	PACEMAKER CARDIAC EXT	EA	1357.02	Z	W	0	
6515011690282	PACEMAKER CARDIAC EXT	EA	1357.02	Z	W	0	
6515011721152	STETHOSCOPE ULTRASONC	PG	443.29	Z	W	0	
6515011721152	STETHOSCOPE ULTRASONC	PG	443.29	Z	W	0	

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.....NSN.....	.........NOMEN.........	UI	.........UP	MUAG	AAC	RIC	ASICE
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	2	•
6515011732053	DEFIBRILLATOR MONITOR	EA	2940.21	3	W	0	•
6515011737054	BRONCHOSCPS.3MM X50CM	EA	5563.78	3	W	0	•
6515011737054	BRONCHOSCPS.3MM X50CM	EA	5563.78	3	W	0	•
6515011737054	BRONCHOSCPS.3MM X50CM	EA	5563.78	3	W	0	
6515011738850	IMPLANT SET ORTHOPED	SE	3449.41	3	O	0	
6515011806962	SUCTION APPARATUS ORO	EA	224.45	Z	W	0	
6515011806962	SUCTION APPARATUS ORO	EA	224.45	Z	W	0	
6515011806962	SUCTION APPARATUS ORO	EA	224.45	Z	W	0	
6515011806962	SUCTION APPARATUS ORO	EA	224.45	Z	W	0	
6515011828001	DERMATOME BROWN	EA	1526.27	Z	W	0	
6515011841235	LIGHT HEAD FIBER OPTI	EA	642.60	Z	W	0	
6515011858446	ANESTHESIA APP NIT OX	EA	6332.76	3	A	0	•
6515011858838	MONITOR-RECORDER ELEC	EA	2429.07	3	A	0	•
6515011876606	THERMOMETER CLINICAL	EA	301.08	Z	W	0	
6515011876606	THERMOMETER CLINICAL	EA	301.08	Z	W	0	
6515011876606	THERMOMETER CLINICAL	EA	301.08	Z	W	0	
6515011876606	THERMOMETER CLINICAL	EA	301.08	Z	W	0	
6515011877777	BRONCHOSCOPE RIGID	EA	355.72	Z	O	0	
6515011865352	MONITOR OXY-CARB DIOX	EA	12269.75	3	A	0	•
6515011865352	MONITOR OXY-CARB DIOX	EA	12269.75	3	A	0	•
6515011865352	MONITOR OXY-CARB DIOX	EA	12269.75	3	A	0	•
6515011929456	ULTRASON UN 120/230 V	EA	707.87	Z	W	0	
6515011929456	ULTRASON UN 120/230 V	EA	707.87	Z	W	0	
6515012042670	SUCTION APPAR SURG	EA	199.96	Z	W	0	
6515012042670	SUCTION APPAR SURG	EA	199.96	Z	W	0	
6515012045316	NEBULIZER ULTRASONIC	EA	743.74	Z	W	0	
6515012045362	STAPLER SURG SUT 50MM	EA	832.46	Z	W	0	
6515012045363	STAPLER SURG SUT CRS	EA	322.08	Z	W	0	
6515012045364	STAPLER SURG SUT CRS	EA	322.08	Z	W	0	
6515012045365	STAPLER SURG SUT 30MM	EA	322.08	Z	W	0	
6515012052292	STIMULATOR NERVE	EA	210.00	Z	W	0	
6515012052379	STAPLER SURG SUT META	EA	1411.03	Z	W	0	
6515012065965	SAW SYSTEM BONE ELECT	EA	5664.02	3	W	0	
6515012066023	CUTTER ORTHO 115V60HZ	EA	249.53	Z	W	0	
6520001351250	COMP DENTAL DEN	EA	1997.31	Z	O	2	•
6525002260917	CASSETTE RAD 14X17 IN	EA	765.21	Z	O	0	
6525000080620	MARKER SE X-RAY FILM	SE	539.48	Z	D	0	
6525011159194	CABINET STORA X-FILM	EA	211.50	Z	L	0	
6525011567636	XRAY APPAR MOBILE300MA	EA	27750.24	3	W	0	
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	Z	W	0	
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	Z	W	0	
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	Z	W	0	
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	Z	W	0	
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	Z	W	0	

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.....NSN.....	.........NOMEN.........	UI	.........UP	MUAG	AAC	RIC	ASICE
6525011608381	ILLUMINATOR X-RAY FLM	EA	188.77	2	W	0	
6525011620249	PROCESSING MACHINE,	EA	5590.98	3	W	0	
6525011893986	X-R APP MOT 190E230 V	EA	98538.49	3	W	0	
6530000275252	STAND SUR ADJ FLD CRM	EA	489.21	2	D	0	
6530000275252	STAND SUR ADJ FLD CRM	EA	489.21	2	D	0	
6530000275252	STAND SUR ADJ FLD CRM	EA	489.21	2	D	0	
6530001429239	TABLE OPERATING FIELD	EA	7555.82	3	A	2	•
6530004423181	TABLE SURG 40X23X38IN	EA	961.19	2	C	0	
6530006800501	TURNING FRAME 84 IN	EA	722.39	2	D	0	
6530006800501	TURNING FRAME 84 IN	EA	722.39	2	D	0	
6530007093000	TABLE EXAMINING STEEL	EA	527.25	2	D	0	
6530007098175	TABLE OPERATING FIELD	EA	1730.77	2	D	2	•
6530007099400	TRACTION APPARAT PTUL	EA	698.11	2	D	0	
6530007741025	CART SURG DRES STEEL	EA	487.96	2	D	0	
6530007741025	CART SURG DRES STEEL	EA	487.96	2	D	0	
6530009262151	STER SURG DRES16X30IN	EA	4024.90	3	A	2	•
6530009264731	TRACTION APPLIANC BED	EA	396.49	2	D	0	
6530009264731	TRACTION APPLIANC BED	EA	396.49	2	D	0	
6530009264731	TRACTION APPLIANC BED	EA	396.49	2	D	0	
6530009264731	TRACTION APPLIANC BED	EA	396.49	2	D	0	
6530010155189	BED,ADJUSTABLE	EA	324.83	2	D	0	
6530010155189	BED,ADJUSTABLE	EA	324.83	2	C	0	
6530010155189	BED,ADJUSTABLE	EA	324.83	2	D	0	
6530010633966	STRETCHER,HOSPITAL	EA	501.44	2	D	0	
6530010985027	STER SURG DRES 115 V	EA	3390.25	3	A	2	•
6530011161049	CART ANESTHES EQUIP	EA	1313.00	2	L	0	
6530011399464	PARALLEL BAR LOFT LG	EA	1262.03	2	L	0	
6530011624443	TABLE FOLDING LEGS	EA	538.36	2	W	0	
6530011624443	TABLE FOLDING LEGS	EA	538.36	2	W	0	
6530011624443	TABLE FOLDING LEGS	EA	538.36	2	W	0	
6530011628237	CABINT PHAR12X36X31IN	EA	494.50	2	D	0	
6530011628237	CABINT PHAR12X36X31IN	EA	494.50	2	D	0	
6530011628237	CABINT PHAR12X36X31IN	EA	494.50	2	D	0	
6530011628237	CABINT PHAR12X36X31IN	EA	494.50	2	D	0	
6530011628237	CABINT PHAR12X36X31IN	EA	494.50	2	D	0	
6530011633760	CABNT BASE18X22X36IN	EA	569.95	2	D	0	
6530011633760	CABNT BASE18X22X36IN	EA	569.95	2	D	0	
6530011633760	CABNT BASE18X22X36IN	EA	569.95	2	D	0	
6530011633760	CABNT BASE18X22X36IN	EA	569.95	2	D	0	
6530011633761	CABINET MED23X18X37IN	EA	490.42	2	D	0	
6530011633761	CABINET MED23X18X37IN	EA	490.42	2	D	0	
6530011633761	CABINET MED23X18X37IN	EA	490.42	2	D	0	
6530011633761	CABINET MED23X18X37IN	EA	490.42	2	D	0	
6530011665093	POSITIONING SET SURG	EA	94.38	2	D	0	
6530011665094	CABINET MOBILE ECG	EA	94.38	2	D	0	
6530011668995	REFRIG120/230V50/60HZ	EA	1420.35	2	W	0	
6530011700647	LOUNGE BLOOD DONOR	EA	583.52	2	L	0	
6530011752319	STERILIZER AGAR DISPE	EA	2738.30	3	A	0	•
6530011760703	TRACTIN APPAR PT PORT	EA	1342.22	2	W	0	
6530011766217	HEATER, HEAT TREATUPK	EA	722.03	2	W	0	
6530011772636	CART RESUSCITA MOBILE	EA	1236.72	2	D	0	

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.....NSN.....	.........NOMEN.........	UI	........UP	MUAC	AAC	RIC	ASIDE
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772636	CART RESUCSITA MOBILE	EA	1236.72	2	D	0	
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772637	VENTILATOR PORT W/COV	EA	11325.96	3	W	0	•
6530011772639	THERMOREG PATNT AC	EA	1795.61	3	W	0	•
6530011800456	LIGHT SRG CEIL50/60HZ	EA	1705.83	2	W	0	
6530011941238	IRRIGATOR,SURGICAL	EA	1809.36	2	W	0	
6530011885304	LIGHT SURG FIELD	EA	1887.66	2	W	0	•
6530011885304	LIGHT SURG FIELD	EA	1887.66	2	W	0	•
6530012070827	CABINET SOLUT110/220V	EA	2831.49	2	W	0	
6530012070827	CABINET SOLUT110/220V	EA	2831.49	2	W	0	
6540011800479	OPHTHALMOSCOPE	EA	763.13	2	W	0	
6540011823770	LIGHT SLIT OPH110/220	EA	5386.83	3	W	0	•
6540011823921	PERIMETER OPHTHALMIC	EA	6264.63	3	A	0	•
6545001186249	CHEST MISS 30X18X19IN	EA	613.28	2	D	0	
6545001186248	CHEST MISS 30X18X19IN	EA	613.28	2	C	0	
6545001186248	CHEST MISS 30X18X19IN	EA	613.28	2	D	0	
6545001186248	CHEST MISS 30X18X19IN	EA	613.28	2	C	0	
6545001186249	CHEST MISS 30X18X19IN	EA	876.11	2	C	0	
6545001186249	CHEST MISS 30X18X19IN	EA	876.11	2	D	0	
6545001316977	CHES MED INS 30X18X19	EA	625.48	2	C	0	
6545002598649	INSERT CAB MED CHEST	EA	191.17	2	D	0	
6545002598649	INSERT CAB MED CHEST	EA	191.17	2	D	0	
6545002598649	INSERT CAB MED CHEST	EA	191.17	2	C	0	
6545002598649	INSERT CAB MED CHEST	EA	191.17	2	O	0	
6545004540309	SPEC REP SET FIELD	SE	1566.96	2	V	0	
6545011312633	OPTOMETRY EQUIP SET	SE	11530.35	2	A	2	•
6545011558344	GENITOURINARY CYSTOSC	EA	10850.97	3	W	0	•
6545011631899	SINK UNIT,SCRUB,FLD	EA	574.47	3	W	0	•
6545011631899	SINK UNIT,SCRUB,FLD	EA	574.47	3	W	0	•
6545011631899	SINK UNIT,SCRUB,FLD	EA	574.47	3	W	0	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•
6545011663525	SINK UNIT SCRUB FIELD	EA	4270.83	3	W	1	•

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.....NSN.....	.........NOMEN..........	UI	........UP	NUAC	AAC	PIC	ASICF
6630004188010	COUNTER BLOOD CELLS	EA	201.28	2	Y	0	
6630011479532	ANALYZER CARBON DIOX	EA	171.60	2	L	0	
6630011769736	ANALYZER POT SOD W/CA	EA	5309.61	3	W	0	•
6630011853296	BD GAS ANA 120/230V	EA	14656.53	3	W	0	•
6630011857835	COAGULATION TIMER	EA	3166.38	3	W	0	•
6640011626953	INCUBATOR DRY HEAT	EA	94.38	2	W	0	
6640011534213	CENTRIFUGE LAB 110230	EA	94.38	2	W	0	
6640011701190	CENTRIFUGE LAB SM120	EA	468.98	2	W	0	
6640011721132	ROTATOR LAB VAR SPEED	EA	239.18	2	W	0	
6640011738927	WATER BATH SEROL2RACK	EA	547.48	2	W	0	
6640011738927	WATER BATH SEROL2RACK	EA	547.48	2	W	0	
6640011738927	WATER BATH SEROL2RACK	EA	547.48	2	W	0	
6640011738927	WATER BATH SEROL2RACK	EA	547.48	2	W	C	
6640011760700	BLENDER FLOD ELECTRIC	EA	196.62	2	D	0	
6640011760735	SHAKING MACH LAB120/	EA	216.92	2	W	0	
6640011766232	STIRRER-HOT PLATE LAB	EA	221.80	2	W	0	
6640011766232	STIRRER-HOT PLATE LAB	EA	221.80	2	W	0	
6640011841564	COUNTER BLDCELL120230	EA	3522.62	3	W	0	•
6640011876621	INCUBATOR,BACTERIOL	EA	5126.03	3	W	0	•
6640012048691	CENTRIFUGE LAB 110V	EA	419.56	2	W	0	
6640012052150	INCLB DRYHEAT110/220	EA	442.66	2	W	0	
6640012052422	CENTRIFUGE LAB RA19V	EA	411.92	2	W	0	
6640012066031	CENTRIFUGE LAB115V50/	EA	94.38	3	W	0	
6640012066031	CENTRIFUGE LAB115V50/	EA	94.38	3	W	0	
6645011876997	CLOCK,ELAPSED TIME	EA	212.36	2	D	0	
6650009133219	REFRACTOMETER HAND	EA	327.43	2	D	0	
6650011857896	SPECTROPHOTOMETER	EA	4371.06	3	W	0	•
6650012070629	MICROSCOPE OPT 20MM	EA	1121.36	2	W	0	
6650012070629	MICROSCOPE OPT 20MM	EA	1321.36	2	W	0	
6670001194623	BALANCE TORSION 120GM	EA	540.53	2	D	0	
7105007100210	TABLE FLDG LEG LAB	EA	148.55	2	D	2	
7105007100210	TABLE FLDG LEG LAB	EA	148.55	2	D	2	
7105007100210	TABLE FLDG LEG LAB	EA	148.55	2	D	2	
7105007100210	TABLE FLDG LEG LAB	EA	148.55	2	D	2	
7110011569023	SAFE 28-.72IN HIGH	EA	1250.27	2	L	0	
7210002958518	MATTRESS KHAKI OR O-D	EA	53.79	2	D	0	
7210002958518	MATTRESS KHAKI OR O-D	EA	53.79	2	D	0	
7210002958518	MATTRESS KHAKI OR O-D	EA	53.79	2	D	0	
7430011417443	IMPRINTER LABEL TYSET	EA	405.00	2	L	0	
7910011770622	CLEANER VACUUM ELEC	EA	294.48	1	W	0	