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Analysis of Requirements for Shipboard Voltage Spike Suppressors

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Electronics and Electrical Engineering
Electrosystems Division
Washington, DC 20234

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Prepared for:

Department of the Navy
Naval Sea Systems Command
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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Abstract

This report describes progress so far in a voltage spike suppressor program, undertaken for the Naval Sea Systems (NAVSEA) Command, with the objective of developing a sound technical basis on which a spike suppressor specification for shipboard equipment could be written. The project contract stated that sufficient field data for such a specification already existed, and needed only to be correlated and analyzed. NBS investigation revealed that existing data were far from adequate for this purpose. It was then recommended that further testing already planned by the Navy be used to collect the required data. Other as yet unreported data were also analyzed. Neither effort succeeded in producing enough meaningful information for carrying out the assigned task.

This report includes documentation of the analysis of all the pertinent data above; a general discussion of the principles involved and of the applicable suppression devices; a discussion of suppressor selection considerations and the key parameters for this; and a review and analysis of the reports provided by the Navy. Finally, the report lists key parameters which must be known, and shows why the available data cannot support the generation of a suppressor specification.

Key words: shipboard spikes; spikes; spike suppressors; suppressor specification; voltage clamping; voltage spikes.

1. INTRODUCTION

In August 1982, a program to develop recommendations for voltage spike suppressor specifications for Navy ships was undertaken by the National Bureau of Standards (NBS). This program was funded by the Naval Sea Systems Command (NAVSEA). The objective of the program was to provide a sound technical basis for shipboard application of spike suppressors. Such specifications would permit the Navy and the manufacturers of suppression devices to determine whether or not such devices met the requirements of the Navy.

The contract for this project stated that suppressor recommendations could be based upon existing field data, which needed only to be correlated and analyzed. In the first phase of the project, NBS investigation revealed that the existing data were far from adequate for the purposes of this program. NBS then recommended that further Navy testing, already planned in the EPIC program, be utilized to collect the required data. In addition, other data previously not made available to NBS were analyzed in an attempt to obtain sufficient meaningful information. Neither the EPIC program nor this additional analysis produced useful results.

Certain commercial instruments are identified in this report to provide the sponsor with the analysis requested in the work statement. NBS has merely reproduced information in reports supplied by the sponsor and has conducted no evaluation on the instruments identified. Identification does not imply recommendation or endorsement by NBS for any purpose, nor does it imply that any identified instruments are the best available for a given purpose.

This report documents the analysis of all the pertinent data made available to NBS. A brief general discussion of the principles of transient suppression is also provided, with emphasis on the types of suppressors which appear to be most suitable for shipboard applications. Selection considerations are given, outlining the key parameters which must be known with some assurance in order to apply suppression devices. Shipboard transient data provided in five Navy reports are reviewed and analyzed, with emphasis on the quality of the data relative to their use in the development of transient suppressor specifications. The report explains which key parameters must be known in order to generate a spike suppressor scheme. It also shows why the available data base cannot support the generation of performance specifications.

2. DEFINITION OF TERMS

The DOD-STD-1399 (NAVY) standard entitled Interface Standards for Shipboard Systems (section 300) defines some of the terms pertinent to this subject somewhat differently than they are commonly defined in industry standards. Specifically, DOD-STD-1399 defines a Voltage Spike as a voltage change of very short (less than one millisecond) duration compared with one cycle of the power system voltage. For definition and test purposes the standard 2500 V 1.2 x 50 μsec lightning impulse is used. But in reality, spike forms can range from single pulses with extremely short rise time and exponential decay to oscillating disturbances persisting for several oscillations within an exponentially decaying envelope.

On the other hand, a Voltage Transient (excluding spikes) is defined as a sudden change in voltage which exceeds the user voltage tolerance limits and returns to and remains within these limits within a specified recovery time after the initiation of the disturbance. In other words, transients are considered to be relatively long-term voltage excursions outside the nominal steady-state voltage level, which may persist from a few to many cycles of the power frequency without significant alteration of the waveform. Often the term "sag-surge" is used as well and has the same general meaning as voltage transient.

Thus, the Navy defines voltage spikes as "short-time" transients that are less than one millisecond in duration. Industry's standards related to protective devices or arrestors do not make a time distinction in power system disturbances. The common term used by industry standards is Surge Voltage. The devices used to limit surges are commonly referred to in industry as Surge Protective Devices. Transient over-voltage is a term commonly used interchangeably with Surge Voltage by authors in the field and manufacturers of protective devices. This report will generally adhere to the use of the term voltage spike as defined in DOD-STD-1399, although the word transient may at times be used to refer to a general disturbance of the power waveform without any reference to its duration.

3. SUPPRESSION PRINCIPLES AND DEVICES

The failure and operational upset of electronic equipment caused by spikes and transients on shipboard power systems has been recognized as a significant obstacle to maintaining reliable equipment operation and to the development of new systems. Of particular concern in the surveys taken aboard ships has been the observation of over-voltage spikes and transients. Equipment designers have recognized the problem and have taken steps to deal with it in their own systems. Another and perhaps more efficient means of dealing with this problem is through the concept of "primary" transient protection on a shipboard power distribution system. Such protection could be implemented by specifying appropriate suppression devices strategically located throughout a given power distribution system to reduce high amplitude spikes to harmless levels. Not only would such a scheme make it unnecessary for every equipment to protect itself but it would allow predictable voltage levels to be maintained. Residual noise or interference on the power line which causes problems to a particular piece of equipment could then be dealt with separately to the degree required. The brief technical discussion of suppression principles and devices which follows is based on the concept of applying suppression devices in a "primary" protection scheme.

Transient suppressors can be divided into two general categories: those that attenuate transients, and those that divert transients away from sensitive loads.

Attenuating a transient is usually accomplished with some type of filter inserted in the circuit. The filter allows the desirable signal to pass while attenuating the undesirable (high frequency) energy contained in a transient. The simplest form of filter is a capacitor placed across the line. The impedance of the capacitor forms a voltage divider with the source impedance, resulting in attenuation of the transient at high frequencies. While such simple filters can offer effective transient protection, they may produce undesirable side effects such as unwanted resonances, high in-rush currents during switching, or excessive reactive loading of the power system. These undesirable effects can be reduced by adding a resistor in series with the capacitor, thus forming the popular RC-type suppression network; but the added resistance tends to make the network a less effective suppressor.

More complex filters comprised of resistors, capacitors, and inductors are often located at the equipment/power line interface, serving the dual function of transient and interference protection. Although such filters can be quite effective, they may be unsuitable for a general primary protective scheme because each network must be specifically designed for the circuit in which it is to be used. For example, filters that employ series reactive elements must be designed to pass the currents of the power system over a wide range without excessive dissipation or compromised performance.

The second method of suppression operates by diverting all or part of the spike away from the circuit to be protected. Diversion devices fall roughly into two categories: (1) voltage-clamping, and (2) voltage-shorting or "crowbar."

As the jargon implies, the "crowbar"-type devices involve a switching action, either by the breakdown of a gas between two electrodes or the firing of a thyristor. After switching on, this device approaches a short circuit or very low impedance, which diverts the transients away from the load. Its primary limitation when used in power circuits is the "follow current" or "power follow" effect. This phenomenon occurs when the current from the power circuit follows an overvoltage spike or transient. Since the "crowbar" effectively short-circuits the source, the current may be very large, and may produce a significant disturbance on the line. Furthermore, the device may or may not clear itself at zero current. Thus, additional devices such as fuses or circuit breakers must be provided if there is no provision for self-clearing action. Because such a suppressor can create significant line disturbances itself, this type is probably not suitable for shipboard application, and will not be discussed any further.

The voltage-clamping suppressor is so named because it "clamps" the voltage across its terminals at an approximately fixed level over a wide range of currents[1] through them. This suppressor has a nonlinear impedance which depends upon the voltage across its terminals. With this device, the protected circuit is unaffected before and after the transient at any voltage level below the clamping level. When a transient exceeds the clamping voltage level, the excess energy of the transient is dissipated in the suppressor and in the resistance of the electrical network source impedance. There are a number of voltage-clamping devices, but the two types most used today are avalanche junction semiconductors and Metal-Oxide-Varistors (MOVs).

Avalanche semiconductor diodes, often referred to as zener diodes, are very effective at clamping and come closest to an ideal constant voltage clamp. These diodes switch abruptly (subnanosecond times) from a non-conducting to a conducting state. Their major limitation is their small energy dissipation capability. However, this has been overcome by several manufacturers by packaging many junctions in a network that is able to dissipate considerable energy.

Although the physics involved are quite different, the MOV has an electrical behavior similar to that of back-to-back avalanche semiconductor (zener) diodes. The physical difference is that the MOV does not clamp by diode switching action, but acts instead as a resistor whose resistance varies inversely with voltage in a highly nonlinear manner. The breakdown into the clamping region is therefore not as sharp, and the MOV switching speed (nanosecond times) is slightly slower than avalanche diode switching speed. However, the energy absorption capability is much greater than for avalanche diodes. Some larger units can absorb several kilojoules.

The manner in which voltage-clamping suppressors operate may be clarified by inspection of the log-log voltage versus current (V-I) curves of these devices, shown schematically in figure 1 (not to scale). For each device there exists a very small idling or standby current below the breakdown or clamping voltage. Thus the suppressor looks essentially like an open circuit over this voltage range. At the entrance to the breakdown voltage region (the "knee" of the V-I curve) both devices change very rapidly from an essentially nonconducting to a highly conducting state. Stated another way, the incremental resistance, $\Delta V/\Delta I$, becomes very small, effectively creating a very low resistance for voltages higher than the clamping voltage. Beyond a certain current, the V-I curves turn up again, ending the clamping voltage region. This upturn region is of interest here only in that circuit design must keep the suppressor current below this level. The two curves are shown with different shapes to emphasize that the avalanche diode switches more abruptly (sharper "knee") and clamps more firmly (less slope in the clamping region) than the MOV.

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[1]An ideal clamping suppressor would maintain an absolutely fixed voltage over an infinite range of current.

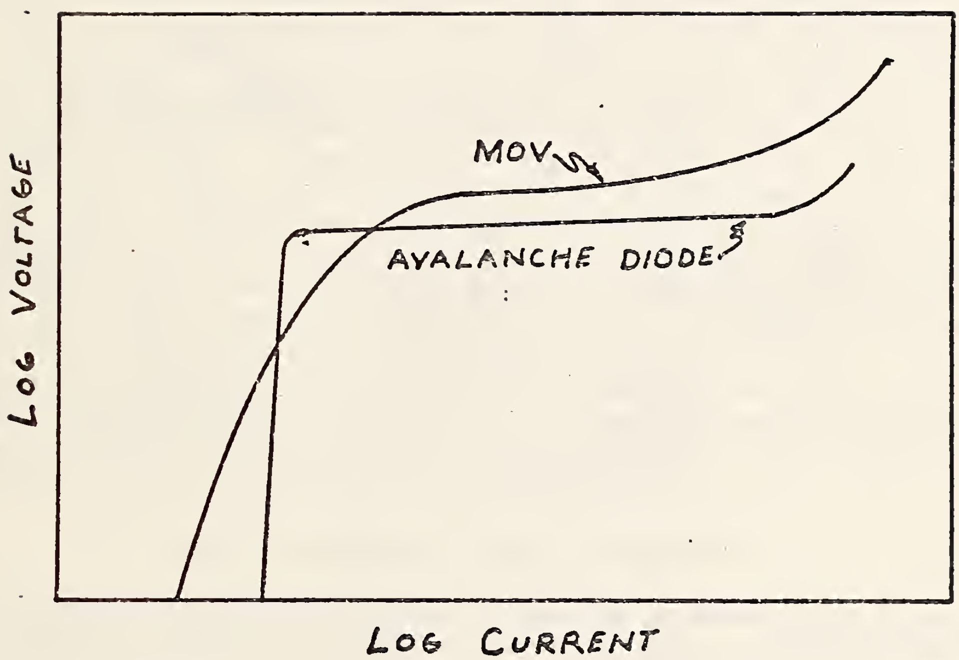

Figure 1. Comparison of the log-log voltage versus current (V-I) curves of MOVs and avalanche diodes (not to scale).

Either clamping-type suppressor can be represented schematically as a variable impedance that attenuates the open-circuit transient voltage as shown in figure 2. As the open-circuit voltage approaches the voltage level where the impedance of the suppressor begins to lower abruptly, voltage division begins to take place. It is important to understand that the device depends on the source impedance (Z_S) to produce the clamping. If the source impedance is low compared to the dynamic clamping resistance of the device, the division ratio will be low, i.e., the clamping action will be poor. As the equation in figure 2 shows, if $Z_S = 0$, $V_C = V_S$, and there is no clamping action. In other words, a suppressor cannot be effective with a zero source impedance. As will be shown, it is the source impedance of the transient which governs the sharing of energy dissipated between the suppressor and the source impedance. Thus, the performance and limitation of a suppression system is directly influenced by the source impedance of the transient.

The function and effectiveness of a clamping-type suppressor can perhaps be visualized more clearly by reference to figure 3, which shows a power system sinusoidal voltage wave with five different types of disturbances impressed upon it. The upper and lower (positive and negative) clamping voltage levels, established by a MOV or by back-to-back avalanche diodes, create an envelope which bounds the voltage that can appear across the protected circuit. Whereas the voltage trace with disturbances superimposed represents the applied voltage in the absence of the suppressor, the trace less the shaded portions represents the applied voltage in the presence of the suppressor. Note that "spikes" 1, 3, and 5 are partially suppressed, whereas "notches" 2 and 4 are not, even though "spike" 2 is comparable in size and "notch" 4 is much larger. Note also that although spike 3 is the largest of all, a large part of it remains unaffected. Thus, clamping-type suppressors are only effective in reducing overvoltage transients which rise above the peak voltage of the power system. As will be explained in the subsequent section, the clamping level cannot be set at exactly the peak level of the power system voltage, hence, by necessity there will always be some overvoltage residuals. If necessary, the additional suppression techniques referred to earlier could deal with the residual disturbances shown in figure 3.

4. SUPPRESSOR SELECTION CONSIDERATION

A voltage-clamping suppressor should operate under steady-state conditions with a very small standby current, and in transient conditions without degradation or failure when subjected to very large peak current and very large energy dissipation. The selection process for a particular suppressor requires specific knowledge of the electrical environment in which it will operate. When the environment is not fully defined, some assumptions can be made but at the risk of possible failures or economic penalties. Among the factors which must be considered in the selection of an appropriate voltage-clamping device for a given circuit are:

(1) Steady-state voltage rating
(2) Transient energy absorbed by the device
(3) Peak transient current through the device

4.1 Steady-State Voltage Rating

The steady-state voltage rating is the voltage that may be applied to the device under normal conditions with allowance for surges (a voltage increase

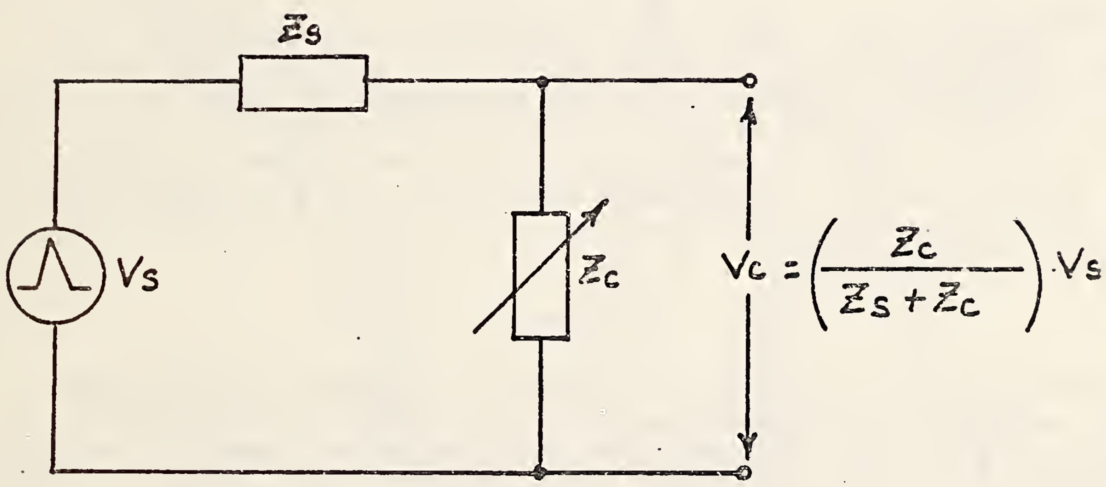

Figure 2. Attenuation of the transient source voltage V_S by the variable impedance Z_C of a clamping-type suppressor.

above the normal operating level persisting for several cycles). The regulation of the line voltage is an important factor, since poor regulation can lead to surges that may cause the device to begin clamping. This can lead to failure since the power capability of the system can greatly exceed the power dissipation capability of any suppressor. Refer again to figure 3, which shows a case in which the steady-state ac voltage of the suppressor has been selected properly, i.e., the clamping voltage is always above the peak of the sine wave. On the other hand, figure 4 represents a case in which the steady-state ac voltage is too high, i.e., the peak of the sine wave exceeds the clamping voltage. In this case, the clamping level is set too low, and the suppressor begins to conduct appreciable current during the peak of the fundamental wave itself. This will cause the suppressor to dissipate excessive amounts of energy even in the absence of spikes, thereby either destroying it or permanently altering its characteristics. The temperature coefficient of the clamping level of most MOVs is negative, so that increased heating of the device causes a subsequent lowering of the clamping level which can lead to thermal runaway failure.

A design tradeoff is involved in the selection of the steady-state voltage rating, in that too high a value (over-conservative design) results in a transient clamping voltage which is too high, i.e., a "clamp ratio" which is too low.[2] The steady-state voltage rating must be selected so as to minimize the idling, or stand-by current, while at the same time holding the clamping voltage as low as possible without allowing a "surge" to push the peak of the sine wave into the clamping region. In systems likely to be subject to surges (most ship systems), selecting a steady-state voltage rating too low is probably the more serious of the two problems.

4.2 Energy

The energy rating of the device is perhaps the single most important parameter, and must be considered carefully in relation to the potential transient energy that can exist in a given electrical environment. The energy rating refers to the energy that must be dissipated in the suppressor during a spike. A circuit which illustrates this concept is shown in figure 5, in which a spike voltage, V_S, is superimposed on a steady-state voltage, V_{SS}. A total voltage, $(V_S + V_{SS})$, is thus imposed upon a circuit which is protected by a clamping suppressor whose clamping voltage is V_C, through the source impedance Z_S. The circuit conditions as shown apply during the time for which $(V_S + V_{SS})$ is greater than the clamping voltage.

Figure 6 represents the graph of the generalized voltage versus time for figure 5. Figure 6 assumes that the spike duration is short relative to the period of the power system voltage, V_{SS}, so that the base line voltage of the spike can be considered constant over the interval of the spike. The crosshatched area delineates the voltage wave during the time it is above clamping voltage V_C. During this time, i_S flows, and the suppressor must absorb energy, E_S where

[2]The "clamp ratio" is defined in industry as the clamping voltage divided by the peak value of the steady state voltage.

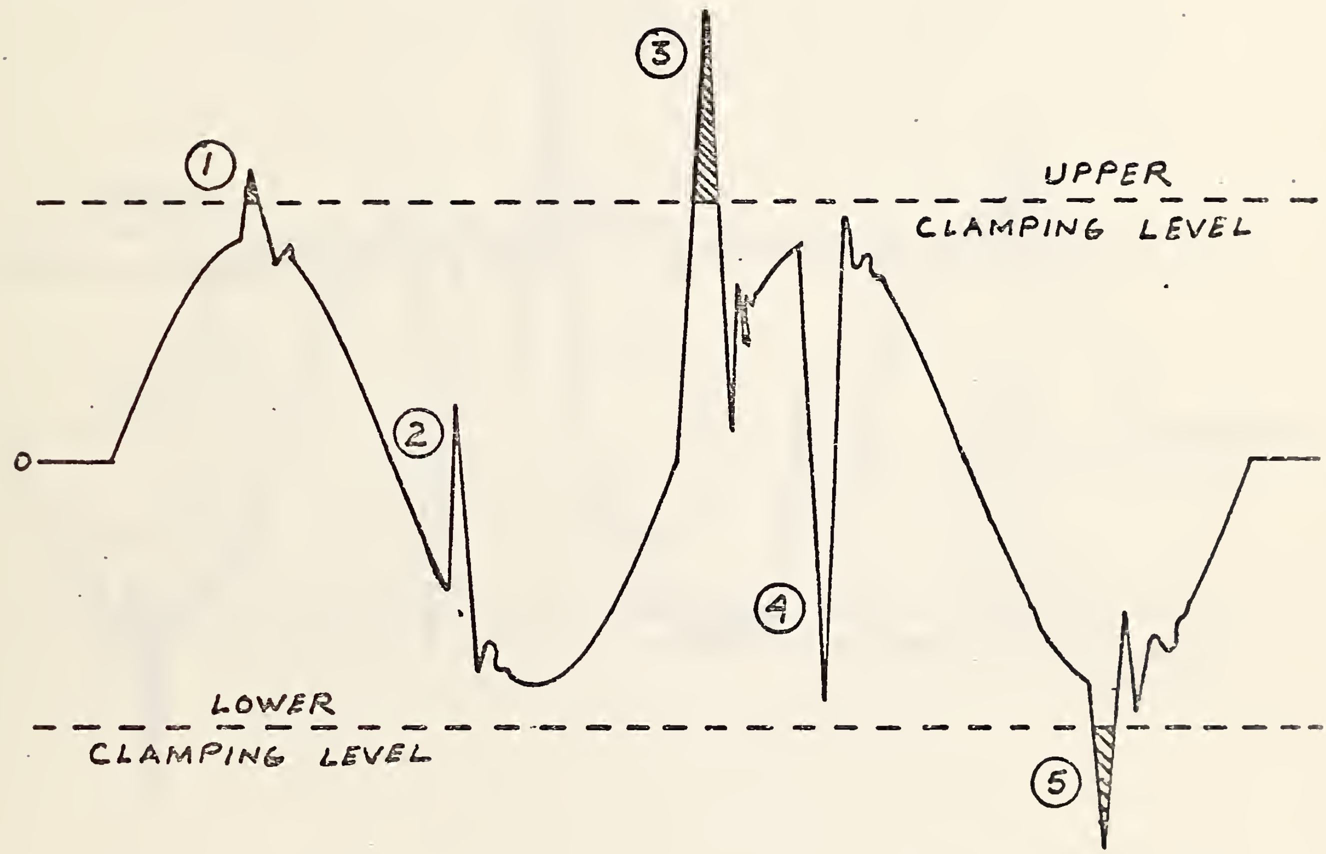

Figure 3. Steady-state power voltage wave (60 Hz or 400 Hz) with superimposed transients, showing the effect of clamping-type suppressors on such transients when the clamping level is set correctly.

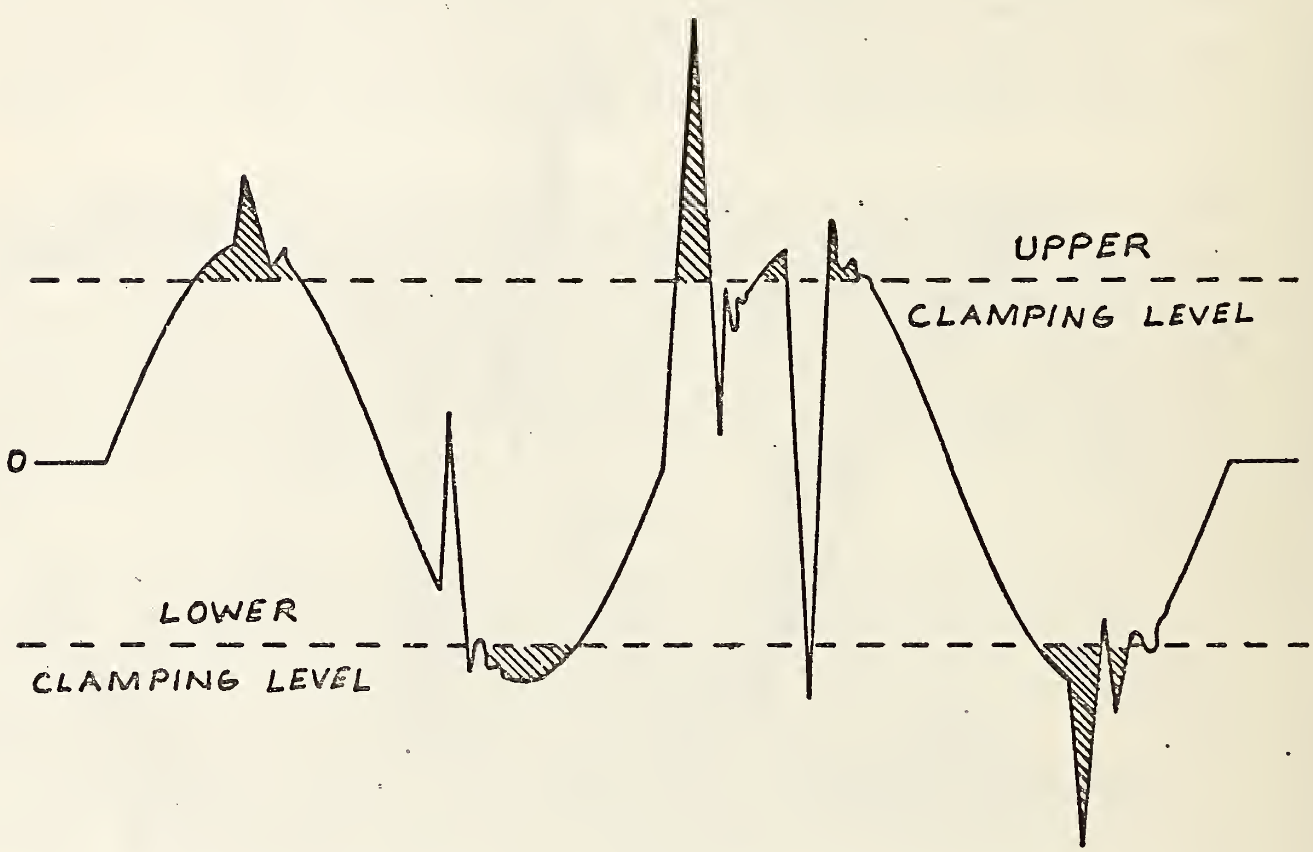

Figure 4. Steady-state power voltage wave (60 Hz or 400 Hz) with superimposed transients, showing the effect of clamping-type suppressors on such transients when the clamping level is set too low.

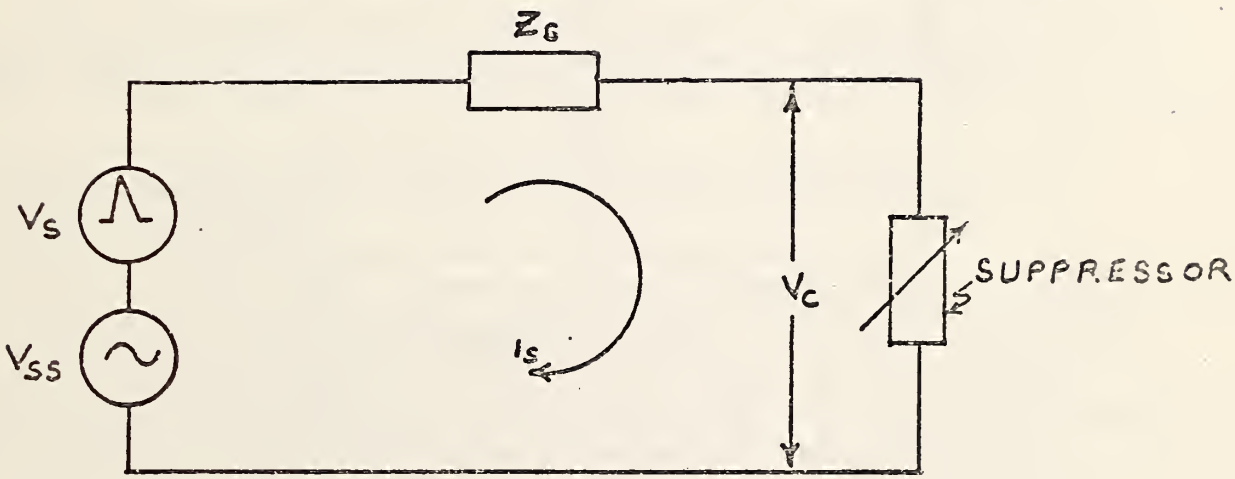

Figure 5. Circuit for calculating the current and the energy dissipated in a clamping suppressor.

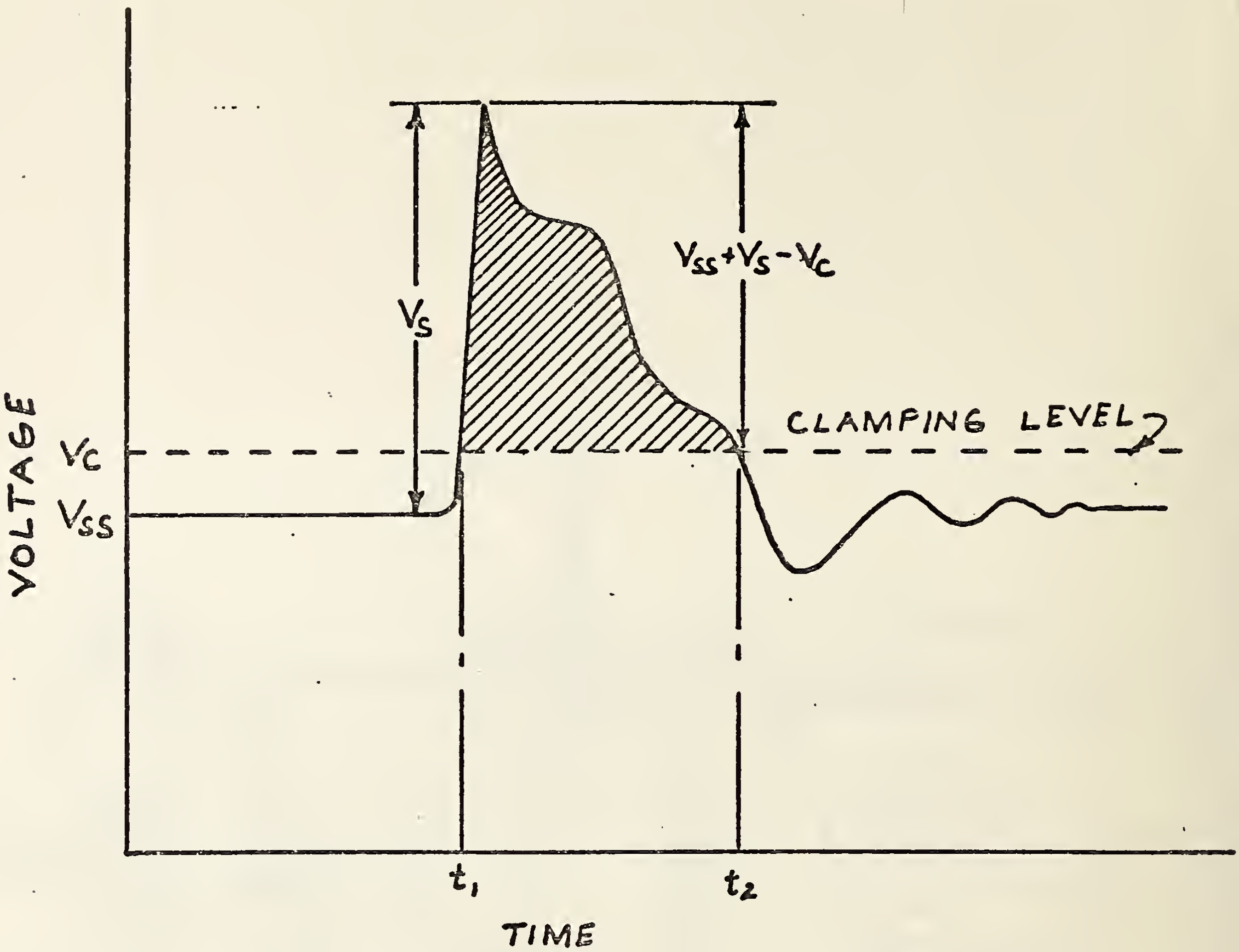

Figure 6. Graphical representation of the voltages in the clamping suppressor circuit of Fig. 5.

$$E_s = V_c \int_{t_1}^{t_2} i_s \, dt \qquad (1)$$

assuming an ideal suppressor, for which V_c is constant.

The most desirable way to determine the above energy would be to measure V_c and i_s at the suppressor, and then perform the indicated integration of the voltage-current product. Since this determination cannot be done in practice, an alternate method is to use the voltage spike recording of figure 6 along with the measured source impedance as a function of frequency. Then from figures 5 and 6, $i_s = (V_{ss} + V_s - V_c)/Z_s$, and equation (1) becomes,

$$E_s = \int_{t_1}^{t_2} \frac{V_c(V_{ss} + V_s - V_c)}{Z_s} \, dt \qquad (2)$$

where $V_c > V_{ss}$, and Z_s is assumed to be constant between times t_1 and t_2.

Thus, with a knowledge of the transient voltage as a function of time and of the source impedance, appropriate algorithms can be used to calculate energy. To summarize, energy calculations require two pieces of information:

1. Transient voltage recordings as a function of time (Fig. 6).
2. Source impedance (Z_s) of the network as a function of frequency (1 kHz to 500 kHz).

Inspection of figure 6 and of equation (2) will show why data on voltage wave shape and duration are important. Since energy is a voltage-squared-time function, it should be apparent that the larger spike voltage V_s is, and the longer its duration above clamping voltage V_c, the larger the energy which must be absorbed by the suppressor. Stated another way, a very large but short spike may represent less energy than a much smaller but much longer spike. Also, the longer spike tends to contain more energy because source impedance Z_s is usually predominantly inductive-resistive in nature, hence increases very significantly with frequency, making it much larger for short spikes than for long ones. From equation (2) energy is inversely proportional to Z_s.

4.3 Peak Transient Current

For reasons only indirectly related to the total energy absorbed during any one pulse, the lifetime of a clamping-type suppressor is related inversely to the peak current through the suppressor. This relationship is quite strong, e.g., a MOV rated for one 2000 A pulse of a given length might typically withstand 2,000 200 A pulses of the same length without degradation. Peak current rating is usually stated as the peak value of a single pulse of current. Repetitive pulsing requires a significant derating of peak pulse current. Thus, the peak current and expected frequency of occurrence of the transients must be considered in relation to the expected life of a given suppressor. Peak current can be determined when the open-circuit peak transient voltage, the clamping voltage, and the source impedance are known (see Fig. 5). Therefore, as was true for energy rating, voltage pulse and circuit impedance data are essential.

5. RELATING THE AVAILABLE DATA TO THE REQUIREMENTS

Part of the data on which this report is based are contained in five reports (5.1 through 5.5) which were provided by NAVSEA at the beginning of the project. These five documents were to be the basis for establishing a suppressor specification for shipboard use. Each report is summarized briefly below, and those which bear most directly on the problem are discussed in more detail. In addition, the data made available from the USS Arkansas (CGN-41) and the data acquired from the EPIC program during the project period are discussed (5.6 and 5.7). A tabular summary of the 5.1 to 5.7 discussion is presented in Section 5.8. Also discussed (5.9 through 5.11) are some of the general problems identified as common to most of the data analyzed thus far.

5.1 <u>Sag/Surge and Interrupt Data Analysis on Shipboard Power Lines</u> by Sachs/Freeman Associates, Inc., dated 12 June 1981.

This document contains sag/surge and interrupt data collected from thirteen ships and analyzed for compliance with DOD STD-1399. These data involve very slow rises and falls (cycles to many seconds) in system voltages, and thus are not applicable to spike voltage characteristics. However, the report does have some relevance to selecting the steady-state voltage rating of a suppressor. For the 115-V system studied, most of the surges were under 130 V.

5.2 <u>Energy Analysis of Transient Pulses on Shipboard Electric Power Systems</u> by Messrs. L. L. Grigsby and S. S. Kelkar of VPI, dated July 1980.

This report is basically theoretical. It develops an algorithm for calculating transient energy from voltage pulse data in the time domain, and the source impedance as a function of frequency. The technique appears useful for calculating the energy of a voltage spike, but as the report points out, considerably more impedance data are necessary before the method can be applied to shipboard systems.

5.3 <u>Investigation of Shore-based Powerline Transients,</u> by Naval Electronic Systems Engineering Activity, dated 30 September 1981.

This report summarizes the results of a transient measurement program on Navy shore-based power very similar to the program discussed in Section 5.5. This program contained much more data (135,000 hours; 27,500 transients). Ninety-four percent of the data were taken with Dranetz recorders. The discussion under section 5.5 also applies to these data.

5.4 <u>Evaluation of Commercial Suppression Components and Commercial Suppressors</u>, Preliminary Data, 5 volumes, by Naval Electronic Activity, dated 10 March 1982.

These documents provide an independent analysis of the characteristics of various suppression components and packaged suppression systems, apart from any equipment they might protect. Three generic types of suppressors (metal oxide varistors, silicon pn junction devices, and gas tubes) were tested to determine if their performances changed with energy ratings, steady-state application ratings, or different manufacturers. The data and the descriptions of the particular packaged off-the-shelf suppression systems may be useful in determining whether a suppressor design can be supplied by an existing commercial unit or by minimal modification of such a unit. However, much more detailed circuit data than those given would be necessary in order to evaluate these commercial packages. Some of the units failed. The report does not make clear whether these failures were due to transients alone, to heating due to excessive idling current (e.g., epoxied "series" suppressors), or to combined causes.

5.5 Identification of Shipboard Powerline Transients, by Naval Electronic Systems Engineering Activity, dated 1 March 1980.

This report presents an extensive survey of transients on thirteen Navy ships, totaling over 9400 monitoring hours and over 2300 transients. The bulk of these data (80%) were obtained using Dranetz Model 606-3 recorders. These recorders give useful general information on the frequency of occurrence, location, and apparent peak voltages of transients in these Navy systems. They record no waveform data (i.e., duration and shape). Due to their somewhat limited bandwidth, it is also possible that they fail to reproduce the full amplitude of the faster transients. Some 5% of the data were taken with a fast digital storage oscilloscope. Because the storage oscilloscope records the complete waveform, both waveshape (duration) and peak voltage can be obtained. These data represent a total of approximately 125 spikes of several different types. In an initial review of the data compiled in the report, a number of discrepancies were noted, particularly in the reported durations of the transients.

As a result, NBS personnel made a trip to the Naval Electronic Systems Engineering Activity (NESEA), St. Inigoes, MD, to reexamine the waveform data stored on magnetic floppy disks. All 125 spikes were reviewed. Only 34 were of possible significance in terms of amplitude or duration. These 34 "worst cases" were copied and returned to NBS for further analysis. They included data from only three of the thirteen ships--LST1188, DDG41, and FF1092. This analysis revealed significant disagreement with the NESEA report, and showed that report to be very pessimistic regarding the significance of the spikes recorded, as related to waveshape and duration (which, in turn, are strongly correlated with the energy dissipated in the suppressor).

Further analysis showed that of the 34 "worst cases" above, all the "significant" spikes were on 440 V lines. Assuming a 450 V MOV, whose clamping voltage is about 1350 V, plus spike occurrence on the peak of the steady-state voltage wave (an additional worst case), only five of the 34 (or 125) spikes recorded would even trigger the suppressor, i.e., exceed the clamping voltage. Furthermore, only two would appear to dissipate significant energy in the suppressor. These two spikes are reproduced in figures 7 and 8. However, the appearance of even these two spikes leads to the suspicion that they are not real, but are artifacts of some sort. There is no obvious mechanism in a Navy power system which would be able to generate transients of this size and duration. Nevertheless, the presence of these two spikes in a relatively small data base means that the possibility of transient problems in Naval shipboard

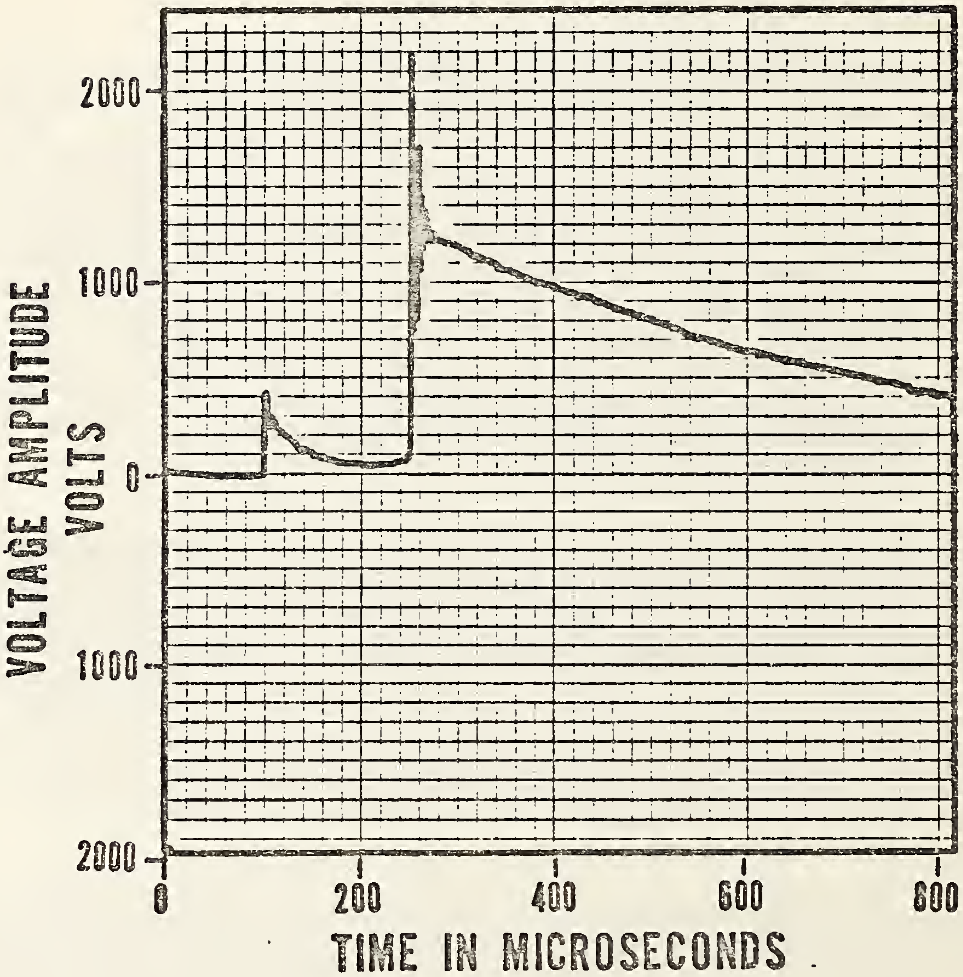

Figure 7. Decaying exponential with initial value of 1200 V and large initial spike of 2192 V. Duration to 50%, about 300 μs from 152 μs point. (Reproduced from St. Inigoes data).

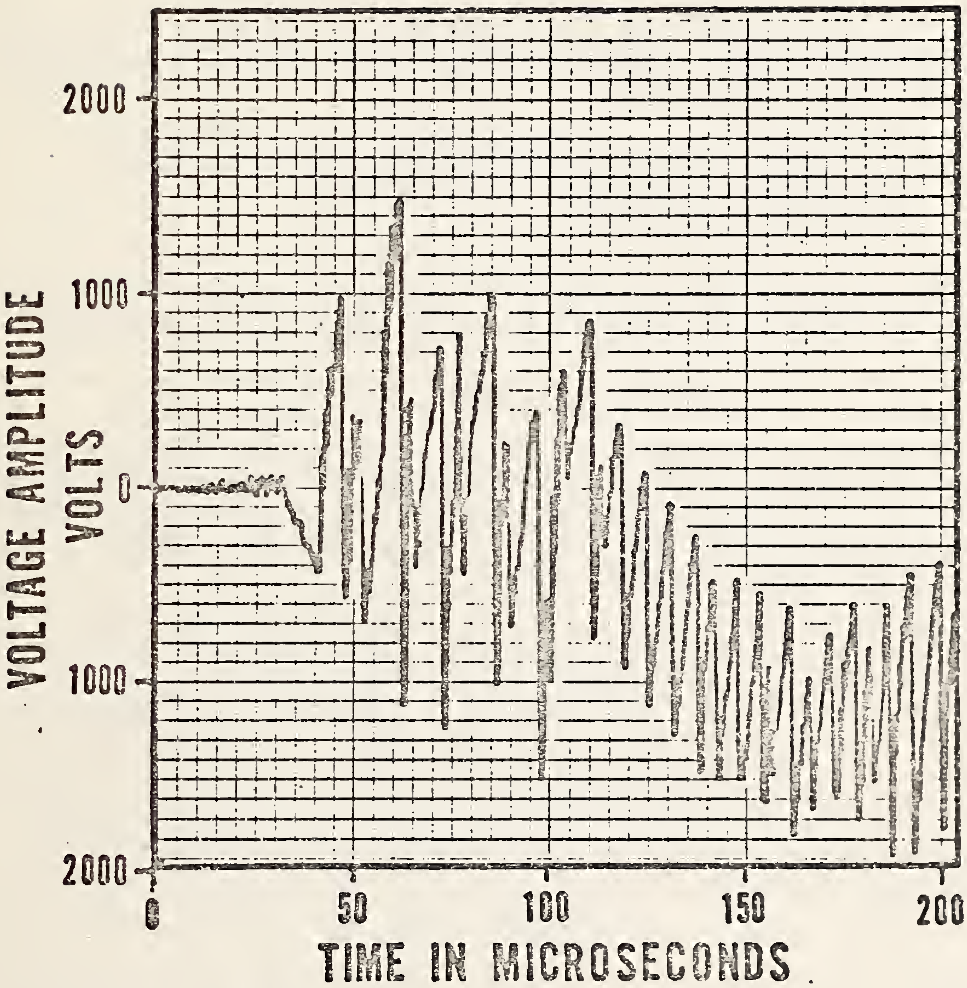

Figure 8. Large 170 kHz oscillation riding on an apparanet 7 kHz "carrier." Duration unknown (goes off screen at about 175 μs). (Reproduced from St. Inigoes data).

power circuits cannot be ruled out. On the other hand, the data base is far too small to be useful in suppressor design.

The total data body probably contains enough information to generate a preliminary specification for the frequency of occurrence of increasing peak voltages, although the Dranetz data may be low by as much as 50% for very fast spikes. Even allowing for this, the highest peak voltage found among 1250 transients on 440 V lines was 1500 V. Among 1100 transients on 120 V lines, the highest peak was 675 V. Since the Dranetz results (95% of the total data) include no data on waveshape or source impedance, they are of use only for analysis of worst case transient amplitude and frequency of occurrence.

In summary, no firm conclusions can be drawn from the very limited data available from this report, and most certainly, no development of suppressor specifications can even be considered.

5.6 USS ARKANSAS (CGN-41) ELECTRICAL POWER MONITORING, 2 volumes, by Raytheon Service Company, dated September 1982.

Two reports present the results of monitoring the electrical power system on CGN-41, under various at-sea conditions. Some data were recorded with Dranetz Model 606-3 and 626 recorders, and the remainder with a HP-3964A magnetic tape recorder. Both models of the Dranetz recorders were designed to enable a direct measure of the differential or phase-to-phase voltage. The magnetic tape recorder, however, because of its single-ended input configuration could only record the common mode or phase-to-ground voltage of each phase on individual channels. Each phase-to-phase voltage had to be reconstructed from the phase-to-ground potential of two channels by appropriate summing and scaling networks and then recorded on an oscillograph.

Approximately 1900 impulses were recorded. The highest transient voltage reported was 2030 V, and a sizable number of durations (about 20%) were greater than 2048 μs (the time base limit of the Dranetz recorder), all on the 440-V lines. No source impedance data were gathered. Only 25 oscillograms were presented and none of these included the "worst" cases; hence, there is little usable waveshape information. Although there were, in many cases, large amplitude and long duration phase-to-ground impulses, the reconstructed phase-to-phase voltage produced practically no transients. The report surmised that transient changes in line-to-ground impedance were the cause for the observed line-to-ground voltage disturbances. Some of the pulses presented appear to be square, or nearly so. If the worst-case pulse voltage and duration cases should happen to be square or triangular waves, they would represent a very severe design requirement for a suppressor. The reports recommend that continued transient monitoring should be conducted under controlled conditions to further determine the cause of transients. Of particular concern is the apparent long duration transients (greater than 2048 μs) indicated by the Dranetz recorders. If these are real, rather than artifacts of the instrumentation, such transients pose a threat to user equipment as well as severe requirements for suppression devices.

It is suspected, however, that the apparent long duration transients are due to the technique utilized by the Dranetz recorder which operates as follows:

the recorder commences clocking a disturbance at the time that the voltage exceeds or falls below a designated threshold value. This threshold value may be well below the peak value, e.g., 20 V or 50 V. When the voltage maximum or minimum is attained, that level is recorded. The duration of the transient is clocked until the voltage level returns to the original threshold value and this time interval is recorded. Thus, the time that is measured is that time from the initial threshold excursion up to the time at which the same threshold level is reacquired. The length of time that the transient remained at the maximum or minimum value (or above the conventional 50% of peak definition for duration) is not recorded.

Since not all of the data taken on magnetic tape had been reviewed and analyzed, it was recommended in the Phase I report that this data be analyzed to help resolve the question of the apparent unusually long duration transients. This recommendation was addressed by the David Taylor Naval Ship Research and Development Center (DTNSRDC). They transcribed the data from magnetic tapes to obtain voltage waveform plots. Analysis of the plots showed no large spikes. However, some unexplained sudden line-to-line voltage offsets were recorded. Thus, the additional data on magnetic tape did not help to resolve or provide any plausible explanation for the long duration transients indicated by the Dranetz instrumentation. Finally, even if one were confident of the data, the data base in these reports is small and involves only one ship.

5.7 EPIC Measurement Program

The Electric Power Interface Compatibility (EPIC) program was established within the Navy to identify, if possible, the sources of incompatibility between power systems and user equipment. Some of the main areas of study identified by the EPIC program were voltage interruptions, voltage drops, harmonic distortion, and voltage spikes. The data-gathering phase of the program consisted of monitoring a number of ship's service power supplies, including measurements at the shore power installation points, selected power distribution points, and selected user equipment locations. Also, the test procedures had outlined where practical the simulation of certain operating scenarios, such as an Automatic Bus Transfer operation or a large motor start up. The data from all the ships monitored was to be used to identify and develop solutions to the documented EPIC problems. For the voltage spike program, the EPIC test procedures called for specific measurements of spike amplitude, waveshape, and frequency of occurrence. Also, the measurement of power system broadband impedance was established as part of the total test procedures.

It was anticipated that the measurements related to voltage spikes from the EPIC program would add significantly to the data base required for the development of a suppressor specification. However, the data from the EPIC program has contributed minimally to the Voltage Spike program discussed here. The result has been that only a very limited amount of impedance data from two ships and a total of 75 power system waveform recordings from one ship have been made available to NBS. These data are discussed in more detail below.

A broadband impedance-measuring system (BIMS) was developed for the Navy by a private contractor. This system automatically measures the complex impedance at multiple points in a shipboard power system without deenergizing the line or interfering with it. The instrument is a one-of-a-kind device that claims to be able to measure the power line impedance on systems up to 440 V over a frequency range from 5 Hz to 700 kHz with accuracies in the order of ±5% of full scale and ±5% of reading.

The first test run of the BIMS was made aboard the USS Ranger (CV-61) in April 1983. Impedance data were recorded from two different test stations on each of the three phases of a 120 V, 400 Hz power circuit. Measurements from the first test station were conducted under two conditions: with the AN/ASM 403 computer energized and with it unenergized. These measurements resulted in a total of nine impedance data sets from the CV-61.

Table 1 shows an impedance data set obtained from the CV-61 on phase A of the 120 V 400 Hz power at Avionics Shop No. 6 and 7 with the AN/ASM 403 computer energized. Figure 9 is a plot of the data of Table 1 showing impedance and phase angle as a function of frequency. The impedance varies from a low of 0.29Ω at 150 Hz to about 17Ω at 175 kHz. Although the phase angle is predominately positive, indicating an equivalent inductive reactance, the phase varies considerably over the 200 kHz bandwidth. This variation implies a fairly complex impedance which cannot be reduced to a single lumped resistance and inductance over the entire bandwidth. The impedance is not greatly affected (especially above 1 kHz) by whether the AN/ASM 403 computer is on or off, and does not vary much among the three phases.

These measurements on the CV-61 and the small amount of data which resulted were intended primarily to demonstrate the operation, installation, and dependability of the BIMS. Although the results seem reasonable, no independent measurements have been reported on the BIMS accuracy, particularly at low impedance and large phase angles.

Subsequent to the above impedance measurements, a limited amount of power system impedance data were obtained from the USS Kitty Hawk (CV-63), during July 1983. Measurements were made at two main stations: 440 V, 60 Hz and 120 V, 400 Hz power. The 60 Hz distribution system was being supplied by shore power. The measurements resulted in a total of seven impedance data sets for the CV-63.

Table 2 shows an impedance data set taken from the 120 V, 400 Hz system located in an aircraft electrical service station of the CV-63. Figure 10 is a plot of the data showing impedance and phase angle as a function of frequency. The impedance varies from a low of 0.02Ω at 90 Hz to about 20Ω at 200 kHz. Comparison of the two data sets of Tables 1 and 2 (CV-61 vs CV-63) shows that the impedance measurements from the CV-63 are lower by as much as a factor of seven at the low frequencies and about the same at frequencies above 100 kHz. However, in the frequency range around 10 kHz where it is believed that considerable spike energy may exist, the CV-63 impedance is three to four times lower than the CV-61 impedance. The significance of the difference in these two impedance data sets cannot be properly evaluated yet because there is insufficient information about the two systems. In particular, no information was made available as to the distances of the measurement system from the generator. Such an evaluation requires a complete mapping of broadband impedance of all representative circuits from the generator to the end of the line on a number of ships. This has not been done. The impedance data provided thus far can only be regarded as trial measurements which demonstrate the

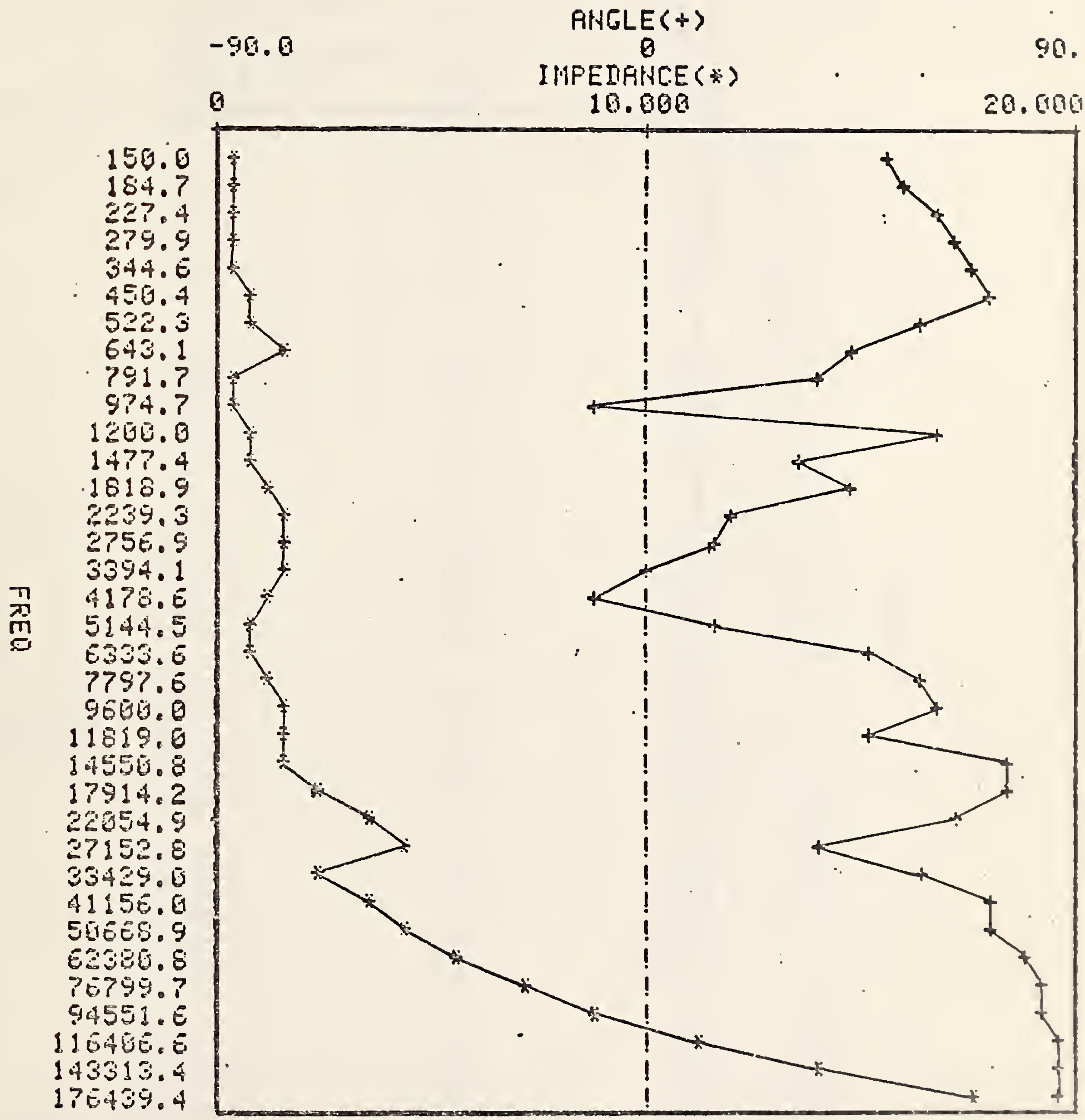

Figure 9. Power system impedance and phase angle plotted as a function of frequency from the data of Table 1.

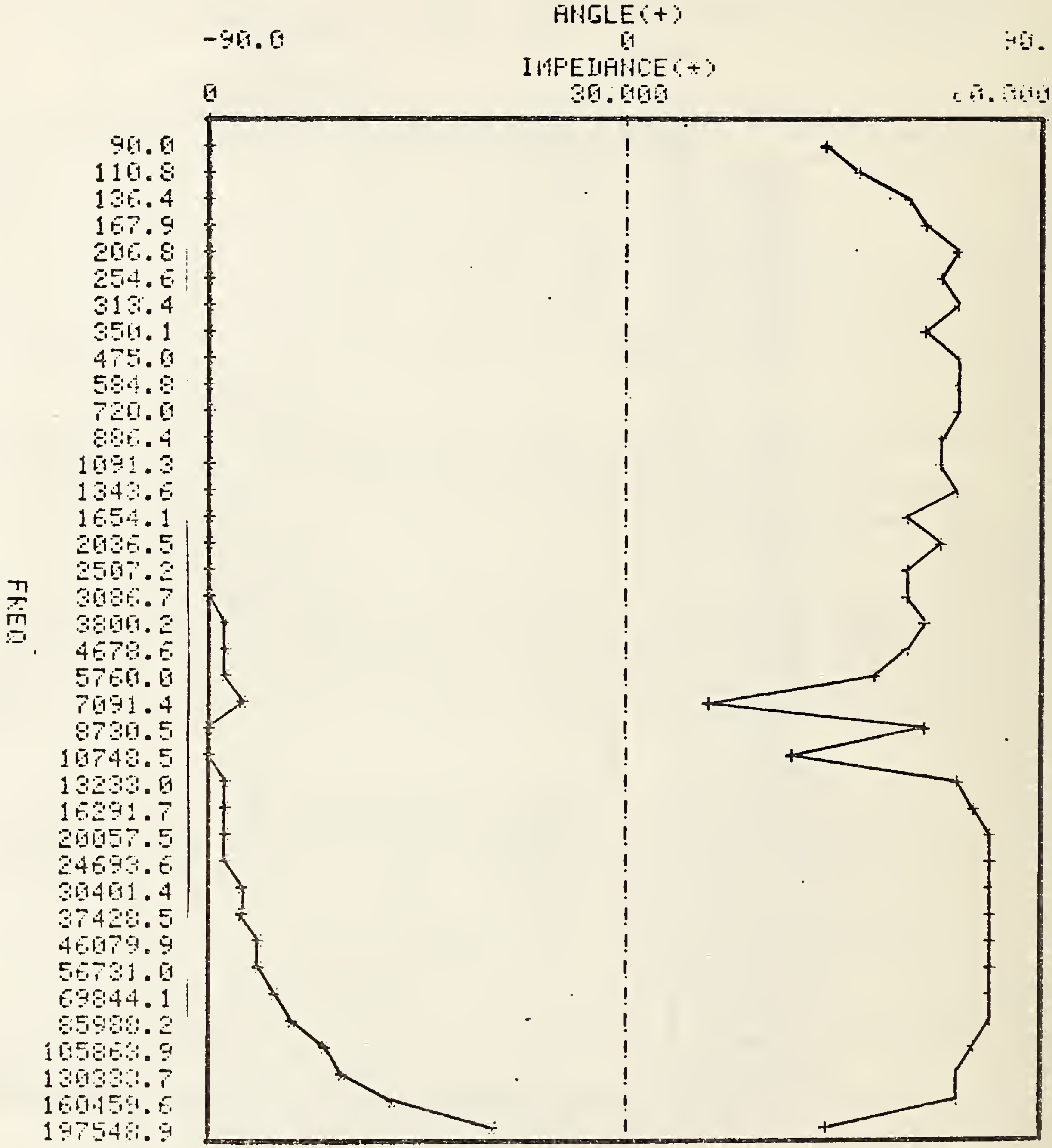

Figure 10. Power system impedance and phase angle plotted as a function of frequency from the data of Table 2.

Table 1. Broadband impedance data from the CV-61 on phase A of the 120 V, 400 Hz power at the avionics shop location No. 6 and 7 with the AN/ASM 403 computer energized.

FREQ. (Hertz)	IMPEDANCE (Ohms)	ANGLE (Degrees)
150.0	0.29	51.5
184.7	0.29	52.6
227.4	0.32	61.3
279.9	0.40	66.0
344.6	0.53	67.0
450.4	0.97	71.1
522.3	0.95	56.3
643.1	1.57	44.4
791.7	0.59	35.1
974.7	0.52	-12.1
1200.0	0.90	62.1
1477.4	0.95	32.8
1818.9	1.32	43.9
2239.3	1.74	18.7
2756.9	1.45	14.0
3394.1	1.55	-0.6
4178.6	1.03	-10.2
5144.5	0.64	15.7
6333.6	0.85	46.1
7797.6	1.08	58.1
9600.0	1.68	60.1
11819.0	1.56	45.7
14550.8	1.77	75.4
17914.2	2.55	75.6
22054.9	3.65	63.7
27152.8	4.29	37.3
33429.0	2.29	57.9
41156.0	3.64	73.4
50668.9	4.41	73.4
62380.8	5.50	80.5
76799.7	7.08	82.2
94551.6	8.87	83.4
116406.6	11.15	85.5
143313.4	14.07	86.9
176439.4	17.46	86.7

Table 2. Broadband impedance data from the CV-63 on the 120 V, 400 Hz system located in an aircraft electrical service station.

FREQ. (Hertz)	IMPEDANCE (Ohms)	ANGLE (Degrees)
90.0	0.02	42.6
110.8	0.03	50.8
136.4	0.04	59.6
167.9	0.04	64.4
206.8	0.06	71.6
254.6	0.06	69.2
313.4	0.07	72.6
350.4	0.10	66.0
475.0	0.13	72.7
584.8	0.15	70.9
720.0	0.19	73.6
886.4	0.24	68.4
1091.3	0.23	67.7
1343.6	0.33	71.5
1654.1	0.38	59.7
2036.5	0.43	69.8
2507.2	0.58	60.2
3086.7	0.54	61.3
3800.2	0.70	64.3
4678.6	0.90	60.2
5760.0	1.22	54.5
7091.4	2.07	17.0
8730.5	0.36	65.2
10748.5	0.44	36.1
13233.0	0.81	70.5
16291.7	1.14	76.6
20057.5	1.46	77.6
24693.6	1.79	78.1
30401.4	2.19	78.5
37428.5	2.76	79.4
46079.9	3.34	80.3
56731.0	4.11	79.4
69844.1	5.17	78.9
85988.2	6.41	77.9
105863.9	8.00	77.4
130333.7	10.13	71.0
160459.6	13.59	72.2
197548.9	20.12	43.8

operability of the BIMS. Also, independent calibrations should be made on the BIMS to provide some indication of accuracy.

From the standpoint of worst-case suppressor design requirements, an equivalent lumped model of impedance may be sufficient. Perhaps the impedances of the various major power circuits can be reduced to a few simple equivalent lumped models. However, far more impedance data would be required to determine this. Computer algorithms are also available for calculating energy and peak current from voltage spike waveform data in the time domain, and discrete impedance data in the frequency domain, similar to the data provided by the BIMS. Correlation of these two approaches would be very useful.

Other than the BIMS, the instrumentation required for the data-gathering phase of the EPIC program has been under the purview of the Naval Ship System Engineering Station (NAVSSES) in Philadelphia, PA. Their responsibility has been to procure the appropriate instrumentation, design the required interfaces, reduce the data, and report the results. The instrumentation for recording voltage spikes on the power waveform at each station consisted of a commercial four-channel digital storage oscilloscope coupled to custom-designed external attenuators and trigger circuitry. NBS personnel travelled to NAVSSES in July 1983 to discuss problems with the instrumentation. Personnel at NAVSSES indicated that most of their inability to obtain reliable spike voltage data aboard ship was due to three problems:

1. Interface circuitry troubles and limitations.

2. Reliability difficulties with the digital oscilloscopes.

3. Equipment operator inexperience aboard ship.

Apparently the external trigger circuitry was bandwidth limited to 150 kHz, but NAVSSES maintained that this was not a severe limitation to capturing voltage spikes. Although the basic problems were never completely solved, the system worked well enough to get some voltage spike data aboard ship. To date the total results of voltage spike waveform measurements made available to NBS from the EPIC program consist of 75 records of spike voltages obtained from the CV-63 at four measurement stations. These data were transcribed by NBS from magnetic disks into waveform plots. Figure 11 shows one of the typical recordings, consisting of about one cycle of each phase of the 440 V, 400 Hz power with voltage spikes on each waveform. None of the records showed spikes much greater than shown in figure 11. In fact, none of the recorded spikes would be affected by a simple clamping type of suppressor. In short, these data showed no significant spikes.

Although impedance and spike waveform data are considered essential for determining energy and peak current requirements of suppression devices, other data that could be used to support a suppressor specification were to be generated from the EPIC program. The program called for measurement of line disturbances and the frequency of occurrence of voltage spikes. As emphasized before, a data base of line disturbance measurements, particularly surges or rises in the line voltage, is important in establishing the minimum steady-state operating voltage of clamping-type suppressors. Also, voltage spike frequency

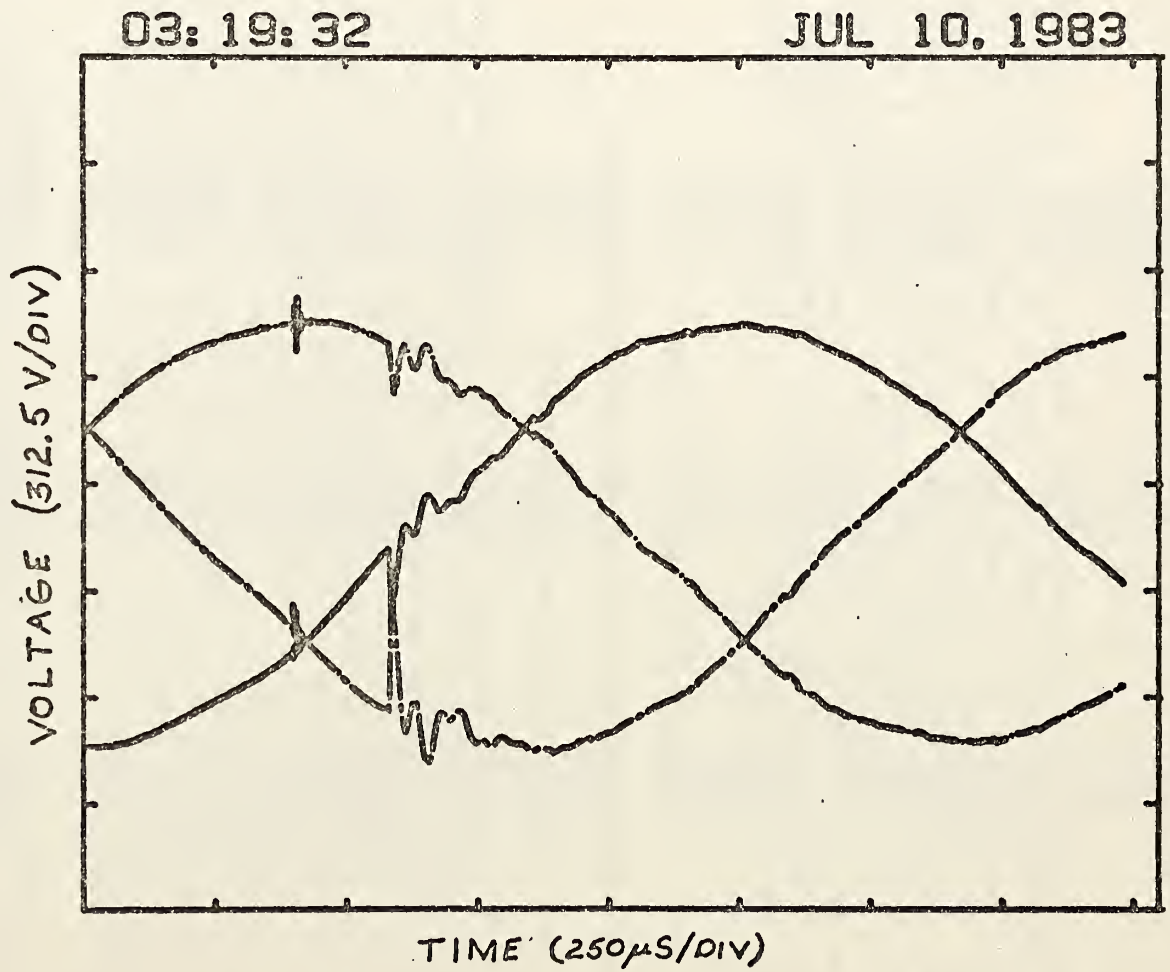

Figure 11. Recording of a typical disturbance on the 440 V, 400 Hz power system of the USS Kitty Hawk (CV-63), July 1983 (from the EPIC program, data furnished by NAVSSES).

of occurrence data is helpful in establishing suppressor lifetime operating requirements. No such data from the EPIC program have been made available to NBS.

5.8 Summary of Available Data

Table 3 presents a comparative summary of the data required for suppressor specifications and the data available from the reports just discussed in sections 5.1 through 5.7. This summary demonstrates that the data base for the two key parameters, source impedance and spike waveform, is extremely limited. Table 3 also points up the necessity for further investigation of surges, since excessive surges can destroy otherwise properly applied suppressors (see figure 4 and the accompanying discussion), and make a practical spike suppression system very difficult to obtain.

5.9 Measuring Power Line Disturbances

Practically all of the voltage spike data from ships reviewed thus far by NBS, with the exception of the 75 waveform recordings from the CV-63 and some data from the CGN-41, were recorded without the disturbance being superimposed on the power voltage waveform. The phase of a disturbance with respect to the power line waveform is important both from the standpoint of user equipment susceptibility and suppressor requirements. As shown in figures 12a and 12b, a disturbance may either decrease or increase the instantaneous amplitude of the sinusoidal power voltage waveform (sometimes distinguished as a "notch" or "spike," respectively). However, if the recording equipment uses high-pass filtering to attenuate the power system waveform, then only the disturbance (high frequency information) is preserved and the distinction between a "notch" and a "spike" is lost. Most of the commercial power line disturbance analyzers record the peak value of a transient excluding the ac line voltage.

All of the spike waveforms recorded on storage oscilloscopes by Naval Electronic Systems Engineering Activity (NESEA) were processed through high-pass filters. Figure 12c shows that the response to high-pass filtering is identical for each type of disturbance. However, the effect on a user equipment and suppressor could be quite different. The disturbance or "notch" of figure 12a is entirely inside the envelope of the power system waveform that may not produce a direct overvoltage threat to equipment. A clamping-type suppressor certainly would have no effect. On the other hand, the spike of figure 12b produces an overvoltage and would be clipped by a clamping-type suppressor. As an extreme example of the necessity to locate the spike on the steady-state waveform, a 440 V power system could conceivably have a 1200 V instantaneous amplitude decrease and rapid recovery at the peak of the waveform (a "notch") and still be within the envelope of the waveform, yet recording equipment preceded by high-pass filtering would record such a "notch" as a voltage spike. Thus, the question arises as to whether disturbances that are within the peak-to-peak system voltage envelope should be considered the same as true overvoltage spikes. From the standpoint of worst-case design for clamping-type suppressors, all spikes could be considered as causing an instantaneous voltage increase at the peak of the power system waveform.

But the point of this discussion is that if surveys are conducted to measure the extent and severity of power line transients, these transients

Table 3. Summary of spike suppressor data requirements and availability.

Data Required	Data Available	Source of Data	Instrumentation	Comments
Power System Broadband Impedance	9 plots imped. vs. freq. 5 plots imped. vs. freq. 2 plots imped. vs. freq.	CV61 120 V 400 Hz CV63 120 V 400 Hz CV63 450 V 60 Hz	BIMS BIMS BIMS	Limited data, taken only under shore power conditions. Require complete mapping of impedance of circuits from source to end of line (see 5.7)
Spike Waveforms	125 records	LST1188, DDG41, FF 1092 450 & 120 V	Nicolet 2090-3	Transient disturbances recorded without power system waveform. Mixture of common mode and differential mode measurements. Result - A very limited waveform data base. (see 5.5 & 5.9)
	75 records	CV-63 450 V 60 & 400 Hz	Nicolet 4094	Spikes recorded with the power waveform. No significant spikes recorded (see 5.7)
	25 oscillograms	CGN-41 450 V 60 & 400 Hz	HP-3964A Honeywell 1885	Disturbances recorded with the power waveform. No significant large amplitude spikes (see 5.6)
Spike Voltage Amplitude	2300 impulses	AOE 4, CG 29, CV 59, CVN 68, CVN69, OD 974, DD 978, DDG 41, FF 1092, LHA 2, LHA 3, LPD 15, LST 1188 450 & 120 V 60 & 400 Hz	Dranetz 606-3	Only peak amplitude data. May be lower in amplitude for fast transients due to bandwidth limitation of recorder. Data useful for general frequency of occurrence specifications.
	952 impulses 2032 V max (2 µs to 2000 µs)	CGN-41 450 V 60 Hz	Dranetz 626	Questionable duration values since a significant number (190) of unusually long duration transients (>2048 µs) which exceeded the limit of the recorder, (see 5.6) were found.
	670 impulses 1552 V max	CGN-41 450 V 400 Hz	Dranetz 606-3	Only peak amplitude, no duration.
Voltage Surges & Sags (Long duration rises above DOD STD-1399 Limits)	667 surges 153 V rms max 616 V rms max	AOE 4, CG 29, CV 59, CVN 68, CVN 69, DD 974, DD 978, DDG 41, FF 1092, LHA 2, LHA 3, LPD 15, 120 V 60 & 400 Hz 450 V 60 & 400 Hz	Dranetz 606-3 Franklin 3500	Questionable duration values.
	155 sag/surges 818 V rms max (0.25 sec)	GCN-41 450 V 60 & 400 Hz	Dranetz 626	A significant no. of high amplitude long duration surges of questionable duration values. (see 5.6) If these amplitude and duration values are real, surges could destroy any otherwise properly applied spike suppressor, and make any practical specification difficult to attain.

Certain commercial instruments are identified in this report to provide the sponsor with the analysis requested in the work statement. NBS has merely reproduced information in reports supplied by the sponsor and has conducted no evaluation on the instruments identified. Identification does not imply recommendation or endorsement by NBS for any purpose, nor does it imply that any identified instruments are the best available for a given purpose.

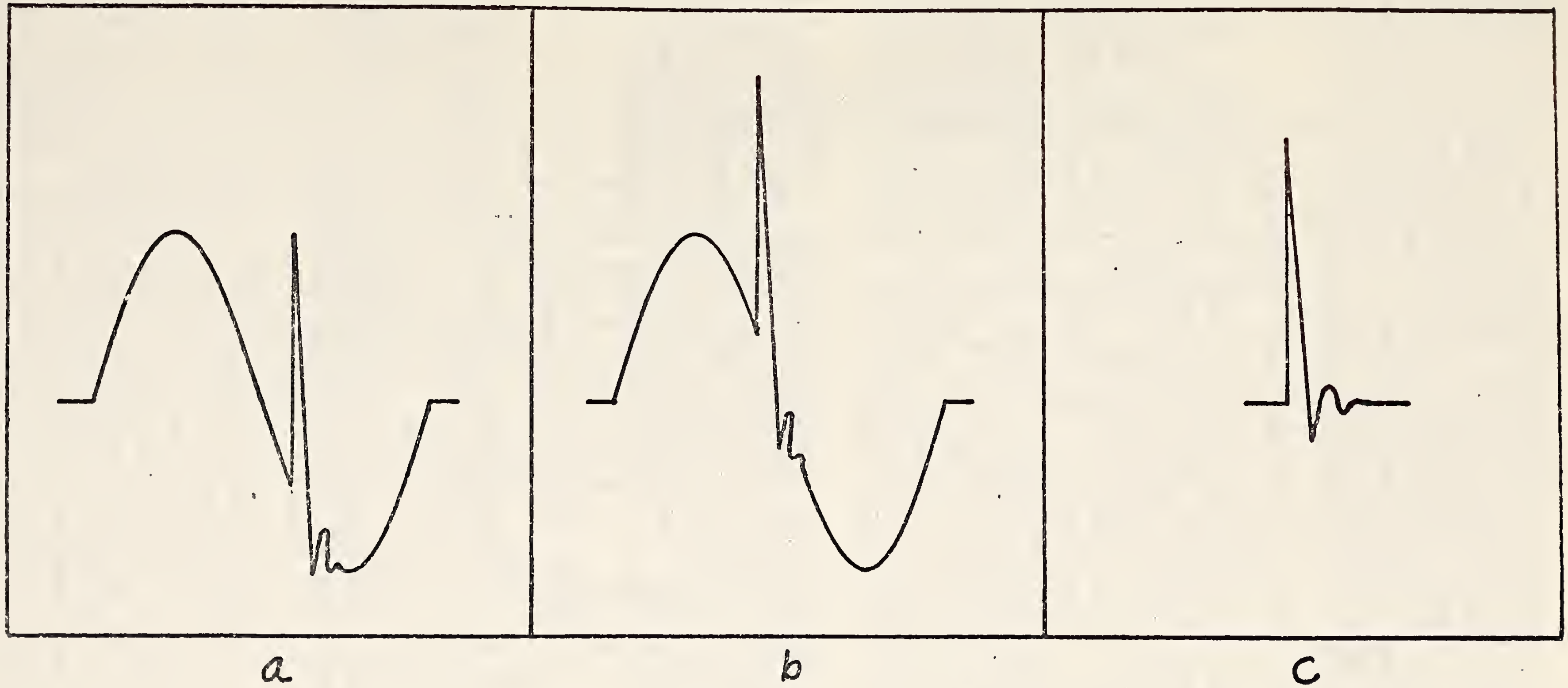

Figure 12. The same disturbance may either decrease (a) or increase (b) the instantaneous amplitude of the sine wave (sometimes distinguished as a "notch" or a "spike," respectively). The output response (c) of a high-pass filter to the waveforms in (a) or (b) is the same.

should be considered in relation to the instantaneous power system voltage, or at least correlated with the different system voltages. A case in point is figure 10 of DOD-STD-1399 (shown here as fig. 13), which shows a seven-day histogram of transient voltage versus number of transients in 115 and 440 V systems. Here the number of transients plotted are the combined totals, without regard to the power system in which they occurred. Obviously, a 1200-V spike on a 115-V system would be more serious than on a 440 V system, but may be a lesser problem on either system if it is a "notch" near the peak.

5.10 Differential/Common Mode Measurements

In all the data made available to NBS thus far, there appears to be an inconsistency in the modes for which data are recorded. There are two possible modes of monitoring the transients, referred to as differential mode (line-to-line) or common mode (line-to-common). According to the NESEA reports, when the Dranetz recorders were connected in the common mode configuration no transients were detected. Therefore, all the spikes recorded were monitored in the differential, mode, or line-to-line. Similar measurements in the differential mode recorded by the Raytheon Service Co. indicated transients whose duration exceeded the range (2048 µsec) of the Dranetz monitoring equipment, whereas common mode data taken with magnetic tape recorders showed mostly large, long-duration offset voltages. When the line-to-line potentials were subsequently reconstructed from the common mode voltage differential recordings, no significant spikes were observed.

Furthermore, the data taken with a digital storage oscilloscope are mixed, consisting primarily of differential measurements taken under shipboard power and common mode measurements taken under shore power. It is not clear why this disparity exists, but these inconsistencies cast further suspicion on the reliability and usefulness of the data. This also raises the question as to whether the line-to-line or the line-to-common mode must be protected. The issue is not clear, and would have to be addressed in a comprehensive specification.

5.11 Energy Measurements

It was noted that in both the shipboard and shore-based transient investigations (sec. 5.3 and 5.5), energy levels of transients were determined from simultaneous recordings of voltage and current waveforms at a given test location. Energy levels were then obtained by multiplying the voltage and current and integrating over time. The reported energy levels calculated with this technique yielded values that were in the millijoule range and below. The report concludes from these few measurements that the energy levels are much less than previously believed. There is a question as to the meaning of these measurements. It is true that such a measurement gives the dissipated energy in the equivalent load at the point of measurement, but it does not indicate the current or energy that a given suppression device would need to withstand at that point. The magnitude of the transient current as reported above depends entirely on the load impedance at the particular test location. To appreciate this contention, consider the extreme case where the voltage and current of a transient are monitored at the end of a branch circuit that has no load. Under this condition the observed transient current would be zero regardless of the transient voltage amplitude, hence would yield zero energy. However, if a voltage-clamping suppressor were placed at this point, the current through the

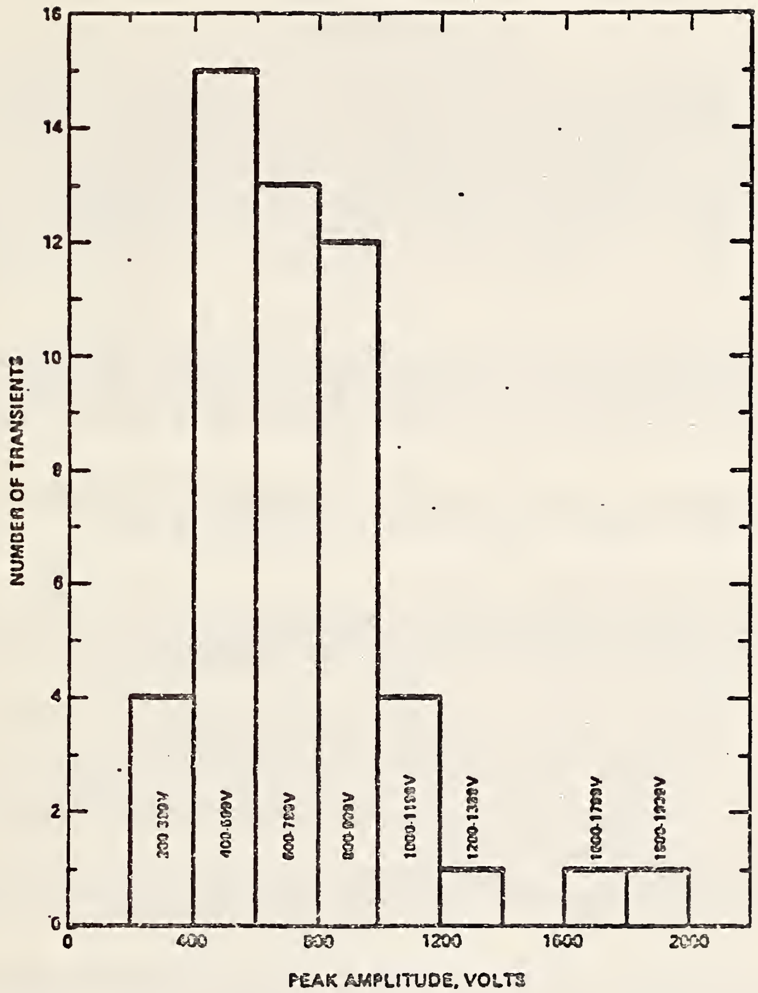

Figure 13. Seven-day histogram of transient voltage versus number of transients in 115- and 440-V systems.

suppressor would be determined by the difference between the transient voltage amplitude ($V_{SS}+V_S$) and the clamping voltage of the suppressor (V_C) divided by the effective source impedance (Z_S), i.e., $(V_{SS}+V_S-V_C)/Z_S$, as discussed in sec. 4.2 and shown in figs. 5 and 6). This example emphasizes once again that the effective impedance of the circuit which introduces the transient is an extremely important parameter in designing a protection scheme.

6. CONCLUSIONS

This report has summarized the work done so far by NBS in the voltage spike suppressor program. Selection considerations for suppression devices have been discussed in relation to the key parameters which must be known. A review of the reports provided by the Navy has been given with a detailed analysis of all known existing shipboard data relevant to suppressor applications. A number of specific conclusions may be derived from this work. These are summarized as follows:

1. Voltage-clamping devices which provide clipping of spikes above the peak value of the line voltage appear to be the most likely candidates for protecting shipboard electrical power systems.

2. The three primary electrical specifications which must be considered in the selection and/or design of a suppressor are:

   a. Steady-state voltage rating.
   b. Transient energy absorbed by the device.
   c. Peak transient current through the device.

3. The two key measurements required to determine the energy that a candidate suppressor must be able to absorb are:

   a. Transient voltage recordings as a function of time, at the suppressor application point.
   b. Source impedance of the network, looking in at the suppressor application point, as a function of frequency.

4. The reliability of the existing data base is questionable for the following reasons:

   a. There is evidence of incorrectly reported transient waveform data from the 125 records reported in Section 5.5.

   b. Some reported values of spike durations seem unusually long (greater than 2 ms).

   c. There are inconsistencies in the results obtained from both common mode and differential mode measurements.

5. The spike voltage waveform, broadband impedance, and surge data base is too small to form a spike suppressor specification that would economically and reliably serve the entire Navy.

7. RECOMMENDATIONS

Recognizing the inadequacy of the present data base for the development of a suppressor specification, and further recognizing that data gathering from operational ships of the fleet is difficult, time consuming, and does not lend itself to a series of well-controlled experiments, an alternate approach is recommended.

Basically the approach consists of developing the theoretical model of a simple shipboard power system, coupled with laboratory measurements to determine the practical limits of observed and potential voltage spikes. This approach attempts to develop a technical basis for a specification of spike suppressors through a judicious combination of laboratory experiments using key components of shipboard power systems, and circuit modeling using a well-developed interactive electromagnetic transient program (EMTP).

To accomplish the goal of developing a clear understanding of the generation and suppression of voltage spikes through modeling and laboratory measurements, a test facility with appropriate power system components, manned by personnel familiar with this problem, must be available and committed to providing support.

A proposal based on this approach was submitted to NAVSEA on October 21, 1983.

It is anticipated that the proposed study would yield substantial information on some of the questions which must be answered before recommendations for a suppressor specification can be generated. Some of these questions are:

1. What are the worst case limits (voltage and current amplitude, duration, waveshape) of spikes in shipboard circuits containing no suppressors?

2. What is the range of broadband source impedances in shipboard power systems?

3. What is the relationship between line-to-line spikes and line-to-ground spikes? Must suppression be provided in both modes?

4. Are there optimal suppressor numbers, ratings, and locations?

5. How effective will simple clamping suppressors be for the worst case spikes, i.e., what will be the residual spike voltage?

6. Are suppressors needed other than those installed in susceptible equipment by the manufacturer needed at all?

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10. SUPPLEMENTARY NOTES

[ ] Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes progress so far in a voltage spike suppressor program, undertaken for the Naval Sea Systems (NAVSEA) Command, with the objective of developing a sound technical basis on which a spike suppressor specification for shipboard equipment could be written. The project contract stated that sufficient field data for such a specification already existed, and needed only to be correlated and analyzed. NBS investigation revealed that existing data were far from adequate for this purpose. It was then recommended that further testing already planned by the Navy be used to collect the required data. Other as yet unreported data were also analyzed. Neither effort succeeded in producing enough meaningful information for carrying out the assigned task.

This report includes documentation of the analysis of all the pertinent data above; a general discussion of the principles involved and of the applicable suppression devices; a discussion of suppressor selection considerations and the key parameters for this; and a review and analysis of the reports provided by the Navy. Finally, the report lists key parameters which must be known, and shows why the available data cannot support the generation of a suppressor specification.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Shipboard spikes; spikes; spike suppressors; suppressor specification; voltage clamping; voltage spikes .

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