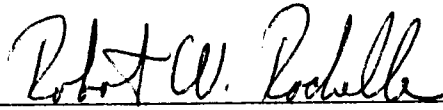


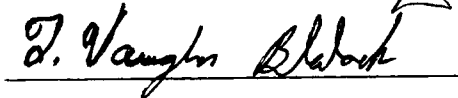
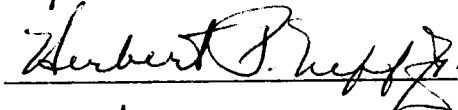
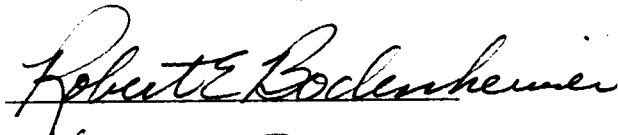
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I am submitting herewith a thesis written by Lawrence E. Jugler entitled "An Electronic Detection System for Use in Identifying Livestock." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Engineering, with a major in Electrical Engineering.

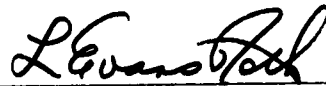


Robert W. Rochelle, Major Professor

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recommend its acceptance:



Accepted for the Council:



Vice Chancellor
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AN ELECTRONIC DETECTION SYSTEM FOR USE
IN IDENTIFYING LIVESTOCK

A Thesis

Presented for the

Master of Engineering

Degree

The University of Tennessee, Knoxville

Lawrence E. Jugler

June 1979

1390000

ACKNOWLEDGMENTS

If proper acknowledgments were made for all those involved with the development of this thesis, an additional volume would be required. Virtually every member of the University of Tennessee Electrical Engineering Department played a part in its formulation.

Special acknowledgments go to the members of my committee Dr. R. W. Rochelle (Chairman), Dr. T. V. Blalock, Dr. R. E. Bodenheimer, and Dr. H. P. Neff for their suggestions, comments, and special handling of this thesis.

Particular appreciation is extended to Dr. Rochelle for his economic and academic support. Dr. Neff and Dr. J. D. Tillman for their aid in the field equations, Dr. D. Rosenberg and Dr. J. W. Waller for their help concerning resonant circuits. Dr. J. F. Pierce for allowing the author a "learn by teaching" experience with PCAP, Dr. Blalock for his eternal question, "are you certain it will work?" and to Dr. R. C. Gonzales for his general interest and guidance.

Appreciation is also expressed to my parents for their aid in typing the second draft as well as their support and encouragement throughout my education.

Acknowledgments are also in order for Los Alamos Scientific Laboratories for the wealth of information they provided in the area of animal identification, and to the law firm of Prickett Ward, Burt and Sanders for use of their photo-reduction facilities for compiling the second draft.

ABSTRACT

Identification of livestock during their growth cycle has become an important consideration in the economics of livestock production. Knowledge of each animal's food intake, weight, environment, and health history can be very helpful in breeding and food production planning. Electronic identification methods are in use to accomplish these needs. The author considers those methods which utilize a passive transducer on the animal so that a power supply is not required. The chosen method which uses coupling induced between orthogonal coils via a third tuned circuit is developed by classical methods. An orthogonal coil system was constructed and its parameters were used to develop a computer simulation model. The system response was tested and compared to the computer predictions. The predictions were found to be within 10 percent of the measured response. The orthogonal-coil approach was found to be a valid method of livestock identification.

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CHAPTER I

INTRODUCTION

With the ever increasing world population, optimization of food production methods is no longer a question of economy but a requirement for mankind's survival. The raw materials required for food production are in short supply and must be conserved. This can be achieved by minimizing the quantity of raw material needed to produce a given amount of foodstuff. In terms of farming, the crop yield per acre must be maximized. The livestock industry must respond by selective breeding of only those animals who exhibit the highest weight gain with respect to foodstuff consumed.

Visual methods of livestock identification are basically unreliable.¹ Electronic identification techniques appear to provide a viable solution to the problem. With the availability of low cost small computer systems, an efficient processing system can be created to compile and record data for almost a limitless number of stock animals. Scales are available to provide the information as to the amount of food consumed by each stock animal at feeding, and the animals themselves can be weighed at periodic intervals to determine their weight change. The method of electronic identification then becomes the only major obstacle to improving the

¹J. C. Hensly and Sanders Holm, "Electronic Management for the Livestock Industry," Los Alamos Scientific Laboratory Publications, LA-UR 76-1193, p. 1.

efficiency of the livestock industry. Overcoming this obstacle is the subject of this thesis.

Chapter II considers several possible identification methods and solidifies the design approach. Chapter III presents the theoretical analysis of this approach. Chapter IV completes the theoretical analysis and describes the experimental results of the method. Conclusions are made in Chapter V.

CHAPTER II

APPROACH POSSIBILITIES

General Architecture

Any electronic identification system requires at least two components:

1. The identifying transducer
2. The sensing unit that detects the presence and identity of the transducer.

The complexities of the two units are interchangeable. A simple transducer would require a relatively elaborate sensor, where a complex transducer is much less restrictive on sensor intelligence. A transducer will be required for each stock animal and a sensor will be needed for every feed bin. Since each feed bin will serve several animals, it becomes apparent that a cost effective approach would simplify the transducer and bear the resulting sensor complexity.

Another important design requirement is that the transducer must not contain an internal power supply. The purpose of this restriction is obvious when considering the maintenance of transducers for large animal populations. A transducer of this type can be achieved using either of two possible approaches. One method is to incorporate only passive components in the transducer. These passive elements are detected by the way they alter a field, of magnetic, electric, or electromagnetic nature, which is produced by the sensor. The second method could again use an alteration in the interrogation field for detection; however,

power can be absorbed from the field to operate active components within the transducer. These active components have the capability of altering the interrogation beam in a more complex manner and therefore allows for a larger identification set.

The physical parameters of the feedbins are also of importance and will vary greatly depending on the type of stock animal they are to serve. Basically there are three main components to the bin:

1. The entrance, where the animal is identified.
2. A gating mechanism which prohibits access to the feed when refilling the bin and waiting for the scale to stabilize for recording.
3. Feed tray and scale including a screw conveyor for automatic refilling at a preset scale reading.

Several bins will be required to serve large populations. Assuming that it is desirable to minimize the total land used by the feed center, crosstalk between bins will be a problem. Considerable crosstalk attenuation can be accomplished either by standard shielding techniques or by multiplexing methods. F.C.C. regulations must also be taken into account with respect to any field effects incorporated into the system. The interrogation beam must then be carefully tailored to provide maximum resolution without excessive radiation.

The biological restrictions on the transducer are also extensive. The transducer must not interfere with the normal behavior of the stock animals, otherwise, detrimental effects to the animals eating habits could occur. Durability of the location is also important. A collar

type transducer would work relatively well with cattle. However, the probability is low that this collar could survive a reasonable period of time in use under the harsh environment associated with swine. Two possible external transducer locations for swine could be ear mounted and snout mounted. The latter method requires the transducer to take the shape of a ring that would normally be placed on the snout to prevent rooting. This can be considered to be a particularly abrasive environment. For this reason, only passive transducers will be considered for the snout mounting location. The environment conditions for the transducer would be much better if located on the ear. Overall size and weight restrictions at this location are necessary to avoid a high loss rate. In-vivo, transducers would be immune to the external environment. They, however, have the drawback of even greater size restrictions than the ear mount, as well as requiring much more care in placing and maintaining. There is also a power loss through the skin of as much as a factor of 25.²

The field strength of the interrogation beam is also a subject of concern. There has been much controversy recently as to the maximum field strength allowable without encountering detrimental biological effects. A power density of 0.05 mW/cm^2 is considered safe for microwave operation by the most conservative regulations.³

²R. E. Bobett, et al., "Passive Electronic Identification and Temperature Monitoring System," Los Alamos Scientific Laboratory Publication, LA-6812-PR, p. 10.

³Ibid., p. 9.

Another consideration that cannot be overlooked is that the casing of the transducer, or more properly any part of the transducer that comes into contact with the animal, must be made of material compatible with biological tissue it contacts. This can easily be achieved by coating the transducer with an epoxy coating composed of an acceptable material. This coating would also provide additional protection to the transducer from the environment. Care must be taken in choosing an epoxy that will pass the field to the transducer without any major attenuation.

International Livestock Code

The International Livestock Brand Conference (ILEC) suggested a coding system capable of uniquely identifying any food producing animal in the world. Our coding does not require this entire identification field. It would be sufficient to use the "Animal" sub fields.(refer to Figure 2.1).

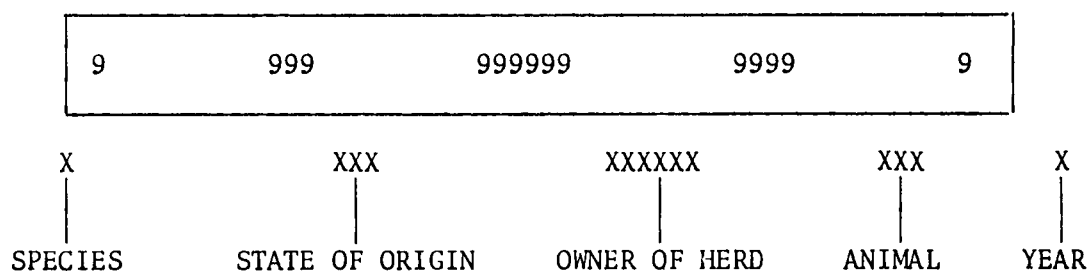


Figure 2.1. Suggested Animal Identification Code.

Grid Dip Meter Approach

There is a wide spectrum of possibilities available for use as approach methods. One of the more classical of these approaches is the grid dip meter method, which detects the presence of a resonant L—C

circuit. In short, this passive transducer oscillates when placed inside a field that is excited at a rate close to its resonance. The coding of identity then can be accomplished by using a combination of resonant circuits whose discrete frequencies make a combination unique to the specific animal. For example, if we were to allow for eight possible frequencies in our identification band, and then require three separate frequencies to identify any particular animal then we would be able to separately identify up to 56 animals. This decoding scheme shall be referred to as the 3 of 8 method.

The actual detection is of particular interest. The most logical approach to the problem is to sweep the grid dip meter in frequency. This sounds simple enough, however, complex calibration procedures are required to maintain reasonable sensitivity upon altering the Grid dip meter's detection frequency. Seven separate grid dip meters could be used to eliminate the frequency shift requirements, but additional effort would then be needed to reduce crosstalk between meters. The detection distance of the commercially available Grid dip meters does not appear to be sufficient for our needs, so a separate unit must be designed for use with this method.

Orthogonal Coil Approach

Retaining the basic transducer type and coding parameters as the Grid Dip Meter approach, an alternative detection method can be employed. Using two large diameter coils, as shown in Figure 2.2 an orthogonal arrangement can be used to attenuate the mutual coupling between the coils to a low level. If a transducer consisting of another coil in parallel

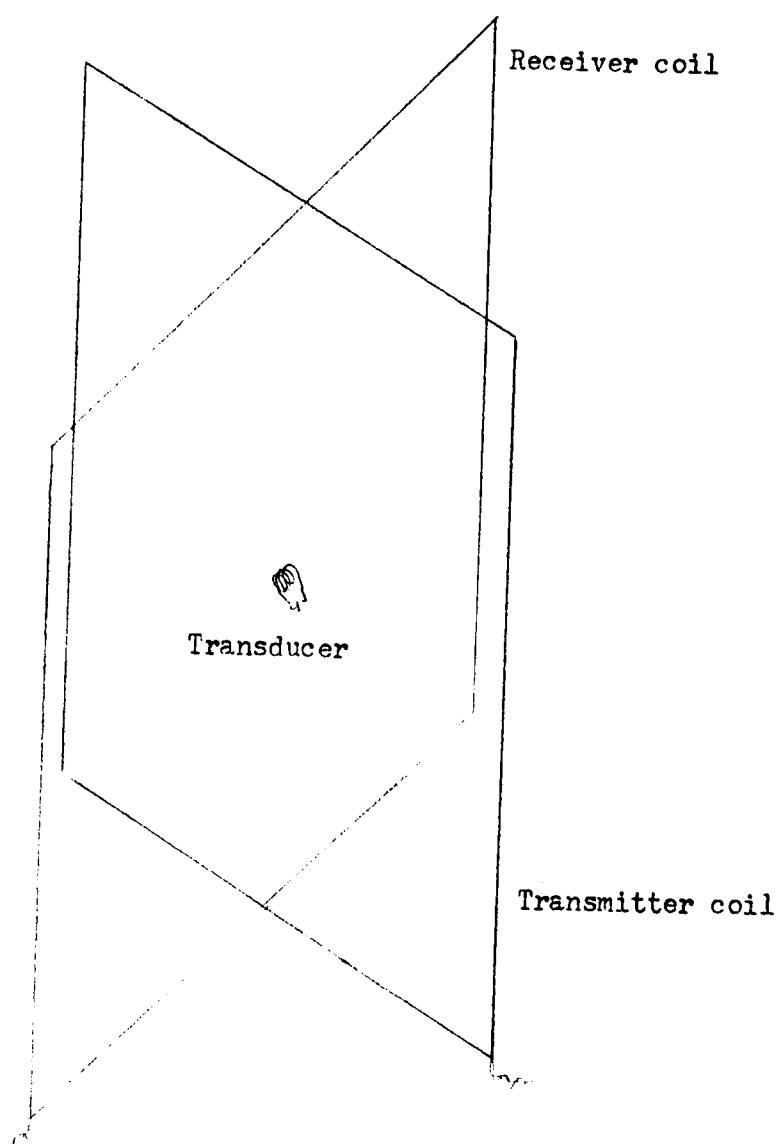


Figure 2.2. Orthogonal Coils and Transducer.

with a capacitor, to produce resonant effects, is placed in proximity to the orthogonal coils, a mutual inductance then exists between the transducer and the orthogonal coils. If the first orthogonal coil is excited at the resonant frequency of the transducer, and if the transducer is placed in such a manner as to achieve an equal value of mutual inductance to both orthogonal coils, then a current is also induced in the second orthogonal coil at that frequency. In short, we would then be creating a mutual coupling between the orthogonal coils if the transducer is present. If the transducer is not present, the mutual inductance is small and practically independent of the frequency of excitation.

The orthogonal coil approach would then detect the presence and identity of the animal by either sweeping or stepping through a frequency spectrum corresponding to the possible transducer resonances on the first, or transmitter coil, while detecting increases in excitation of the second, or receiving coil. The three of eight coding scheme would work satisfactorily with this method.

A particular advantage of this approach is the ease in containing the interrogation field. The animal can be required to pass internally to the orthogonal coils for detection. The detection would then rely on the close field effects of the orthogonal coils; therefore the field strength can be held relatively constant at the maximum permissible value in the interrogation area. Since the external field drops off with the square of the coil diameter, crosstalk between feedbins can be reduced in part by thoughtful arrangement of feedbins. Additional crosstalk attenuation can be achieved by shielding the sides of the

orthogonal coils, thus reducing the external field to the front of the unit. In this way feed bins can be placed side by side without degrading the sensitivity of the detectors. The physical arrangement of the orthogonal coil in the entrance way can also be made to insure close to equal coupling from the transducer to both orthogonal coils and therefore maximize the detector's capabilities.

Inductive Coupling of Power

The previously discussed systems made use of completely passive transducers. Allowing the presence of active devices within the transducer permits the use of several other detection formats. The simplest extension of our previous methods would again use the close field effect of the transmitter coil to couple to the transducer. However, the transducer would now rectify and filter the received sinusoidal excitation to supply power to the internal active devices. One possible coding scheme could then be to short out the transducer's coil at a rate, pulse coded to identify the animal (refer to Figure 2.3). The power needed to run the active devices for the time that the transducer's coil was shorted could be stored on a capacitor. This would, of course, negate the need of sweeping the transmitter coil and thus result in a much simpler transmitter design. The receiver would then detect a backscatter type of modulation on the carrier wave if a transducer is present. Otherwise, it would receive only the carrier wave. The possibility of false detection is greatly minimized by this technique. Due to the increased signal to noise ratio encountered in removing the modulation from the carrier, greater problems in detection can be

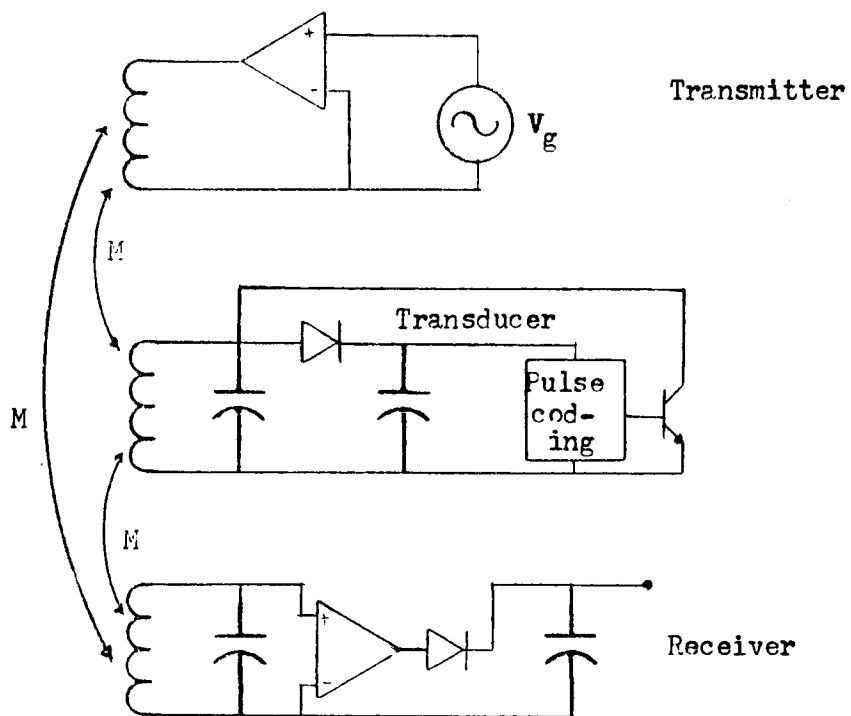


Figure 2.3. Inductive Power Coupling for Active Transducer.

expected. This would cause an increase in receiver complexity if good detection sensitivity is to be maintained.

Frequency Limitations of Inductive Approaches

The previous design methods have made use of the mutual coupling of inductors to achieve transducer identification. Because of this, the frequency of operation has an upper limit in the low megahertz range. This limitation occurs for a variety of reasons. One limiting factor occurs with the use of orthogonal coils. Due to the large physical size of these coils, orthogonal nulling is not totally independent of frequency. It is physically difficult to achieve right angles between all points of both coils. When the wavelength of the transmitted wave form becomes comparable to the length of those small portions of the coils, which are not orthogonal, transmission between the orthogonal coils occurs without the presence of a transducer. Experimentally it has been found that transmitter frequencies in excess of a few megahertz causes a large reduction of the nulling of the orthogonal coils. The coils can be repositioned at higher frequencies to some extent. However, the base level of mutual inductance would no longer be small. The lower limit of the units would be in the audio range of the stock animals, since the perception of the interrogation beam could alter the feeding habits of the animals. A safe lower limit on operating frequencies would then be in the order of 30kHz. The frequency band used by these previously discussed methods would be approximately two decades, allowing seven to eight possible detector frequencies.

L.A.S.L.'s Approach

Another approach possibility has been investigated by Los Alamos Scientific Laboratories. If the frequency of operation of the device was increased to the point that the wavelength of the interrogation beam is comparable to the physical dimensions of the transducer, then dipole antennas can be used as the transmission element. The Los Alamos version works similarly to the active transducer approach discussed previously, except with the replacement of the physically large transducer coil with a dipole antenna; the incident radiation on the transducer is again transformed to power the active devices internal to the unit, and the detection is also achieved by detection of the backscatter produced by the coded shorting of the transducer's antenna. The information content of the backscatter technique is orders of magnitudes larger than the three of eight coding method. Los Alamos labs expect to code the fifteen decimal digits of identification requested for the I.L.B.C. along with the animal's temperature in a subdermally implanted monolithic transducer. The expected frequency of operation of their device is in the range of 400 MHz to 1GHz. They have achieved a detection distance of approximately one meter using a less complex hybrid prototype. Since this unit was conceived for use with International Identification Code, it is much more elaborate than what would be required for a single farm livestock feeding record acquisition program. The planned large scale use of this method, however, may reduce the cost of this expensive system in the future, thus allowing its use for our purposes.

Other advantages of the Los Alamos version predominately concerns transducer size. The subdermal implant technique, although requiring

more sophisticated attachment methods than the external mode, has a higher level of durability since the animal must effectively harm itself before harming the transducer. Also worth noting is the fact that if this monolithic transducer was attached externally to the animal, greater detection distances can be achieved. Disadvantages of this transducer type is basically involved with the transmitter. Due to the high frequencies involved, the transmitter will be a good deal more expensive than the previously discussed versions. For this reason the separate transmitters for each feedbin appears impractical. Using a single transmitter for all of the bins also appears difficult since Los Alamos is already using what they consider to be the maximum safe transmission level to achieve their one meter detection distance.

Frequency Multiplication Method

Increasing the resolution distance of the dipole antenna approach so as to allow a single transmitter for the entire feed area is definitely desirable if this approach is to be made cost effective. This could be achieved by several means. Since the problem is a result of the receiver requirement of modulating the incoming carrier frequency, obvious advantages would result if we could receive a separate frequency from that of the transmitter so that the high level of field strength of the transmitter did not affect the receiver. The simplest method of frequency shifting in the transducer would be the rectification of the incident radiation and thus allowing the retransmission at twice the carrier frequency. Although in theory the frequency multiplication is easily achieved with high-speed diodes, the physical layout of the circuit is

very critical. This is because small values of stray capacitance would cause low-pass filtering of the rectified wave reducing the level of excitation used for retransmission. Another drawback of this method is that the transmitter which previously could be allowed to be of the free running type, would now require either phase lock loop techniques or extensive filtering to achieve the low levels of second harmonic transmission needed for this approach. This would definitely increase the cost of an already expensive transmitter. The receiver for this approach does not require the sensitivity of the previous scheme and therefore should be less expensive. Due to the complexity of the transducer, added expense can be expected in its production as well. Since we only desire a single transmitter, the added cost of its production is not considered inhibitory. The low-cost receiver increases this system's feasibility as well. The primary degrading factor of this approach then becomes the cost of the transducer.

Frequency-Division Method

If the retransmitted signal was at a lower frequency than the original transmission, the added transmitter complexity of the previous approach could be avoided. Complete isolation of the transmission frequency could be achieved if the transducer contained a separate transmitter which only relied on the original transmission for its power. The largest single problem with this technique is the requirement of a high-frequency time base on the transducer. The intensity of the retransmission would also be expected to be much smaller than the rectification technique previously discussed. Moreover, due to the

frequency down shift, the receiver would have less difficulty detecting the transducer. This method would reduce the cost of the transmitter of the frequency-multiplying method with the added stipulation of increased transducer complexity.

One possible extension of the above scheme is the addition of frequency-division techniques to the transducer. High-speed division circuitry would then be used to reduce the original transmission to a lower frequency. Here we see a basic trade-off. The original transmission frequency must be high to minimize the dipole antenna size. The retransmission also must observe this criteria. The trade-off occurs when considering the electronics required for the frequency division. It has long been realized that a speed-power trade-off exists with this circuitry.⁴ The faster the division circuitry must operate, the higher levels of power must be consumed. To achieve maximum power transfer to the transducer, the transmitter frequency must be kept high. It is, therefore, very doubtful that this method is achievable at this time due to this trade-off. It should be noted, however, that state of the art improvements in the speed-power ratio could allow this to be a legitimate design alternative. It is doubtful, in view of past rates of improvement in this area, that this technological advancement would occur within a reasonable time frame with respect to this project.

⁴E. J. Kennedy, class notes on linear active devices (EE5510) UTK.

Design Decision

With the knowledge of the various approach possibilities a decision must now be made to determine the most practical of the formats. The Grid Dip Meter approach does not appear to be easily adaptable to our needs due to the complexity of the nulling required for shifting frequencies. The orthogonal-coil approach shows promise, and is deserving of additional investigation. Coupling of power for active devices via mutual inductance suffers from several drawbacks. Primarily the use of inductors in connection with active devices in the transducer causes physical size problems which makes this format unusable for our purposes.

The Los Alamos version using backscatter techniques has been proven to be a practical method of livestock identification. We must, however, determine if this method is the most cost effective of our design considerations. The adaptations previously discussed to the Los Alamos version appear possible for the most part, but require the transducer design to be at or beyond present state of the art techniques. Since state-of-the-art designs tend to be expensive, it would not appear that these methods are practical for our present needs.

The remaining design options would then be the orthogonal-coil approach and the Los Alamos backscatter technique. Due to the radical differences in these approaches, comparison of their attributes is difficult. The orthogonal coil approach uses an extremely simple transducer, composed only of set of three inductors and their frequency determining capacitors. The simplicity, however, does not completely overshadow the large physical size of the transducer. This would not be

a major problem when used with cattle since the around-the-neck location can be used, but use with swine can be more difficult. The through-the-nose mounting is possible due to the high durability of the transducer. The size reduction required for mounting this transducer on the ear may cause sensitivity problems at the receiver.

The size of the transducer of the Los Alamos version has definite advantages over the orthogonal coil model. Subdermal implants are possible but not necessary for our purposes. Ear mounting is the most suitable location due to the increased resolution over the in-vivo method. This unit is a great deal more susceptible to environmental damage than the purely passive version. For this reason packaging of the unit should be considered critical. Attachment of the active transducer to the ear should be relatively simple due to its small size and weight. However antenna orientation is important for maximum coupling capabilities. This will prove most important with respect to the receiving antenna due to the small signal levels involved. An array of receiving antennas could be used to minimize this problem at the cost of increased receiver complexity. The receiver would then be required to determine which of the antennas had the highest signal strength. Scanning techniques could be the possible solution to this particular problem.

The interrogation fields of the two methods differ greatly. The Los Alamos model requires an intense high-frequency beam of radiant energy to provide power to the transducer. The transmitter for this unit, as previously stated, can be expected to be relatively expensive. The physical layout of bins is critical if a single transmitter with multiple

receivers format is planned. This will cause a limitation on the number of bins available in each feed center. Apparently a rotating transmitter base will be required to orientate the beam to the proper feed bin causing a time lag in interrogation of each bin as the transmitter sequences through the feed center. Separate transmitters would solve the delay problem. However, the additional cost can be considered prohibitive. Maximum safe field-strength levels of the interrogation beam will definitely be a limiting factor in determining the maximum number of feed bins served by a single transmitter. Ten units can be considered a very liberal estimate of the maximum serviceable units.

The interrogation field of the orthogonal coils is much less critical than that of the Los Alamos version. Containment of the field, as previously stated, can be accomplished with relative ease. Transmitter-transducer-receiver orientation can be predetermined when using the snout-mount transducer and proper structuring of the bin entrance. The available band width of the identification system is limited to approximately an eight octave spread. This in turn limits the quantity of data set members. With the multiplexing technique capacitors can be digitally selected causing resonant effect of the transmission coil circuit at the transmission frequency. This would result in a significant cost advantage over the transmitter required for the Los Alamos approach.

Although the suggested National Livestock Identification Code contains fifteen decimal digits of information, only the four decimal digit "animal" field of the code require decoding at the feed center. The orthogonal coil transducer would allow partial coding of the field

where as the Los Alamos approach allows its full use. Since the transducers of the Los Alamos method will be mass produced, full N.L.I.C. numbers can be used when mixing herds at times of sale. The orthogonal coil approach allows simultaneous tuning of transmission and receiving coils; reasonable receiver sensitivity should be possible using relatively inexpensive components. Transducer size should be maximized for the best receiver sensitivity. This, of course, contradicts the previous requirement that the transducer size be minimized for mounting purposes. This trade-off appears to be the fundamental design restriction of this method. The Los Alamos version's sensitivity appears to have its fundamental restriction concerning maximum radiation levels; this is particularly troublesome as the number of bins served by each transmitter becomes large.

The single most important design restriction is that the cost of the entire system must be kept to a minimum while retaining a high identification reliability and low maintenance requirements. Assuming the use of commercial available I.C. amplifiers for the transmitter and receiver of the orthogonal coils approach, the cost of this method will be dominated by the construction cost of the bins. The effectiveness of using the Los Alamos method for our needs would be influenced by the cost of the high-frequency transmitter.

The low per-unit-cost of the transducers of both methods allows for sizeable animal populations. This is offset in the Los Alamos approach by the transmitter cost per bin. The orthogonal coils methods requires that the total population accessing a given feed center must be less than

36 animals. Larger populations must be grouped into subsets containing less than this maximum number. This will result in inefficient land utilization and added costs for separate housing, etc. For populations less than the maximum identification set size stated above, the orthogonal coils approach has definite cost advantages. With proper land usage, this cost advantage could possibly be retained for a factor of two to three times the maximum set size. For example, a single feed center could serve two populations provided they did not require simultaneous access to the center. The group could be identified by using gates to allow entrance to the center by only one population at a time. Which gate is open can be electronically noted and stored as an additional bit in the decoded identification field.

If the system is needed for use with very large animal populations, the orthogonal coil method does not appear to be the most effective of the two approaches. The Los Alamos method would not require the additional segregation outlined above, unless the total population size of a single species exceeded 9,999. Needless to say, it is very improbable that larger population sizes than this will be desired. A single feed center would then be all that is needed to serve a very large population as opposed to multiple or multiplexed feed-center requirements of the orthogonal-coil approach to the same population size.

In summary both the use of orthogonal coils and a purely passive transducer as well as the Los Alamos backscatter technique using mass produced monolithic transducers, appear to be valid methods of animal identification at feeding. Table I gives a comparison of the two approaches. The orthogonal coil approach proves the most effective

TABLE I
COMPARISON OF TWO APPROACHES

	Orthogonal Coils	Los Alamos Version Ten Bins/Transmitter
Transmitter Cost/Bin	Very Low, assuming use of commercially available I.C.	Relatively High
Identifica- tion Speed	Estimated less than one sec. for verified I.D.	Relatively slow due to rotation requirements of transmitter
Receiver Cost	Low, using OP-Amps	Slightly high but allows for a larger I.D. field
Possible Transducer Locations	Snout Ear Neck (Collar for cattle only)	Subdermal (at higher cost) Ear Neck (collar for cattle only)
Transducer Cost/Unit	Low passive components	Low, mass produced
System Cost	Low	Relatively high due to transmitter cost

for smaller animal populations while larger populations causes this advantage to go to the Los Alamos method. For all population sizes, the transducers used for both methods meet our requirement of cost, durability and size. It should also be noted that several groups are presently developing systems of the Los Alamos approach for commercial use. It would appear desirable as well as potentially profitable to develop the orthogonal coil approach to allow the small and medium scale livestock raiser an economical means of livestock identification at feeding. It is the intention of the writer to determine the working parameters of the orthogonal coil approach with specific focusing on the transmitter, transducer, receiver coordination required for accurate identification.

CHAPTER III

THEORETICAL ANALYSIS OF THE ORTHOGONAL COIL APPROACH

In this chapter the magnetic field intensity of the transmitter is found for any point within the coil. From this the mutual inductance of the orthogonal coils and transducer system is theoretically developed. Resonance, stray capacitance and orthogonal nulling are also discussed.

Magnetic Field Intensity

The differential magnetic field intensity, $d\bar{H}$ for differential current element $I d\bar{L}$ can be determined from the Biot-Savart Law (refer to Fig. 3.1).

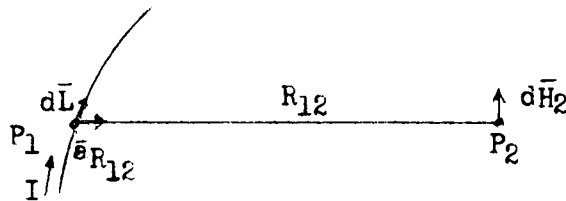


Figure 3.1. Magnetic Field Intensity at P_2 from Current Element $I d\bar{L}$.

$$d\bar{H}_2 = \frac{I_1 d\bar{L} \times \bar{a}_R}{4 \pi R_{12}^2} \quad 3.1$$

or

$$\bar{H} = \oint \frac{I d\bar{L} \times \bar{a}_R}{4 \pi R^2} \quad 3.2$$

The cross product of the integral causes H to be orthogonal to both the current element $I d\bar{L}$ and its projection to the point of interest,

$R_{12} \mathbf{a}_R$. Where R_{12} is the magnitude of the distance between the point 1 and 2, and $\mathbf{a}_R$ is a unit vector denoting the direction from P_1 to P_2 . If the filamentary wire was made to conform to the Z axis, the direction of the magnetic field would be the ϕ direction. Thus for this filamentary wire

$$\bar{\mathbf{H}} = \mathbf{a}_\phi H_\phi \quad 3.3$$

for an infinitely long wire, the location on the Z axis does not alter the field.⁵ This is not the case for a finite length wire.

Derivation of the Magnetic Field Intensity for a Square Loop

The magnetic field intensity for a finite length wire placed along the z axis will still retain the ϕ direction. However, its magnitude will vary with the proximity of the test point to the ends. The magnitude of $\bar{\mathbf{H}}$ can be found by superposition of the contributions of each current element, $I d\bar{\mathbf{L}}$ of the wire. The minimum radial distance of a current element $I d\bar{\mathbf{L}}_K$, is orthogonal to the filamentary wire. The radial distance of the other current elements $I d\bar{\mathbf{L}}_1$ is shown in Figure 3.2. The magnitude of $\bar{\mathbf{H}}$ is now:⁶

$$|\bar{\mathbf{H}}| = H_\phi = \frac{I}{4\pi\rho} \left[\frac{h + z}{\sqrt{\rho^2 + (h + z)^2}} + \frac{h - z}{\sqrt{\rho^2 + (h - z)^2}} \right] \quad 3.4$$

⁵W. H. Hayt, Engineering Electromagnetics (3rd ed.; New York: McGraw-Hill, 1974), p. 236.

⁶H. Neff, class notes on electro-magnetic fields, UTK.

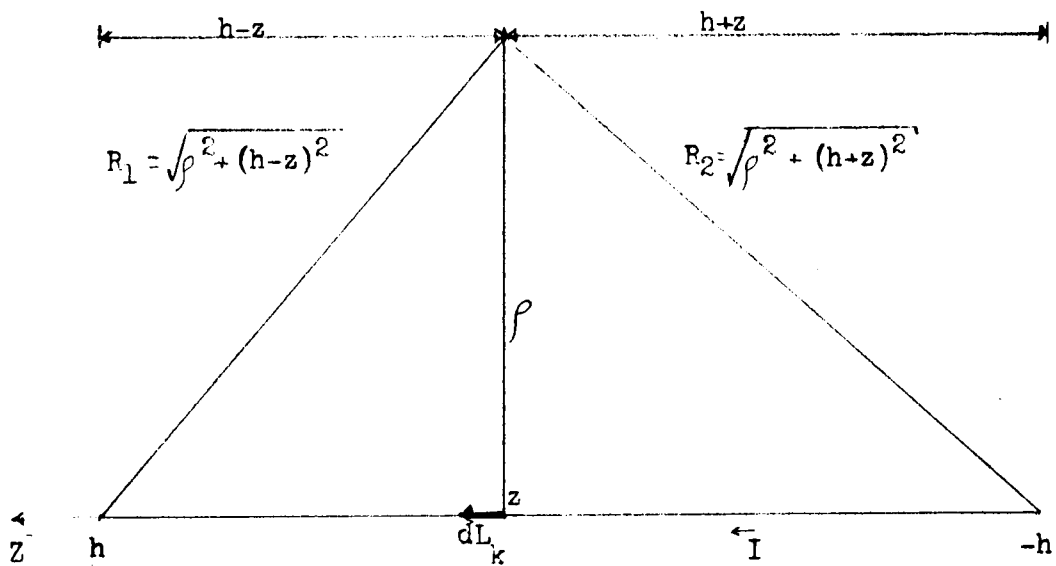


Figure 3.2. The Case of a Finite Length Wire.

The x and y components of this field are then:

$$H_x = H_\phi \sin \phi = H_\phi \frac{y}{\rho} \quad 3.5$$

$$H_y = H_\phi \cos \phi = H_\phi \frac{x}{\rho} \quad 3.6$$

Our application is a rectangular coil of N turns each with current I. For simplicity we can approximate this coil as N coincident turns of a square coil of filamentary wire having sides of length 2h. We can now use the above result with the principle of superposition to determine the magnitude and direction of the Magnetic field intensity at any point in space (refer to Figure 3.3).

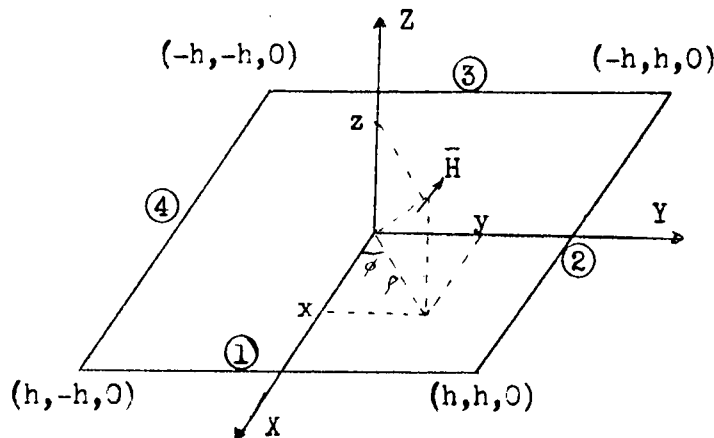


Figure 3.3. Magnetic Field for a Square Loop.

Placing the loop in the $Z = 0$ plane centered at the origin we can find the portion of the magnetic field induced by leg (1) (refer to Figure 3.4). Using equation 3.4 we have:

H_{x1} = The component of the magnetic field intensity in the x direction caused by leg (1)

$$= \left[\frac{I}{4\pi\sqrt{z^2 + (h-x)^2}} \right] \left[\frac{z}{z^2 + (h-x)^2} \right] \left[\frac{h+y}{\sqrt{z^2 + (h-x)^2 + (h+y)^2}} + \frac{h-y}{\sqrt{z^2 + (h-x)^2 + (h-y)^2}} \right] \quad (3.7)$$

Also

$$H_{z1} = H_{x1} \left[\frac{h-x}{z} \right], \quad (3.8)$$

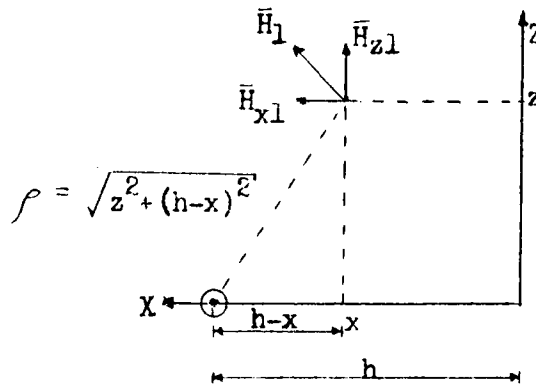


Figure 3.4. $\vec{H}$ Contribution from leg (1).

For leg (2) the relationships remain the same but all x terms are interchanged with y terms so

$$H_{y2} = \left[\frac{I}{4\pi\sqrt{z^2 + (h-y)^2}} \right] \left[\frac{z}{z^2 + (h-y)^2} \right] \left[\frac{h-x}{\sqrt{z^2 + (h-y)^2 + (h-x)^2}} + \frac{h+x}{\sqrt{z^2 + (h-y)^2 + (h+x)^2}} \right], \quad (3.9)$$

And

$$H_{z2} = H_{y2} \left(\frac{h-y}{2} \right) \quad (3.10)$$

The components of the magnetic field due to current leg (3) and leg (4) are slightly different from leg 1 and leg 2 due to the test point position with respect to the origin (refer to Figure 3.5). Now for leg (3)

$$H_{x3} = - \left[\frac{I}{4\pi\sqrt{z^2 + (h+x)^2}} \right] \left[\frac{z}{z^2 + (h+x)^2} \right] \left[\frac{h-y}{\sqrt{z^2 + (h+x)^2 + (h-y)^2}} + \frac{h+y}{\sqrt{z^2 + (h+x)^2 + (h+y)^2}} \right], \quad (3.11)$$

and

$$H_{z3} = H_{x3} \left[\frac{h+x}{z} \right]. \quad (3.12)$$

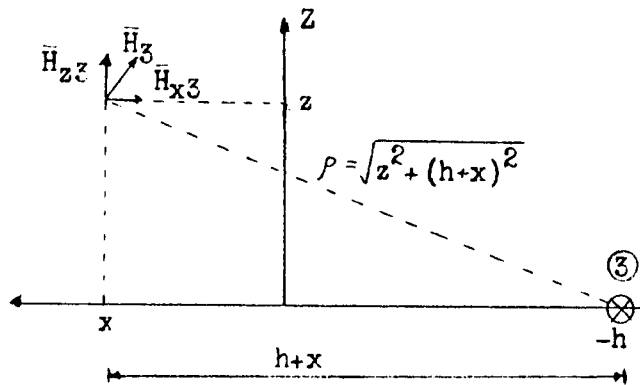


Figure 3.5. $\bar{H}$ Contribution from Leg (3).

Similar for (4)

$$H_{y4} = \left[\frac{I}{4\pi\sqrt{z^2 + (h+y)^2}} \right] \left[\frac{z}{z^2 + (h+y)^2} \right] \left[\frac{h+x}{\sqrt{z^2 + (h+y)^2 + (h+x)^2}} + \frac{h-x}{\sqrt{z^2 + (h+y)^2 + (h-x)^2}} \right], \quad (3.13)$$

and

$$H_{z4} = H_{y4} \left[\frac{(h+y)}{z} \right]. \quad (3.14)$$

The magnetic field intensity at any point inside the coil is

$$\vec{H} = H_x \hat{i} + H_y \hat{j} + H_z \hat{k}, \quad (3.15)$$

where

$$H_x = \left[\frac{I}{4\pi} \right] \left[\frac{z}{z^2 + (h-x)^2} \left[\frac{h+y}{\sqrt{z^2 + (h-x)^2 + (h+y)^2}} + \frac{h-y}{\sqrt{z^2 + (h-x)^2 + (h-y)^2}} \right] - \frac{z}{z^2 + (h+x)^2} \left[\frac{h+y}{\sqrt{z^2 + (h+x)^2 + (h+y)^2}} + \frac{h-y}{\sqrt{z^2 + (h+x)^2 + (h-y)^2}} \right] \right] \quad (3.16)$$

$$H_y = \left[\frac{I}{4\pi} \right] \left[\frac{z}{z^2 + (h-y)^2} \left[\frac{h+x}{\sqrt{z^2 + (h+x)^2 + (h-y)^2}} + \frac{h-x}{\sqrt{z^2 + (h-x)^2 + (h-y)^2}} \right] - \frac{z}{z^2 + (h+y)^2} \left[\frac{h+x}{\sqrt{z^2 + (h+x)^2 + (h+y)^2}} + \frac{h-x}{\sqrt{z^2 + (h-x)^2 + (h+y)^2}} \right] \right] \quad (3.17)$$

$$H_z = \left[\frac{I}{4\pi} \right] \left[\frac{h-x}{z^2 + (h-x)^2} \left[\frac{h+y}{\sqrt{z^2 + (h-x)^2 + (h+y)^2}} + \frac{h-y}{\sqrt{z^2 + (h-x)^2 + (h-y)^2}} \right] + \frac{h-y}{z^2 + (h-y)^2} \left[\frac{h+x}{\sqrt{z^2 + (h+x)^2 + (h-y)^2}} + \frac{h-x}{\sqrt{z^2 + (h-x)^2 + (h-y)^2}} \right] \right] \quad (3.18)$$

$$\begin{aligned}
& + \frac{h+x}{z^2 + (h+x)^2} \left[\frac{h+y}{\sqrt{z^2 + (h+x)^2 + (h+y)^2}} \right. \\
& \left. + \frac{h-y}{\sqrt{z^2 + (h+x)^2 + (h-y)^2}} \right] + \frac{h+y}{z^2 + (h+y)^2} \\
& \left[\frac{h+x}{\sqrt{z^2 + (h+x)^2 + (h+y)^2}} + \frac{h-x}{\sqrt{z^2 + (h-x)^2 + (h+y)^2}} \right] \Bigg].
\end{aligned}$$

Now we have a full description of the magnetic field intensity induced by a single filamentary coil of square geometry. To determine the intensity for N loops we can by superposition multiply this $\bar{H}$ by the scalar, N . To determine more of the nature of the field, it is advantageous to evaluate $\bar{H}$ for certain planes of interest. For the $x = 0$ plane.

$$H_x = 0 \quad (3.19)$$

For the $y = 0$ plane,

$$H_y = 0 \quad (3.20)$$

from this we see that for any point lying on the z axis

$$\bar{H} = H_z \hat{k} \quad (3.21)$$

$$\begin{aligned}
\bar{H}_{z \text{ axis}} = H_z \hat{k} &= \frac{I}{4\pi} \left[\frac{h}{z^2 + h^2} \right] \left[\frac{2h}{\sqrt{z^2 + 2h^2}} \right] (4) \hat{k} \quad (3.22) \\
&= \frac{I}{\pi} \frac{2h^2}{\sqrt{(z^2 + h^2)^2} (z^2 + 2h^2)} \hat{k}.
\end{aligned}$$

For the origin

$$H_{\text{origin}} = H_z k = \frac{I}{\sqrt{2}h^3} = \frac{\sqrt{2}}{\pi} \frac{I}{h} \hat{k} \quad (3.23)$$

for N turns

$$H_{\text{origin}} = \frac{\sqrt{2} N I}{\pi h} \hat{k} \quad (3.24)$$

Proof of Orthogonal Nulling

Returning to the calculation of H_x for the $x = 0$ plane we would like to determine the coupling of this coil to a similar coil placed in the $x = 0$ plane. The magnetic flux density of the field is defined as

$$\vec{B} = \mu_0 \vec{H}, \quad (3.25)$$

Where, $\mu_0 \equiv$ permeability of free space

$$= 4\pi \times 10^{-7} \text{ H/m}. \quad (3.26)$$

The magnetic flux, Φ is the integral of the flux density over a surface

$$\Phi = \int_S \vec{B} \cdot d\vec{s} \quad (3.27)$$

The amount of flux linkage between the two coils determines the amount of coupling for the $x = 0$ plane.

$$\begin{aligned} \Phi &= \iint_S \vec{B}|_S \cdot d\vec{s} = \int_{-h}^h \int_{-h}^h \mu_0 \vec{H}_S \cdot \vec{a}_x dy dz \\ &= \int_{-h}^h \int_{-h}^h \mu_0 H_x|_{x=0} dx dy \\ &= 0. \end{aligned} \quad (3.28)$$

Therefore no coupling occurs between orthogonal coils! See Figure 3.6.

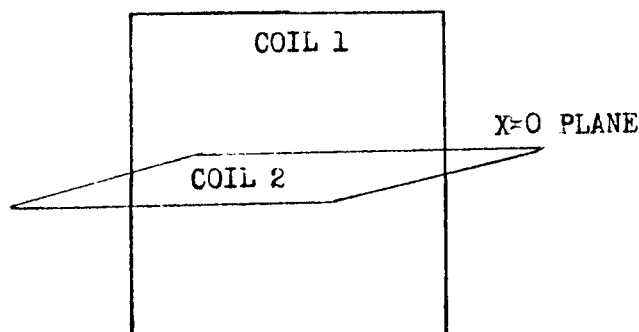


Figure 3.6. Orthogonal Nulling.

Flux Density for an Arbitrary Surface at the Origin

We are now ready to determine the theoretical coupling between the transmitting coil and the transducer. We will model the transducer as a planer filamentary loop of radius r_d . If $r_d \ll h$, then we can assume that the magnetic field intensity is constant across the surface defined by the filamentary loop. We now define a vector quantity $\bar{S}$ whose magnitude is surface area

$$|\bar{S}| = \pi r_d^2, \quad (3.29)$$

and whose orientation is the normal of the surface originating at the center of the surface. If we place the center of the transducer loop at the center of the square loop the magnetic flux density is

$$\bar{B}|_{\text{origin}} = \mu_0 \bar{H}|_{\text{origin}} = \mu_0 \frac{\sqrt{2} N I}{\pi h} \hat{k}, \quad (3.30)$$

See Figure 3.7.

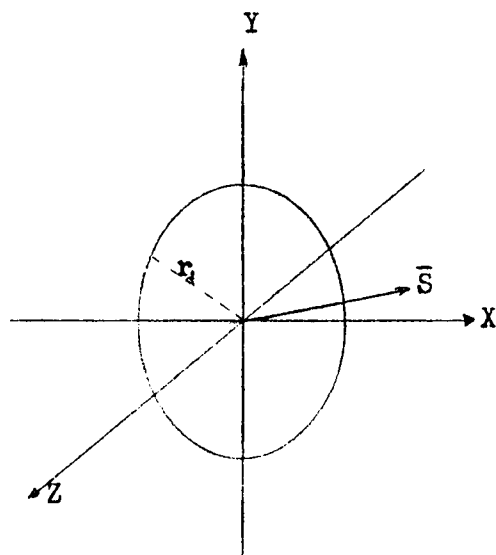


Figure 3.7. Surface Vector Defined.

The flux passing through the surface is⁷

$$\Phi = \int_s \mu_0 \frac{\sqrt{2} N I}{\pi h} \hat{k} \cdot d\vec{S} = \mu_0 \frac{\sqrt{2} N I}{\pi h} \int_s \hat{k} \cdot d\vec{S} \quad (3.31)$$

If we let

$$\vec{S} = S_x \hat{i} + S_y \hat{j} + S_z \hat{k},$$

and therefore

$$d\vec{S} = dS_x \hat{i} + dS_y \hat{j} + dS_z \hat{k}, \quad (3.32)$$

Now

$$\begin{aligned} \Phi &= \mu_0 \frac{\sqrt{2} N I}{\pi h} \int_s \hat{k} \cdot dS_x \hat{i} + dS_y \hat{j} + dS_z \hat{k}, \\ &= \mu_0 \frac{\sqrt{2} N I}{\pi h} \int_s dS_z = \mu_0 \frac{\sqrt{2} N I}{\pi h} S_z. \end{aligned} \quad (3.33)$$

⁷W. H. Hayt, p. 260.

Stray Capacitance of a Large Coil

Another important consideration of the coil is the stray capacitance associated with these N turns of closely spaced wire. The capacitance per unit length of two wires separated by a distance, $2d$ having radius a can be found from the formula.⁸

$$C/\text{Unit length} = \frac{\pi \epsilon}{\cosh^{-1} (d/a)} \quad (3.34)$$

If these conductors are placed so that they are touching, the distance between them $2d$, is equal to twice the radius a and the equation 3.28 reduces to

$$C/\text{Unit length} = \frac{\pi \epsilon}{\cosh^{-1} 1} \sim \infty$$

Our approximation shows the capacitance to be infinite unless accurate evaluation including the thickness of the insulation is made. These values are very critical so numerical calculations by this method will not be attempted. A more fundamental equation for two infinitely long parallel conductors relates the inductance and capacitance per unit length as⁹

$$LC = \mu\epsilon \text{ Henry-Farad/m}^2. \quad (3.35)$$

⁸N. N. Rao, Basic Electromagnetics with Applications (Englewood Cliffs, N.J.: Prentice-Hall, 1972) p. 382.

⁹Ibid., p. 381.

Since the resonance of the circuit occurs at

$$f_o = \frac{1}{2\pi\sqrt{LC}}, \quad (3.36)$$

we note that decreasing the total inductance and capacitance by decreasing the total length of the coil increases the square of the frequency of resonance. In short, the frequency of resonance, f_o , due to the stray capacitance is inversely proportional to the length (which is directly proportional to the number of turns, N).

$$f_o = K \frac{1}{N^2} \quad (3.37)$$

Since we are interested in the fields produced by the inductors, we would like to work where the coil is mostly inductive; at resonance the capacitive and inductive components are equal. See Figure 3.8.

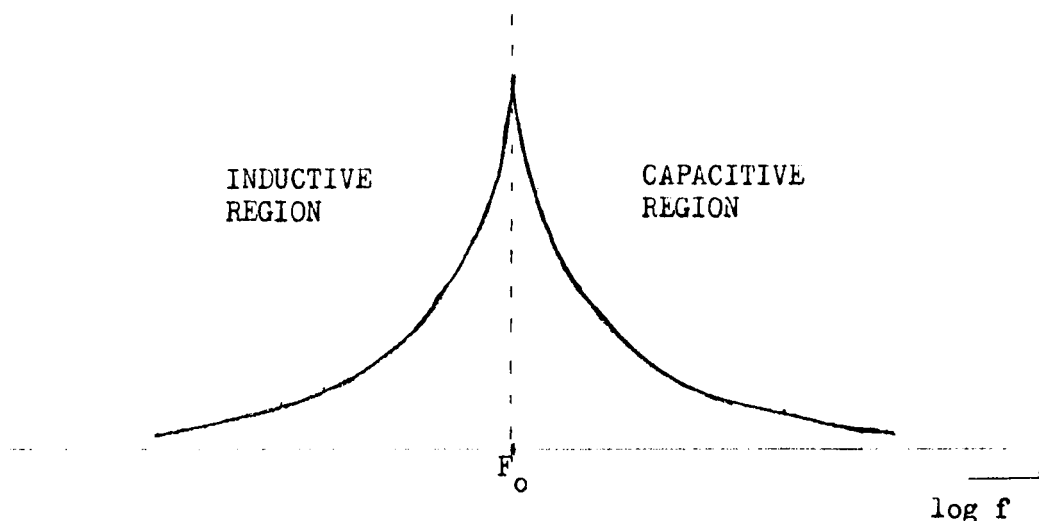


Figure 3.8. Inductive and Capacitive Regions of a Resonant Circuit.

The impedance of the coil at frequencies below resonance is mostly inductive. We then desire to have f_0 due to stray capacitance as high as possible to allow the largest possible bandwidth. If operation at resonance is desired, additional capacitance can be added to tune the coil. To determine the number of turns required for f_0 to be greater than the maximum operating frequency, we need only make a test coil of the desired physical size with an arbitrary number of turns. f_0 can then be measured and used in equation 3.37 to find K . Using the desired value of f_0 with this K , the proper number of turns can be calculated.

Determination of Mutual Inductance

The mutual inductance, M , between the transmitter and transducer coils is defined as:¹⁰

$$M = \frac{\text{Flux linkages in second coil Produced by the current in the first coil}}{\text{Current in the first coil}} = \frac{N_2 \Phi_{12}}{I_1}, \quad (3.38)$$

$$= \frac{\text{Flux linkages in the first coil Produced by the current in the second coil}}{\text{Current in the second coil}} = \frac{N_1 \Phi_{21}}{I_2}.$$

The flux linkages in the second coil produced by the first coil is found from Equation 3.38. The number of turns of the second coil effectively multiplies this flux linkage value resulting in a mutual inductance at the center of the large coil as

¹⁰F. E. Terman, Electronic and Radio Engineering (4th ed.; New York: McGraw-Hill, 1955) p. 19.

$$M = \frac{\sqrt{2} N_1 N_2 I_1}{h} \frac{S_z}{I_1} = \frac{\sqrt{2} N_1 N_2}{h} S_z. \quad (3.39)$$

Where S_z is the transducer area as view from the z axis.

If the transducer is oriented totally in the $z = 0$ plane then

$$S_z \Big|_{z=0 \text{ plane}} = \pi r_d^2 \quad (3.40)$$

Now:

$$M_{\max} \Big|_{x,y,z=0} = \mu_0 \frac{\sqrt{2} N_1 N_2}{h} \pi r_d^2 \quad (3.41)$$

By symmetry we find for equal coupling to exist between the transducer and both the orthogonal coils the transducer orientation should be 45° from the $z = 0$ plane.

So

$$M_{45^\circ} \Big|_{x,y,z=0} = \mu_0 \frac{N_1 N_2}{\pi h} \pi r_d^2. \quad (3.42)$$

Since $M_{12} = M_{21}$ and since the third coil is identical to the first we can assume

$$M_{12} = M_{21} = M_{23} = M_{32}. \quad (3.43)$$

Resonance Considerations

The transducer coil can be modeled as a solenoid of radius r , length b and N turns. The inductance of the coil can be calculated from

the formula¹¹

$$L(\mu h) = \frac{r^2 N^2}{9r + 10b} , \quad (3.44)$$

where r and b are measured in inches. The principle causes of energy loss in air core coils are stated to be¹²

1. Skin effect of the conductor,
2. Proximity effect resulting from the closeness of turns,
3. Dielectric losses due to stray capacitances,
4. Eddy current losses associated with nearby metal surfaces.

At high frequencies most of the current in a conductor is confined to the region close to the surface. Skin depth is defined to be the depth of the conductor where the current density has dropped to 36.8 percent of its surface value.¹³

The skin effect increases the value of resistance seen by the circuit at the particular operating frequency. This in turn increases the energy loss of the coil. To reduce the energy loss due to skin effect, multi-stranded wire is desirable.

The proximity effect is due to uneven current flow in the coil wire due to the magnetic field of the adjacent turns. This can also be reduced by use of stranded wire.

¹¹D. DeMaw, The Radio Amateur's Handbook (48th ed.; Newington, Conn.: American Radio Relay League, 1971).

¹²F. E. Terman, p. 30.

¹³Ibid., p. 23.

The transmitter coil need not be tuned provided the frequency of operation is less than the resonant frequency of the coil due to stray capacitances. The transducer and receiving coils, however, must be tuned and therefore the bandwidth of the tuned circuits must be determined to properly separate the identification frequencies. The resonant frequency, f_0 , of a tuned circuit can be found by the formula

$$f_0 = \frac{1}{2\pi \sqrt{LC}} . \quad (3.45)$$

The capacitance is then chosen to tune the coil to the proper frequency. The series resistance of the inductor and the parallel resistance of the capacitance cause energy loss in the circuit. For simplicity the resistance shunting the capacitance will be (see Figure 3.9)

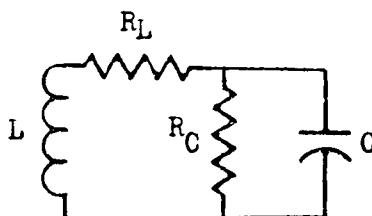


Figure 3.9. Model for Resonant Circuit.

ignored. The quality factor Q of the tuned circuit is defined as¹⁴

$$Q = \frac{\text{reactance of the capacitor or inductor in ohms}}{\text{Series Resistance in ohms (measured)}} . \quad (3.46)$$

Since the circuit shows its maximum impedance at f_0 , then a convenient measure of bandwidth is the frequency band where the circuit attenuates

¹⁴D. DeMaw, p. 43.

its response by 3db of this maximum value. The bandwidth can be determined from the formula¹⁵ (See Figure 3.10.)

$$\text{Bandwidth}_{-3\text{db}} = f_o/Q \quad (3.47)$$

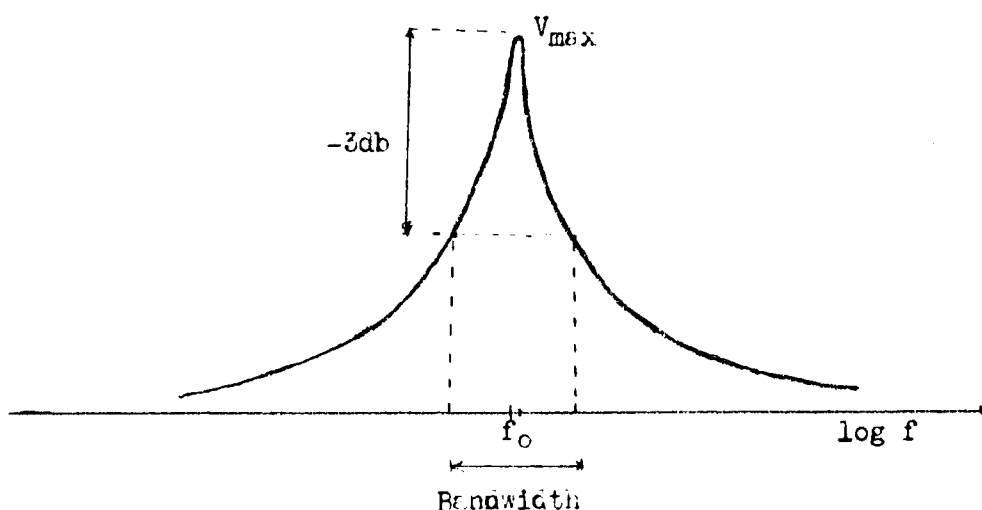


Figure 3.10. Bandwidth of a Resonant Circuit.

Directional Stray Coupling

Although we have considered the transmitter and receiver coils to be perfectly orthogonal, this is difficult to achieve and some stray coupling is likely to occur. This stray coupling is inherently directional and will cause a phase shift at the receiver depending on this stray coupling.

Figure 3.11A shows the ideal orthogonal coils noting the direction of the transmitter $\vec{H}$ field. Figure 3.11B shows a shift in the receiver coil causing a directional stray coupling with the receiver. Figure 3.11C

¹⁵D. DeMaw, p. 44.

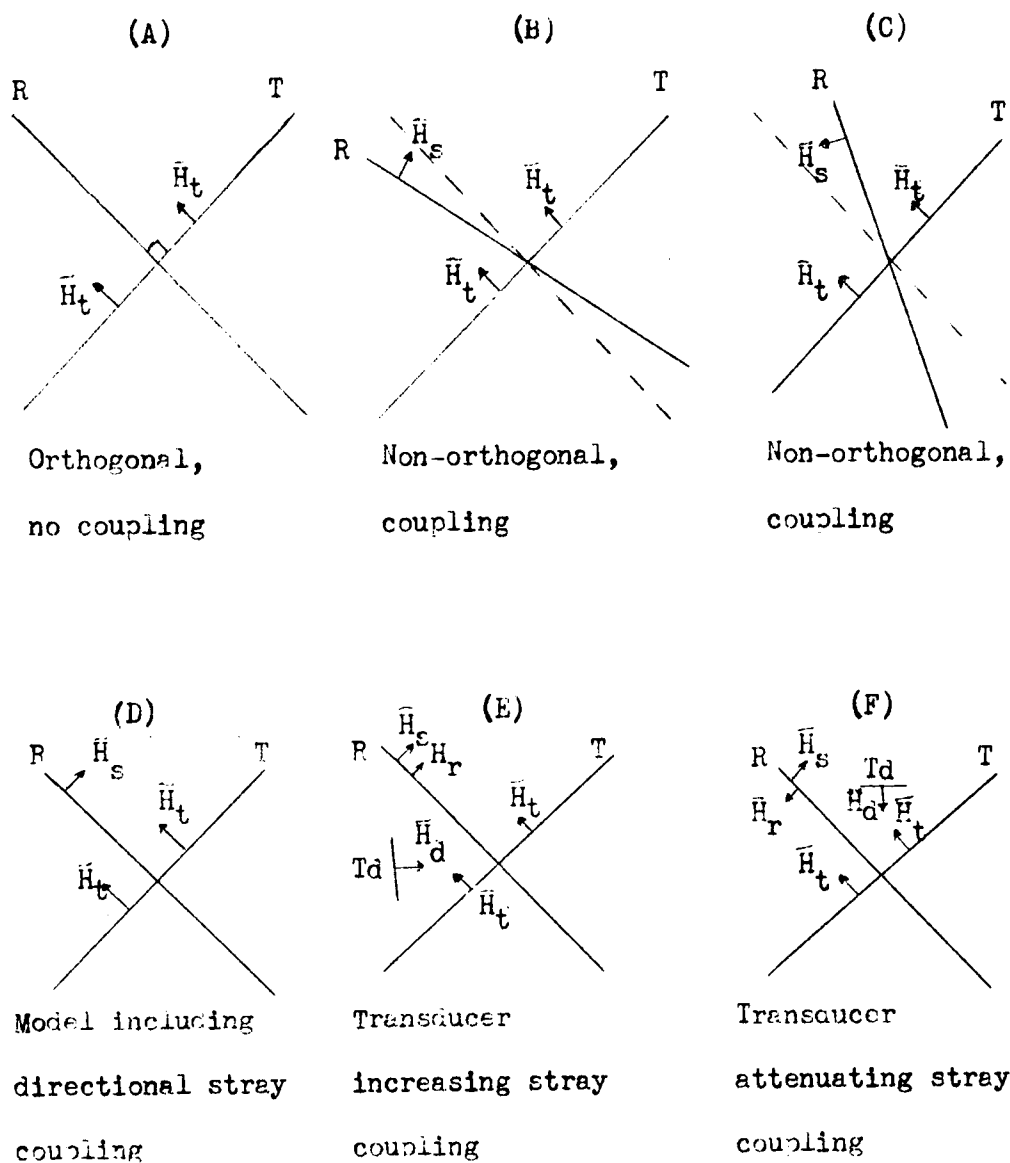


Figure 3.11. Directional Coupling of the Orthogonal Coils.

shows a shift to the opposite side causing the stray coupling to be in the opposite direction.

If we assume a stray coupling as shown in Figure 3.11D, two methods of coupling with the transducer are possible. Allowing the transducer to enter the field in the direction shown in Figure 3.11E, the transducer will mutual couple the transmitter and receiver in a direction that enhances the stray coupling and therefore immediately cause an increase in current in the receiver coil. If the transducer enters as shown in Figure 3.11F, the transducer coupling will be in the opposite direction of the stray. This will have the effect of cancelling out the stray field and reduce the total $\bar{H}$ field passing through the receiver coil. The current in the receiver coil would then decrease until the stray field had been totally cancelled out, after which any additional field created by the transducer would increase the current. Since the transducer orientation is predetermined, the orthogonality of the coils should then be adjusted so that any stray coupling is in the direction of the transducer coupling, thus allowing immediate identification.

CHAPTER IV

CIRCUIT ANALYSIS AND EXPERIMENTAL MEASUREMENTS

In this chapter a circuit model for the system is derived for the resonant condition. PCAP analysis of the circuit is formatted. Physical limitations on the orthogonal coils are discussed. Measurements are made of the circuit elements of the system. The mutual inductance of the transmitter-transducer system is found experimentally and compared to the theoretical value. Stray coupling of transmitter to receiver is added to the PCAP model. Measured system response is compared to PCAP predictions. The entry of a transducer into the field of the orthogonal coils is simulated, and the frequency resolution of the system is considered.

Circuit Analysis

Using the theoretical analysis of the previous chapter we are now in a position to develop a circuit model of the transmitter-transducer-receiver system. Due to the complexities involved in the theoretical determination of these circuit parameters, the analytical values of the components of the system will be immediately compared to the measured values. The system's transfer function will be evaluated using the measured values. Using this approach the accuracy of the transfer function should be improved.

When coils are mutually coupled, the impedance of the secondary coil circuit is reflected back to the primary circuit. Using the

circuit model diagrammed in Figure 4.1A, the impedance of the secondary is viewed via the primary circuit as shown in Figure 4.1B. The inductors L_p and L_s represent the mutual inductances of the primary and secondary circuits respectively. Similarly the impedances, Z_p and Z_s represent the impedances of the primary and secondary circuits. A voltage generator, E_p , excites the primary circuit at a sinusoidal rate of ω radians per second. This excitation causes a primary current, I_p , to flow through L_p . The mutual coupling, M , of the two inductors causes a secondary current, I_s , to flow through L_s . This I_s produces a voltage, E_s to appear across Z_s . The two mesh equations of the circuit are¹⁶

$$E_p = I_p Z_p + j\omega M I_s, \quad (4.1)$$

$$E_s = -j\omega M I_p = I_s Z_s. \quad (4.2)$$

The secondary current can be described in terms of the primary current using Equation 4.2.

$$I_s = \frac{j\omega M I_p}{Z_s}. \quad (4.3)$$

Using this result in equation 4.1 we have

$$E_p = I_p \left(Z_p + \frac{(\omega M)^2}{Z_s} \right). \quad (4.4)$$

From this result we note that the reflected impedance, Z_r , of the secondary circuit to the primary circuit to the primary circuit is

¹⁶F. E. Terman, p. 28.

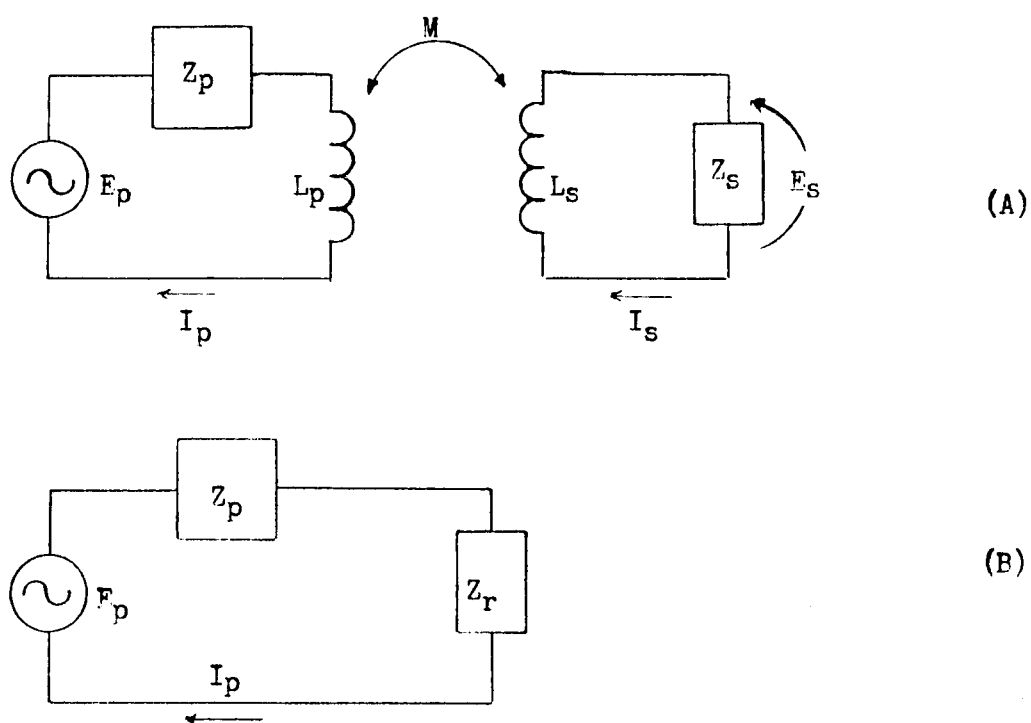


Figure 4.1. (A) Basic Transmitter-Transducer Model
(B) Reflected Impedance Model

$$Z_R = (\omega M)^2 / Z_S . \quad (4.5)$$

The currents of the primary and secondary circuits can now be calculated as

$$I_p = E_p / (Z_p + (\omega M)^2 / Z_S , \quad (4.6)$$

$$I_s = (-j M E_p) / Z_p Z_S + (\omega M)^2 . \quad (4.7)$$

This value of primary current can be used in equation 4.2 to determine the ratio of primary to secondary voltage.

$$\begin{aligned} E_p / E_s &= (Z_p Z_S + (\omega M)^2 / (-j \omega M Z_S) , \\ &= j ((Z_p / \omega M) + (\omega M / Z_S)) . \end{aligned} \quad (4.8)$$

If the primary circuit is driven at a frequency well below its resonance the reactance of the primary circuit is mostly inductive (due to the physical inductance of the primary, L_a). Ignoring the stray capacitance and its shunt resistance, the impedance of the primary circuit can be represented as

$$Z_p = R_p + j \omega L_a , \quad (4.9)$$

where R_p is the series resistance associated with the physical inductance L_a . If the secondary is tuned to the operating frequency of the generator, the capacitance of the secondary circuit cannot be ignored. We will, for ease in computation, neglect the shunt resistance of this capacitance. The impedance of the secondary circuit can then be represented as

$$Z_s = R_s + j (\omega L_b - 1 / \omega C_s) , \quad (4.10)$$

where R_s is the series resistance of the physical secondary inductance, L_b , and C_s is the capacitance across the inductor. The reflected impedance to the primary circuit will then be

$$Z_r = (\omega M)^2 / R_s + j(\omega L_b - 1/\omega C_s). \quad (4.11)$$

At resonance the capacitive reactance is equal to the inductive reactance so the imaginary component of the secondary is zero, causing a purely resistive reflected impedance.

$$Z_r \text{ (at resonance)} = (\omega M)^2 / R_s. \quad (4.12)$$

PCAP Programming

Regretfully, the assumption of resonance is not always valid, particularly when considering mass production of these transducers. Other sources of deviation from pure resonance occur due to environmental considerations and aging of the capacitor. Reflected impedance of the receiver affects these impedances as well. In addition to the expected reflected impedance from receiver to transducer, stray coupling to the transmitter circuit allows additional impedance reflection. For this reason a resonance solution to the system transfer function is not considered adequate for our needs. Due to the number of parameters allowed to vary in this system, a computer-aided solution to the problem appears applicable. The Princeton Circuit Analysis Program (PCAP) solves problems in circuit analysis by matrix techniques, thus providing maximum attainable accuracy for the solution. Using the experimental voltage induced in the receiver due to stray coupling to the transmitter,

the amount of stray coupling can be added to the model resulting in better correlation of theoretical and measured values.

To allow for PCAP programming, the circuit must first be drawn in its fundamental form as shown in Figure 4.2. All of the nodes and branches now must be numbered consecutively. The current generator does not require a number and is located by its characteristic resistance. The AC analysis subprogram will be used so all circuit elements must be referenced from the AC ground node, Node 0. To symbolize the transducer's floating nature, a resistor isolating it from ground is included in our diagram. This resistor, however, is not necessary since no AC signals can pass through the ground node. For this reason the programmed resistance value is small. The mutual inductances are also assigned numbers. From this diagram the data statements for the program can be written (see Figure 4.3).

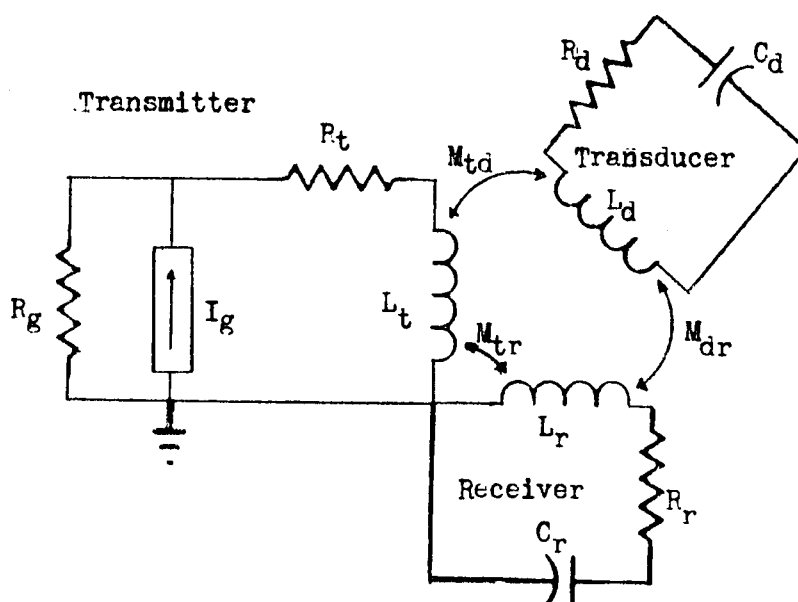
The circuit elements are then listed by branch number and referenced to their respective nodes. For example, if branch two (B2) contains one ohm of resistance, noting that it connects nodes one and two, N(1,2), the data card states

B2 N(1,2),R = 1.

The mutual inductances are also tabulated and referenced to the inductive legs they couple. If M_2 was a mutual inductance of 8 uH, it would be listed as

M2 B(3,8),L = 8E-6.

Once in this format PCAP can supply tabulations and plots of voltage and current responses with respect to frequency or variations of circuit



Where:

L_t = transmitter inductance

R_t = transmitter resistance

I_g = generator current

R_g = generator resistance

L_d = transducer inductance

R_d = transducer resistance

C_d = transducer capacitance

L_r = receiver inductance

R_r = receiver resistance

C_r = receiver capacitance

Mutual Inductances:

M_{td} = transmitter-transducer

M_{dr} = transducer-receiver

M_{tr} = transmitter-receiver

Figure 4.2. Circuit Model for Transmitter-Transducer-Receiver System.

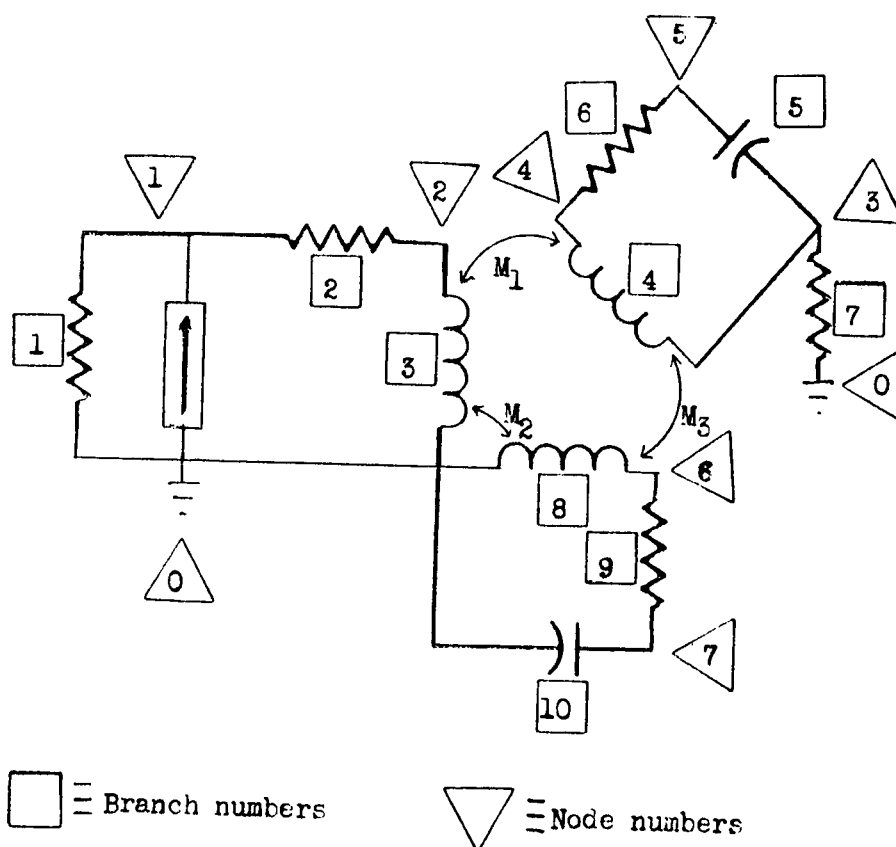


Figure 4.3. PCAP Circuit Diagram.

values. A more in-depth analysis of the structuring of PCAP (PCAP 3 is used in this analysis) is available from its "Programming Notes" by Princeton University Department of Electrical Engineering.

Physical Requirement of the Orthogonal Coils

Physical size requirements are the primary design limitations of the coils of the system. The orthogonal coils must be large enough to allow the animal's head to pass through to the feed bin. The minimum orthogonal coil size was chosen to be 2 foot square to meet this criteria. The frame of the coils should not contain any large quantity of ferro-magnetic material which would alter the magnetic flux distribution. Ferro-magnetic material can be used in small quantities to reduce the flux contribution at points on the coils where winding problems cause flux contributions which deviate from the theoretical values. This attenuation of stray field effects is particularly advantageous at the corners of the square coils, due to the inability to achieve a perfect 90-degree bend for these turns. The frame material used for the orthogonal coil prototype will be wood. The bonding of the frame elements will be achieved by the use of ferro-magnetic nails. Since the placement of these nails coincides with the corners of the coils some attenuation of the stray effects will occur with their use. Further attenuation of strays is achieved by placing steel screws at the corners and forming the right angles required for the coil about these screws.

An adjustment for adjusting the orthogonality of the transmitter and receiver coils will be needed. This adjustment is easily achieved

if one of the coils is allowed to pivot about the axis of symmetry of the other. Two parameters can be effected with this adjustment. First the orthogonality is adjusted to achieve minimum receiver excitation without the presence of a transducer. Although in theory this nulling should exhibit no excitation of the receiver coil by the transmitter coil, total nulling is not expected for several reasons discussed earlier. The second parameter of adjustment is the directionality of the stray coupling discussed in the previous chapter. A small change in orthogonality can alter the direction of the stray coupling so to enhance the detection of a transducer entering the field with a specified orientation. Since this effect attenuates the detector's abilities for transducers entering orthogonal to the specified orientation, great care must be taken in making this adjustment.

To determine the maximum number of turns allowable for the transmitter and receiver coils, a measurement of stray capacitance is required. A wood frame of dimensions 29 by 26 inches was constructed and used to mount a one-hundred-turn coil of enameled copper wire (18 gage). The resonant frequency of the coil due to stray capacitance was measured using a high-output-impedance voltage generator across the coil and noting the circuit's resonant voltage peak. This peak occurred at 45 kHz for the 100-turn coil. Using equation 3.37, we find the constant K to be

$$K = (45 \times 10^3)(100^2)^{\frac{1}{2}} = 4.5 \times 10^6$$

To achieve a stray evoked resonance at 1MHz the number of turns should then be

$$N = 4.5 \times 10^6 / 10^6 = 4.5 \text{ turns.}$$

Measurement of System Parameters

A 5-turn coil was then mounted on the frame and a resonance due to stray capacitance was observed to occur at 1.2MHz, showing relatively good correlation with the approximation. The inductance of the 5-turn coil along with its series resistance was measured with an Electro Scientific Industries Model 252 Impedance Meter. Another coil and frame was constructed with similar dimensions and the same number of turns to serve the receiver coil. The receiver coil showed parasitic resonance at approximately the same frequency as the transmitter. The measured inductance and series resistance for both coils is shown below:

$$L_{tm} = \text{measured transmitter inductance} = 67\mu\text{H}$$

$$R_{tm} = \text{measured transmitter resistance} = 0.31 \text{ ohms}$$

$$L_{rm} = \text{measured receiver inductance} = 70.5 \mu\text{H}$$

$$R_{rm} = \text{measured receiver resistance} = 0.32 \text{ ohms}$$

A transducer coil was also constructed using 14 turns of number 18 stranded copper wire, having a radius of one-half inch and a length of one-third inch. Using equation 3.44 the expected inductance of the coil can be calculated:

$$L_{dc} = \text{calculated transducer inductance}$$

$$= \left(\frac{1}{2}\right)^2 (14)^2 / ((9)\left(\frac{1}{2}\right) + (10)(1/3))$$

$$= 6.26 \mu\text{H}$$

The measured inductance and series resistance are listed below.

L_{dm} = measured transducer inductance = 6.1 μ H

R_{dm} = measured transducer resistance - 0.079 ohms

The calculated inductance agrees with the measured value within 3 percent error. A measured capacitance of 0.412 μ F was placed across the transducer coil resulting in a measured resonance at 101.8 kHz. The bandwidth and resonant frequency measurement of a high-Q tuned circuit is difficult particularly when the inductance of the circuit is small, since the test lead inductance can effect the measurement. The measured bandwidth of the circuit was approximately 3 kHz. Using the measured bandwidth and F_0 with equation 3.47 the measured Q of the transducer is

$$Q_d \text{ (measured)} = F_0/Bw = 3/101.8 = 33.9$$

The expected resonant frequency is found using the measured inductance and capacitance with equation 3.45

$$F_0 \text{ (calc)} = 0.159/(LC)^{\frac{1}{2}} = 100.4 \text{ kHz}$$

The error between calculated and measured F_0 is 1.38 percent. A calculation of Q can be made using the measured inductance and capacitance at the calculated resonance with equation 3.46.

$$Q_d(\text{calc}) = 2 (6.1 \times 10^{-6})(100.4 \times 10^3)/0.079$$

The 30 percent error between calculated and measured Q's is believed to be caused by the test set-up. Q's as low as 7 were measured on the same transducer with minor alterations of the parameters such as the test lead type and signal generator impedance.

Transmitter-Transducer Mutual Inductance

The maximum theoretical mutual inductance between the transmitter and transducer at the center of the transmitter coil can be calculated using the physical dimensions of the coils and equation. Note that this equation assumes a co-planer orientation of the coils.

$$M_{\max} = \mu_0 (2)^{\frac{1}{2}} (N_t N_d r_d) / h,$$

$$= 29.3 \text{ nH},$$

where

h = average transmitter side length in meters = 0.686,

N_t = number of turns of transmitter coil = 5,

N_d = number of turns of transducer coil = 14,

r_d = transducer coil radius in meters = 0.0127,

$\mu_0 = 4 \pi \times 10^{-7} \text{ h/m}.$

The transducer was placed in the transmitter field which was excited at the resonant frequency of the transducer. The transducer's voltage was found to be dependent on the radial distance from the closest transmitter coil leg, as predicted from the magnetic field analysis. Variation from co-planer orientation produces the theoretical attenuation of the transducer response up to measurement accuracy. The transducer's response is plotted using equi-potential lines for the $Z = 0, 5'', 10''$ planes in Figures 4.4, 4.5, 4.6. Transducer orientation with respect to the constant z planes at specific points in the field are noted in these figures as well. The voltage across the transmitter coil for these tests

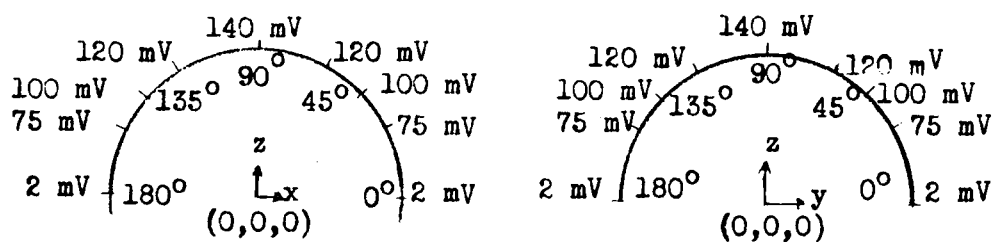
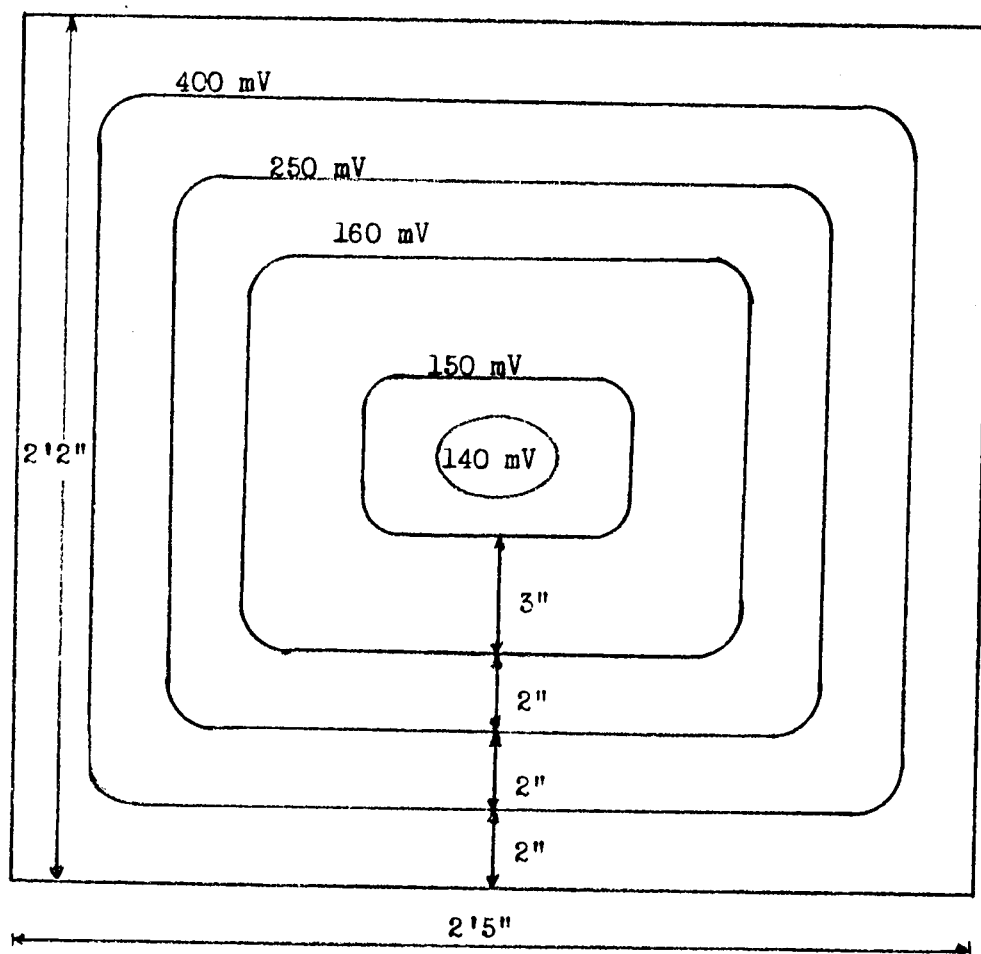


Figure 4.4. Transmitter Field Measurements for the $z = 0$ Plane.

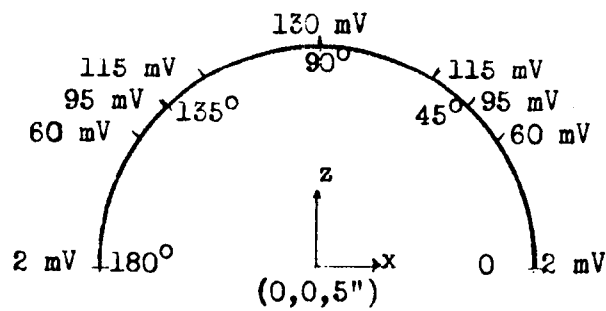
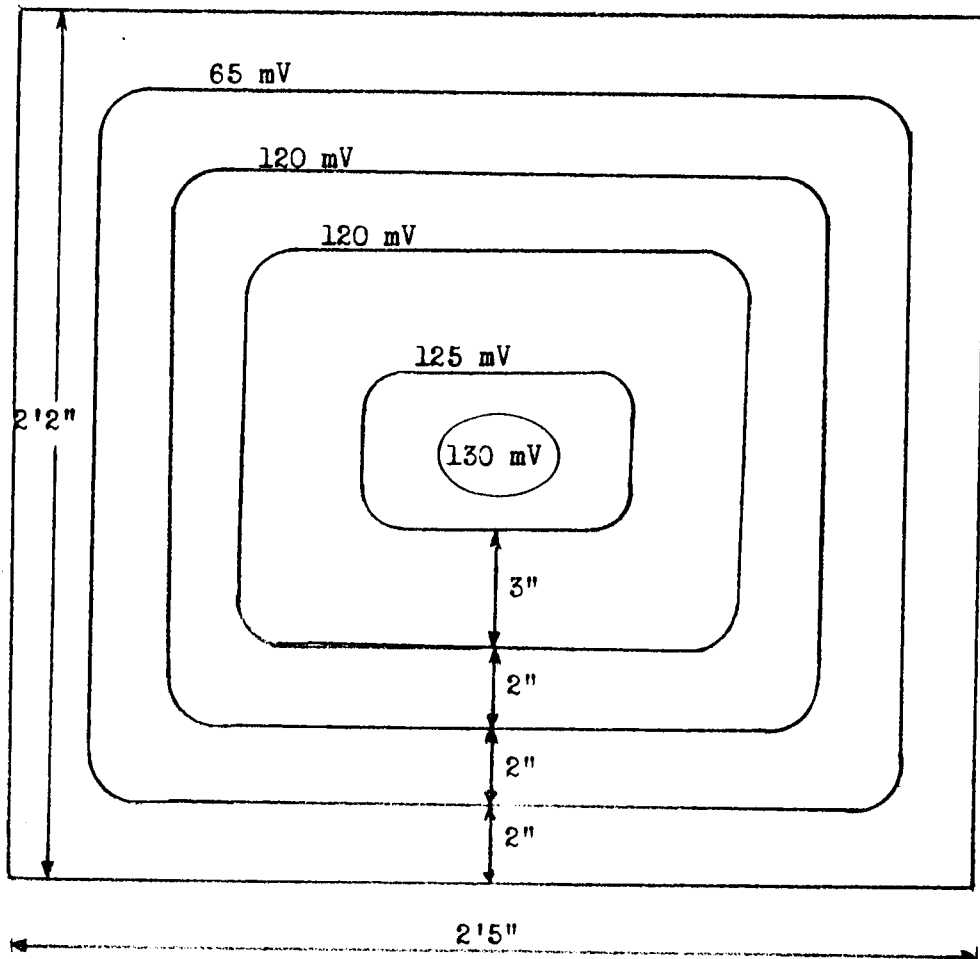


Figure 4.5. Transmitter Field Measurements for the $z = 5''$ Plane.

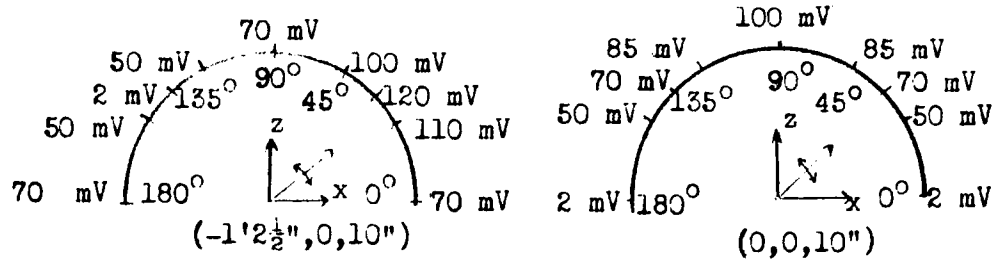
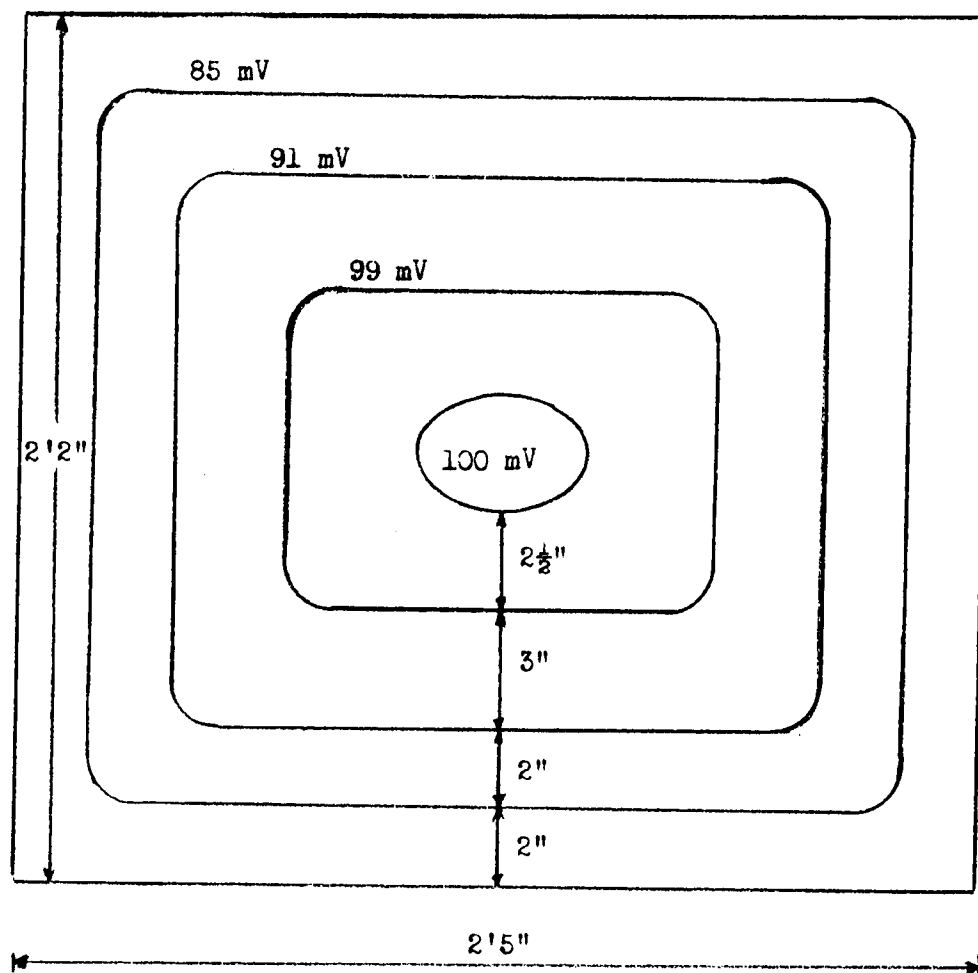


Figure 4.6. Transmitter Field Measurements for the $z = 10"$ Plane.

was $7V_{rms}$ at a frequency of 100.4 kHz. This corresponds to a current of 218 mA through the transmitter coil.

A PCAP Program can now be constructed using the measured values of the transmitter-transducer system (B1 through B7 and M1). The mutual inductance can be stepped through a range of values about the expected value and the transducer voltage response can be tabulated for each inductance value. Since the voltage measured across the transducer at the center of the coil with co-planar orientation was found to be 140 mV_{rms} , we can associate a mutual inductance to this voltage by noting the value of mutual inductance stated by PCAP to produce the same response. Appendix A contains the PCAP programs, tabulations and plots for this analysis. Program 1 was written to supply the mutual inductance versus voltage tabulations. Note that listing number 57 of this program shows the 140mV response to correspond to $2.7467 \times 10^{-8}\text{H}$ of mutual coupling. Using this as the experimentally measured coupling we find the error between theoretical and experimental coupling to be

$$\text{Error (measured-theoretical coupling)} = 6.67 \text{ percent,}$$

which shows very good correlation of the two figures. Program 2 shows the system frequency response using the measured value of coupling. Tabulation and plots of currents through branches 3,4,5 and the voltage across the transducer capacitor (B5) are given with respect to frequency. This output shows the resonant frequency at 100.4 kHz which matches our hand calculation. This is how it should be since PCAP uses an equivalent method of evaluation. This correlation shows that the model we programmed

into PCAP is the model we want to investigate. If these number were to vary, an error in data input would be apparent. Since our model appears accurate to both theoretical and experimental values we can now expand it to include the receiver coil.

Stray Coupling of Transmitter and Receiver

The addition of the receiver coil to the model brings with it some special problems. The physical construction of the orthogonal coils causes stray coupling to occur between transmitter and receiver coils. To account for this, a mutual inductance is added to the model at a value which produces the same value of null voltage measured on the receiver coil. This measured value of null voltage on the receiver (V_{nr}) was measured with the same transmitter excitation as above. Its value is

$$V_{nr} = 30 \text{ mV}_{rms} .$$

Program 3 was created to step this stray inductance through reasonable values and list it with respect to receiver voltage. No coupling of transducer to the receiver was made in this program. The value of mutual inductance that corresponds to 30 mV of receiver excitation is found in tabulation number 82 of this print-out. This is the value that will be used for M2 of the model for future programs; it is

$$M2 = 5.44 \times 10^{-8} .$$

The receiver of this model is tuned with the measured value of capacitance applied to the receiver coil. Its value is

$$C_r = 37.2 \times 10^{-9} \text{ f .}$$

System Response with Transducer Present

Program 4 shows the transmitter-receiver systems response with respect to frequency. Note that its resonant peak occurs slightly higher than the transducer resonance. This allows for the physical difficulty in maintaining the same resonance for the receiver and all the transducers. The 101.06 kHz predicted resonance differs from the measured resonance of 104 kHz by 2.9 percent. Since both transducer and receiver resonance occur at approximately the same percentage increase over the theoretical values, this model is not believed to suffer to any large extent due to these inaccuracies. A double plot showing the transducer and receiver voltages when coupling of transducer and receiver is added is shown in the output Program 5. The plots were made with respect to frequency. Note that the receiver voltage at the transducer resonance of 100.4 kHz is shown in tabulation 77 to be 35.22 mV which is a 3.57 mV increase over the stray value given in the same tabulation of Program 4. Note also that the transducer coupling to both orthogonal coils is maximized at 45° from the $Z = 0$ plane and x axis so the value of mutual inductance will be reduced to 0.707 as predicted by Equation 2.42.

A plot of equal-potential lines as viewed on the $Y = 0$ plane is shown with respect to receiver excitation vs. transducer position in Figure 4.7 and 4.8. Figure 4.7 shows the measurements for the

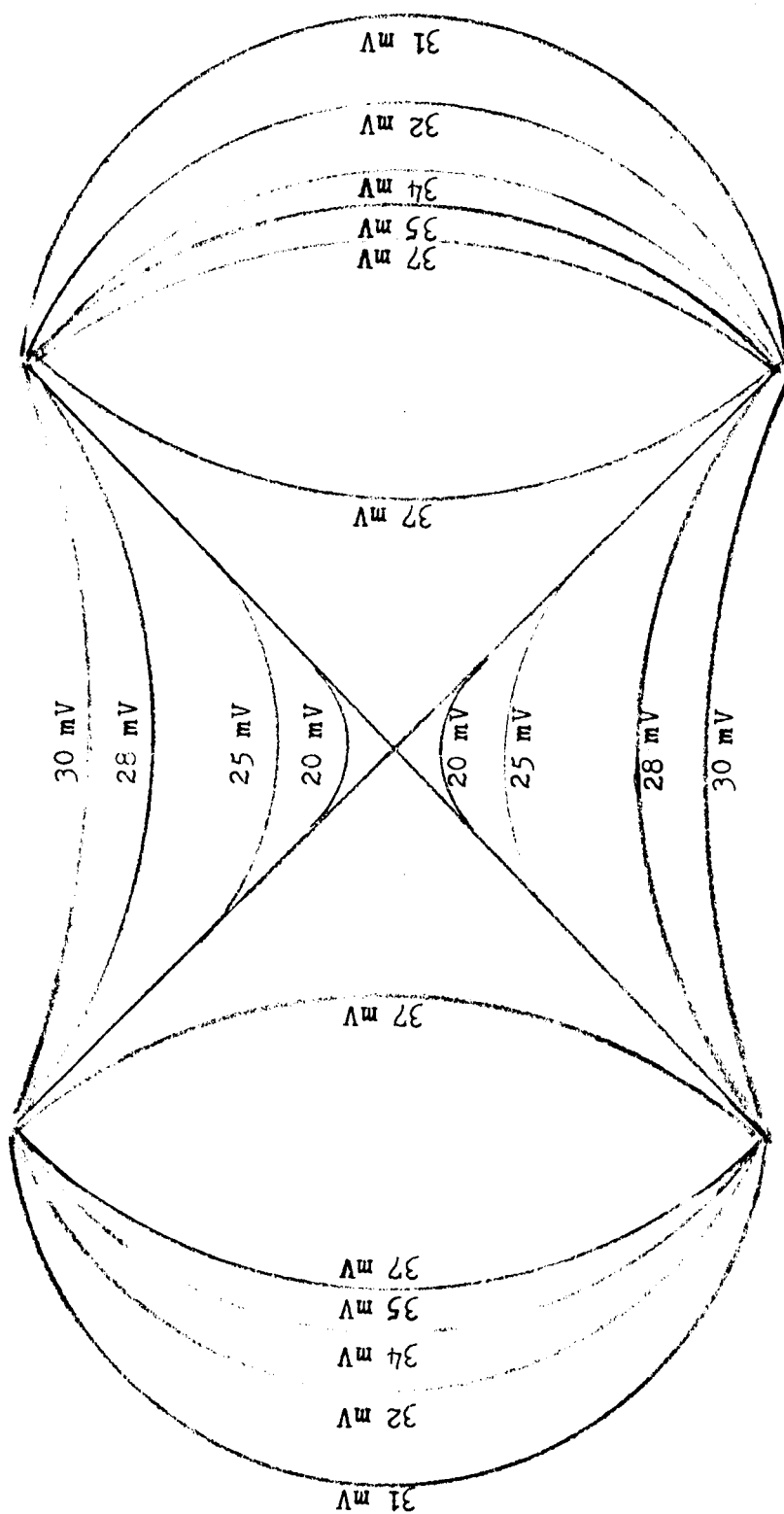


Figure 4.7. Orthogonal Coil Field for a Transducer Orientation Always toward the Center of the Coils. ($y = 0$ Plane)

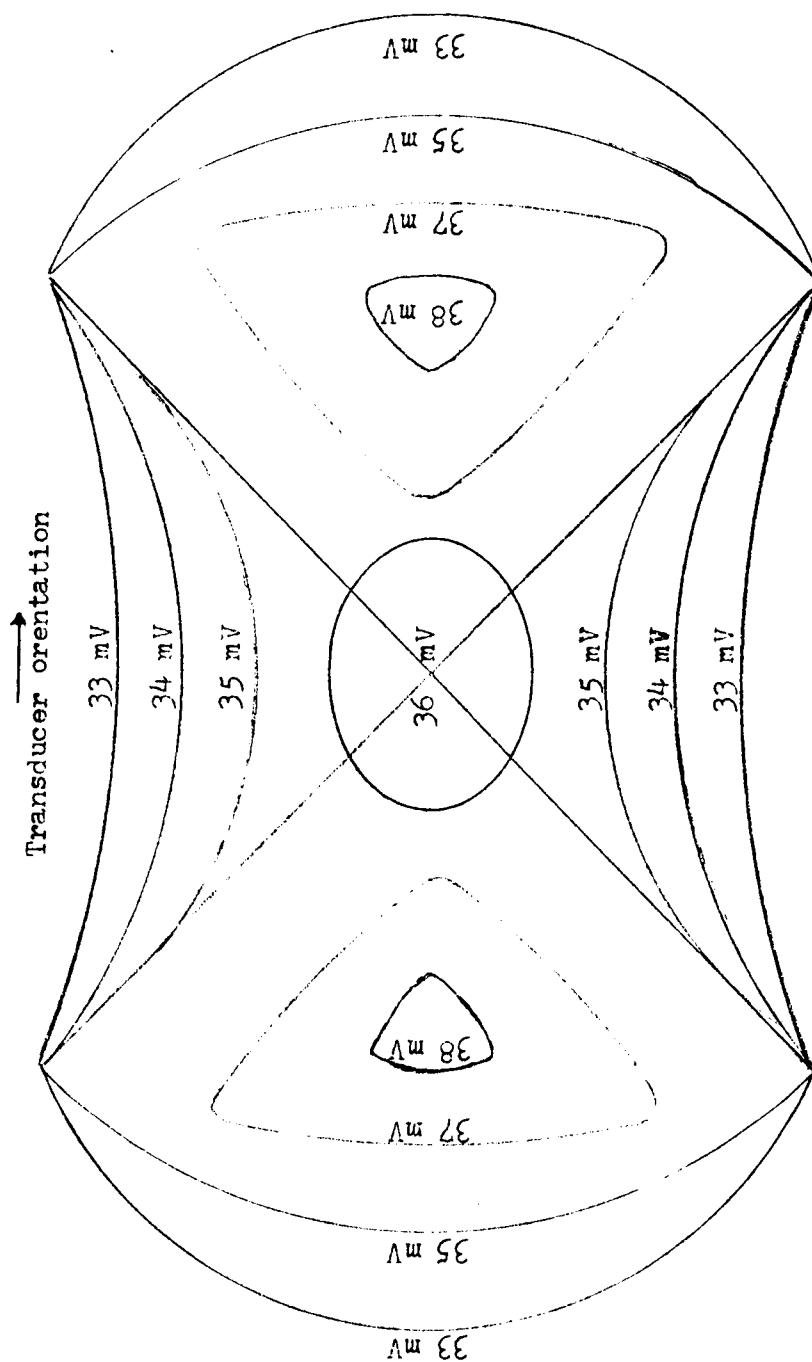


Figure 4.8. Orthogonal Coil Field for Constant Transducer Orientation.
($y = 0$ Plane)

transducer axial orientation always toward the origin. Figure 4.8 shows measurements for the transducer's axis parallel to the z axis. Note that the 45° orientation at the center of the coils produces a 6-mV increase over the stray 30-mV coupling. This increase is easily detectable with commercially available voltage comparators. The computer prediction of a 3.5-mV increase compares quite well with experimental values. If the stray coupling was adjusted to achieve the measured value of stray excitation more accurately, even better correlation could be expected.

Program 6 shows all major branch currents with respect to frequency for our model. This program completes the circuit description of our model.

Transducer Entry Simulation

Further PCAP programming is useful in predicting the system response to transducer entry in the interrogation field as well as response of the system to transducers resonating at frequencies other than the test frequency. Transducer entry is simulated by Program 7. This simulation is achieved by stepping the transducer mutual inductance to the receiver from very small values to the maximum theoretical value for 45° orientation. As expected this plot shows a rapid increase in response from the stray excitation to the maximum level for the linearly increasing coupling.

System Frequency Resolution

Perhaps the singly most important criteria of the system is the frequency resolution of the transducers. If the transducers resonance

is too widely separated the total systems bandwidth will not be large enough to allow a large enough identification set. To determine the practical channel width, the receiver voltage was tabulated with respect to transducer capacitance. Since this capacitance controls the resonance of the transducers, this tabulation allows calculation of the channel width. Program 8 shows this tabulation, and we note from it that a 1mV increase in receiver excitation occurs when the transducer capacitance is within 0.723 of its normal value. The receiver response is attenuated for larger values approximately up to the reciprocal of this value. Noting that the resonant frequency is inversely proportional to the square root of the capacitance, we can find the bandwidth with respect to the center frequency to be

$$BW(\min) = 0.34F_0 .$$

CHAPTER V

CONCLUSION AND SUMMARY

In conclusion, the orthogonal-coil approach is a predictable and easily reproducible method of passive transducer detection. The cost effectiveness of an identification system using resonant coupling of the orthogonal coils makes a high mark for competitive systems. The initial estimate of required channel bandwidth (octave separation) proved conservative. For the same system bandwidth (30K—1MHz) the channel bandwidth predicted by PCAP would allow 22 channels to the previously estimated 8. An identifying set of 56 was available with the 8 assumed channels. The new identification set size, assuming a 3 of 22 scheme, is 1540. This set appears adequate for our needs. In larger set sizes a combination of 4 out of 22 could be used to provide 7,315 identities. The maximum available set size would use a combination of 11 out of 22 which allows for 705,432 individuals. The bulk of the 11 resonant circuit transducer would be inhibitive for normal applications.

The stray coupling of the orthogonal coils was found experimentally not to significantly degrade the performance of the detection unit. In fact, if the transducer orientation is known, as it is for the transducer locations under investigation, then the detection can actually be aided by proper use of these stray effects.

The derivation of the magnetic field intensity was found to correlate with the experimental measurements to a high level of accuracy. The simplicity of the numerical evaluation of the theoretical analysis

of this intensity along the z axis allows its use in the orthogonal coil dimensional design. The fundamental relationship between the number of turns of these coils and the resonance due to stray capacitance, shown in equation 3.37, completes the information required for their physical design after a single measurement.

The use of PCAP programming involving measured circuit parameters offers an easily executed and accurate prediction of the experimental system's response.

The programming format is summarized below:

1. Programming the measured values of inductance, resistance, capacitance and generator excitation, the transducer response is tabulated with respect to the mutual inductance between transducer and transmitter. Locating the measured value of transducer response on this tabulation provides a "measured" value of mutual inductance. This "measured" value is compared to the theoretical value to note their correlation. Note that this should be a coplaner measurement requiring the use of equation 3.41 for comparison.

2. The receiver is now added to the model; however, only its stray coupling to the transmitter is considered in this run. This stray mutual inductance is then stepped in value through a reasonable range and tabulated against the receiver response. The measured value of stray induced receiver excitation is found on this table and the associated value of transmitter-receiver coupling is then used for future programs.

3. The entire system is now modeled using the value of stray coupling found in part two. The transducer is assumed to be at a 45°

angle from both the transmitter and receiver so the coupling to either coil from the transducer is assumed to be the same and attenuated by a factor of $1/\sqrt{2}$ from the "measured" value of program 1. The response of the system with the centered transducer can now be evaluated with respect to frequency and the net increase in receiver voltage at the transducer resonant frequency predicts the detection excitation of the receiver. This should be an increase in voltage over the voltage programmed as the null voltage of part 2, and can be compared to the experimental values to check accuracy.

4. Simulation of the transducer entering the field can be achieved by the parameterization of the transducer-receiver coupling with respect to the receiver excitation. The minimum value of mutual inductance required to increase the receiver voltage over the stray coupling level can be determined from this analysis.

5. To determine the transducer detection bandwidth, the receiver response with respect to variations in transducer capacitance can be tabulated. Since the resonant frequency of the transducer is proportional to the reciprocal of the square root of this capacitance, the frequency resolution of the detector can be determined from this data.

The results of this study of the transmitter-transducer receiver system of the orthogonal-coil approach shows this method of livestock identification to be both electronically and economically feasible. When used in conjunction with a data acquisition system concerning animal feeding habits, this method appears to be by far the best design alternative with respect to presently developed systems as well as the

theoretical approaches discussed. The simplicity of the system is its major point of merit, particularly with respect to the electronics required for its implementation. In short, commercialization of this unit would provide both a reasonable profit for the producer as well as a low cost sophisticated identification and data acquisition system for the livestock industry.

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APPENDICES

APPENDIX A

PCAP PROGRAMS

```
*****  
**                                     **  
**          PCAP                      **  
**                                     **  
**      DOUBLE PRECISION              **  
**                                     **  
**      SERIAL NUMBER =   4.0         **  
**                                     **  
**      DATE =    01/11/79            **  
**      TIME =    23.07.28           **  
**                                     **  
**      *****                       **  
**      *****                       **  
*****
```

```

81 AC ANALYSIS
82 N(1,1)R=50,I=2.18E-1
83 N(1,2)R=0.31
84 N(2,0)I=67E-6
85 N(3,4)I=6.1E-6
86 N(3,5)I=0.412E-6
87 N(4,5)R=0.079
88 N(1,3)R=0.001
      FREQ=100.4E3
      R(3,4)I=2.97E-8
      PRINT,M1
      TAB=RV(5)
      EXECUTE

```

*** NODAL ADMITTANCE MATRIX ***

[illegible]

NODES	EQUIVALENT CURRENT VECTOR
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	0
32	0
33	0
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35	0
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82	0
83	0
84	0
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86	0
87	0
88	0
89	0
90	0
91	0
92	0
93	0
94	0
95	0
96	0
97	0
98	0
99	0
100	0

REAL	1-5	-2.18000D-01	0.0	0.0	0.0
IMAG		0.0	0.0	0.0	0.0

FREQUENCY	BRANCHES	BRANCH VOLTAGES						
1.004000 05	1- 6	MAG	7.011140 00	5.142220-02	7.010950 00	1.513920-01	1.513610-01	3.107780-03
		ANG	49.5424	139.9687	-130.0373	140.7966	139.6203	49.6203
1.004000 05	7- 7	MAG	1.974680-19					
		ANG	-45.8744					

EXECUTION TIME = 0.483 SEC

MODIFY

***** MODIFIED PROBLEM *****

CANCEL
 M1 8(3.4),L=2E-8(150)4E-8
 PLOT,8V(5)
 EXECUTE

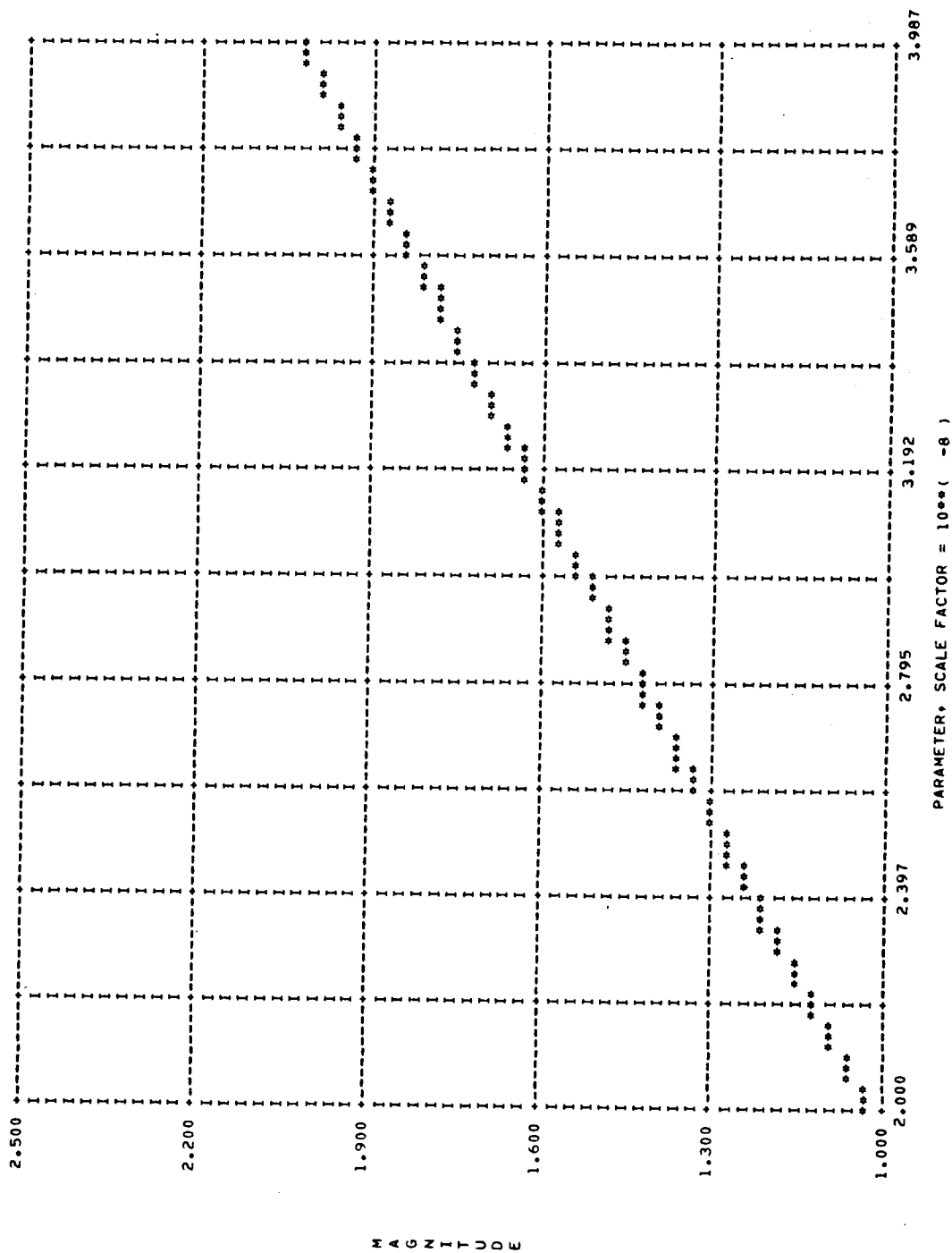
TABLE OF DATA PLOTTED, PARAMETER = LM

POINT	PARAMETER	B.V.	5 ***	ANGLE
		MAG		
1	2.0000E-08	1.019E-01		139.62
2	2.0133E-08	1.026E-01		139.62
3	2.0267E-08	1.033E-01		139.62
4	2.0400E-08	1.040E-01		139.62
5	2.0533E-08	1.046E-01		139.62
6	2.0667E-08	1.053E-01		139.62
7	2.0800E-08	1.060E-01		139.62
8	2.0933E-08	1.067E-01		139.62
9	2.1067E-08	1.074E-01		139.62
10	2.1200E-08	1.080E-01		139.62
11	2.1333E-08	1.087E-01		139.62
12	2.1467E-08	1.094E-01		139.62
13	2.1600E-08	1.101E-01		139.62
14	2.1733E-08	1.108E-01		139.62
15	2.1867E-08	1.114E-01		139.62
16	2.2000E-08	1.121E-01		139.62
17	2.2133E-08	1.128E-01		139.62
18	2.2267E-08	1.135E-01		139.62
19	2.2400E-08	1.142E-01		139.62
20	2.2533E-08	1.148E-01		139.62
21	2.2667E-08	1.155E-01		139.62
22	2.2800E-08	1.162E-01		139.62
23	2.2933E-08	1.169E-01		139.62
24	2.3067E-08	1.176E-01		139.62
25	2.3200E-08	1.182E-01		139.62
26	2.3333E-08	1.189E-01		139.62

27	2.3467E-08	1.196E-01	139.62
28	2.3600E-08	1.203E-01	139.62
29	2.3733E-08	1.210E-01	139.62
30	2.3867E-08	1.216E-01	139.62
31	2.4000E-08	1.223E-01	139.62
32	2.4133E-08	1.230E-01	139.62
33	2.4267E-08	1.237E-01	139.62
34	2.4400E-08	1.244E-01	139.62
35	2.4533E-08	1.250E-01	139.62
36	2.4667E-08	1.257E-01	139.62
37	2.4800E-08	1.264E-01	139.62
38	2.4933E-08	1.271E-01	139.62
39	2.5067E-08	1.277E-01	139.62
40	2.5200E-08	1.284E-01	139.62
41	2.5333E-08	1.291E-01	139.62
42	2.5467E-08	1.298E-01	139.62
43	2.5600E-08	1.305E-01	139.62
44	2.5733E-08	1.311E-01	139.62
45	2.5867E-08	1.318E-01	139.62
46	2.6000E-08	1.325E-01	139.62
47	2.6133E-08	1.332E-01	139.62
48	2.6267E-08	1.339E-01	139.62
49	2.6400E-08	1.345E-01	139.62
50	2.6533E-08	1.352E-01	139.62
51	2.6667E-08	1.359E-01	139.62
52	2.6800E-08	1.366E-01	139.62
53	2.6933E-08	1.373E-01	139.62
54	2.7067E-08	1.379E-01	139.62
55	2.7200E-08	1.386E-01	139.62
56	2.7333E-08	1.393E-01	139.62
57	2.7467E-08	1.400E-01	139.62
58	2.7600E-08	1.407E-01	139.62
59	2.7733E-08	1.413E-01	139.62
60	2.7867E-08	1.420E-01	139.62
61	2.8000E-08	1.427E-01	139.62
62	2.8133E-08	1.434E-01	139.62
63	2.8267E-08	1.441E-01	139.62
64	2.8400E-08	1.447E-01	139.62
65	2.8533E-08	1.454E-01	139.62
66	2.8667E-08	1.461E-01	139.62
67	2.8800E-08	1.468E-01	139.62
68	2.8933E-08	1.475E-01	139.62
69	2.9067E-08	1.481E-01	139.62
70	2.9200E-08	1.488E-01	139.62
71	2.9333E-08	1.495E-01	139.62
72	2.9467E-08	1.502E-01	139.62
73	2.9600E-08	1.509E-01	139.62
74	2.9733E-08	1.515E-01	139.62
75	2.9867E-08	1.522E-01	139.62
76	3.0000E-08	1.529E-01	139.62
77	3.0133E-08	1.536E-01	139.62
78	3.0267E-08	1.542E-01	139.62
79	3.0400E-08	1.549E-01	139.62
80	3.0533E-08	1.556E-01	139.62
81	3.0667E-08	1.563E-01	139.62
82	3.0800E-08	1.570E-01	139.62
83	3.0933E-08	1.576E-01	139.62
84	3.1067E-08	1.583E-01	139.62
85	3.1200E-08	1.590E-01	139.62
86	3.1333E-08	1.597E-01	139.62
87	3.1467E-08	1.604E-01	139.62

88	3.1600E-08	1.610E-01	139.62
89	3.1733E-08	1.617E-01	139.62
90	3.1867E-08	1.624E-01	139.62
91	3.2000E-08	1.631E-01	139.62
92	3.2133E-08	1.638E-01	139.62
93	3.2267E-08	1.644E-01	139.62
94	3.2400E-08	1.651E-01	139.62
95	3.2533E-08	1.658E-01	139.62
96	3.2667E-08	1.665E-01	139.62
97	3.2800E-08	1.672E-01	139.62
98	3.2933E-08	1.678E-01	139.62
99	3.3067E-08	1.685E-01	139.62
100	3.3200E-08	1.692E-01	139.62
101	3.3333E-08	1.699E-01	139.62
102	3.3467E-08	1.706E-01	139.62
103	3.3600E-08	1.712E-01	139.62
104	3.3733E-08	1.719E-01	139.62
105	3.3867E-08	1.726E-01	139.62
106	3.4000E-08	1.733E-01	139.62
107	3.4133E-08	1.740E-01	139.62
108	3.4267E-08	1.746E-01	139.62
109	3.4400E-08	1.753E-01	139.62
110	3.4533E-08	1.760E-01	139.62
111	3.4667E-08	1.767E-01	139.62
112	3.4800E-08	1.773E-01	139.62
113	3.4933E-08	1.780E-01	139.62
114	3.5067E-08	1.787E-01	139.62
115	3.5200E-08	1.794E-01	139.62
116	3.5333E-08	1.801E-01	139.62
117	3.5467E-08	1.807E-01	139.62
118	3.5600E-08	1.814E-01	139.62
119	3.5733E-08	1.821E-01	139.62
120	3.5867E-08	1.828E-01	139.62
121	3.6000E-08	1.835E-01	139.62
122	3.6133E-08	1.841E-01	139.62
123	3.6267E-08	1.848E-01	139.62
124	3.6400E-08	1.855E-01	139.62
125	3.6533E-08	1.862E-01	139.62
126	3.6667E-08	1.869E-01	139.62
127	3.6800E-08	1.875E-01	139.62
128	3.6933E-08	1.882E-01	139.62
129	3.7067E-08	1.889E-01	139.62
130	3.7200E-08	1.896E-01	139.62
131	3.7333E-08	1.903E-01	139.62
132	3.7467E-08	1.909E-01	139.62
133	3.7600E-08	1.916E-01	139.62
134	3.7733E-08	1.923E-01	139.62
135	3.7867E-08	1.930E-01	139.62
136	3.8000E-08	1.937E-01	139.62
137	3.8133E-08	1.943E-01	139.62
138	3.8267E-08	1.950E-01	139.62
139	3.8400E-08	1.957E-01	139.62
140	3.8533E-08	1.964E-01	139.62
141	3.8667E-08	1.971E-01	139.62
142	3.8800E-08	1.977E-01	139.62
143	3.8933E-08	1.984E-01	139.62
144	3.9067E-08	1.991E-01	139.62
145	3.9200E-08	1.998E-01	139.62
146	3.9333E-08	2.004E-01	139.62
147	3.9467E-08	2.011E-01	139.62
148	3.9600E-08	2.018E-01	139.62

PLOT OF B.V. 5, SF = 10**(-1), VERSUS LM



FREQUENCY	BRANCHES	BRANCH VOLTAGES	
1.004000 05	1- 6	MAG	7.011190 00
		ANG	5.142250-02
			139.9683
1.004000 05	7- 7	MAG	7.011000 00
		ANG	-130.0368
			140.7962
			139.6200
			1.401500-01
			2.877600-03
			49.6200

EXECUTION TIME = 0.533 SEC

MODIFY

CANCEL
 FREQ=8E+(*1.003)1.3E5
 PLOT,BV(S)
 PLOT,I(3+4,5)
 EXECUTE

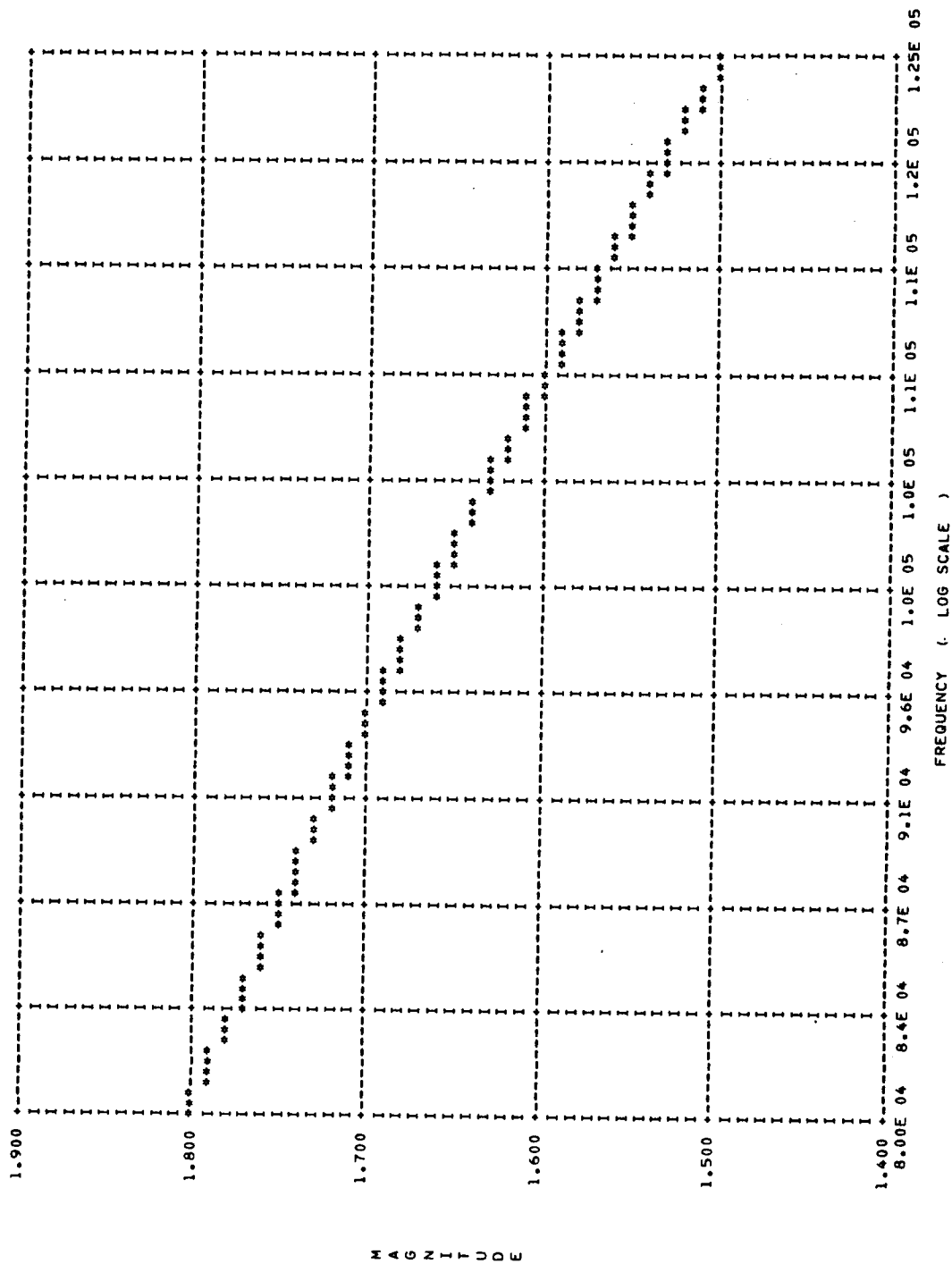
TABLE OF DATA PLOTTED, PARAMETER = FREQ

POINT	FREQUENCY	I	3 ***	MAG	ANGLE	I	4 ***	MAG	ANGLE	I	5 ***	MAG	ANGLE	B.V.	5 ***	MAG	ANGLE
1	8.0000E 04	1.800E-01	146.20	1.411E-03	143.63	1.411E-03	143.63	1.411E-03	143.63	1.411E-03	143.63	1.411E-03	143.63	6.811E-03	126.37	6.811E-03	126.37
2	8.0240E 04	1.799E-01	146.12	1.433E-03	143.52	1.433E-03	143.52	1.433E-03	143.52	1.433E-03	143.52	1.433E-03	143.52	6.897E-03	126.48	6.897E-03	126.48
3	8.0481E 04	1.797E-01	146.04	1.455E-03	143.41	1.455E-03	143.41	1.455E-03	143.41	1.455E-03	143.41	1.455E-03	143.41	6.986E-03	126.59	6.986E-03	126.59
4	8.0722E 04	1.795E-01	145.96	1.479E-03	143.29	1.479E-03	143.29	1.479E-03	143.29	1.479E-03	143.29	1.479E-03	143.29	7.076E-03	126.71	7.076E-03	126.71
5	8.0964E 04	1.794E-01	145.88	1.503E-03	143.17	1.503E-03	143.17	1.503E-03	143.17	1.503E-03	143.17	1.503E-03	143.17	7.169E-03	126.83	7.169E-03	126.83
6	8.1207E 04	1.792E-01	145.80	1.527E-03	143.05	1.527E-03	143.05	1.527E-03	143.05	1.527E-03	143.05	1.527E-03	143.05	7.265E-03	126.95	7.265E-03	126.95
7	8.1451E 04	1.790E-01	145.72	1.553E-03	142.93	1.553E-03	142.93	1.553E-03	142.93	1.553E-03	142.93	1.553E-03	142.93	7.364E-03	127.07	7.364E-03	127.07
8	8.1695E 04	1.789E-01	145.64	1.579E-03	142.81	1.579E-03	142.81	1.579E-03	142.81	1.579E-03	142.81	1.579E-03	142.81	7.465E-03	127.19	7.465E-03	127.19
9	8.1940E 04	1.787E-01	145.56	1.605E-03	142.69	1.605E-03	142.69	1.605E-03	142.69	1.605E-03	142.69	1.605E-03	142.69	7.569E-03	127.31	7.569E-03	127.31
10	8.2186E 04	1.785E-01	145.48	1.633E-03	142.57	1.633E-03	142.57	1.633E-03	142.57	1.633E-03	142.57	1.633E-03	142.57	7.676E-03	127.43	7.676E-03	127.43
11	8.2433E 04	1.783E-01	145.40	1.662E-03	142.44	1.662E-03	142.44	1.662E-03	142.44	1.662E-03	142.44	1.662E-03	142.44	7.786E-03	127.56	7.786E-03	127.56
12	8.2680E 04	1.782E-01	145.32	1.691E-03	142.31	1.691E-03	142.31	1.691E-03	142.31	1.691E-03	142.31	1.691E-03	142.31	7.900E-03	127.68	7.900E-03	127.68
13	8.2928E 04	1.780E-01	145.24	1.721E-03	142.19	1.721E-03	142.19	1.721E-03	142.19	1.721E-03	142.19	1.721E-03	142.19	8.017E-03	127.81	8.017E-03	127.81
14	8.3177E 04	1.778E-01	145.16	1.752E-03	142.06	1.752E-03	142.06	1.752E-03	142.06	1.752E-03	142.06	1.752E-03	142.06	8.138E-03	127.94	8.138E-03	127.94
15	8.3426E 04	1.777E-01	145.08	1.784E-03	141.93	1.784E-03	141.93	1.784E-03	141.93	1.784E-03	141.93	1.784E-03	141.93	8.263E-03	128.07	8.263E-03	128.07
16	8.3677E 04	1.775E-01	145.00	1.818E-03	141.79	1.818E-03	141.79	1.818E-03	141.79	1.818E-03	141.79	1.818E-03	141.79	8.392E-03	128.21	8.392E-03	128.21
17	8.3928E 04	1.773E-01	144.92	1.852E-03	141.66	1.852E-03	141.66	1.852E-03	141.66	1.852E-03	141.66	1.852E-03	141.66	8.525E-03	128.34	8.525E-03	128.34
18	8.4179E 04	1.771E-01	144.84	1.888E-03	141.52	1.888E-03	141.52	1.888E-03	141.52	1.888E-03	141.52	1.888E-03	141.52	8.662E-03	128.48	8.662E-03	128.48
19	8.4432E 04	1.770E-01	144.76	1.924E-03	141.38	1.924E-03	141.38	1.924E-03	141.38	1.924E-03	141.38	1.924E-03	141.38	8.804E-03	128.62	8.804E-03	128.62
20	8.4685E 04	1.768E-01	144.68	1.962E-03	141.24	1.962E-03	141.24	1.962E-03	141.24	1.962E-03	141.24	1.962E-03	141.24	8.951E-03	128.76	8.951E-03	128.76
21	8.4939E 04	1.766E-01	144.60	2.002E-03	141.10	2.002E-03	141.10	2.002E-03	141.10	2.002E-03	141.10	2.002E-03	141.10	9.103E-03	128.90	9.103E-03	128.90
22	8.5194E 04	1.764E-01	144.52	2.042E-03	140.95	2.042E-03	140.95	2.042E-03	140.95	2.042E-03	140.95	2.042E-03	140.95	9.261E-03	129.05	9.261E-03	129.05
23	8.5450E 04	1.762E-01	144.43	2.085E-03	140.81	2.085E-03	140.81	2.085E-03	140.81	2.085E-03	140.81	2.085E-03	140.81	9.424E-03	129.19	9.424E-03	129.19
24	8.5706E 04	1.761E-01	144.35	2.129E-03	140.66	2.129E-03	140.66	2.129E-03	140.66	2.129E-03	140.66	2.129E-03	140.66	9.594E-03	129.34	9.594E-03	129.34
25	8.5963E 04	1.759E-01	144.27	2.174E-03	140.50	2.174E-03	140.50	2.174E-03	140.50	2.174E-03	140.50	2.174E-03	140.50	9.770E-03	129.50	9.770E-03	129.50

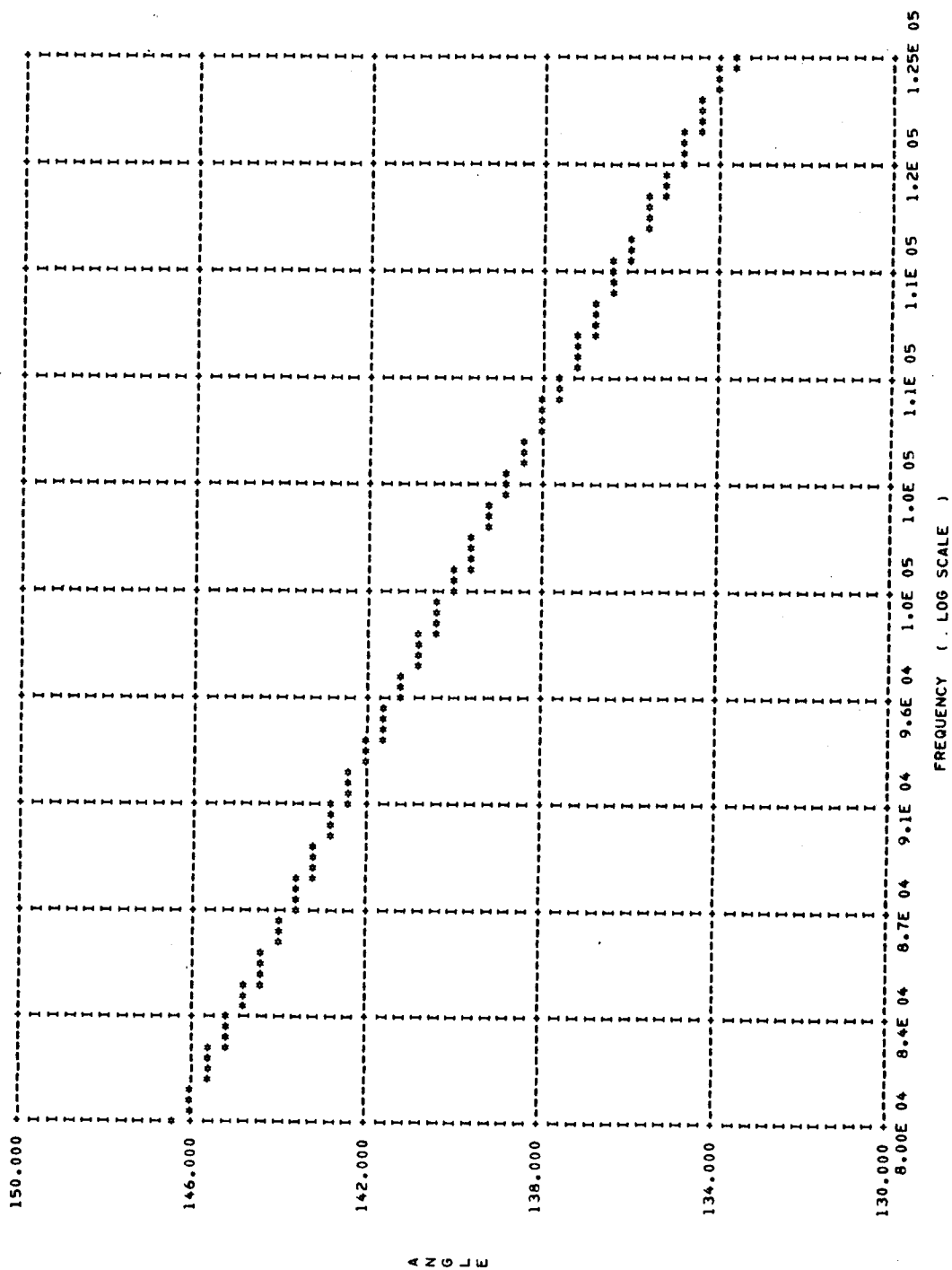
26	8.6221E 04	1.757E-01	144.19	2.221E-03	140.35	2.221E-03	-39.65	9.953E-03	-129.65
27	8.6480E 04	1.755E-01	144.11	2.271E-03	140.19	2.271E-03	-39.81	1.014E-02	-129.81
28	8.6739E 04	1.753E-01	144.03	2.322E-03	140.03	2.322E-03	-39.97	1.034E-02	-129.97
29	8.6999E 04	1.752E-01	143.95	2.375E-03	139.86	2.375E-03	-40.14	1.055E-02	-130.14
30	8.7260E 04	1.750E-01	143.86	2.431E-03	139.69	2.431E-03	-40.31	1.076E-02	-130.31
31	8.7522E 04	1.748E-01	143.78	2.489E-03	139.52	2.489E-03	-40.48	1.098E-02	-130.48
32	8.7785E 04	1.746E-01	143.70	2.549E-03	139.34	2.549E-03	-40.66	1.122E-02	-130.66
33	8.8048E 04	1.744E-01	143.62	2.612E-03	139.16	2.612E-03	-40.84	1.146E-02	-130.84
34	8.8312E 04	1.742E-01	143.54	2.679E-03	138.97	2.679E-03	-41.03	1.172E-02	-131.03
35	8.8577E 04	1.741E-01	143.45	2.748E-03	138.78	2.748E-03	-41.22	1.198E-02	-131.22
36	8.8843E 04	1.739E-01	143.37	2.821E-03	138.58	2.821E-03	-41.42	1.226E-02	-131.42
37	8.9109E 04	1.737E-01	143.29	2.897E-03	138.38	2.897E-03	-41.62	1.256E-02	-131.62
38	8.9377E 04	1.735E-01	143.21	2.977E-03	138.17	2.977E-03	-41.83	1.287E-02	-131.83
39	8.9645E 04	1.733E-01	143.13	3.061E-03	137.96	3.061E-03	-42.04	1.319E-02	-132.04
40	8.9914E 04	1.731E-01	143.04	3.150E-03	137.73	3.150E-03	-42.27	1.353E-02	-132.27
41	9.0184E 04	1.729E-01	142.96	3.244E-03	137.50	3.244E-03	-42.50	1.390E-02	-132.50
42	9.0454E 04	1.728E-01	142.88	3.343E-03	137.27	3.343E-03	-42.73	1.428E-02	-132.73
43	9.0725E 04	1.726E-01	142.80	3.448E-03	137.02	3.448E-03	-42.98	1.468E-02	-132.98
44	9.0998E 04	1.724E-01	142.71	3.559E-03	136.76	3.559E-03	-43.24	1.511E-02	-133.24
45	9.1271E 04	1.722E-01	142.63	3.677E-03	136.49	3.677E-03	-43.51	1.556E-02	-133.51
46	9.1544E 04	1.720E-01	142.55	3.802E-03	136.21	3.802E-03	-43.79	1.604E-02	-133.79
47	9.1819E 04	1.718E-01	142.46	3.936E-03	135.91	3.936E-03	-44.09	1.656E-02	-134.09
48	9.2095E 04	1.716E-01	142.38	4.079E-03	135.61	4.079E-03	-44.39	1.711E-02	-134.39
49	9.2371E 04	1.714E-01	142.30	4.232E-03	135.28	4.232E-03	-44.72	1.770E-02	-134.72
50	9.2648E 04	1.712E-01	142.22	4.396E-03	134.94	4.396E-03	-45.06	1.833E-02	-135.06
51	9.2926E 04	1.710E-01	142.13	4.572E-03	134.57	4.572E-03	-45.43	1.901E-02	-135.43
52	9.3205E 04	1.708E-01	142.05	4.762E-03	134.19	4.762E-03	-45.81	1.974E-02	-135.81
53	9.3484E 04	1.706E-01	141.97	4.968E-03	133.78	4.968E-03	-46.22	2.053E-02	-136.22
54	9.3765E 04	1.703E-01	141.88	5.191E-03	133.34	5.191E-03	-46.66	2.139E-02	-136.66
55	9.4046E 04	1.701E-01	141.80	5.434E-03	132.87	5.434E-03	-47.13	2.232E-02	-137.13
56	9.4328E 04	1.701E-01	141.72	5.699E-03	132.37	5.699E-03	-47.63	2.334E-02	-137.63
57	9.4611E 04	1.699E-01	141.63	5.990E-03	131.82	5.990E-03	-48.18	2.446E-02	-138.18
58	9.4895E 04	1.697E-01	141.55	6.311E-03	131.23	6.311E-03	-48.77	2.569E-02	-138.77
59	9.5180E 04	1.695E-01	141.46	6.665E-03	130.58	6.665E-03	-49.42	2.705E-02	-139.42
60	9.5465E 04	1.693E-01	141.38	7.060E-03	129.86	7.060E-03	-50.14	2.857E-02	-140.14
61	9.5752E 04	1.691E-01	141.30	7.501E-03	129.07	7.501E-03	-50.93	3.026E-02	-140.93
62	9.6039E 04	1.689E-01	141.21	7.998E-03	128.18	7.998E-03	-51.82	3.217E-02	-141.82
63	9.6327E 04	1.687E-01	141.13	8.560E-03	127.19	8.560E-03	-52.81	3.433E-02	-142.81
64	9.6616E 04	1.685E-01	141.05	9.203E-03	126.07	9.203E-03	-53.93	3.679E-02	-143.93
65	9.6906E 04	1.683E-01	140.96	9.942E-03	124.78	9.942E-03	-55.22	3.963E-02	-145.22
66	9.7197E 04	1.681E-01	140.88	1.080E-02	123.28	1.080E-02	-56.72	4.293E-02	-146.72
67	9.7488E 04	1.679E-01	140.79	1.181E-02	121.53	1.181E-02	-58.47	4.680E-02	-148.47
68	9.7781E 04	1.677E-01	140.71	1.301E-02	119.44	1.301E-02	-60.56	5.138E-02	-150.56
69	9.8074E 04	1.675E-01	140.63	1.444E-02	116.92	1.444E-02	-63.08	5.689E-02	-153.08
70	9.8368E 04	1.673E-01	140.54	1.619E-02	113.81	1.619E-02	-66.19	6.357E-02	-156.19
71	9.8663E 04	1.671E-01	140.46	1.833E-02	109.90	1.833E-02	-70.10	7.176E-02	-160.10
72	9.8959E 04	1.669E-01	140.37	2.097E-02	104.87	2.097E-02	-75.13	8.187E-02	-165.13
73	9.9256E 04	1.667E-01	140.29	2.421E-02	98.28	2.421E-02	-81.72	9.424E-02	-171.72
74	9.9554E 04	1.665E-01	140.20	2.805E-02	89.50	2.805E-02	-90.50	1.089E-01	-179.50
75	9.9853E 04	1.663E-01	140.12	3.213E-02	77.89	3.213E-02	-102.11	1.243E-01	-167.89
76	1.0015E 05	1.660E-01	140.04	3.541E-02	63.25	3.541E-02	-116.75	1.366E-01	-153.25
77	1.0045E 05	1.658E-01	139.95	3.638E-02	46.69	3.638E-02	-133.31	1.399E-01	-136.69
78	1.0075E 05	1.656E-01	139.87	3.446E-02	30.64	3.446E-02	-149.36	1.321E-01	-120.64
79	1.0106E 05	1.654E-01	139.78	3.079E-02	17.14	3.079E-02	-162.86	1.177E-01	-107.14
80	1.0136E 05	1.652E-01	139.70	2.679E-02	6.70	2.679E-02	-173.30	1.021E-01	-96.70
81	1.0166E 05	1.650E-01	139.62	2.321E-02	-1.14	2.321E-02	-178.86	8.820E-02	-88.86
82	1.0197E 05	1.648E-01	139.53	2.024E-02	-7.06	2.024E-02	-172.94	6.732E-02	-78.94
83	1.0227E 05	1.646E-01	139.45	1.782E-02	-11.61	1.782E-02	-168.39	6.732E-02	-78.39
84	1.0258E 05	1.644E-01	139.36	1.586E-02	-15.17	1.586E-02	-164.83	5.972E-02	-74.83
85	1.0289E 05	1.642E-01	139.28	1.425E-02	-18.03	1.425E-02	-161.97	5.351E-02	-71.97
86	1.0320E 05	1.640E-01	139.19	1.292E-02	-20.37	1.292E-02	-159.63	4.838E-02	-69.63

87	1.0351E 05	1.638E-01	139.11	1.181E-02	-22.32	1.181E-02	157.68	4.408E-02	67.68
88	1.0382E 05	1.636E-01	139.02	1.087E-02	-23.96	1.087E-02	156.04	4.044E-02	66.04
89	1.0413E 05	1.634E-01	138.93	1.006E-02	-25.37	1.006E-02	154.63	3.733E-02	64.63
90	1.0444E 05	1.631E-01	138.85	9.365E-03	-26.60	9.365E-03	153.40	3.464E-02	63.40
91	1.0475E 05	1.629E-01	138.76	8.758E-03	-27.67	8.758E-03	152.33	3.230E-02	62.33
92	1.0507E 05	1.627E-01	138.68	8.224E-03	-28.62	8.224E-03	151.38	3.024E-02	61.38
93	1.0538E 05	1.625E-01	138.59	7.751E-03	-29.46	7.751E-03	150.54	2.841E-02	60.54
94	1.0570E 05	1.623E-01	138.51	7.330E-03	-30.22	7.330E-03	149.78	2.679E-02	59.78
95	1.0602E 05	1.621E-01	138.42	6.953E-03	-30.91	6.953E-03	149.09	2.533E-02	59.09
96	1.0634E 05	1.619E-01	138.34	6.613E-03	-31.54	6.613E-03	148.46	2.402E-02	58.46
97	1.0665E 05	1.616E-01	138.25	6.305E-03	-32.12	6.305E-03	147.88	2.284E-02	57.88
98	1.0697E 05	1.614E-01	138.17	6.025E-03	-32.65	6.025E-03	147.35	2.176E-02	57.35
99	1.0730E 05	1.612E-01	138.08	5.769E-03	-33.15	5.769E-03	146.85	2.077E-02	56.85
100	1.0762E 05	1.610E-01	138.00	5.534E-03	-33.60	5.534E-03	146.40	1.987E-02	56.40
101	1.0794E 05	1.608E-01	137.91	5.319E-03	-34.03	5.319E-03	145.97	1.903E-02	55.97
102	1.0826E 05	1.606E-01	137.83	5.120E-03	-34.43	5.120E-03	145.57	1.827E-02	55.57
103	1.0859E 05	1.604E-01	137.74	4.935E-03	-34.81	4.935E-03	145.19	1.756E-02	55.19
104	1.0891E 05	1.601E-01	137.66	4.764E-03	-35.17	4.764E-03	144.83	1.690E-02	54.83
105	1.0924E 05	1.599E-01	137.57	4.605E-03	-35.51	4.605E-03	144.49	1.628E-02	54.49
106	1.0957E 05	1.597E-01	137.48	4.456E-03	-35.83	4.456E-03	144.17	1.571E-02	54.17
107	1.0990E 05	1.595E-01	137.40	4.317E-03	-36.13	4.317E-03	143.87	1.517E-02	53.87
108	1.1023E 05	1.593E-01	137.31	4.187E-03	-36.43	4.187E-03	143.57	1.467E-02	53.57
109	1.1056E 05	1.590E-01	137.23	4.064E-03	-36.71	4.064E-03	143.29	1.420E-02	53.29
110	1.1089E 05	1.588E-01	137.14	3.949E-03	-36.97	3.949E-03	143.03	1.376E-02	53.03
111	1.1122E 05	1.586E-01	137.06	3.841E-03	-37.23	3.841E-03	142.77	1.334E-02	52.77
112	1.1156E 05	1.584E-01	136.97	3.738E-03	-37.48	3.738E-03	142.52	1.294E-02	52.52
113	1.1189E 05	1.582E-01	136.89	3.641E-03	-37.72	3.641E-03	142.28	1.257E-02	52.28
114	1.1223E 05	1.579E-01	136.80	3.549E-03	-37.95	3.549E-03	142.05	1.222E-02	52.05
115	1.1256E 05	1.577E-01	136.71	3.462E-03	-38.17	3.462E-03	141.83	1.188E-02	51.83
116	1.1290E 05	1.575E-01	136.63	3.380E-03	-38.39	3.380E-03	141.61	1.156E-02	51.61
117	1.1324E 05	1.573E-01	136.54	3.301E-03	-38.60	3.301E-03	141.40	1.126E-02	51.40
118	1.1358E 05	1.570E-01	136.46	3.226E-03	-38.80	3.226E-03	141.20	1.097E-02	51.20
119	1.1392E 05	1.568E-01	136.37	3.155E-03	-39.00	3.155E-03	141.00	1.070E-02	51.00
120	1.1426E 05	1.566E-01	136.29	3.087E-03	-39.19	3.087E-03	140.81	1.044E-02	50.81
121	1.1460E 05	1.564E-01	136.20	3.022E-03	-39.38	3.022E-03	140.62	1.018E-02	50.62
122	1.1495E 05	1.562E-01	136.11	2.959E-03	-39.56	2.959E-03	140.44	9.945E-03	50.44
123	1.1529E 05	1.559E-01	136.03	2.900E-03	-39.74	2.900E-03	140.26	9.716E-03	50.26
124	1.1564E 05	1.557E-01	135.94	2.843E-03	-39.92	2.843E-03	140.08	9.496E-03	50.08
125	1.1599E 05	1.555E-01	135.86	2.788E-03	-40.09	2.788E-03	139.91	9.285E-03	49.91
126	1.1633E 05	1.552E-01	135.77	2.735E-03	-40.26	2.735E-03	139.74	9.082E-03	49.74
127	1.1668E 05	1.550E-01	135.69	2.685E-03	-40.42	2.685E-03	139.58	8.888E-03	49.58
128	1.1703E 05	1.548E-01	135.60	2.636E-03	-40.59	2.636E-03	139.41	8.701E-03	49.41
129	1.1738E 05	1.546E-01	135.51	2.589E-03	-40.74	2.589E-03	139.26	8.521E-03	49.26
130	1.1774E 05	1.543E-01	135.43	2.544E-03	-40.90	2.544E-03	139.10	8.348E-03	49.10
131	1.1809E 05	1.541E-01	135.34	2.501E-03	-41.06	2.501E-03	138.94	8.181E-03	48.94
132	1.1844E 05	1.539E-01	135.26	2.459E-03	-41.21	2.459E-03	138.79	8.021E-03	48.79
133	1.1880E 05	1.537E-01	135.17	2.419E-03	-41.36	2.419E-03	138.64	7.865E-03	48.64
134	1.1916E 05	1.534E-01	135.08	2.380E-03	-41.50	2.380E-03	138.50	7.715E-03	48.50
135	1.1951E 05	1.532E-01	135.00	2.342E-03	-41.65	2.342E-03	138.35	7.571E-03	48.35
136	1.1987E 05	1.530E-01	134.91	2.306E-03	-41.79	2.306E-03	138.21	7.431E-03	48.21
137	1.2023E 05	1.527E-01	134.83	2.271E-03	-41.93	2.271E-03	138.07	7.295E-03	48.07
138	1.2059E 05	1.525E-01	134.74	2.237E-03	-42.07	2.237E-03	137.93	7.165E-03	47.93
139	1.2095E 05	1.523E-01	134.66	2.204E-03	-42.21	2.204E-03	137.79	7.038E-03	47.79
140	1.2132E 05	1.520E-01	134.57	2.172E-03	-42.34	2.172E-03	137.66	6.915E-03	47.66
141	1.2168E 05	1.518E-01	134.48	2.141E-03	-42.48	2.141E-03	137.52	6.796E-03	47.52
142	1.2205E 05	1.516E-01	134.40	2.111E-03	-42.61	2.111E-03	137.39	6.680E-03	47.39
143	1.2241E 05	1.514E-01	134.31	2.081E-03	-42.74	2.081E-03	137.26	6.568E-03	47.26
144	1.2278E 05	1.511E-01	134.23	2.053E-03	-42.87	2.053E-03	137.13	6.460E-03	47.13
145	1.2315E 05	1.509E-01	134.14	2.026E-03	-43.00	2.026E-03	137.00	6.354E-03	47.00
146	1.2352E 05	1.507E-01	134.06	1.999E-03	-43.13	1.999E-03	136.87	6.252E-03	46.87
147	1.2389E 05	1.504E-01	133.97	1.973E-03	-43.26	1.973E-03	136.74	6.152E-03	46.74

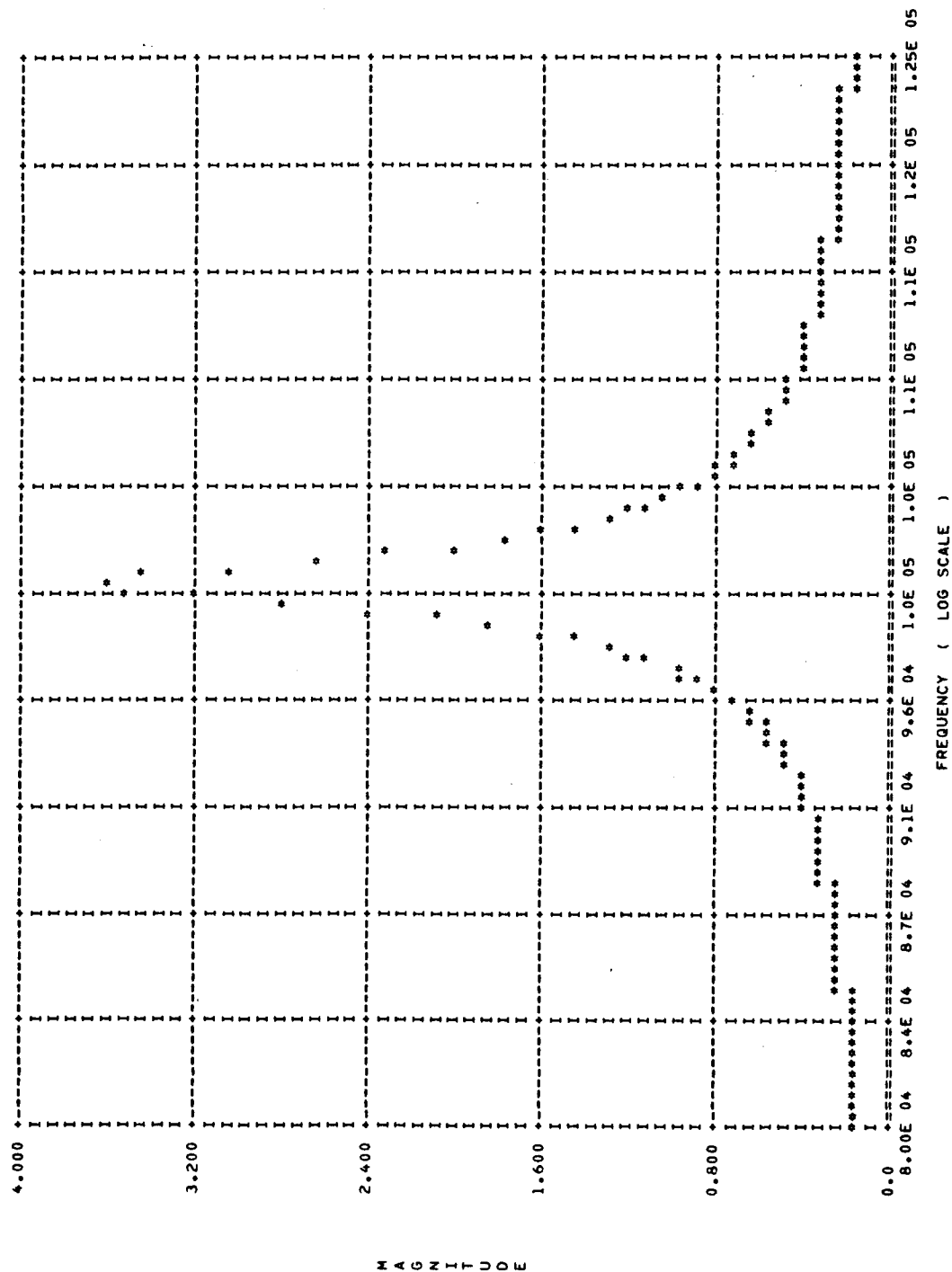
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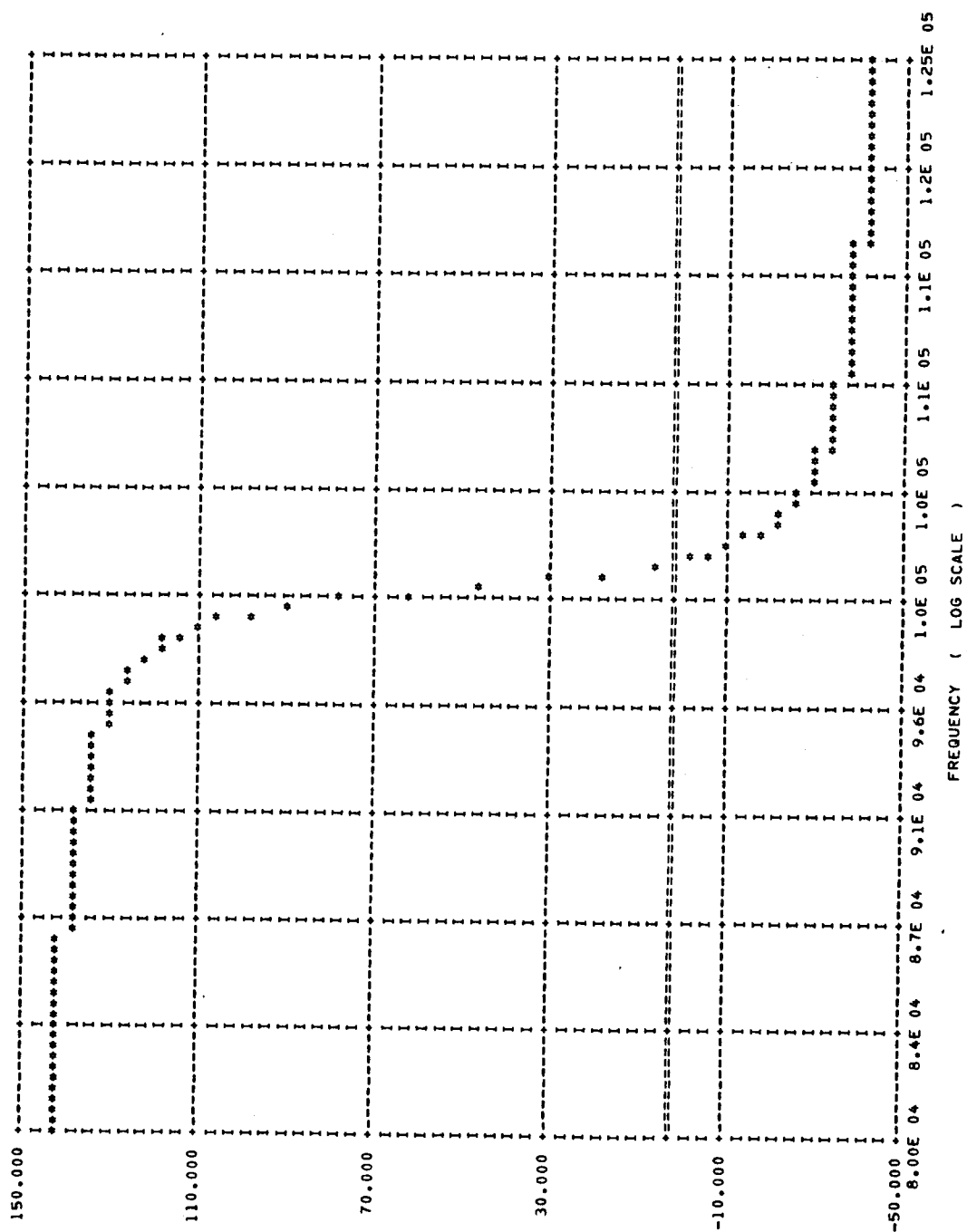
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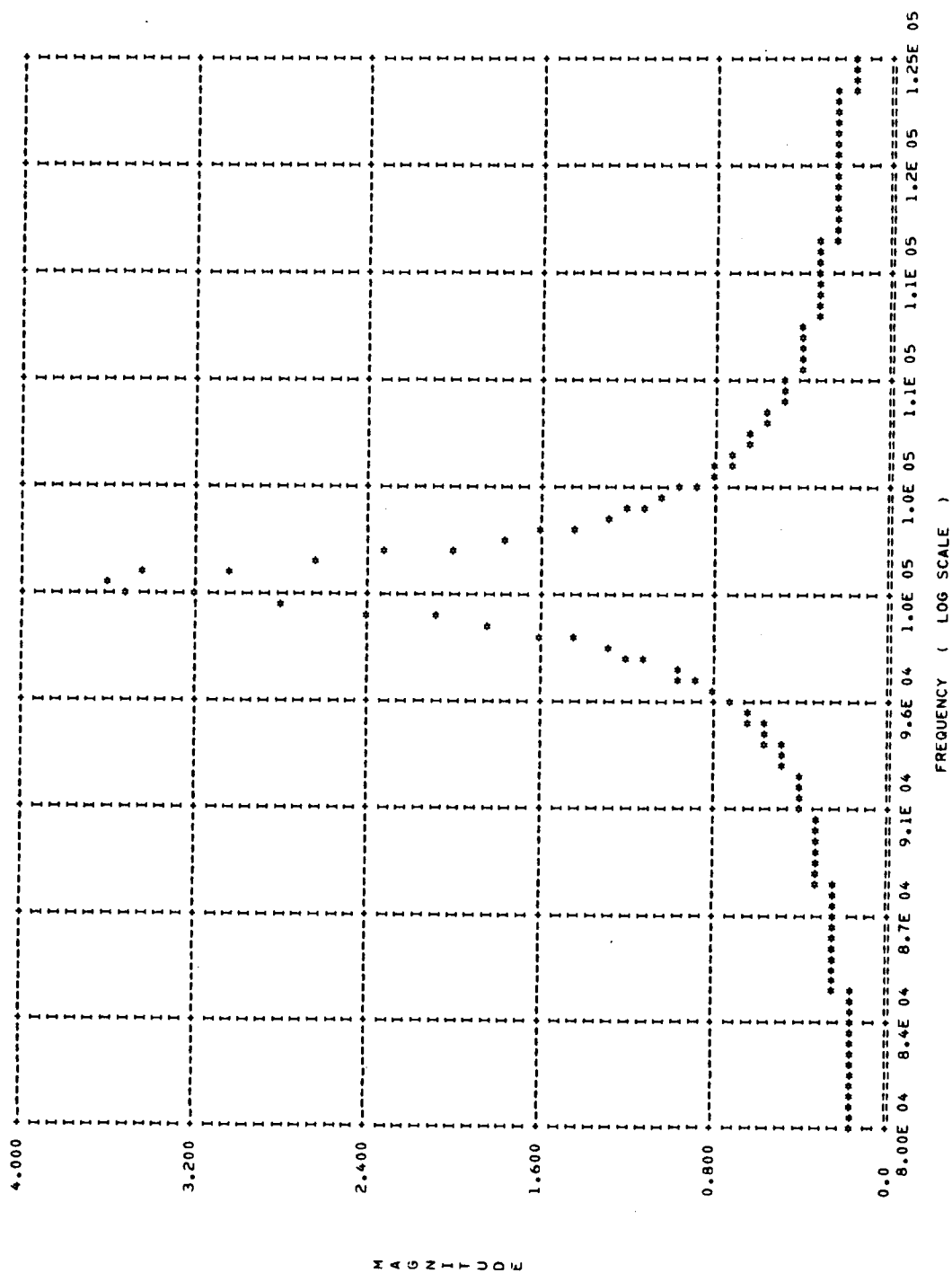
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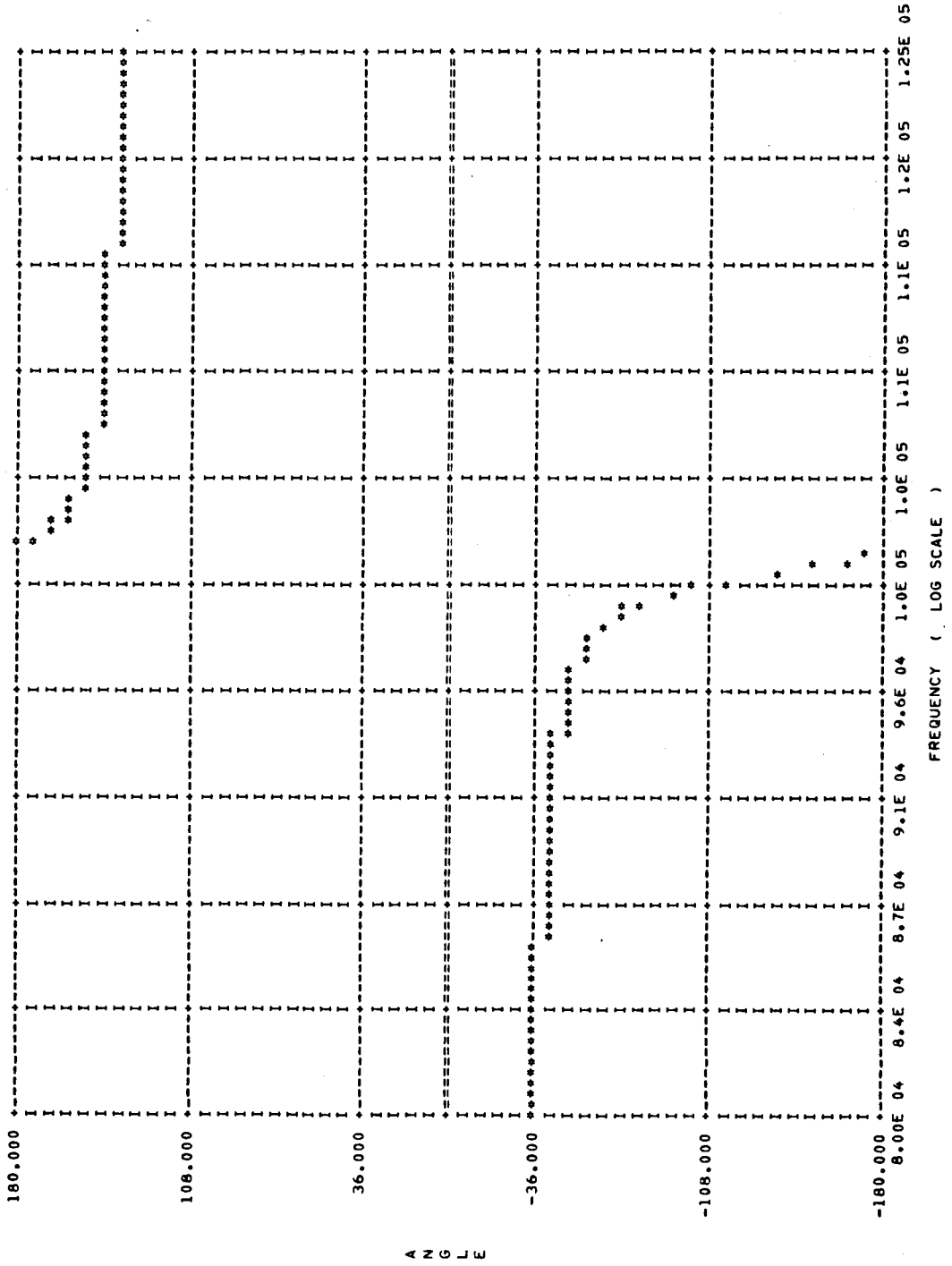
PLOT OF I 4 VERSUS FREQ

A
N
G
L
E

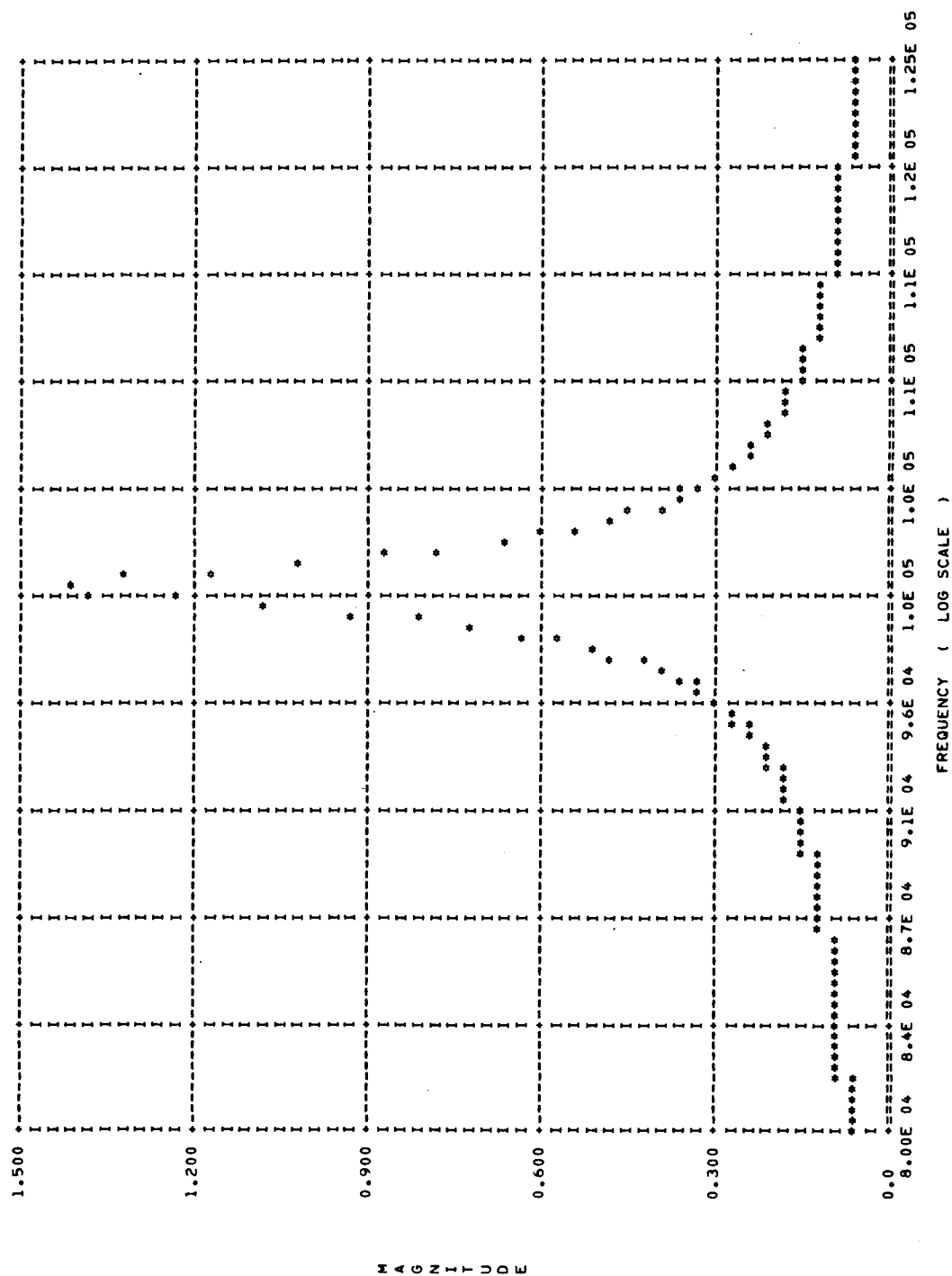
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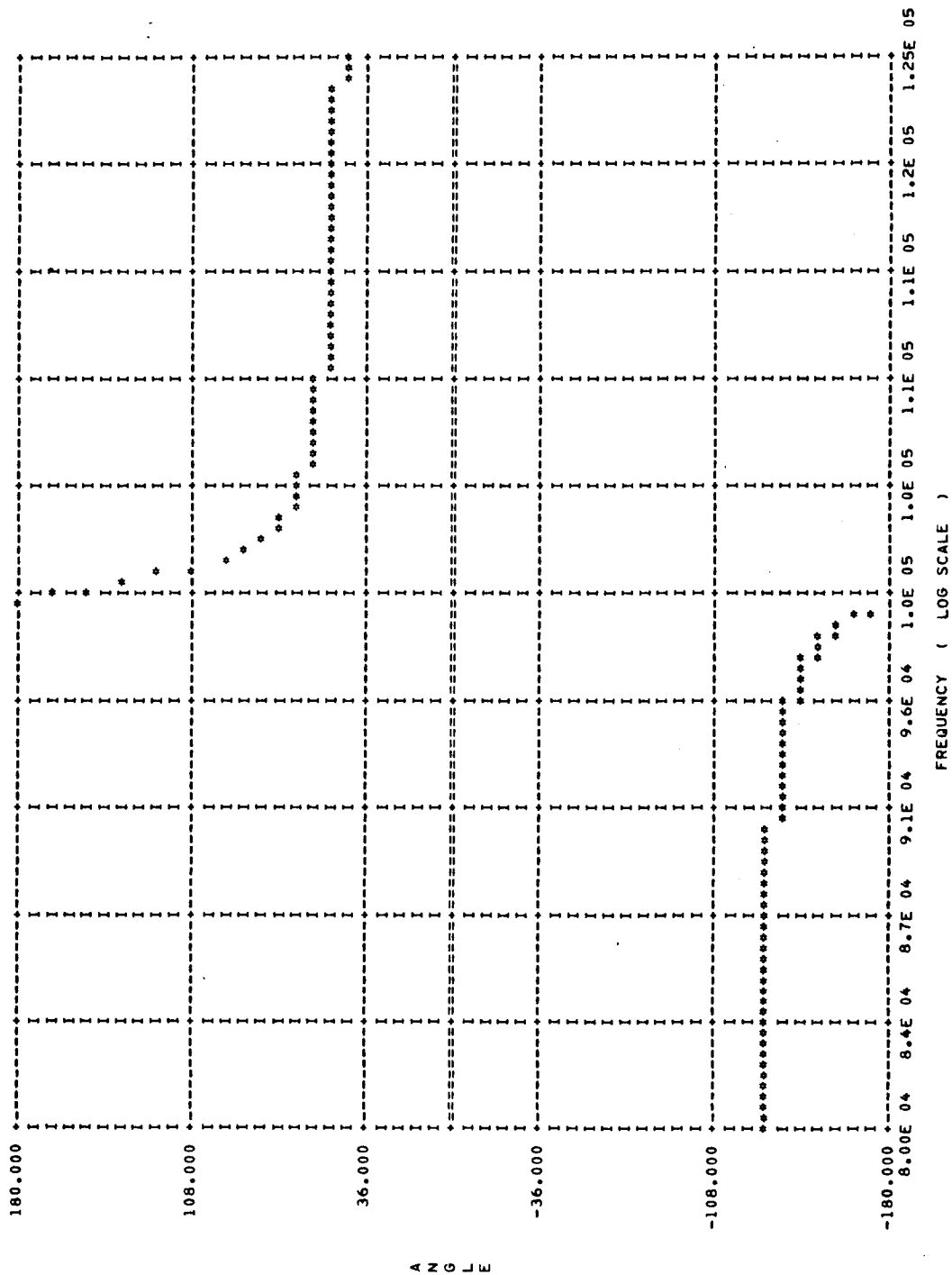
PLOT OF I S VERSUS FREQ



PLOT OF B.V. 5. SF = 10**(-1), VERSUS FREQ



PLOT OF B.V. 5 VERSUS FREQ



END

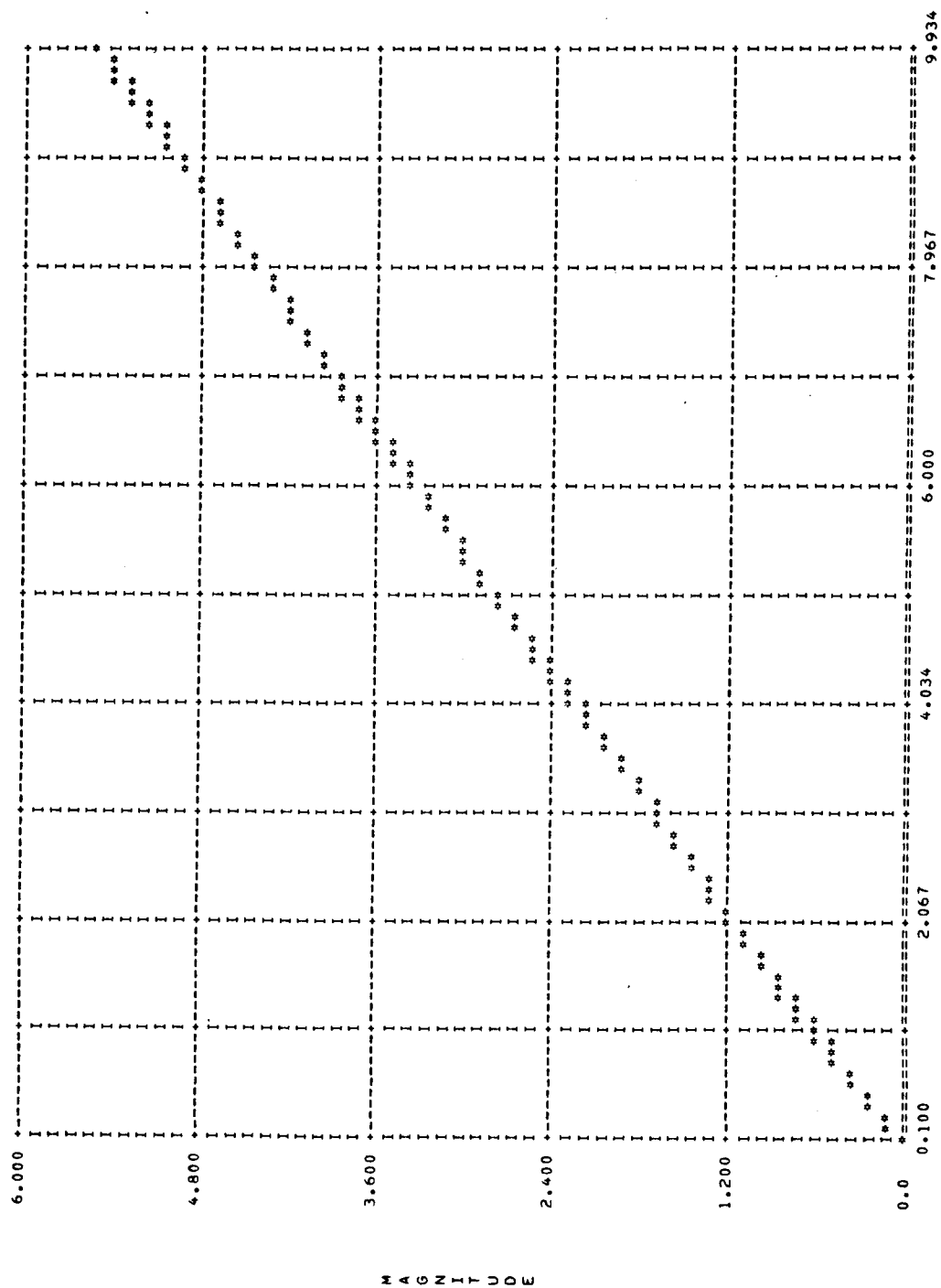
EXECUTION TIME = 6.383 SEC

POINT	PARAMETER	N.V. 7 *** MAG	ANGLE
1	1.0000E-09	5.533E-03	24.23
2	1.6600E-09	9.185E-03	24.23
3	2.3200E-09	1.284E-02	24.23
4	2.9800E-09	1.649E-02	24.23
5	3.6400E-09	2.014E-02	24.23
6	4.3000E-09	2.379E-02	24.23
7	4.9600E-09	2.745E-02	24.23
8	5.6200E-09	3.110E-02	24.23
9	6.2800E-09	3.475E-02	24.23
10	6.9400E-09	3.840E-02	24.23
11	7.6000E-09	4.205E-02	24.23
12	8.2600E-09	4.571E-02	24.23
13	8.9200E-09	4.936E-02	24.23
14	9.5800E-09	5.301E-02	24.23
15	1.0240E-08	5.666E-02	24.23
16	1.0900E-08	6.031E-02	24.23
17	1.1560E-08	6.397E-02	24.23
18	1.2220E-08	6.762E-02	24.23
19	1.2880E-08	7.127E-02	24.23
20	1.3540E-08	7.492E-02	24.23
21	1.4200E-08	7.857E-02	24.23
22	1.4860E-08	8.223E-02	24.23
23	1.5520E-08	8.588E-02	24.23
24	1.6180E-08	8.953E-02	24.23
25	1.6840E-08	9.318E-02	24.23
26	1.7500E-08	9.683E-02	24.23
27	1.8160E-08	1.005E-01	24.23
28	1.8820E-08	1.041E-01	24.23
29	1.9480E-08	1.078E-01	24.23
30	2.0140E-08	1.114E-01	24.23
31	2.0800E-08	1.151E-01	24.23
32	2.1460E-08	1.187E-01	24.23
33	2.2120E-08	1.224E-01	24.23
34	2.2780E-08	1.260E-01	24.23
35	2.3440E-08	1.297E-01	24.23
36	2.4100E-08	1.334E-01	24.23
37	2.4760E-08	1.370E-01	24.23
38	2.5420E-08	1.407E-01	24.23
39	2.6080E-08	1.443E-01	24.23
40	2.6740E-08	1.480E-01	24.23
41	2.7400E-08	1.516E-01	24.23
42	2.8060E-08	1.553E-01	24.23
43	2.8720E-08	1.589E-01	24.23
44	2.9380E-08	1.626E-01	24.23
45	3.0040E-08	1.662E-01	24.23
46	3.0700E-08	1.699E-01	24.23
47	3.1360E-08	1.735E-01	24.23
48	3.2020E-08	1.772E-01	24.23
49	3.2680E-08	1.808E-01	24.23
50	3.3340E-08	1.845E-01	24.23
51	3.4000E-08	1.881E-01	24.23
52	3.4660E-08	1.918E-01	24.23
53	3.5320E-08	1.954E-01	24.23
54	3.5980E-08	1.991E-01	24.23
55	3.6640E-08	2.027E-01	24.23

56	3.7300E-08	2.064E-01	24.23
57	3.7960E-08	2.100E-01	24.23
58	3.8620E-08	2.137E-01	24.23
59	3.9280E-08	2.173E-01	24.23
60	3.9940E-08	2.210E-01	24.23
61	4.0600E-08	2.247E-01	24.23
62	4.1260E-08	2.283E-01	24.23
63	4.1920E-08	2.320E-01	24.23
64	4.2580E-08	2.356E-01	24.23
65	4.3240E-08	2.393E-01	24.23
66	4.3900E-08	2.429E-01	24.23
67	4.4560E-08	2.466E-01	24.23
68	4.5220E-08	2.502E-01	24.23
69	4.5880E-08	2.539E-01	24.23
70	4.6540E-08	2.575E-01	24.23
71	4.7200E-08	2.612E-01	24.23
72	4.7860E-08	2.648E-01	24.23
73	4.8520E-08	2.685E-01	24.23
74	4.9180E-08	2.721E-01	24.23
75	4.9840E-08	2.758E-01	24.23
76	5.0500E-08	2.794E-01	24.23
77	5.1160E-08	2.831E-01	24.23
78	5.1820E-08	2.867E-01	24.23
79	5.2480E-08	2.904E-01	24.23
80	5.3140E-08	2.940E-01	24.23
81	5.3800E-08	2.977E-01	24.23
82	5.4460E-08	3.013E-01	24.23
83	5.5120E-08	3.050E-01	24.23
84	5.5780E-08	3.086E-01	24.23
85	5.6440E-08	3.123E-01	24.23
86	5.7100E-08	3.159E-01	24.23
87	5.7760E-08	3.196E-01	24.23
88	5.8420E-08	3.233E-01	24.23
89	5.9080E-08	3.269E-01	24.23
90	5.9740E-08	3.306E-01	24.23
91	6.0400E-08	3.342E-01	24.23
92	6.1060E-08	3.379E-01	24.23
93	6.1720E-08	3.415E-01	24.23
94	6.2380E-08	3.452E-01	24.23
95	6.3040E-08	3.488E-01	24.23
96	6.3700E-08	3.525E-01	24.23
97	6.4360E-08	3.561E-01	24.23
98	6.5020E-08	3.598E-01	24.23
99	6.5680E-08	3.634E-01	24.23
100	6.6340E-08	3.671E-01	24.23
101	6.7000E-08	3.707E-01	24.23
102	6.7660E-08	3.744E-01	24.23
103	6.8320E-08	3.780E-01	24.22
104	6.8980E-08	3.817E-01	24.22
105	6.9640E-08	3.853E-01	24.22
106	7.0300E-08	3.890E-01	24.22
107	7.0960E-08	3.926E-01	24.22
108	7.1620E-08	3.963E-01	24.22
109	7.2280E-08	3.999E-01	24.22
110	7.2940E-08	4.036E-01	24.22
111	7.3600E-08	4.072E-01	24.22
112	7.4260E-08	4.109E-01	24.22
113	7.4920E-08	4.145E-01	24.22
114	7.5580E-08	4.182E-01	24.22
115	7.6240E-08	4.218E-01	24.22
116	7.6900E-08	4.255E-01	24.22

117	7.7560E-08	4.292E-01	24.22
118	7.8220E-08	4.328E-01	24.22
119	7.8880E-08	4.365E-01	24.22
120	7.9540E-08	4.401E-01	24.22
121	8.0200E-08	4.438E-01	24.22
122	8.0860E-08	4.474E-01	24.22
123	8.1520E-08	4.511E-01	24.22
124	8.2180E-08	4.547E-01	24.22
125	8.2840E-08	4.584E-01	24.22
126	8.3500E-08	4.620E-01	24.22
127	8.4160E-08	4.657E-01	24.22
128	8.4820E-08	4.693E-01	24.22
129	8.5480E-08	4.730E-01	24.22
130	8.6140E-08	4.766E-01	24.22
131	8.6800E-08	4.803E-01	24.22
132	8.7460E-08	4.839E-01	24.22
133	8.8120E-08	4.876E-01	24.22
134	8.8780E-08	4.912E-01	24.22
135	8.9440E-08	4.949E-01	24.22
136	9.0100E-08	4.985E-01	24.22
137	9.0760E-08	5.022E-01	24.22
138	9.1420E-08	5.058E-01	24.22
139	9.2080E-08	5.095E-01	24.22
140	9.2740E-08	5.131E-01	24.22
141	9.3400E-08	5.168E-01	24.22
142	9.4060E-08	5.204E-01	24.22
143	9.4720E-08	5.241E-01	24.22
144	9.5380E-08	5.277E-01	24.22
145	9.6040E-08	5.314E-01	24.22
146	9.6700E-08	5.350E-01	24.22
147	9.7360E-08	5.387E-01	24.22
148	9.8020E-08	5.423E-01	24.22
149	9.8680E-08	5.460E-01	24.22
150	9.9340E-08	5.496E-01	24.22
151	1.0000E-07	5.533E-01	24.22

PLOT OF N.V. 7, SF = 10**(-1), VERSUS LM



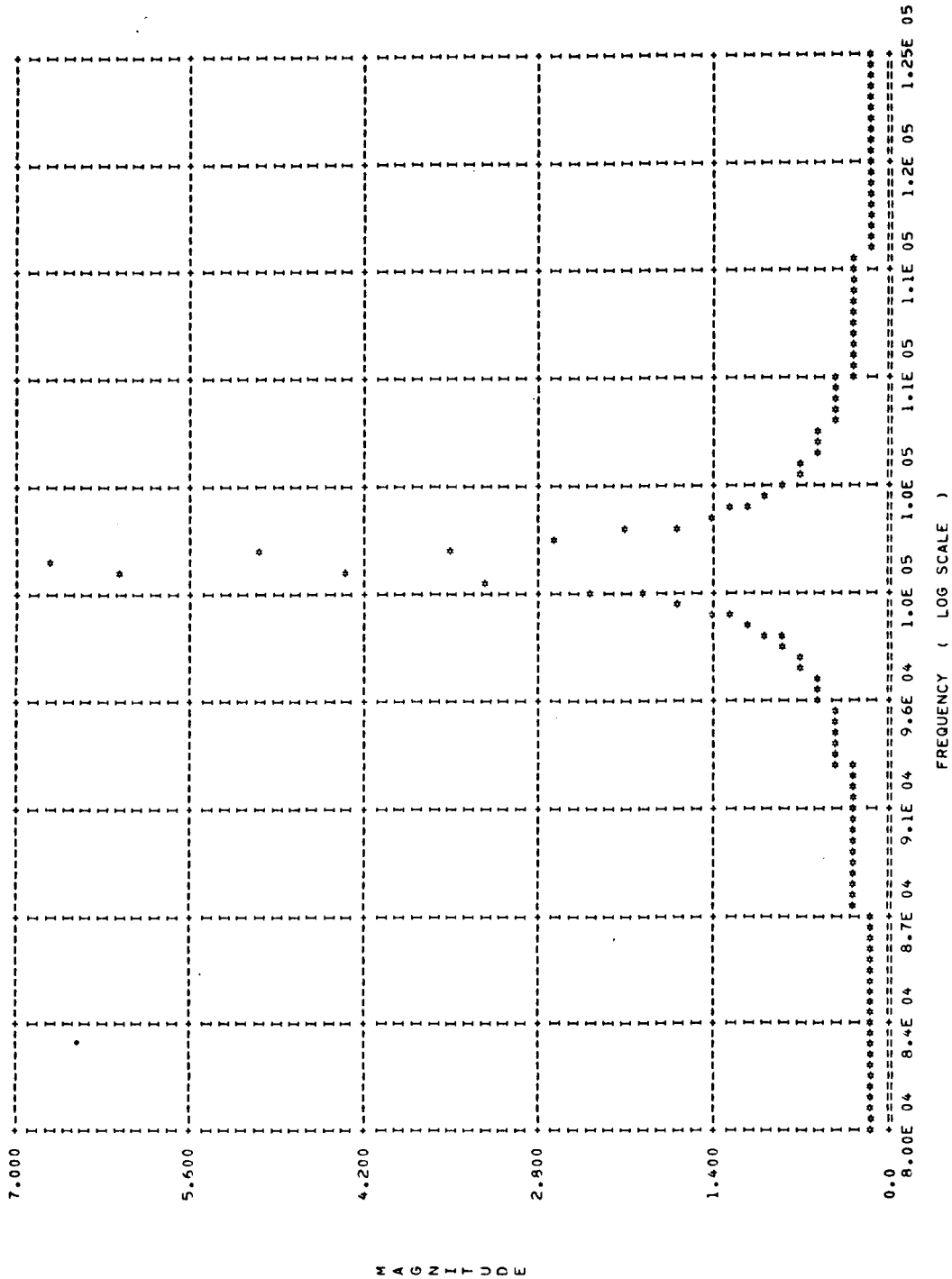
PARAMETER, SCALE FACTOR = 10**(-8)

POINT	FREQUENCY	N.V. MAG	7 *** ANGLE
1	8.0000E 04	1.309E-03	55.20
2	8.0240E 04	1.325E-03	55.11
3	8.0481E 04	1.342E-03	55.02
4	8.0722E 04	1.358E-03	54.93
5	8.0964E 04	1.376E-03	54.83
6	8.1207E 04	1.393E-03	54.74
7	8.1451E 04	1.411E-03	54.64
8	8.1695E 04	1.430E-03	54.55
9	8.1940E 04	1.448E-03	54.45
10	8.2186E 04	1.469E-03	54.36
11	8.2433E 04	1.489E-03	54.26
12	8.2680E 04	1.510E-03	54.16
13	8.2928E 04	1.531E-03	54.06
14	8.3177E 04	1.554E-03	53.96
15	8.3426E 04	1.576E-03	53.87
16	8.3677E 04	1.600E-03	53.77
17	8.3928E 04	1.624E-03	53.66
18	8.4179E 04	1.649E-03	53.56
19	8.4432E 04	1.675E-03	53.46
20	8.4685E 04	1.701E-03	53.36
21	8.4939E 04	1.729E-03	53.25
22	8.5194E 04	1.757E-03	53.15
23	8.5450E 04	1.787E-03	53.04
24	8.5706E 04	1.817E-03	52.94
25	8.5963E 04	1.849E-03	52.83
26	8.6221E 04	1.882E-03	52.72
27	8.6480E 04	1.915E-03	52.61
28	8.6739E 04	1.951E-03	52.50
29	8.6999E 04	1.988E-03	52.39
30	8.7260E 04	2.026E-03	52.28
31	8.7522E 04	2.066E-03	52.16
32	8.7785E 04	2.107E-03	52.05
33	8.8048E 04	2.150E-03	51.93
34	8.8312E 04	2.195E-03	51.81
35	8.8577E 04	2.242E-03	51.69
36	8.8843E 04	2.291E-03	51.57
38	8.9377E 04	2.397E-03	51.31
39	8.9645E 04	2.453E-03	51.18
40	8.9914E 04	2.513E-03	51.05
41	9.0184E 04	2.575E-03	50.92
42	9.0454E 04	2.641E-03	50.78
43	9.0725E 04	2.710E-03	50.64
44	9.0998E 04	2.783E-03	50.50
45	9.1271E 04	2.860E-03	50.35
46	9.1544E 04	2.942E-03	50.20
47	9.1819E 04	3.029E-03	50.05
48	9.2095E 04	3.121E-03	49.89
49	9.2371E 04	3.219E-03	49.72
50	9.2648E 04	3.324E-03	49.55
51	9.2926E 04	3.436E-03	49.38
52	9.3205E 04	3.556E-03	49.19
53	9.3484E 04	3.685E-03	49.00
54	9.3765E 04	3.824E-03	48.81
55	9.4046E 04	3.974E-03	48.60

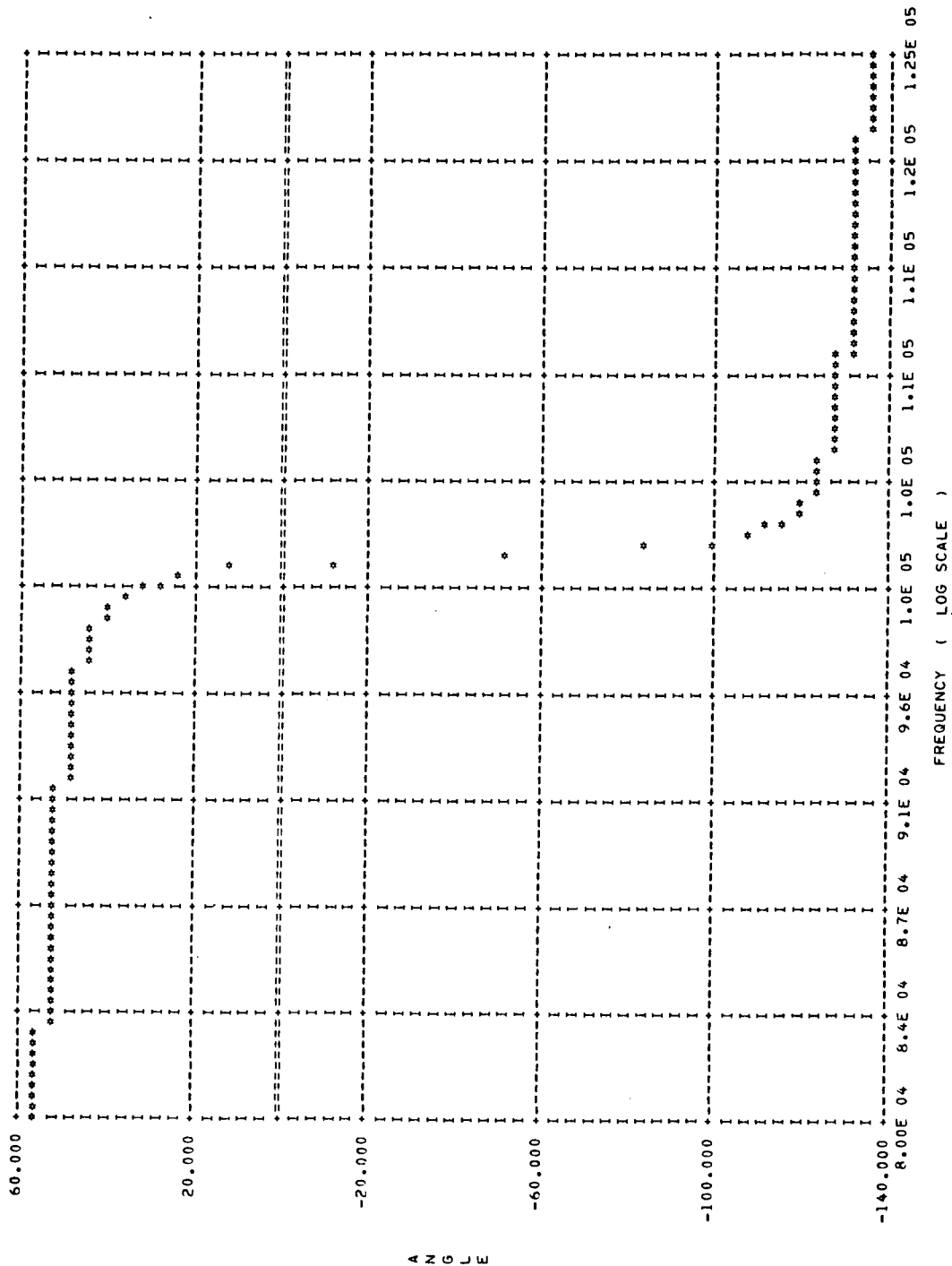
56	9.4328E 04	4.136E-03	48.38
57	9.4611E 04	4.313E-03	48.15
58	9.4895E 04	4.507E-03	47.90
59	9.5180E 04	4.718E-03	47.64
60	9.5465E 04	4.951E-03	47.37
61	9.5752E 04	5.209E-03	47.07
62	9.6039E 04	5.495E-03	46.75
63	9.6327E 04	5.816E-03	46.40
64	9.6616E 04	6.177E-03	46.01
65	9.6906E 04	6.586E-03	45.59
66	9.7197E 04	7.054E-03	45.11
67	9.7488E 04	7.595E-03	44.54
68	9.7781E 04	8.226E-03	43.97
69	9.8074E 04	8.973E-03	43.26
70	9.8368E 04	9.869E-03	42.42
71	9.8663E 04	1.096E-02	41.42
72	9.8959E 04	1.233E-02	40.18
73	9.9256E 04	1.409E-02	38.62
74	9.9554E 04	1.641E-02	36.55
75	9.9853E 04	1.963E-02	33.70
76	1.0015E 05	2.433E-02	29.51
77	1.0045E 05	3.165E-02	22.78
78	1.0075E 05	4.378E-02	10.83
79	1.0106E 05	6.179E-02	-13.59
80	1.0136E 05	6.740E-02	-52.81
81	1.0166E 05	5.011E-02	-83.77
82	1.0197E 05	3.541E-02	-99.53
83	1.0227E 05	2.653E-02	-107.86
84	1.0258E 05	2.100E-02	-112.84
85	1.0289E 05	1.730E-02	-116.12
86	1.0320E 05	1.457E-02	-118.44
87	1.0351E 05	1.272E-02	-120.18
88	1.0382E 05	1.122E-02	-121.53
89	1.0413E 05	1.003E-02	-122.62
90	1.0444E 05	9.062E-03	-123.51
91	1.0475E 05	8.262E-03	-124.26
92	1.0507E 05	7.589E-03	-124.91
93	1.0538E 05	7.016E-03	-125.47
94	1.0570E 05	6.521E-03	-125.97
95	1.0602E 05	6.091E-03	-126.42
96	1.0634E 05	5.712E-03	-126.82
97	1.0665E 05	5.377E-03	-127.18
98	1.0697E 05	5.074E-03	-127.51
99	1.0730E 05	4.809E-03	-127.82
100	1.0762E 05	4.567E-03	-128.11
101	1.0794E 05	4.348E-03	-128.39
102	1.0826E 05	4.148E-03	-128.63
103	1.0859E 05	3.965E-03	-128.87
104	1.0891E 05	3.797E-03	-129.09
105	1.0924E 05	3.642E-03	-129.31
106	1.0957E 05	3.499E-03	-129.51
107	1.0990E 05	3.366E-03	-129.71
108	1.1023E 05	3.243E-03	-129.89
109	1.1056E 05	3.128E-03	-130.07
110	1.1089E 05	3.020E-03	-130.25
111	1.1122E 05	2.920E-03	-130.42
112	1.1156E 05	2.825E-03	-130.58
113	1.1189E 05	2.737E-03	-130.74
114	1.1223E 05	2.653E-03	-130.90
115	1.1256E 05	2.574E-03	-131.05
116	1.1290E 05	2.499E-03	-131.19

117	1.1324E 05	2.429E-03	-131.34
118	1.1358E 05	2.362E-03	-131.44
119	1.1392E 05	2.298E-03	-131.62
120	1.1426E 05	2.238E-03	-131.75
121	1.1460E 05	2.180E-03	-131.89
122	1.1495E 05	2.126E-03	-132.02
123	1.1529E 05	2.073E-03	-132.15
124	1.1564E 05	2.023E-03	-132.27
125	1.1599E 05	1.976E-03	-132.40
126	1.1633E 05	1.930E-03	-132.52
127	1.1668E 05	1.886E-03	-132.65
128	1.1703E 05	1.844E-03	-132.77
129	1.1738E 05	1.804E-03	-132.89
130	1.1774E 05	1.765E-03	-133.00
131	1.1809E 05	1.728E-03	-133.12
132	1.1844E 05	1.692E-03	-133.24
133	1.1880E 05	1.658E-03	-133.35
134	1.1916E 05	1.625E-03	-133.44
135	1.1951E 05	1.593E-03	-133.58
136	1.1987E 05	1.562E-03	-133.69
137	1.2023E 05	1.532E-03	-133.80
138	1.2059E 05	1.503E-03	-133.91
139	1.2095E 05	1.475E-03	-134.02
140	1.2132E 05	1.448E-03	-134.12
141	1.2168E 05	1.422E-03	-134.23
142	1.2205E 05	1.397E-03	-134.34
143	1.2241E 05	1.373E-03	-134.44
144	1.2278E 05	1.349E-03	-134.55
145	1.2315E 05	1.326E-03	-134.65
146	1.2352E 05	1.304E-03	-134.76
147	1.2389E 05	1.292E-03	-134.84
148	1.2426E 05	1.261E-03	-134.96
149	1.2463E 05	1.241E-03	-135.07
150	1.2501E 05	1.221E-03	-135.17
151	1.3036E 05	9.926E-04	-136.54

PLOT OF N.V. 7, SF = 10**(-2), VERSUS FREQ



PLOT OF N.V. 7 VERSUS FREQ



EXECUTION TIME = 5.583 SEC

END

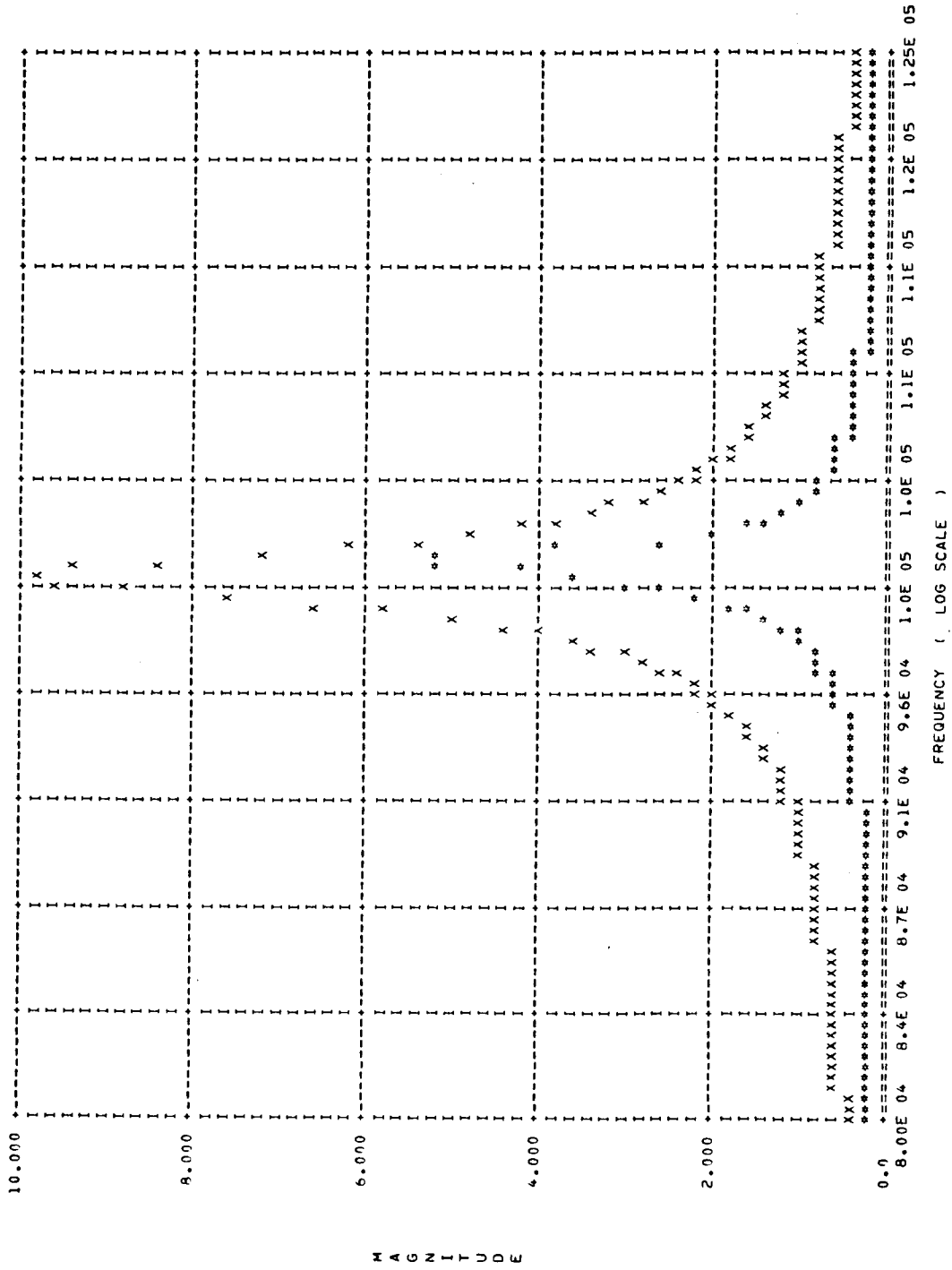
TABLE OF DATA PLOTTED. PARAMETER = FREQ

POINT	FREQUENCY	N.V. MAG	7 *** ANGLE	N.V. MAG	5 *** ANGLE
1	8.0000E 04	1.335E-03	55.15	4.806E-03	53.63
2	8.0240E 04	1.352E-03	55.04	4.866E-03	53.52
3	8.0481E 04	1.368E-03	54.97	4.929E-03	53.41
4	8.0722E 04	1.387E-03	54.87	4.993E-03	53.29
5	8.0964E 04	1.405E-03	54.78	5.058E-03	53.17
6	8.1207E 04	1.423E-03	54.68	5.126E-03	53.05
7	8.1451E 04	1.442E-03	54.58	5.195E-03	52.93
8	8.1695E 04	1.462E-03	54.49	5.267E-03	52.81
9	8.1940E 04	1.482E-03	54.39	5.340E-03	52.69
10	8.2186E 04	1.503E-03	54.29	5.416E-03	52.57
11	8.2433E 04	1.524E-03	54.19	5.494E-03	52.44
12	8.2680E 04	1.546E-03	54.09	5.574E-03	52.31
13	8.2928E 04	1.569E-03	53.99	5.657E-03	52.19
14	8.3177E 04	1.592E-03	53.89	5.742E-03	52.06
15	8.3426E 04	1.616E-03	53.79	5.830E-03	51.93
16	8.3677E 04	1.641E-03	53.68	5.921E-03	51.79
17	8.3928E 04	1.667E-03	53.58	6.015E-03	51.66
18	8.4179E 04	1.694E-03	53.48	6.112E-03	51.52
19	8.4432E 04	1.721E-03	53.37	6.212E-03	51.38
20	8.4685E 04	1.749E-03	53.26	6.316E-03	51.24
21	8.4939E 04	1.778E-03	53.16	6.423E-03	51.10
22	8.5194E 04	1.809E-03	53.05	6.535E-03	50.95
23	8.5450E 04	1.840E-03	52.94	6.650E-03	50.81
24	8.5706E 04	1.873E-03	52.83	6.770E-03	50.66
25	8.5963E 04	1.906E-03	52.72	6.894E-03	50.50
26	8.6221E 04	1.942E-03	52.60	7.023E-03	50.35
27	8.6480E 04	1.978E-03	52.49	7.157E-03	50.19
28	8.6739E 04	2.016E-03	52.37	7.296E-03	50.03
29	8.6999E 04	2.056E-03	52.25	7.442E-03	49.86
30	8.7260E 04	2.097E-03	52.14	7.593E-03	49.69
31	8.7522E 04	2.140E-03	52.01	7.751E-03	49.52
32	8.7785E 04	2.184E-03	51.89	7.916E-03	49.34
33	8.8048E 04	2.231E-03	51.77	8.088E-03	49.16
34	8.8312E 04	2.280E-03	51.64	8.268E-03	48.97
35	8.8577E 04	2.331E-03	51.51	8.457E-03	48.78
36	8.8843E 04	2.385E-03	51.38	8.654E-03	48.58
37	8.9109E 04	2.441E-03	51.24	8.862E-03	48.38
38	8.9377E 04	2.500E-03	51.11	9.080E-03	48.17
39	8.9645E 04	2.562E-03	50.94	9.309E-03	47.96
40	8.9914E 04	2.627E-03	50.82	9.551E-03	47.73
41	9.0184E 04	2.696E-03	50.67	9.806E-03	47.50
42	9.0454E 04	2.769E-03	50.52	1.008E-02	47.26
43	9.0725E 04	2.845E-03	50.37	1.036E-02	47.02
44	9.0998E 04	2.927E-03	50.21	1.066E-02	46.76
45	9.1271E 04	3.013E-03	50.04	1.098E-02	46.49
46	9.1544E 04	3.105E-03	49.87	1.132E-02	46.21
47	9.1819E 04	3.202E-03	49.69	1.168E-02	45.91
48	9.2095E 04	3.306E-03	49.51	1.207E-02	45.60
49	9.2371E 04	3.418E-03	49.31	1.249E-02	45.28
50	9.2648E 04	3.537E-03	49.11	1.294E-02	44.94
51	9.2926E 04	3.665E-03	48.90	1.341E-02	44.57
52	9.3205E 04	3.803E-03	48.68	1.393E-02	44.19
53	9.3484E 04	3.952E-03	48.45	1.449E-02	43.78
54	9.3765E 04	4.114E-03	48.20	1.509E-02	43.34

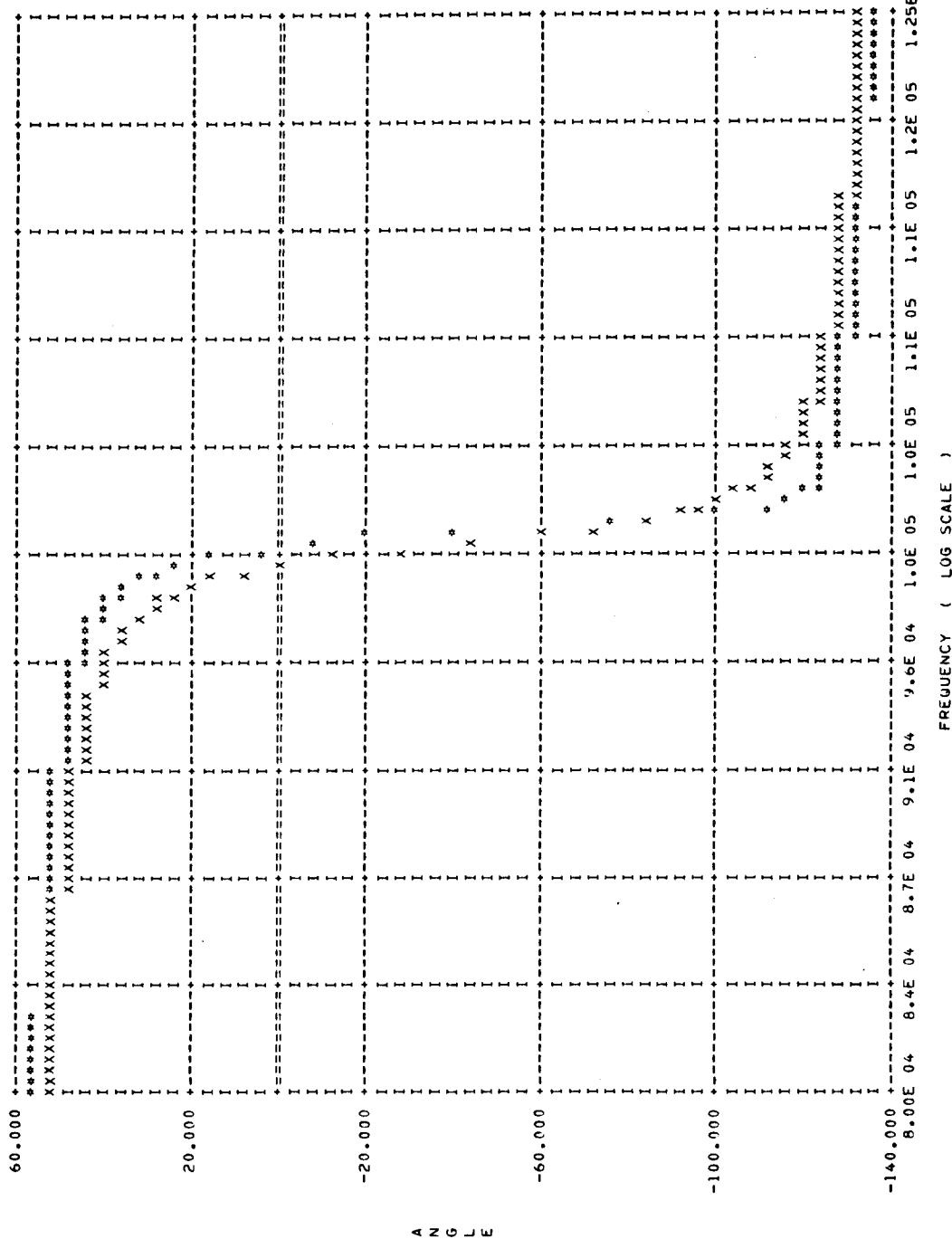
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56	9.4328E 04	4.481E-03	47.65	1.647E-02	42.37
57	9.4611E 04	4.691E-03	47.35	1.726E-02	41.82
58	9.4895E 04	4.922E-03	47.02	1.813E-02	41.22
59	9.5180E 04	5.178E-03	46.67	1.910E-02	40.57
60	9.5465E 04	5.462E-03	46.28	2.017E-02	39.86
61	9.5752E 04	5.777E-03	45.85	2.136E-02	39.06
62	9.6039E 04	6.135E-03	45.37	2.271E-02	38.18
63	9.6327E 04	6.539E-03	44.83	2.424E-02	37.19
64	9.6616E 04	7.001E-03	44.21	2.598E-02	36.06
65	9.6906E 04	7.532E-03	43.51	2.799E-02	34.77
66	9.7197E 04	8.150E-03	42.69	3.032E-02	33.27
67	9.7488E 04	8.876E-03	41.71	3.305E-02	31.52
68	9.7781E 04	9.741E-03	40.53	3.630E-02	29.43
69	9.8074E 04	1.079E-02	39.09	4.019E-02	26.90
70	9.8368E 04	1.207E-02	37.27	4.492E-02	23.79
71	9.8663E 04	1.366E-02	34.94	5.072E-02	19.87
72	9.8959E 04	1.569E-02	31.85	5.787E-02	14.84
73	9.9256E 04	1.825E-02	27.69	6.664E-02	8.22
74	9.9554E 04	2.152E-02	22.00	7.699E-02	-0.58
75	9.9853E 04	2.552E-02	14.30	8.794E-02	-12.23
76	1.0015E 05	3.011E-02	4.46	9.864E-02	-26.92
77	1.0045E 05	3.522E-02	-6.94	9.896E-02	-43.55
78	1.0075E 05	4.209E-02	-20.31	9.341E-02	-59.68
79	1.0106E 05	5.200E-02	-41.34	8.302E-02	-73.29
80	1.0136E 05	5.252E-02	-75.08	7.172E-02	-83.66
81	1.0166E 05	3.808E-02	-100.74	6.193E-02	-91.30
82	1.0197E 05	2.698E-02	-112.36	5.389E-02	-97.13
83	1.0227E 05	2.052E-02	-117.64	4.735E-02	-101.65
84	1.0258E 05	1.655E-02	-120.42	4.203E-02	-105.20
85	1.0289E 05	1.389E-02	-122.12	3.768E-02	-108.05
86	1.0320E 05	1.199E-02	-123.29	3.407E-02	-110.39
87	1.0351E 05	1.056E-02	-124.14	3.105E-02	-112.33
88	1.0382E 05	9.445E-03	-124.84	2.849E-02	-113.97
89	1.0413E 05	8.545E-03	-125.43	2.630E-02	-115.38
90	1.0444E 05	7.804E-03	-125.92	2.441E-02	-116.60
91	1.0475E 05	7.182E-03	-126.35	2.276E-02	-117.67
92	1.0507E 05	6.652E-03	-126.74	2.131E-02	-118.62
93	1.0538E 05	6.195E-03	-127.08	2.002E-02	-119.47
94	1.0570E 05	5.797E-03	-127.40	1.888E-02	-120.23
95	1.0602E 05	5.447E-03	-127.69	1.786E-02	-120.92
96	1.0634E 05	5.136E-03	-127.97	1.693E-02	-121.55
97	1.0665E 05	4.858E-03	-128.22	1.610E-02	-122.12
98	1.0697E 05	4.608E-03	-128.44	1.534E-02	-122.66
99	1.0730E 05	4.382E-03	-128.69	1.464E-02	-123.15
100	1.0762E 05	4.177E-03	-128.90	1.401E-02	-123.61
101	1.0794E 05	3.990E-03	-129.10	1.342E-02	-124.04
102	1.0826E 05	3.819E-03	-129.30	1.288E-02	-124.44
103	1.0859E 05	3.661E-03	-129.49	1.238E-02	-124.81
104	1.0891E 05	3.515E-03	-129.67	1.191E-02	-125.17
105	1.0924E 05	3.380E-03	-129.84	1.148E-02	-125.51
106	1.0957E 05	3.255E-03	-130.01	1.108E-02	-125.83
107	1.0990E 05	3.139E-03	-130.14	1.070E-02	-126.14
108	1.1023E 05	3.030E-03	-130.33	1.035E-02	-126.43
109	1.1056E 05	2.928E-03	-130.49	1.001E-02	-126.71
110	1.1089E 05	2.833E-03	-130.64	9.701E-03	-126.97
111	1.1122E 05	2.743E-03	-130.79	9.406E-03	-127.23
112	1.1156E 05	2.658E-03	-130.93	9.128E-03	-127.48
113	1.1189E 05	2.579E-03	-131.07	8.865E-03	-127.72
114	1.1223E 05	2.504E-03	-131.21	8.615E-03	-127.95
115	1.1256E 05	2.433E-03	-131.35	8.379E-03	-128.17

116	1.1290E 05	2.365E-03	-131.44	8.154E-03	-128.39
117	1.1324E 05	2.301E-03	-131.61	7.941E-03	-128.80
118	1.1359E 05	2.240E-03	-131.74	7.738E-03	-128.80
119	1.1392E 05	2.182E-03	-131.86	7.544E-03	-129.00
120	1.1426E 05	2.127E-03	-131.99	7.359E-03	-129.19
121	1.1460E 05	2.075E-03	-132.11	7.182E-03	-129.38
122	1.1495E 05	2.025E-03	-132.23	7.013E-03	-129.56
123	1.1529E 05	1.977E-03	-132.35	6.852E-03	-129.74
124	1.1564E 05	1.931E-03	-132.47	6.697E-03	-129.92
125	1.1599E 05	1.887E-03	-132.59	6.548E-03	-130.09
126	1.1633E 05	1.845E-03	-132.71	6.405E-03	-130.26
127	1.1668E 05	1.804E-03	-132.82	6.268E-03	-130.42
128	1.1703E 05	1.765E-03	-132.94	6.136E-03	-130.59
129	1.1738E 05	1.728E-03	-133.05	6.010E-03	-130.75
130	1.1774E 05	1.692E-03	-133.16	5.888E-03	-130.90
131	1.1809E 05	1.658E-03	-133.27	5.770E-03	-131.06
132	1.1844E 05	1.624E-03	-133.38	5.656E-03	-131.21
133	1.1880E 05	1.592E-03	-133.49	5.547E-03	-131.36
134	1.1916E 05	1.561E-03	-133.60	5.441E-03	-131.50
135	1.1951E 05	1.531E-03	-133.71	5.339E-03	-131.65
136	1.1987E 05	1.503E-03	-133.82	5.241E-03	-131.79
137	1.2023E 05	1.475E-03	-133.92	5.145E-03	-131.93
138	1.2059E 05	1.448E-03	-134.03	5.053E-03	-132.07
139	1.2095E 05	1.422E-03	-134.13	4.963E-03	-132.21
140	1.2132E 05	1.396E-03	-134.24	4.877E-03	-132.34
141	1.2168E 05	1.372E-03	-134.34	4.793E-03	-132.48
142	1.2205E 05	1.348E-03	-134.45	4.712E-03	-132.61
143	1.2241E 05	1.325E-03	-134.55	4.633E-03	-132.74
144	1.2278E 05	1.303E-03	-134.65	4.556E-03	-132.87
145	1.2315E 05	1.281E-03	-134.75	4.481E-03	-133.00
146	1.2352E 05	1.260E-03	-134.85	4.409E-03	-133.13
147	1.2389E 05	1.240E-03	-134.96	4.339E-03	-133.26
148	1.2426E 05	1.220E-03	-135.06	4.271E-03	-133.36
149	1.2463E 05	1.201E-03	-135.16	4.204E-03	-133.51
150	1.2501E 05	1.182E-03	-135.26	4.139E-03	-133.63
151	1.3036E 05	9.650E-04	-136.62	3.388E-03	-135.26

PLOT OF N.V. 7 (*), SF = 10**(-2), AND 5 (X), SF = 10**(-2), VERSUS FREQ



PLOT OF N.V. 7 AND N.V. 5 VERSUS FREQ



EXECUTION TIME = 6.250 SEC

END

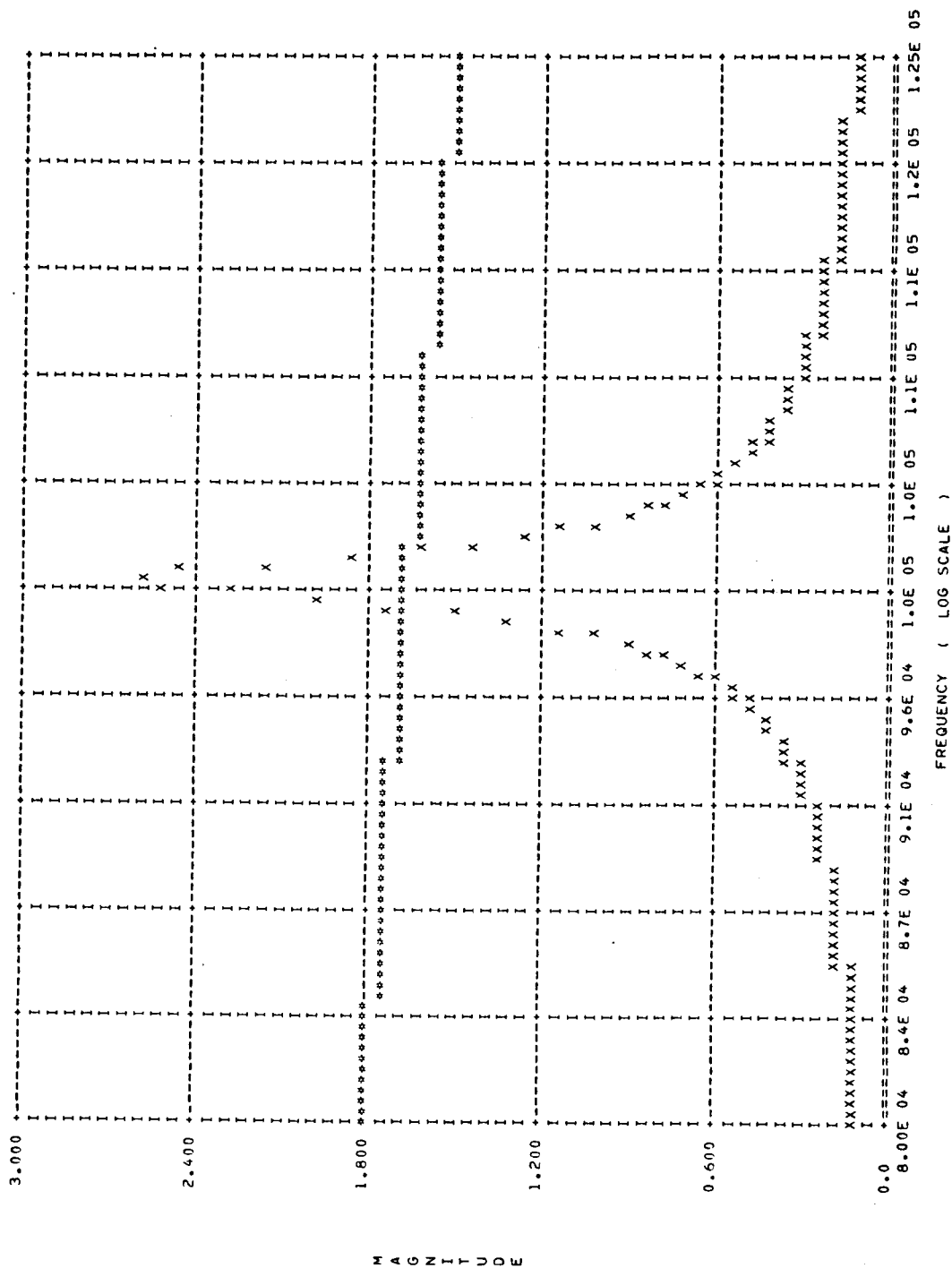
TABLE OF DATA PLOTTED, PARAMETER = FREQ

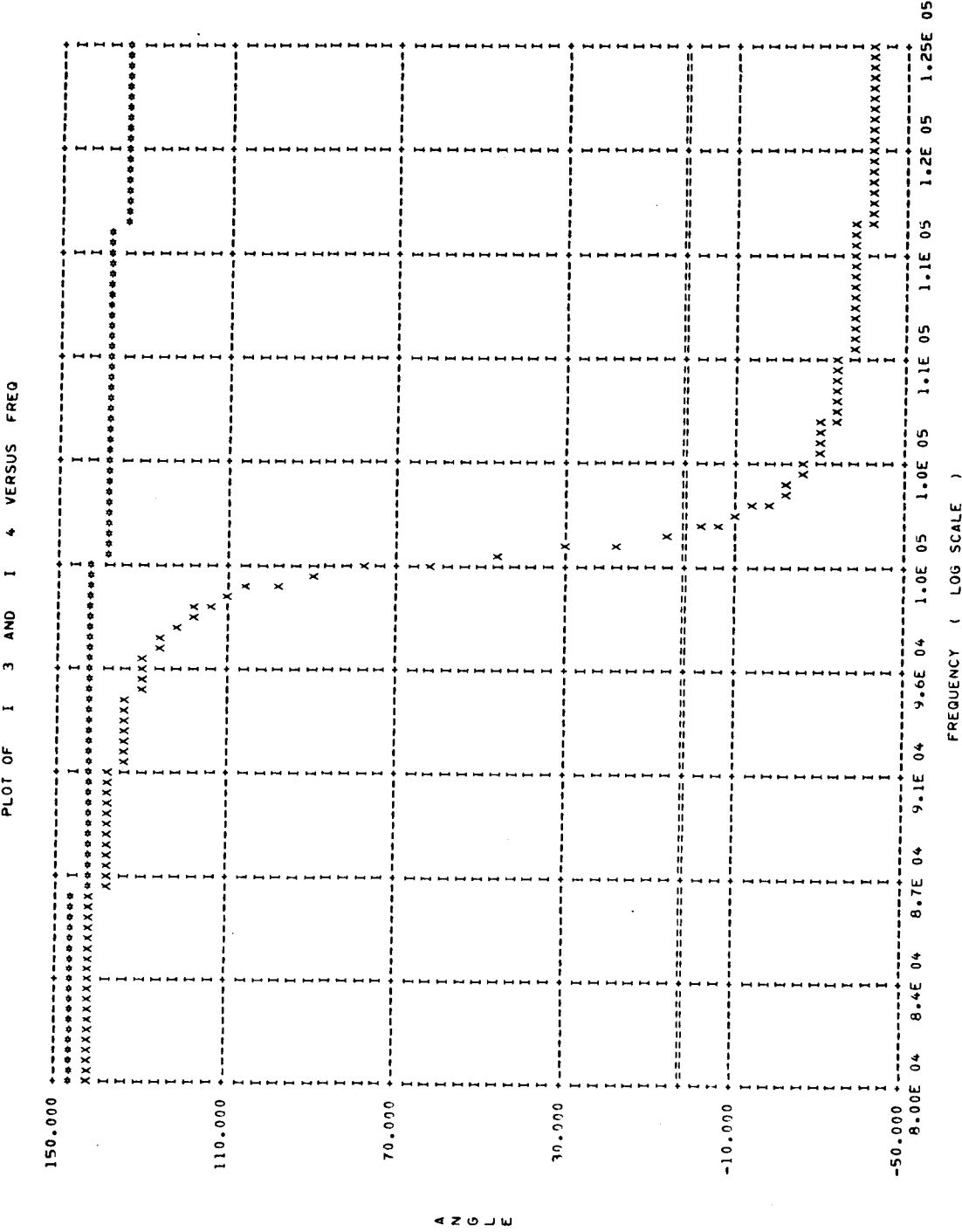
POINT	FREQUENCY	I	3 *** ANGLE	MAG	I	4 *** ANGLE	MAG	I	5 *** ANGLE	MAG	I	8 *** ANGLE
1	8.0000E 04	1.800E-01	146.20	9.952E-04	143.63	9.952E-04	143.63	9.952E-04	-36.37	2.497E-05	145.15	
2	8.0240E 04	1.799E-01	146.17	1.011E-03	143.52	1.011E-03	143.52	1.011E-03	-36.48	2.536E-05	145.06	
3	8.0481E 04	1.797E-01	146.04	1.027E-03	143.41	1.027E-03	143.41	1.027E-03	-36.59	2.575E-05	144.97	
4	8.0722E 04	1.795E-01	145.96	1.043E-03	143.29	1.043E-03	143.29	1.043E-03	-36.71	2.616E-05	144.87	
5	8.0964E 04	1.794E-01	145.88	1.060E-03	143.17	1.060E-03	143.17	1.060E-03	-36.83	2.658E-05	144.78	
6	8.1207E 04	1.792E-01	145.80	1.078E-03	143.05	1.078E-03	143.05	1.078E-03	-36.95	2.701E-05	144.68	
7	8.1451E 04	1.790E-01	145.72	1.095E-03	142.93	1.095E-03	142.93	1.095E-03	-37.07	2.746E-05	144.58	
8	8.1695E 04	1.789E-01	145.64	1.114E-03	142.81	1.114E-03	142.81	1.114E-03	-37.19	2.791E-05	144.49	
9	8.1940E 04	1.787E-01	145.56	1.133E-03	142.69	1.133E-03	142.69	1.133E-03	-37.31	2.838E-05	144.39	
10	8.2184E 04	1.785E-01	145.48	1.152E-03	142.57	1.152E-03	142.57	1.152E-03	-37.43	2.887E-05	144.29	
11	8.2433E 04	1.783E-01	145.40	1.172E-03	142.44	1.172E-03	142.44	1.172E-03	-37.56	2.936E-05	144.19	
12	8.2680E 04	1.782E-01	145.32	1.193E-03	142.31	1.193E-03	142.31	1.193E-03	-37.69	2.988E-05	144.09	
13	8.2928E 04	1.780E-01	145.24	1.214E-03	142.19	1.214E-03	142.19	1.214E-03	-37.81	3.041E-05	143.99	
14	8.3177E 04	1.778E-01	145.16	1.236E-03	142.06	1.236E-03	142.06	1.236E-03	-37.94	3.095E-05	143.89	
15	8.3425E 04	1.777E-01	145.08	1.259E-03	141.93	1.259E-03	141.93	1.259E-03	-38.07	3.151E-05	143.79	
16	8.3677E 04	1.775E-01	145.00	1.283E-03	141.79	1.283E-03	141.79	1.283E-03	-38.21	3.209E-05	143.68	
17	8.3928E 04	1.773E-01	144.92	1.307E-03	141.66	1.307E-03	141.66	1.307E-03	-38.34	3.269E-05	143.58	
18	8.4179E 04	1.771E-01	144.84	1.332E-03	141.52	1.332E-03	141.52	1.332E-03	-38.48	3.331E-05	143.48	
19	8.4432E 04	1.770E-01	144.76	1.358E-03	141.38	1.358E-03	141.38	1.358E-03	-38.62	3.395E-05	143.37	
20	8.4685E 04	1.768E-01	144.68	1.385E-03	141.24	1.385E-03	141.24	1.385E-03	-38.76	3.462E-05	143.26	
21	8.4939E 04	1.766E-01	144.60	1.412E-03	141.10	1.412E-03	141.10	1.412E-03	-38.90	3.530E-05	143.16	
22	8.5194E 04	1.764E-01	144.52	1.441E-03	140.95	1.441E-03	140.95	1.441E-03	-39.05	3.601E-05	143.05	
23	8.5450E 04	1.762E-01	144.43	1.471E-03	140.81	1.471E-03	140.81	1.471E-03	-39.19	3.675E-05	142.94	
24	8.5705E 04	1.761E-01	144.35	1.502E-03	140.66	1.502E-03	140.66	1.502E-03	-39.34	3.751E-05	142.83	
25	8.5963E 04	1.759E-01	144.27	1.534E-03	140.50	1.534E-03	140.50	1.534E-03	-39.50	3.831E-05	142.72	
26	8.6221E 04	1.757E-01	144.19	1.567E-03	140.35	1.567E-03	140.35	1.567E-03	-39.65	3.913E-05	142.60	
27	8.6480E 04	1.755E-01	144.11	1.602E-03	140.19	1.602E-03	140.19	1.602E-03	-39.81	3.998E-05	142.49	
28	8.6739E 04	1.753E-01	144.03	1.638E-03	140.03	1.638E-03	140.03	1.638E-03	-39.97	4.087E-05	142.37	
29	8.6998E 04	1.752E-01	143.95	1.676E-03	139.86	1.676E-03	139.86	1.676E-03	-40.14	4.180E-05	142.25	
30	8.7260E 04	1.750E-01	143.86	1.715E-03	139.69	1.715E-03	139.69	1.715E-03	-40.31	4.276E-05	142.14	
31	8.7522E 04	1.748E-01	143.78	1.756E-03	139.52	1.756E-03	139.52	1.756E-03	-40.48	4.377E-05	142.01	
32	8.7785E 04	1.746E-01	143.70	1.799E-03	139.34	1.799E-03	139.34	1.799E-03	-40.66	4.482E-05	141.89	
33	8.8048E 04	1.744E-01	143.62	1.843E-03	139.16	1.843E-03	139.16	1.843E-03	-40.84	4.592E-05	141.77	
34	8.8312E 04	1.742E-01	143.54	1.890E-03	138.97	1.890E-03	138.97	1.890E-03	-41.03	4.706E-05	141.64	
35	8.8577E 04	1.741E-01	143.45	1.939E-03	138.78	1.939E-03	138.78	1.939E-03	-41.22	4.826E-05	141.51	
36	8.8843E 04	1.739E-01	143.37	1.990E-03	138.58	1.990E-03	138.58	1.990E-03	-41.42	4.952E-05	141.38	
37	8.9109E 04	1.737E-01	143.29	2.044E-03	138.38	2.044E-03	138.38	2.044E-03	-41.62	5.084E-05	141.24	
38	8.9377E 04	1.735E-01	143.21	2.101E-03	138.17	2.101E-03	138.17	2.101E-03	-41.83	5.222E-05	141.11	
39	8.9645E 04	1.733E-01	143.13	2.160E-03	137.96	2.160E-03	137.96	2.160E-03	-42.04	5.368E-05	140.96	
40	8.9914E 04	1.731E-01	143.04	2.223E-03	137.73	2.223E-03	137.73	2.223E-03	-42.27	5.521E-05	140.82	
41	9.0184E 04	1.729E-01	142.96	2.289E-03	137.50	2.289E-03	137.50	2.289E-03	-42.50	5.683E-05	140.67	
42	9.0455E 04	1.728E-01	142.88	2.358E-03	137.26	2.358E-03	137.26	2.358E-03	-42.74	5.853E-05	140.52	
43	9.0725E 04	1.726E-01	142.80	2.433E-03	137.02	2.433E-03	137.02	2.433E-03	-42.98	6.034E-05	140.37	
44	9.0998E 04	1.724E-01	142.71	2.512E-03	136.76	2.512E-03	136.76	2.512E-03	-43.24	6.225E-05	140.21	
45	9.1271E 04	1.722E-01	142.63	2.595E-03	136.49	2.595E-03	136.49	2.595E-03	-43.51	6.427E-05	140.04	
46	9.1544E 04	1.720E-01	142.55	2.683E-03	136.21	2.683E-03	136.21	2.683E-03	-43.79	6.643E-05	139.87	
47	9.1819E 04	1.718E-01	142.46	2.778E-03	135.91	2.778E-03	135.91	2.778E-03	-44.09	6.872E-05	139.69	
48	9.2095E 04	1.716E-01	142.38	2.879E-03	135.60	2.879E-03	135.60	2.879E-03	-44.40	7.117E-05	139.51	
49	9.2371E 04	1.714E-01	142.30	2.987E-03	135.28	2.987E-03	135.28	2.987E-03	-44.72	7.379E-05	139.31	
50	9.2648E 04	1.712E-01	142.22	3.102E-03	134.94	3.102E-03	134.94	3.102E-03	-45.06	7.659E-05	139.11	
51	9.2926E 04	1.710E-01	142.13	3.227E-03	134.57	3.227E-03	134.57	3.227E-03	-45.43	7.960E-05	138.90	
52	9.3205E 04	1.708E-01	142.05	3.361E-03	134.19	3.361E-03	134.19	3.361E-03	-45.81	8.285E-05	138.68	
53	9.3484E 04	1.706E-01	141.97	3.506E-03	133.78	3.506E-03	133.78	3.506E-03	-46.22	8.636E-05	138.45	
54	9.3765E 04	1.705E-01	141.88	3.664E-03	133.34	3.664E-03	133.34	3.664E-03	-46.66	9.016E-05	138.20	

55	9.4046E 04	1.703E-01	141.80	3.835E-03	132.87	3.835E-03	-47.13	9.429E-05	137.94
56	9.4328E 04	1.701E-01	141.72	4.023E-03	132.37	4.023E-03	-47.63	9.880E-05	137.65
57	9.4611E 04	1.699E-01	141.63	4.228E-03	131.82	4.228E-03	-48.18	1.037E-04	137.35
58	9.4895E 04	1.697E-01	141.55	4.455E-03	131.22	4.455E-03	-48.78	1.092E-04	137.02
59	9.5180E 04	1.695E-01	141.47	4.705E-03	130.57	4.705E-03	-49.43	1.152E-04	136.67
60	9.5465E 04	1.693E-01	141.38	4.984E-03	129.86	4.984E-03	-50.14	1.219E-04	136.28
61	9.5752E 04	1.691E-01	141.30	5.296E-03	129.06	5.296E-03	-50.94	1.293E-04	135.85
62	9.6039E 04	1.689E-01	141.21	5.647E-03	128.18	5.647E-03	-51.82	1.377E-04	135.37
63	9.6327E 04	1.687E-01	141.13	6.044E-03	127.19	6.044E-03	-52.81	1.472E-04	134.83
64	9.6616E 04	1.685E-01	141.05	6.498E-03	126.06	6.498E-03	-53.94	1.581E-04	134.21
65	9.6906E 04	1.683E-01	140.96	7.021E-03	124.77	7.021E-03	-55.23	1.706E-04	133.51
66	9.7197E 04	1.681E-01	140.88	7.628E-03	123.27	7.628E-03	-56.73	1.851E-04	132.69
67	9.7488E 04	1.679E-01	140.79	8.341E-03	121.52	8.341E-03	-58.48	2.023E-04	131.71
68	9.7781E 04	1.677E-01	140.71	9.187E-03	119.40	9.187E-03	-60.57	2.226E-04	130.53
69	9.8074E 04	1.675E-01	140.63	1.020E-02	116.90	1.020E-02	-63.10	2.472E-04	129.09
70	9.8368E 04	1.673E-01	140.54	1.144E-02	113.79	1.144E-02	-66.21	2.774E-04	127.27
71	9.8663E 04	1.671E-01	140.46	1.295E-02	109.87	1.295E-02	-70.13	3.151E-04	124.94
72	9.8959E 04	1.669E-01	140.37	1.483E-02	104.84	1.483E-02	-75.16	3.626E-04	121.85
73	9.9256E 04	1.667E-01	140.29	1.712E-02	98.22	1.712E-02	-81.78	4.234E-04	117.69
74	9.9554E 04	1.665E-01	140.20	1.984E-02	89.42	1.984E-02	-90.58	5.007E-04	112.00
75	9.9853E 04	1.663E-01	140.12	2.273E-02	77.77	2.273E-02	-102.23	5.957E-04	104.30
76	1.0015E 05	1.661E-01	140.04	2.506E-02	63.08	2.506E-02	-116.92	7.049E-04	94.46
77	1.0045E 05	1.658E-01	139.95	2.573E-02	46.45	2.573E-02	-133.55	8.270E-04	83.02
78	1.0075E 05	1.656E-01	139.87	2.536E-02	30.32	2.536E-02	-149.68	9.910E-04	69.69
79	1.0106E 05	1.654E-01	139.78	2.472E-02	16.71	2.472E-02	-163.29	1.228E-03	48.62
80	1.0136E 05	1.652E-01	139.70	1.982E-02	6.34	1.982E-02	-173.66	1.244E-03	14.92
81	1.0166E 05	1.650E-01	139.61	1.630E-02	-1.30	1.630E-02	-178.70	9.048E-04	-10.76
82	1.0197E 05	1.648E-01	139.53	1.422E-02	-7.13	1.422E-02	-172.87	6.429E-04	-22.36
83	1.0227E 05	1.646E-01	139.44	1.254E-02	-11.65	1.254E-02	-168.35	4.906E-04	-27.64
84	1.0258E 05	1.644E-01	139.36	1.116E-02	-15.20	1.116E-02	-164.80	3.969E-04	-30.42
85	1.0289E 05	1.642E-01	139.27	1.003E-02	-18.05	1.003E-02	-161.95	3.342E-04	-32.12
86	1.0320E 05	1.640E-01	139.19	9.101E-03	-20.39	9.101E-03	-159.61	2.893E-04	-33.29
87	1.0351E 05	1.638E-01	139.10	8.319E-03	-22.33	8.319E-03	-157.67	2.556E-04	-34.16
88	1.0382E 05	1.636E-01	139.02	7.657E-03	-23.97	7.657E-03	-156.03	2.292E-04	-34.86
89	1.0413E 05	1.633E-01	138.93	7.089E-03	-25.38	7.089E-03	-154.62	2.080E-04	-35.43
90	1.0444E 05	1.631E-01	138.85	6.599E-03	-26.60	6.599E-03	-153.40	1.905E-04	-35.92
91	1.0475E 05	1.629E-01	138.76	6.171E-03	-27.67	6.171E-03	-152.33	1.758E-04	-36.35
92	1.0507E 05	1.627E-01	138.68	5.796E-03	-28.62	5.796E-03	-151.38	1.634E-04	-36.74
93	1.0538E 05	1.625E-01	138.59	5.463E-03	-29.47	5.463E-03	-150.53	1.526E-04	-37.08
94	1.0570E 05	1.623E-01	138.51	5.166E-03	-30.23	5.166E-03	-149.77	1.432E-04	-37.40
95	1.0602E 05	1.621E-01	138.42	4.901E-03	-30.92	4.901E-03	-149.08	1.350E-04	-37.69
96	1.0634E 05	1.619E-01	138.34	4.661E-03	-31.55	4.661E-03	-148.45	1.276E-04	-37.97
97	1.0665E 05	1.616E-01	138.25	4.444E-03	-32.12	4.444E-03	-147.88	1.211E-04	-38.22
98	1.0697E 05	1.614E-01	138.17	4.247E-03	-32.66	4.247E-03	-147.34	1.152E-04	-38.46
99	1.0730E 05	1.612E-01	138.08	4.067E-03	-33.15	4.067E-03	-146.85	1.099E-04	-38.69
100	1.0762E 05	1.610E-01	138.00	3.902E-03	-33.61	3.902E-03	-146.39	1.051E-04	-38.90
101	1.0794E 05	1.608E-01	137.91	3.750E-03	-34.04	3.750E-03	-145.96	1.007E-04	-39.10
102	1.0826E 05	1.606E-01	137.83	3.609E-03	-34.44	3.609E-03	-145.56	9.663E-05	-39.30
103	1.0859E 05	1.604E-01	137.74	3.480E-03	-34.81	3.480E-03	-145.19	9.291E-05	-39.49
104	1.0891E 05	1.601E-01	137.66	3.359E-03	-35.17	3.359E-03	-144.83	8.949E-05	-39.67
105	1.0924E 05	1.599E-01	137.57	3.247E-03	-35.51	3.247E-03	-144.49	8.631E-05	-39.84
106	1.0957E 05	1.597E-01	137.48	3.142E-03	-35.83	3.142E-03	-144.17	8.336E-05	-40.01
107	1.0990E 05	1.595E-01	137.40	3.044E-03	-36.14	3.044E-03	-143.86	8.062E-05	-40.18
108	1.1023E 05	1.593E-01	137.31	2.952E-03	-36.43	2.952E-03	-143.57	7.806E-05	-40.33
109	1.1056E 05	1.590E-01	137.23	2.866E-03	-36.71	2.866E-03	-143.29	7.566E-05	-40.49
110	1.1089E 05	1.588E-01	137.14	2.785E-03	-36.97	2.785E-03	-143.03	7.342E-05	-40.64
111	1.1122E 05	1.586E-01	137.06	2.708E-03	-37.23	2.708E-03	-142.77	7.131E-05	-40.79
112	1.1156E 05	1.584E-01	136.97	2.636E-03	-37.48	2.636E-03	-142.52	6.932E-05	-40.93
113	1.1189E 05	1.582E-01	136.89	2.568E-03	-37.72	2.568E-03	-142.28	6.744E-05	-41.07
114	1.1223E 05	1.579E-01	136.80	2.503E-03	-37.95	2.503E-03	-142.05	6.567E-05	-41.21
115	1.1256E 05	1.577E-01	136.71	2.442E-03	-38.17	2.442E-03	-141.83	6.400E-05	-41.35

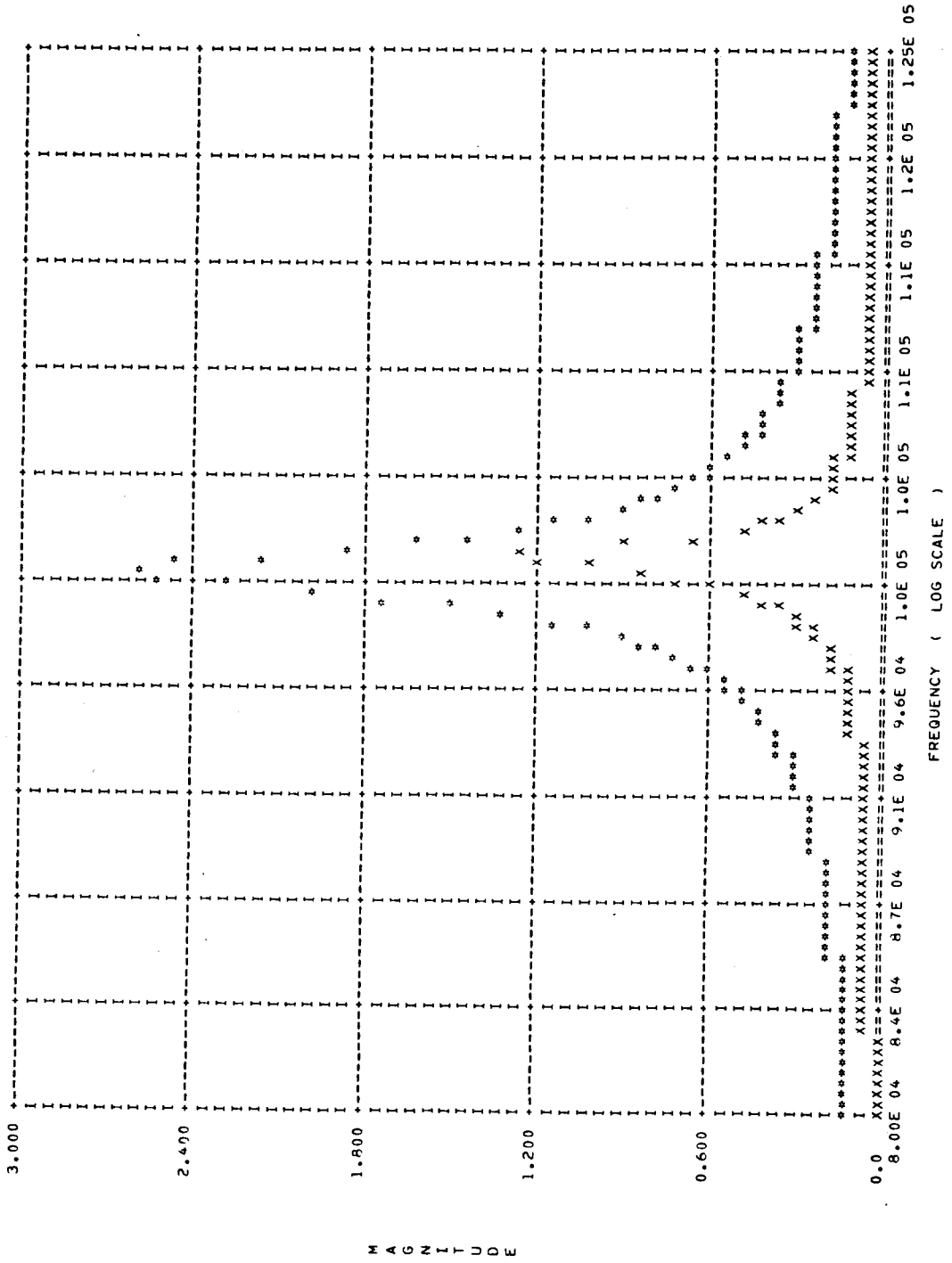
116	1.1290E 05	1.575E-01	136.63	2.343E-03	-38.39	2.343E-03	141.61	6.241E-05	-41.48
117	1.1324E 05	1.573E-01	136.54	2.328E-03	-38.60	2.328E-03	141.40	6.091E-05	-41.61
118	1.1358E 05	1.570E-01	136.44	2.275E-03	-38.80	2.275E-03	141.20	5.947E-05	-41.74
119	1.1392E 05	1.568E-01	136.37	2.225E-03	-39.00	2.225E-03	141.00	5.811E-05	-41.86
120	1.1426E 05	1.566E-01	136.29	2.177E-03	-39.19	2.177E-03	140.81	5.682E-05	-41.99
121	1.1460E 05	1.564E-01	136.20	2.131E-03	-39.38	2.131E-03	140.62	5.558E-05	-42.11
122	1.1495E 05	1.561E-01	136.11	2.087E-03	-39.56	2.087E-03	140.44	5.440E-05	-42.23
123	1.1529E 05	1.559E-01	136.03	2.045E-03	-39.74	2.045E-03	140.26	5.327E-05	-42.35
124	1.1564E 05	1.557E-01	135.94	2.005E-03	-39.92	2.005E-03	140.08	5.219E-05	-42.47
125	1.1599E 05	1.555E-01	135.86	1.966E-03	-40.09	1.966E-03	139.91	5.115E-05	-42.59
126	1.1633E 05	1.552E-01	135.77	1.929E-03	-40.26	1.929E-03	139.74	5.016E-05	-42.71
127	1.1668E 05	1.550E-01	135.69	1.893E-03	-40.42	1.893E-03	139.58	4.921E-05	-42.82
128	1.1703E 05	1.548E-01	135.60	1.859E-03	-40.59	1.859E-03	139.41	4.829E-05	-42.94
129	1.1738E 05	1.546E-01	135.51	1.826E-03	-40.75	1.826E-03	139.25	4.741E-05	-43.05
130	1.1774E 05	1.543E-01	135.43	1.794E-03	-40.90	1.794E-03	139.10	4.657E-05	-43.16
131	1.1809E 05	1.541E-01	135.34	1.764E-03	-41.06	1.764E-03	138.94	4.575E-05	-43.27
132	1.1844E 05	1.539E-01	135.26	1.734E-03	-41.21	1.734E-03	138.79	4.497E-05	-43.38
133	1.1880E 05	1.537E-01	135.17	1.706E-03	-41.36	1.706E-03	138.64	4.421E-05	-43.49
134	1.1916E 05	1.534E-01	135.04	1.678E-03	-41.50	1.678E-03	138.50	4.348E-05	-43.60
135	1.1951E 05	1.532E-01	135.00	1.652E-03	-41.65	1.652E-03	138.35	4.278E-05	-43.71
136	1.1987E 05	1.530E-01	134.91	1.626E-03	-41.79	1.626E-03	138.21	4.210E-05	-43.82
137	1.2023E 05	1.527E-01	134.83	1.601E-03	-41.93	1.601E-03	138.07	4.144E-05	-43.92
138	1.2059E 05	1.525E-01	134.74	1.577E-03	-42.07	1.577E-03	137.93	4.081E-05	-44.03
139	1.2095E 05	1.523E-01	134.66	1.554E-03	-42.21	1.554E-03	137.79	4.019E-05	-44.13
140	1.2132E 05	1.520E-01	134.57	1.532E-03	-42.34	1.532E-03	137.66	3.960E-05	-44.24
141	1.2169E 05	1.518E-01	134.48	1.510E-03	-42.48	1.510E-03	137.52	3.902E-05	-44.34
142	1.2205E 05	1.516E-01	134.40	1.489E-03	-42.61	1.489E-03	137.39	3.846E-05	-44.45
143	1.2241E 05	1.514E-01	134.31	1.468E-03	-42.74	1.468E-03	137.26	3.792E-05	-44.55
144	1.2278E 05	1.511E-01	134.23	1.448E-03	-42.87	1.448E-03	137.13	3.739E-05	-44.65
145	1.2315E 05	1.509E-01	134.14	1.429E-03	-43.00	1.429E-03	137.00	3.688E-05	-44.75
146	1.2352E 05	1.507E-01	134.06	1.410E-03	-43.13	1.410E-03	136.87	3.639E-05	-44.85
147	1.2389E 05	1.504E-01	133.97	1.391E-03	-43.26	1.391E-03	136.74	3.591E-05	-44.96
148	1.2426E 05	1.502E-01	133.89	1.374E-03	-43.38	1.374E-03	136.62	3.544E-05	-45.06
149	1.2463E 05	1.500E-01	133.80	1.356E-03	-43.51	1.356E-03	136.49	3.498E-05	-45.16
150	1.2501E 05	1.497E-01	133.71	1.339E-03	-43.63	1.339E-03	136.37	3.454E-05	-45.26
151	1.3036E 05	1.464E-01	132.51	1.143E-03	-45.26	1.143E-03	134.74	2.940E-05	-46.62

PLOT OF I 3 (*), $SF = 10^{**}(-1)$, AND 4 (X), $SF = 10^{**}(-2)$, VERSUS FREQ

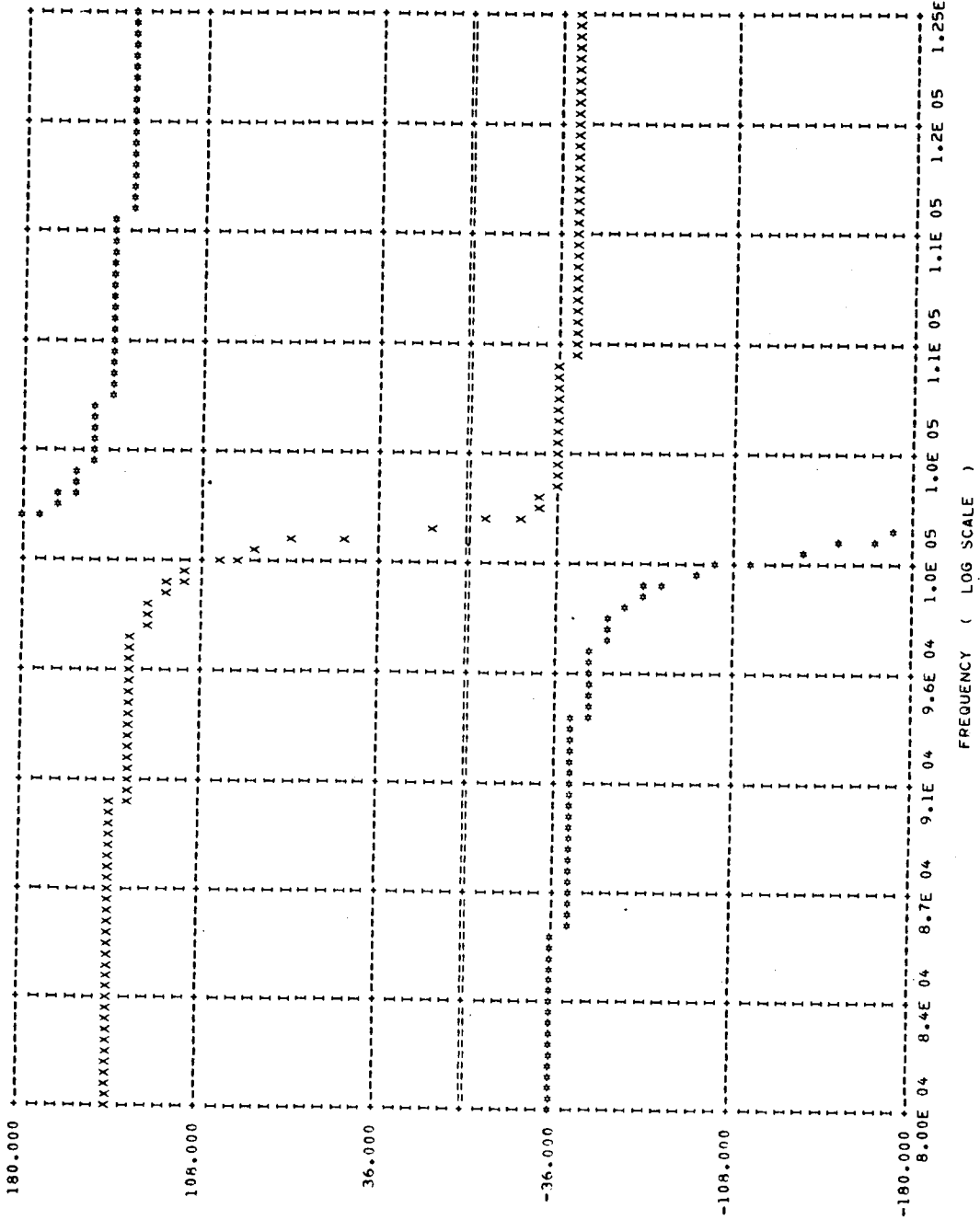




PLOT OF I 5 (*), SF = 10**(-2), AND 8 (X), SF = 10**(-3), VERSUS FREQ



PLOT OF I 5 AND I 8 VERSUS FREQ



EXECUTION TIME = 6.817 SEC

END

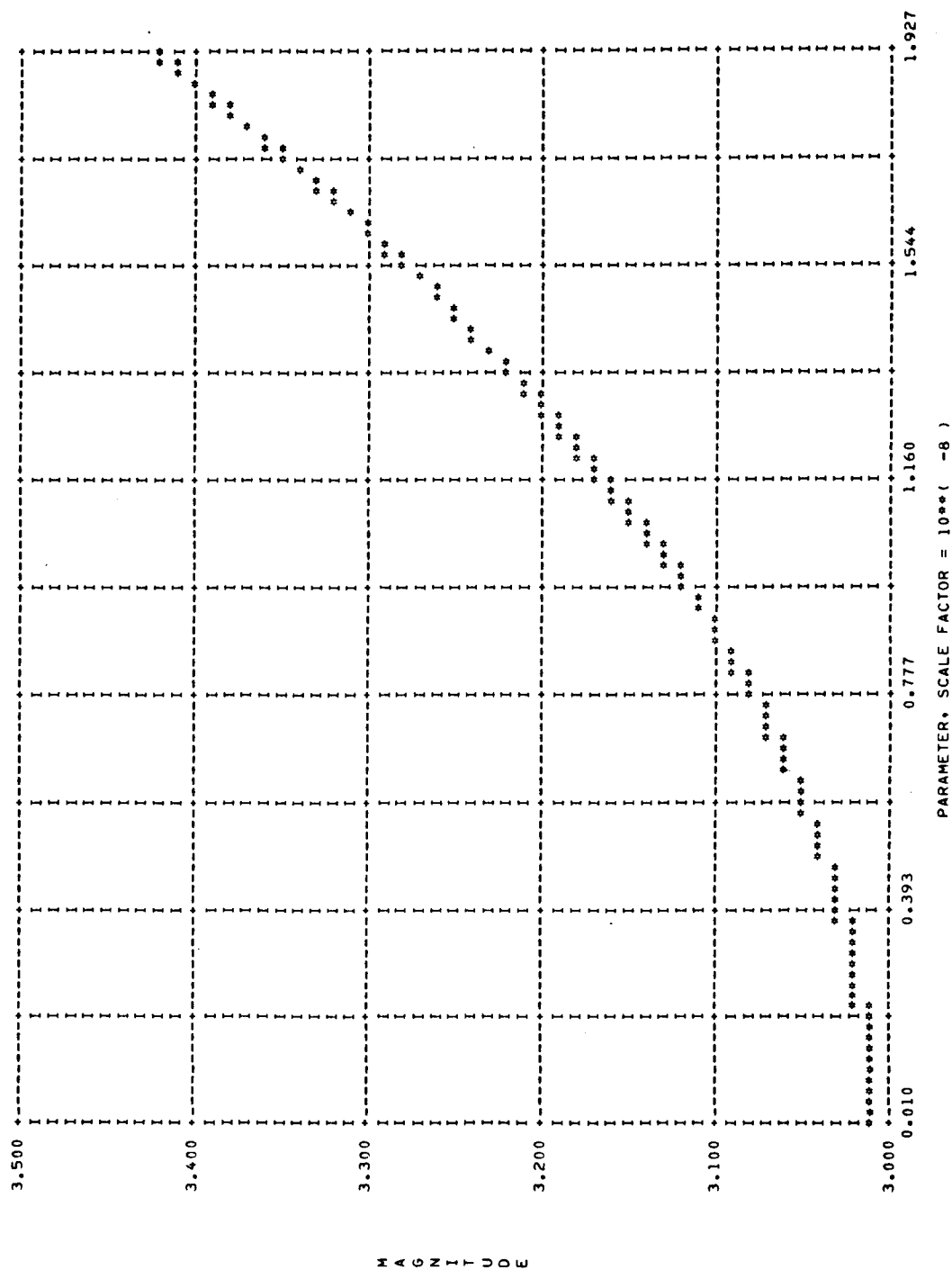
TABLE OF DATA PLOTTED. PARAMETER = LM

POINT	PARAMETER	N.V. MAG	7 *** ANGLE
1	1.0000E-10	3.010E-02	24.06
2	2.2867E-10	3.010E-02	23.85
3	3.5733E-10	3.010E-02	23.64
4	4.8600E-10	3.010E-02	23.43
5	6.1467E-10	3.010E-02	23.22
6	7.4333E-10	3.010E-02	23.01
7	8.7200E-10	3.011E-02	22.80
8	1.0007E-09	3.011E-02	22.59
9	1.1293E-09	3.011E-02	22.38
10	1.2580E-09	3.011E-02	22.17
11	1.3867E-09	3.012E-02	21.94
12	1.5153E-09	3.012E-02	21.75
13	1.6440E-09	3.013E-02	21.54
14	1.7727E-09	3.013E-02	21.33
15	1.9013E-09	3.014E-02	21.12
16	2.0300E-09	3.014E-02	20.91
17	2.1587E-09	3.015E-02	20.71
18	2.2873E-09	3.015E-02	20.50
19	2.4160E-09	3.016E-02	20.29
20	2.5447E-09	3.017E-02	20.04
21	2.6733E-09	3.017E-02	19.87
22	2.8020E-09	3.018E-02	19.66
23	2.9307E-09	3.019E-02	19.45
24	3.0593E-09	3.020E-02	19.24
25	3.1880E-09	3.021E-02	19.03
26	3.3167E-09	3.022E-02	18.82
27	3.4453E-09	3.023E-02	18.62
28	3.5740E-09	3.024E-02	18.41
29	3.7027E-09	3.025E-02	18.20
30	3.8313E-09	3.026E-02	17.99
31	3.9600E-09	3.027E-02	17.74
32	4.0887E-09	3.028E-02	17.57
33	4.2173E-09	3.029E-02	17.37
34	4.3460E-09	3.031E-02	17.16
35	4.4747E-09	3.032E-02	16.95
36	4.6033E-09	3.033E-02	16.75
37	4.7320E-09	3.035E-02	16.54
38	4.8607E-09	3.036E-02	16.33
39	4.9893E-09	3.038E-02	16.12
40	5.1180E-09	3.039E-02	15.92
41	5.2467E-09	3.041E-02	15.71
42	5.3753E-09	3.042E-02	15.51
43	5.5040E-09	3.044E-02	15.30
44	5.6327E-09	3.045E-02	15.09
45	5.7613E-09	3.047E-02	14.89
46	5.8900E-09	3.049E-02	14.68
47	6.0187E-09	3.051E-02	14.44
48	6.1473E-09	3.052E-02	14.27
49	6.2760E-09	3.054E-02	14.07
50	6.4047E-09	3.056E-02	13.87
51	6.5333E-09	3.058E-02	13.66
52	6.6620E-09	3.060E-02	13.46
53	6.7907E-09	3.062E-02	13.25
54	6.9193E-09	3.064E-02	13.05

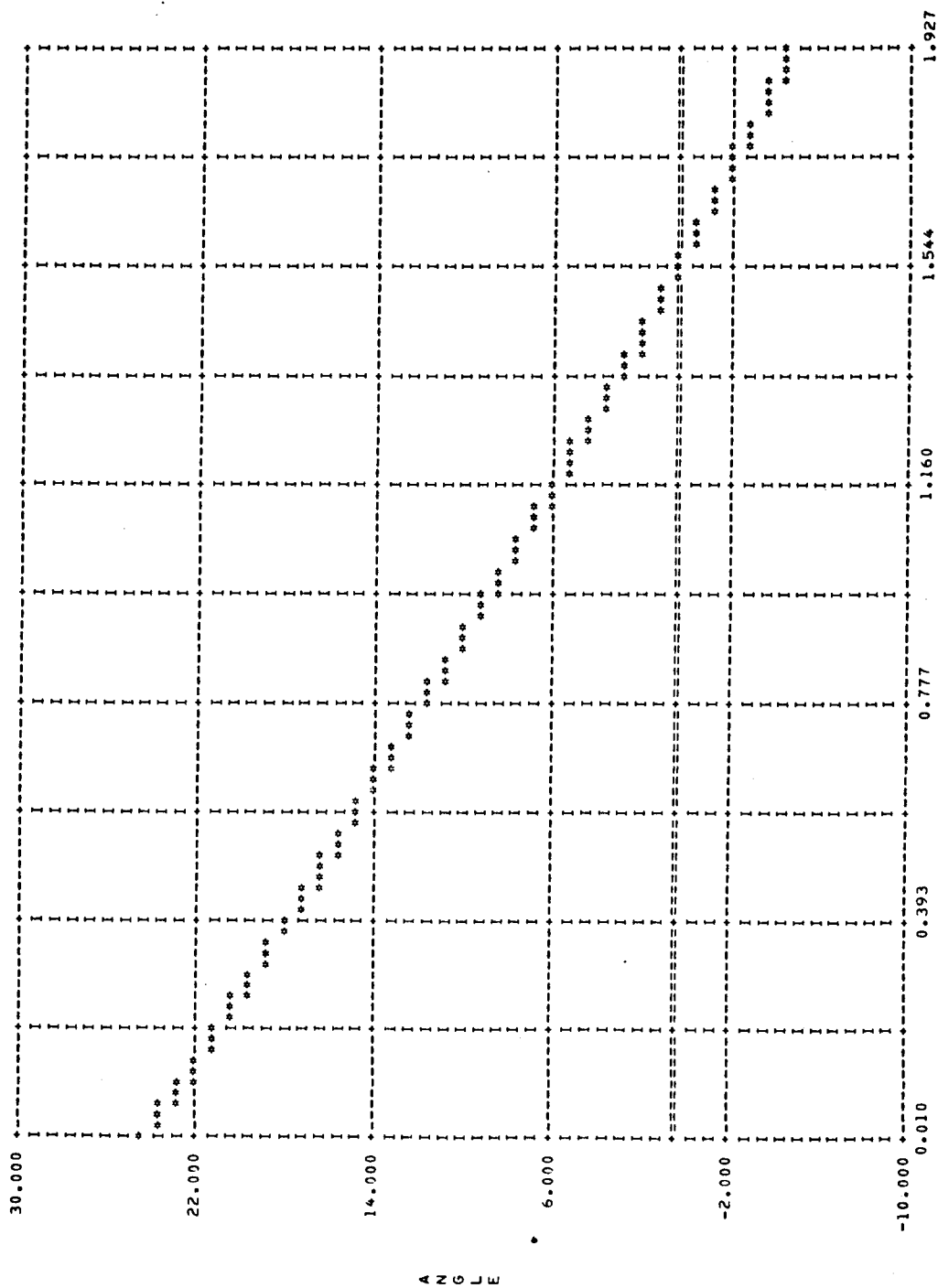
55	7.0490E-09	3.066E-02	12.85
56	7.1767E-09	3.068E-02	12.65
57	7.3053E-09	3.070E-02	12.64
58	7.4340E-09	3.073E-02	12.24
59	7.5627E-09	3.075E-02	12.04
60	7.6913E-09	3.077E-02	11.84
61	7.8200E-09	3.079E-02	11.64
62	7.9487E-09	3.082E-02	11.43
63	8.0773E-09	3.084E-02	11.23
64	8.2060E-09	3.087E-02	11.03
65	8.3347E-09	3.089E-02	10.83
66	8.4633E-09	3.091E-02	10.63
67	8.5920E-09	3.094E-02	10.43
68	8.7207E-09	3.097E-02	10.24
69	8.8493E-09	3.099E-02	10.04
70	8.9780E-09	3.102E-02	9.84
71	9.1067E-09	3.104E-02	9.64
72	9.2353E-09	3.107E-02	9.44
73	9.3640E-09	3.110E-02	9.24
74	9.4927E-09	3.113E-02	9.05
75	9.6213E-09	3.115E-02	8.85
76	9.7500E-09	3.118E-02	8.65
77	9.8787E-09	3.121E-02	8.46
78	1.0007E-08	3.124E-02	8.26
79	1.0136E-08	3.127E-02	8.07
80	1.0265E-08	3.130E-02	7.87
81	1.0393E-08	3.133E-02	7.68
82	1.0522E-08	3.136E-02	7.49
83	1.0651E-08	3.139E-02	7.29
84	1.0779E-08	3.142E-02	7.09
85	1.0908E-08	3.145E-02	6.90
86	1.1037E-08	3.149E-02	6.71
87	1.1165E-08	3.152E-02	6.52
88	1.1294E-08	3.155E-02	6.32
89	1.1423E-08	3.159E-02	6.13
90	1.1551E-08	3.162E-02	5.94
91	1.1680E-08	3.165E-02	5.75
92	1.1809E-08	3.169E-02	5.56
93	1.1937E-08	3.172E-02	5.37
94	1.2066E-08	3.176E-02	5.18
95	1.2195E-08	3.179E-02	4.99
96	1.2323E-08	3.183E-02	4.80
97	1.2452E-08	3.186E-02	4.61
98	1.2581E-08	3.190E-02	4.43
99	1.2709E-08	3.194E-02	4.24
100	1.2838E-08	3.197E-02	4.05
101	1.2967E-08	3.201E-02	3.86
102	1.3095E-08	3.205E-02	3.68
103	1.3224E-08	3.209E-02	3.49
104	1.3353E-08	3.212E-02	3.31
105	1.3481E-08	3.216E-02	3.12
106	1.3610E-08	3.220E-02	2.94
107	1.3739E-08	3.224E-02	2.75
108	1.3867E-08	3.228E-02	2.57
109	1.3996E-08	3.232E-02	2.39
110	1.4125E-08	3.236E-02	2.20
111	1.4253E-08	3.240E-02	2.02
112	1.4382E-08	3.244E-02	1.84
113	1.4511E-08	3.248E-02	1.66
114	1.4639E-08	3.252E-02	1.48
115	1.4768E-08	3.256E-02	1.30

116	1.4897E-08	3.261E-02	1.11
117	1.5025E-08	3.265E-02	0.94
118	1.5154E-08	3.269E-02	0.76
119	1.5283E-08	3.273E-02	0.59
120	1.5411E-08	3.278E-02	0.40
121	1.5540E-08	3.282E-02	0.22
122	1.5669E-08	3.287E-02	0.04
123	1.5797E-08	3.291E-02	-0.13
124	1.5926E-08	3.295E-02	-0.31
125	1.6055E-08	3.300E-02	-0.49
126	1.6183E-08	3.304E-02	-0.66
127	1.6312E-08	3.309E-02	-0.84
128	1.6441E-08	3.313E-02	-1.01
129	1.6569E-08	3.318E-02	-1.18
130	1.6698E-08	3.323E-02	-1.34
131	1.6827E-08	3.327E-02	-1.53
132	1.6955E-08	3.332E-02	-1.70
133	1.7084E-08	3.337E-02	-1.88
134	1.7213E-08	3.342E-02	-2.05
135	1.7341E-08	3.346E-02	-2.22
136	1.7470E-08	3.351E-02	-2.39
137	1.7599E-08	3.356E-02	-2.56
138	1.7727E-08	3.361E-02	-2.73
139	1.7856E-08	3.366E-02	-2.90
140	1.7985E-08	3.371E-02	-3.07
141	1.8113E-08	3.376E-02	-3.24
142	1.8242E-08	3.381E-02	-3.41
143	1.8371E-08	3.386E-02	-3.57
144	1.8499E-08	3.391E-02	-3.74
145	1.8628E-08	3.396E-02	-3.91
146	1.8757E-08	3.401E-02	-4.07
147	1.8885E-08	3.406E-02	-4.24
148	1.9014E-08	3.411E-02	-4.40
149	1.9143E-08	3.416E-02	-4.57
150	1.9271E-08	3.421E-02	-4.73
151	1.9400E-08	3.427E-02	-4.89

PLOT OF N.V. 7, SF = 10**(-2), VERSUS LM



PLOT OF N.V. 7 VERSUS LM



PARAMETER, SCALE FACTOR = 10**(-8)

EXECUTION TIME = 5.767 SEC

END

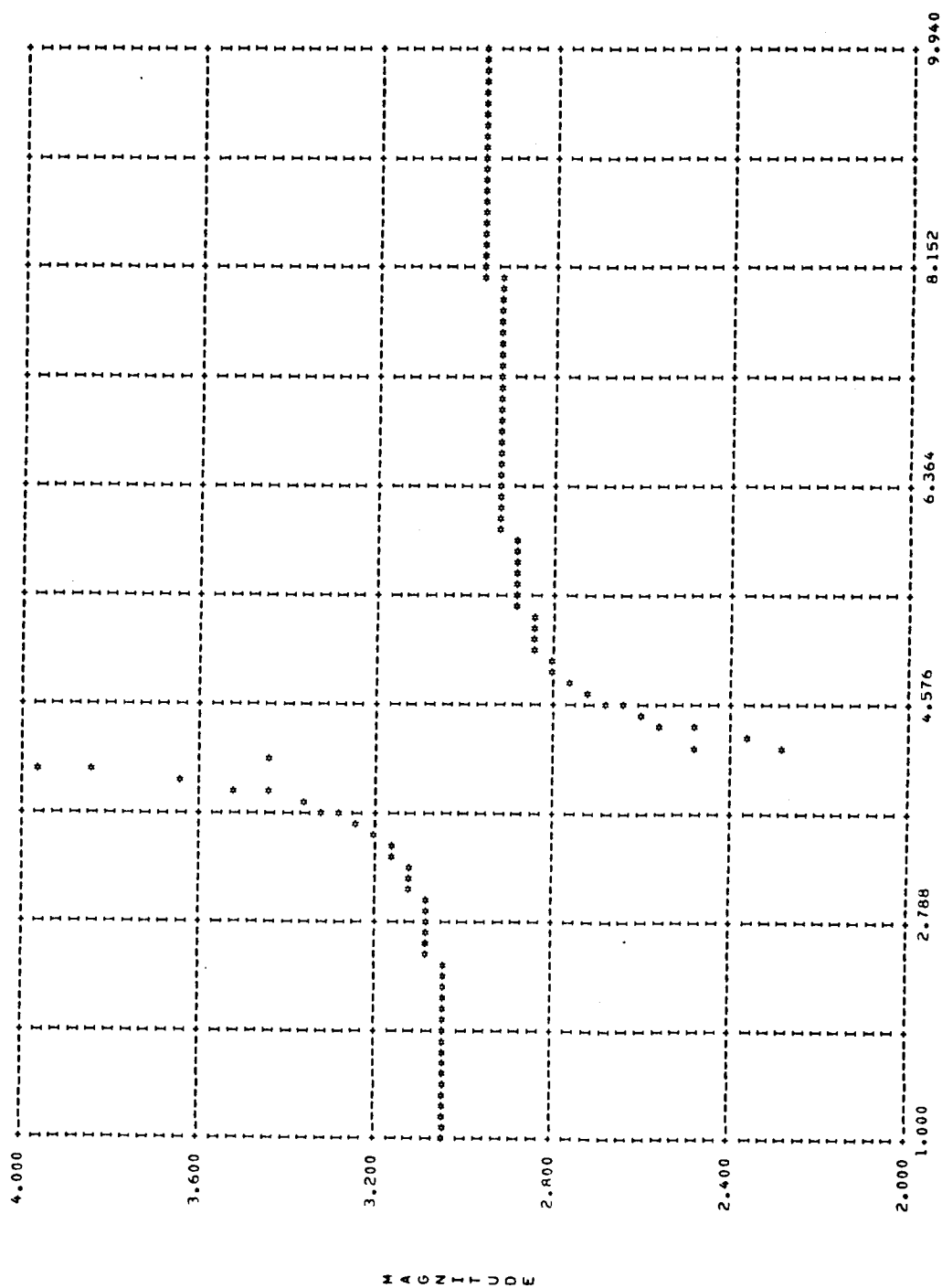
TABLE OF DATA PLOTTED. PARAMETER = C

POINT	PARAMETER	N.V. MAG	7 *** ANGLE
1	1.0000E-07	3.021E-02	24.22
2	1.0600E-07	3.022E-02	24.22
3	1.1200E-07	3.023E-02	24.22
4	1.1800E-07	3.024E-02	24.22
5	1.2400E-07	3.025E-02	24.22
6	1.3000E-07	3.026E-02	24.22
7	1.3600E-07	3.027E-02	24.22
8	1.4200E-07	3.028E-02	24.22
9	1.4800E-07	3.029E-02	24.22
10	1.5400E-07	3.031E-02	24.22
11	1.6000E-07	3.032E-02	24.22
12	1.6600E-07	3.033E-02	24.22
13	1.7200E-07	3.035E-02	24.22
14	1.7800E-07	3.036E-02	24.22
15	1.8400E-07	3.038E-02	24.22
16	1.9000E-07	3.040E-02	24.21
17	1.9600E-07	3.041E-02	24.21
18	2.0200E-07	3.043E-02	24.21
19	2.0800E-07	3.045E-02	24.21
20	2.1400E-07	3.047E-02	24.21
21	2.2000E-07	3.049E-02	24.21
22	2.2600E-07	3.052E-02	24.20
23	2.3200E-07	3.054E-02	24.20
24	2.3800E-07	3.057E-02	24.20
25	2.4400E-07	3.060E-02	24.20
26	2.5000E-07	3.063E-02	24.19
27	2.5600E-07	3.066E-02	24.19
28	2.6200E-07	3.070E-02	24.18
29	2.6800E-07	3.074E-02	24.14
30	2.7400E-07	3.078E-02	24.17
31	2.8000E-07	3.083E-02	24.16
32	2.8600E-07	3.088E-02	24.15
33	2.9200E-07	3.093E-02	24.14
34	2.9800E-07	3.100E-02	24.13
35	3.0400E-07	3.106E-02	24.12
36	3.1000E-07	3.114E-02	24.10
37	3.1600E-07	3.123E-02	24.08
38	3.2200E-07	3.132E-02	24.06
39	3.2800E-07	3.143E-02	24.03
40	3.3400E-07	3.156E-02	23.99
41	3.4000E-07	3.171E-02	23.94
42	3.4600E-07	3.188E-02	23.87
43	3.5200E-07	3.209E-02	23.79
44	3.5800E-07	3.234E-02	23.68
45	3.6400E-07	3.264E-02	23.52
46	3.7000E-07	3.303E-02	23.29
47	3.7600E-07	3.354E-02	22.95
48	3.8200E-07	3.421E-02	22.41
49	3.8800E-07	3.514E-02	21.49
50	3.9400E-07	3.646E-02	19.76
51	4.0000E-07	3.826E-02	16.14
52	4.0600E-07	3.954E-02	7.93
53	4.1200E-07	3.427E-02	-4.89
54	4.1800E-07	2.484E-02	-2.33

55	4.2400E-07	2.290E-02	9.81
56	4.3000E-07	2.373E-02	16.46
57	4.3600E-07	2.473E-02	19.54
58	4.4200E-07	2.552E-02	21.11
59	4.4800E-07	2.612E-02	22.00
60	4.5400E-07	2.659E-02	22.55
61	4.6000E-07	2.695E-02	22.92
62	4.6600E-07	2.724E-02	23.17
63	4.7200E-07	2.748E-02	23.35
64	4.7800E-07	2.768E-02	23.49
65	4.8400E-07	2.784E-02	23.59
66	4.9000E-07	2.799E-02	23.67
67	4.9600E-07	2.811E-02	23.74
68	5.0200E-07	2.822E-02	23.79
69	5.0800E-07	2.831E-02	23.84
70	5.1400E-07	2.840E-02	23.87
71	5.2000E-07	2.847E-02	23.91
72	5.2600E-07	2.854E-02	23.93
73	5.3200E-07	2.860E-02	23.96
74	5.3800E-07	2.865E-02	23.98
75	5.4400E-07	2.870E-02	23.99
76	5.5000E-07	2.875E-02	24.01
77	5.5600E-07	2.879E-02	24.02
78	5.6200E-07	2.883E-02	24.03
79	5.6800E-07	2.886E-02	24.05
80	5.7400E-07	2.889E-02	24.06
81	5.8000E-07	2.893E-02	24.06
82	5.8600E-07	2.895E-02	24.07
83	5.9200E-07	2.898E-02	24.09
84	5.9800E-07	2.901E-02	24.09
85	6.0400E-07	2.903E-02	24.09
86	6.1000E-07	2.905E-02	24.10
87	6.1600E-07	2.907E-02	24.10
88	6.2200E-07	2.909E-02	24.11
89	6.2800E-07	2.911E-02	24.11
90	6.3400E-07	2.913E-02	24.12
91	6.4000E-07	2.914E-02	24.12
92	6.4600E-07	2.916E-02	24.12
93	6.5200E-07	2.917E-02	24.13
94	6.5800E-07	2.919E-02	24.13
95	6.6400E-07	2.920E-02	24.13
96	6.7000E-07	2.922E-02	24.14
97	6.7600E-07	2.923E-02	24.14
98	6.8200E-07	2.924E-02	24.14
99	6.8800E-07	2.925E-02	24.14
100	6.9400E-07	2.926E-02	24.14
101	7.0000E-07	2.927E-02	24.15
102	7.0600E-07	2.928E-02	24.15
103	7.1200E-07	2.929E-02	24.15
104	7.1800E-07	2.930E-02	24.15
105	7.2400E-07	2.931E-02	24.15
106	7.3000E-07	2.932E-02	24.16
107	7.3600E-07	2.933E-02	24.16
108	7.4200E-07	2.933E-02	24.16
109	7.4800E-07	2.934E-02	24.16
110	7.5400E-07	2.935E-02	24.16
111	7.6000E-07	2.936E-02	24.16
112	7.6600E-07	2.936E-02	24.16
113	7.7200E-07	2.937E-02	24.16
114	7.7800E-07	2.938E-02	24.17
115	7.8400E-07	2.938E-02	24.17

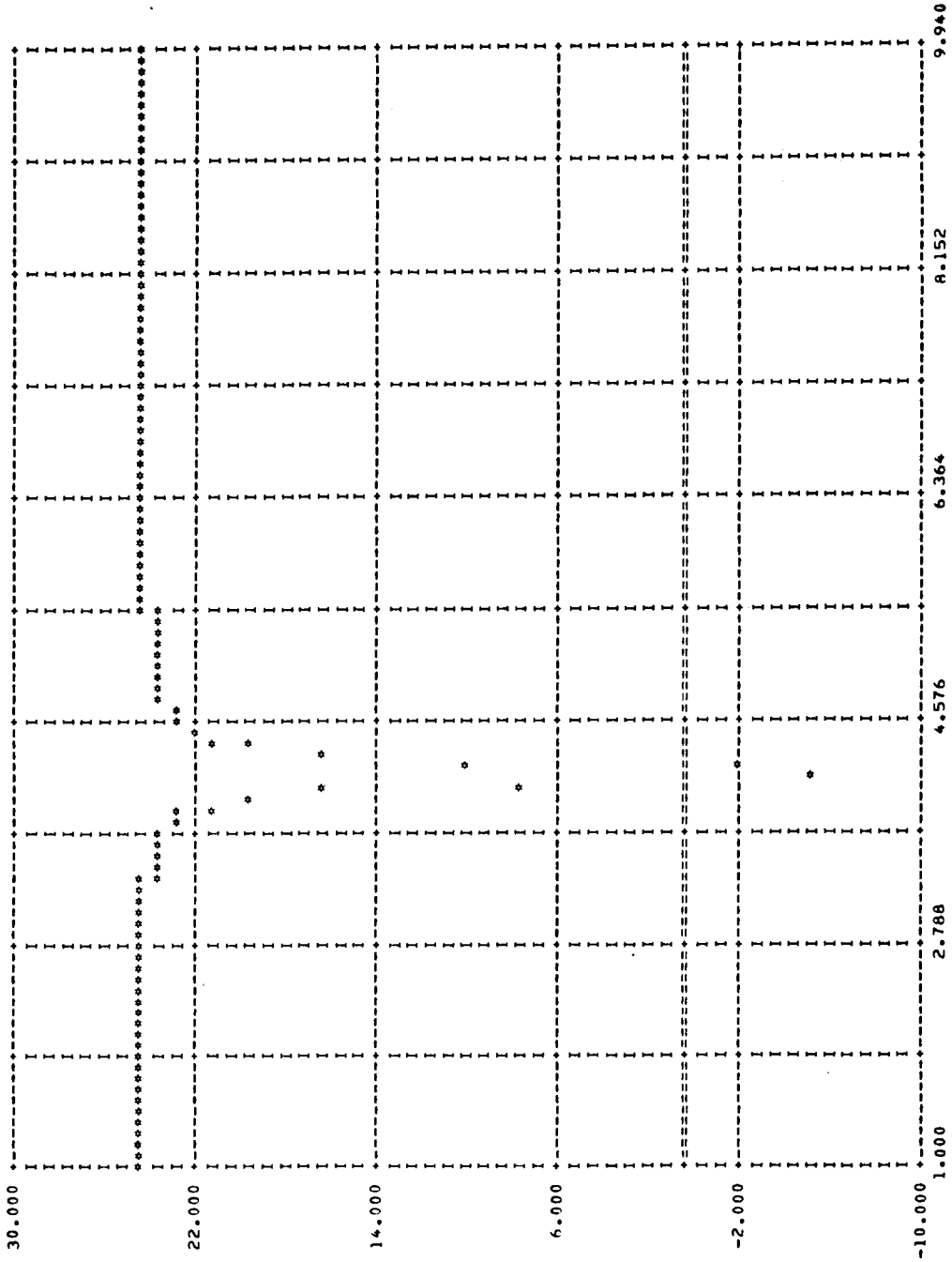
116	7.9000E-07	2.939E-02	24.17
117	7.9600E-07	2.939E-02	24.17
118	8.0200E-07	2.940E-02	24.17
119	8.0800E-07	2.940E-02	24.17
120	8.1400E-07	2.941E-02	24.17
121	8.2000E-07	2.941E-02	24.17
122	8.2600E-07	2.942E-02	24.17
123	8.3200E-07	2.942E-02	24.17
124	8.3800E-07	2.943E-02	24.17
125	8.4400E-07	2.943E-02	24.17
126	8.5000E-07	2.944E-02	24.18
127	8.5600E-07	2.944E-02	24.18
128	8.6200E-07	2.945E-02	24.18
129	8.6800E-07	2.945E-02	24.18
130	8.7400E-07	2.946E-02	24.18
131	8.8000E-07	2.946E-02	24.18
132	8.8600E-07	2.946E-02	24.18
133	8.9200E-07	2.947E-02	24.18
134	8.9800E-07	2.947E-02	24.18
135	9.0400E-07	2.947E-02	24.18
136	9.1000E-07	2.948E-02	24.18
137	9.1600E-07	2.948E-02	24.18
138	9.2200E-07	2.949E-02	24.18
139	9.2800E-07	2.949E-02	24.18
140	9.3400E-07	2.949E-02	24.18
141	9.4000E-07	2.949E-02	24.18
142	9.4600E-07	2.950E-02	24.18
143	9.5200E-07	2.950E-02	24.18
144	9.5800E-07	2.950E-02	24.18
145	9.6400E-07	2.950E-02	24.19
146	9.7000E-07	2.951E-02	24.19
147	9.7600E-07	2.951E-02	24.19
148	9.8200E-07	2.951E-02	24.19
149	9.8800E-07	2.952E-02	24.19
150	9.9400E-07	2.952E-02	24.19
151	1.0000E-06	2.952E-02	24.19

PLOT OF N.V. $7 \cdot SF = 10^{**}(-2)$, VERSUS C



PARAMETER, SCALE FACTOR = $10^{**}(-7)$

PLOT OF N.V. 7 VERSUS C



PARAMETER, SCALE FACTOR = 10**(-7)

EXECUTION TIME = 5.350 SEC

END

APPENDIX B

LIST OF VARIABLES

A_ϕ = Unit Vector in the Azimuth Direction
 A_{R12} = Unit Vector Describing Direction from Points 1 to 2
 $\bar{B}$ = Vector Magnetic Flux Density
 BW = Band Width
 C = Capacitance
 C_d = Transducer Capacitance
 C_r = Receiver Capacitance
 E_p = Primary Voltage of Coupled Circuit
 E_s = Voltage Across the Secondary
 f_o = Resonant Frequency of A Tuned Circuit
 h = 1/2 Length of Finite Wire
 $\bar{H}$ = Vector Magnetic Field Intensity
 $\bar{H}_d$ = $\bar{H}$ from the Transducer
 $\bar{H}_r$ = Component of $\bar{H}_d$ Coupling with Receiver
 $\bar{H}_s$ = Stray $\bar{H}$ Coupling
 $\bar{H}_t$ = Magnetic Field of the Transmitter
 H_x = Component of $\bar{H}$ in x Direction
 H_y = Component of $\bar{H}$ in y Direction
 H_z = Component of $\bar{H}$ in z Direction
 H_ϕ = Component of $\bar{H}$ in the Azimuth Direction
 I = Current
 I_g = Generator Current
 I_p = Current in Primary
 I_s = Current in Secondary
 $\hat{i}$ = Unit Vector in the x Direction

$\hat{j}$	= Unit Vector in the y Direction
$\hat{k}$	= Unit Vector in the z Direction
K	= Constant
L	= Inductance
$\bar{L}$	= Vectored Filimentary Wire Contour
M	= Mutual Inductance
N	= Number of Turns
Q	= Quality Factor of a Resonant Circuit
R	= Receiver
R_C	= Parallel Resistance of a Capacitor
R_d	= Resistance of the Transducer Windings
r_d	= Transducer Radius
R_g	= Generator Resistance
R_L	= Series Resistance of an Inductor
R_r	= Resistance of the Receiver Windings
R_t	= Resistance of the Transmitter Windings
R_{12}	= Distance from Point 1 to Point 2
$\bar{S}$	= Surface Vector
S_x	= Component of $\bar{S}$ in the x Direction
S_y	= Component of $\bar{S}$ in the y Direction
S_z	= Component of $\bar{S}$ in the z Direction
T	= Transmitter
Td	= Transducer
ω	= Frequency in Radians/Second
Z_p	= Primary Impedance of Coupled Circuit

- Z_r = Secondary Impedance Reflected to Primary
 Z_s = Impedance of the Secondary
 μ_0 = Permeability of Free Space
 ϵ_0 = Permittivity of Free Space
 Φ = Magnetic Flux
 ∞ = Infinity
 ρ = Radial Distance in Cylindrical Coordinates

VITA

Lawrence E. Jugler was born in Wilmington, Delaware on July 30, 1954. His primary and secondary school education was in Wilmington and he graduated from Salesianum High School in June 1972. He then attended the University of Delaware as a full and part-time student as well as working as an operator at E. I. DuPont Pigment Plant at Edgemoor, Delaware. In January 1975 he entered University of Tennessee, Knoxville at the freshman level. He received a Bachelor of Science Degree in Electrical Engineering with a concentration in electronics and instrumentation in August 1977.

He entered the Graduate School of the University of Tennessee, Knoxville in September 1977 where he fulfilled the requirements for a Master of Science degree in March 1979. His areas of concentration were Electronics and Instrumentation and Computer Design.

The Author is a member of Eta Kappa Nu and the Institute of Electrical and Electronic Engineers.