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An Automated Immittance Measuring System for Electroacoustic Transducers

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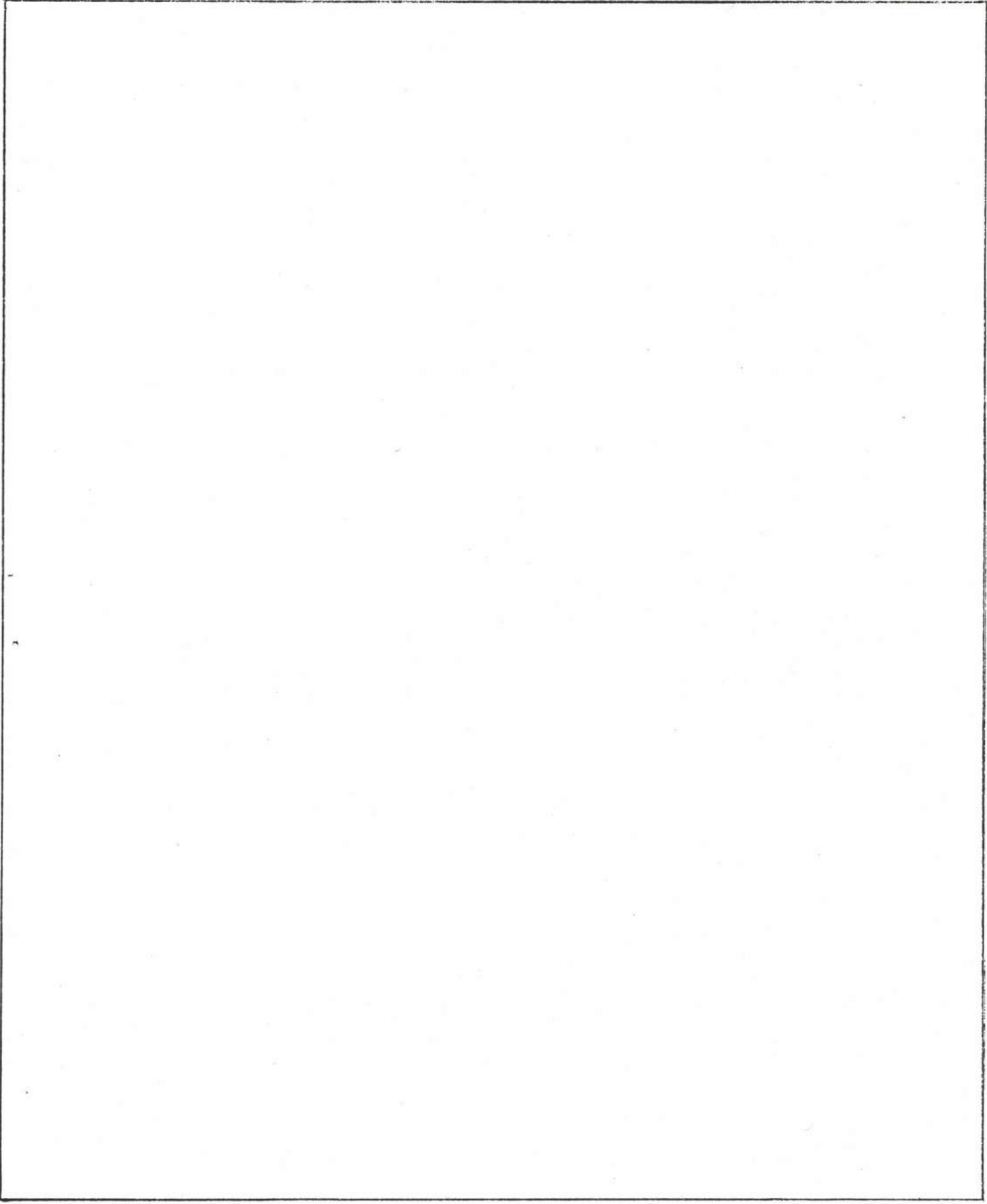


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AN AUTOMATED MEASURING SYSTEM FOR ELECTROACOUSTIC TRANSDUCERS

INTRODUCTION

The precise measurement of immittance is a valuable tool for the analysis of electroacoustic transducers and piezoelectric materials. Immittance is used in the determination of transducer efficiency, electrical matching, and the tuning and analysis of transducer performance and of material parameters of active transducer materials. Previous techniques for immittance measurements involved the use of such devices as impedance bridges, analog voltmeters, phase meters, and some special analog devices like the vector impedance meter. All of the before mentioned devices suffer from one or more restrictions; e.g., speed, precision, or stability.

The HP Model 4192A Digital Network Analyzer is computer controlled and has the ability to make immittance measurements at high speed with excellent precision and stability. Combined with the developed circular approximation algorithm, the measurements can be made with greater efficiency to provide the maximum amount of information with the minimum number of data points. This method also allows for fast, accurate computation of critical points of immittance without knowing the series (parallel) resonance of the transducer. The optimization of data points is achieved by the determination of frequencies that will be quasi-uniformly distributed around the immittance circle as opposed to the "clustering" of frequencies above and below the frequency of maximum immittance.

Figure 1 compares an immittance circle defined by a linear sequence of frequencies with one in which the frequencies are generated from the circular approximation method. There are two hundred points in the linear frequency sweep of Fig. 1a and only fifty points in Fig. 1b. This circular approximation method has been implemented on various piezoelectric transducers and works exceptionally well in most cases. The timesaving is greatest when measuring high-Q transducers. Linear-spaced frequency points appear diluted on the steep slopes of the imaginary part of a high-Q immittance, as shown in Fig. 2. For low-Q curves the frequency distribution is more evenly spaced. When the data are presented in the form of imaginary verses real immittance, the data from high-Q systems are

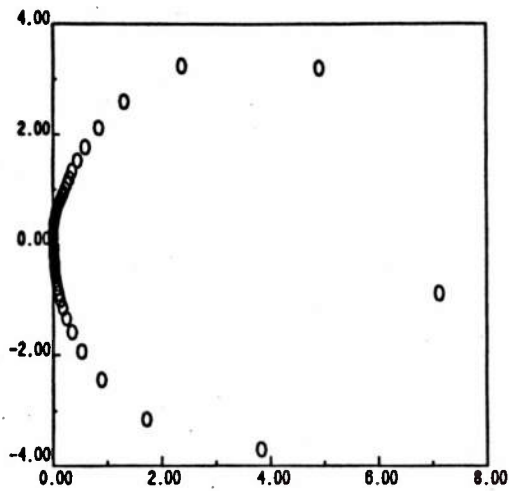


Fig. 1a - Immittance loop showing the distribution of data points resulting from a linear sweep of two hundred frequency steps.

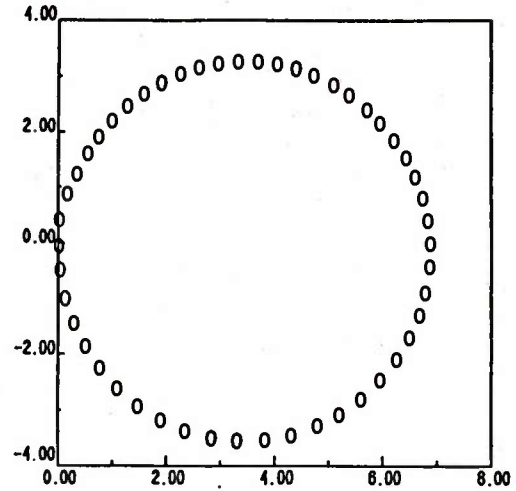


Fig. 1b - Immittance loop showing the more uniform distribution of only 50 data points when frequencies are determined by the circular approximation method.

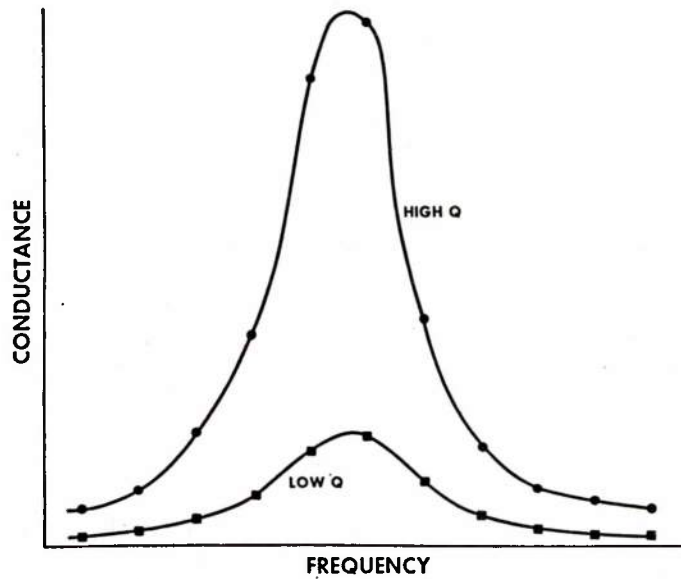


Fig. 2 - Distribution of data points for equally spaced frequencies on the imaginary part of the immittance curve for a high-Q system and for a low-Q system.

concentrated near the beginning and end of the immittance circle. For low-Q systems the data points approach a uniform distribution.

CIRCULAR APPROXIMATION ALGORITHM

The circular approximation method can be applied to admittance and impedance loops. Because of the similarity of application to impedance and admittance, and to avoid writing "impedance or admittance", the two quantities are implied when the term immittance is used in the following text. The differences between the admittance terms and the impedance terms will be discussed in the PROGRAM section of this report. Throughout this report the word "points" appears many times with various meanings. To assure clarity three symbols are defined:

- o The term "points(f)" refers to a frequency.
- o The term "points(c)" refers to the ordered pair on the the theoretical circle.
- o The term "points(i)" refers to the real and imaginary position on the immittance loop.

The method presented here will be based on the following equation:

$$\tan(\Theta) = \frac{L[\omega^2 - \omega_i^2]}{\omega R}. \quad [1]$$

This equation is derived [1] from a simple equivalent circuit of a piezoelectric resonator, where L is the inductance, ω is the angular frequency, ω_i is a resonant frequency (series resonance when measuring admittance, parallel resonance when measuring impedance), Θ is the phase angle, and R is the resistance. Cady uses ω_0 (angular frequency of zero crossing) in Eq. (1) instead of ω_i . But ω_i is also an angular frequency at a zero crossing since a transformation of axes is performed with the circular approximation method. It is algebraically convenient to write Eq. (1) in the following form: Given ω , R, and Θ for three points(f), ω_i

and L are determined by applying Cramer's rule [2] to this expression:

$$\omega_i^2 + \frac{1}{L} \omega R \tan(\Theta) = \omega^2. \quad [2]$$

By using the following equation

$$L\omega^2 - L\omega_i^2 - \omega R \tan(\Theta) = 0, \quad [3]$$

the angular frequencies (ω) are determined as a function of the angle Θ by solving the quadratic equation. Equations (2) and (3) are the key equations used in the circle approximation method and will be referred to many times in the text of this paper. The argument used for applying Eqs. (1) through (3) to both impedance and admittance is found in Appendix A.

The algorithm used in determining the admittance or impedance loops consists of two major parts. First, the "best fit" circle that approximates the immittance loop is determined from parameters of the simple equivalent circuit of a piezoelectric resonator. Secondly, the circular approximation is then divided into equal arcs that are used to determine quasi-equally spaced points(i) on the immittance loop.

To determine the "best-fit" circle, one must first identify any three frequency points(f) on the immittance loop with the abscissa and ordinate identified as conductance and susceptance (or resistance and reactance), respectively. If previous knowledge exists about the transducer to be measured, these three points(f) are easy to identify. If however, there is no previous knowledge about the transducer, the program will assist the user in determining the three points(f).

The HP 4192 Impedance Analyzer measures the real and imaginary parts of immittance at each of these frequency points(f) and the ordered pairs of data are stored as (x_i, y_i) , where i goes from 1 to 3 corresponding to each of the three frequency points(f). These ordered pairs are used in the general form of the equation of a circle:

$$x_1 D + y_1 E + F = -[x_1^2 + y_1^2] \quad [4]$$

$$\text{of center } \left[\frac{-D}{2}, \frac{-E}{2} \right] \text{ and radius } \frac{1}{2} [D^2 + E^2 - 4F]^{1/2}. \quad [5]$$

To find D, E, and F, we impose the condition that the coordinates of each of the given points(i&c) satisfy Eq. (4). When these values for D, E, and F are substituted in Eq. (5), we have the radius and center of the circle through the given points(i&c). By using the calculated radius and center, two points(c) located 120 degrees from a fixed initial point(i&c) are found as shown by the boxes in Fig. 1. The authors have arbitrarily chosen the fixed point(c) to be the second initial point(i). One may use any initial point(i) as long as it remains consistent throughout the entire procedure.

In order that this procedure apply both to loaded and unloaded transducers, a translation of axes is performed on all points(i) used in Eqs. (2) and (3). The formulas for the translation of axes are:

$$x_t = x_o - x_c + r \quad \text{and} \quad y_t = y_o - y_c \quad [6]$$

where $(x_c + r, y_c)$ is the new origin. The ordered pair (x_c, y_c) is the center of the circle, r is the radius, (x_o, y_o) are the old coordinates, and (x_t, y_t) are the old coordinates with the new origin. The slope $[\tan(\theta)]$ is determined by first applying Eqs. (6) to a given point(i). The resistance R , also found in the Eqs. (2) and (3), is replaced by the diameter or reciprocal of the diameter of the circle depending on which immittance loop is chosen. The quantities ω_1 and L are calculated using Eq. (2) and the data of two initial points(i) along with information from the circle. With the calculated parameters $(\omega_1, L, \text{ and } \theta)$ of the two 120-degree points(c), the frequencies $(\omega/2\pi)$ at the 120-degree points(c) are calculated by applying Eq. (3). The HP 4192 Impedance Analyzer measures the conductance and susceptance (or resistance and reactance) at each frequency, and the points(i) are stored. These points(i) are illustrated by the "triangles" in Fig. 3.

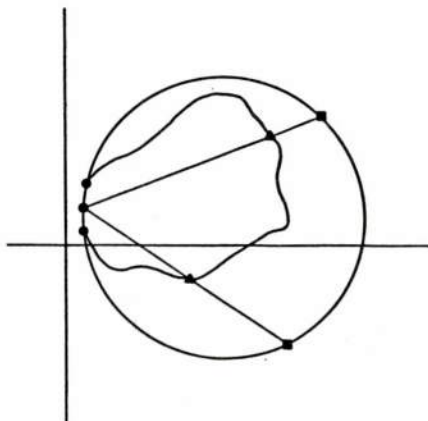


Fig. 3 - An immittance loop with a first-circle approximation.
 Dots indicate the first three frequencies chosen.
 Squares mark the 120° points.
 Triangles represent associated points on immittance loop.

Now a new circle is calculated using the two 120-degree points(c) (triangles in Fig. 3) and the second initial point(i&c). Note that this new circle will be a better approximation to the immittance loop than was the previous one. This procedure iterates until two successive circles are within the desired tolerance. The result of this convergence is a "best-fit" circle, which is then divided into equal sectors, as shown in Fig. 4; the frequencies are found at each "triangle" location by applying Eq. (3).

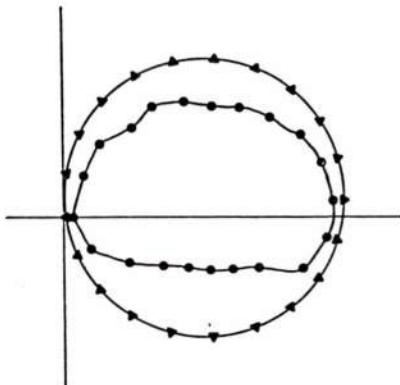


Fig. 4 - An immittance loop with a first-circle approximation.
 Equally spaced points on the circle create quasi-equally spaced points on the immittance loop.

The HP 4192 Impedance Analyzer measures the conductance and susceptance at the "triangle" frequencies, and the immittance values are stored in a file. Note the dots on the immittance loop in Fig. 4 are not exactly "equally spaced", but certainly there is a better distribution of points(i)

than is obtained from a linear frequency sweep. This is what we previously referred to as quasi-equally spaced points(i).

CRITICAL FREQUENCIES

Once the loop is characterized with the desired number of quasi-equally spaced points(i), specific frequency points(f) are needed for later calculations of various transducer parameters. The frequency points(f) [3] that are of interest are:

f_m : frequency at maximum admittance (minimum impedance)

f_n : frequency at maximum impedance (minimum admittance)

f_g : frequency at maximum conductance

f_p : frequency at maximum resistance

f_r : resonance frequency (susceptance is zero)

f_a : antiresonance frequency (susceptance is zero)

f_{h_a} : frequency at maximum susceptance

f_{l_a} : frequency at minimum susceptance

f_{h_i} : frequency at maximum reactance

f_{l_i} : frequency at minimum reactance

When characterizing an admittance loop, the frequency points(f) f_m , f_g , f_r , f_p , f_{h_a} , and f_{l_a} are determined by a maze technique that will be described in the program section of this report. When an impedance loop is characterized, the frequency points(f) f_a , f_p , f_n , f_g , f_h , and f_l are determined. One may note that the frequency sets differ when calculating

impedance or admittance loops. The authors believe that the two most important points(f) are the series and parallel resonance (f_s and f_p). These points(f) can easily be found, and they occur for both loaded and unloaded transducers. Both of these conditions do not apply to the frequency pairs f_m, f_n and f_a, f_r . To determine the frequencies f_m, f_n one must do a frequency sweep, which can be rather time consuming. The points(f) f_a, f_r are easy to find by implementing root-finding techniques; however these points(f) do not always occur in loaded transducers. For these reasons, the focus has been on obtaining f_s, f_p . The reader may note that f_s is the frequency at maximum conductance; however, it is not the frequency of minimum resistance as can be seen in Fig. 5.

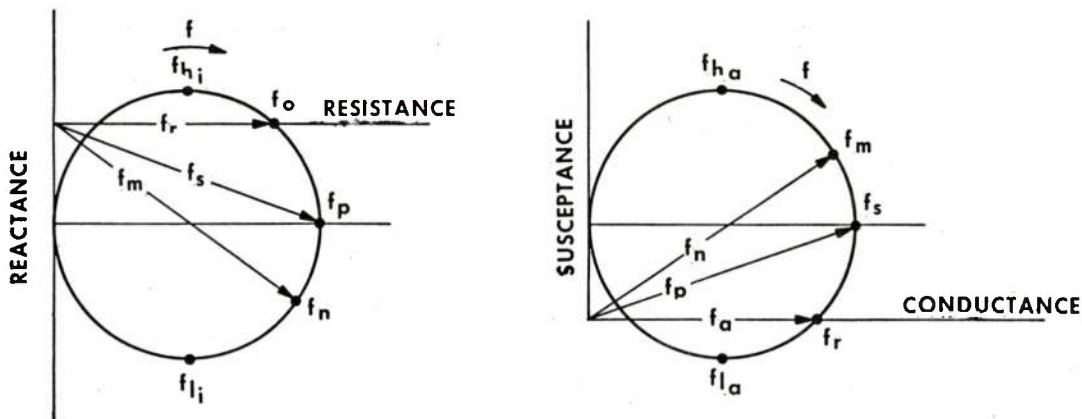


Fig. 5 - Impedance loop (5a) and admittance loop (5b), showing their critical frequencies.

Analogously, f_p is the frequency at maximum resistance; but it is not the frequency of minimum conductance.

The points(f) of secondary importance are the frequencies of minimum and maximum susceptance (f_{h_a} and f_{l_a}). These points(f), sometimes called half-power points(f), are used to compute the electrical quality factor Q . We also compute the frequencies of minimum and maximum reactance (f_{h_r} and f_{l_r}). These points(f), however, are not the half-power points(f) and cannot be used for calculating the quality factor Q . The only purpose for determining these points(f) is that they locate the frequencies at the top and bottom of the loop. The remaining frequencies are easily determined for the particular immittance loop calculated, and they serve as helpful

parameters for detecting problems.

PROGRAM

The computer program MICAM, presented herein, is by no means the best implementation of the circular approximation method. However, the authors feel confident that this program can be refined in a manner that would be applicable in any research or manufacturing environment. The MICAM program, written in FORTRAN 77, is run on a Digital Equipment Corporation VAX 11/780 computer at the Underwater Sound Reference Detachment of the Naval Research Laboratory as a research tool as well as a quality-control problem detector. A version of this program is also written in HP Basic and can be executed on the HP 9836. The MICAM program has been tested on various transducers, both in air and in water, and seems to perform exceptionally well. It does have limitations, which will be explained in detail in the RESTRICTIONS section of this report. Since the program is quite involved, the line-by-line descriptions of MICAM and the program listings are included in Appendix B. The purpose of examining individual program lines is to:

- o Show how the algorithm has been implemented.
- o Give differences in admittance and impedance loops.
- o Explain how critical frequencies are determined.

The program MICAM calls three subroutines; SIMEQ, RSORT, and FILE. The SIMEQ subroutine solves simultaneous equations. The RSORT subroutine sorts numbers in descending or ascending order. And the FILE subroutine stores the immittance information in FORTRAN files.

RESTRICTIONS

Limitations exist in all algorithms and should be used as one criteria for choosing one method over another. The following paragraphs identify two examples where a linear frequency sweep would be preferable to

determining frequencies by the circular approximation method.

One problem occurs when running very low-Q or highly damped transducers where no loops are formed. Since the circular approximation method is designed to emulate the immittance loop with a circle, the algorithm fails to converge on very low-Q or highly damped transducers. The MICAM program accommodates this problem by allowing the user to perform a frequency sweep. If the transducer is of low Q, a linear frequency sweep will give quasi-equally spaced points(i), as illustrated in Fig. 2.

A second problem occurs when two or more resonances are in the same frequency region. They may appear as small or large satellite loops. Usually the small satellite loops are not a problem and MICAM will converge to the larger loop. Nevertheless, when immittance is the combination of loops of relatively the same size, MICAM converges to one of them, depending on the initial frequency given. This loop may not necessarily be the one desired. However, the authors feel that MICAM may be optimized for specific applications by relatively minor programming changes.

CONCLUSION

The circular approximation algorithm, when used with the HP 4192A Impedance Analyzer, makes a highly efficient system for measuring impedance and admittance of resonant electromechanical devices. The system has proven to be applicable to the measurement of active electromechanical materials as well as composite transducers. The algorithm has been used with excellent results on a VAX computer as well as on personal computers.

Although specifically developed as a research tool, the automated immittance measuring system is extremely well suited for quality-control and production testing of electromechanical transducers and materials.

ACKNOWLEDGMENTS

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APPENDIX A

Analysis for Applying Equations to Both Imittance Loops

The characteristic electrical property of a piezoelectric resonator is the equivalent series chain RLC in Fig. A1. The graphical representation of the RLC branch is more easily represented by the admittance which is represented as a circle referred to as the fiducial circle [1]. The graph can be easily extended to more complicated networks connected in parallel, such as C_o .

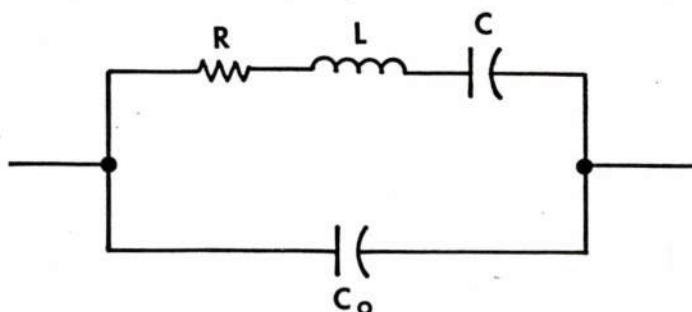


Fig. A1 - Simple equivalent circuit of a piezoelectric resonator.

The simple form of admittance of the RLC chain is all that is necessary to approximate the fiducial circle. The argument extends to the impedance representation in that all the information for the impedance circle is contained in the admittance circle. If

$$Y(\omega) = G(\omega) - jB(\omega),$$

then

$$\tan(\theta) = \frac{-B(\omega)}{G(\omega)}. \quad [A1]$$

Since $Z(\omega)$ is the complex reciprocal of $Y(\omega)$, $Z(\omega)$ can be written as

$$Z(\omega) = \frac{G(\omega)}{G^2(\omega) + B^2(\omega)} + j \frac{B(\omega)}{G^2(\omega) + B^2(\omega)}, \quad [A2]$$

or $Z(\omega)$ can be written as

$$Z(\omega) = R(\omega) + jX(\omega). \quad [A3]$$

Equating the real and imaginary parts of Eqs. (A2) and (A3) results in the following expressions:

$$R(\omega) = \frac{G(\omega)}{G^2(\omega) + B^2(\omega)}, \quad [A4]$$

and

$$X(\omega) = \frac{B(\omega)}{G^2(\omega) + B^2(\omega)}. \quad [A5]$$

For an impedance loop, $\tan(\Theta)$ can be written as

$$\tan(\Theta) = \frac{X(\omega)}{R(\omega)}, \quad [A6]$$

or can be equivalently expressed by using Eqs. (A4) and (A5) as

$$\tan(\Theta) = \frac{-B(\omega)}{G(\omega)}.$$

Note that Eqs. (A1) and (A6) are identical except for being opposite in sign. Therefore for any ω in the admittance circle there is a corresponding ω of the same value in the impedance circle with the same but negative phase value.

APPENDIX B

Program Description and Listing

DESCRIPTION

This appendix contains a detailed description of MICAM as well as program listing. The program description supplements the CIRCULAR APPROXIMATION ALGORITHM section of this report and is necessary for a full understanding of this method. Program lines 1-76 are array declarations while lines 94-145 contain the interactive input section. There are several items of interest in this section. A question regarding speed is asked at line 98. Low speed provides an average measurement mode (approximately one measurement per second) to obtain measurement data of higher resolution and repeatability than at medium speed (5 measurements per second) or high speed (10 measurements per second). At line 112, the number of points(i) refers to the number of quasi-equally spaced points(i) that are desired on the immittance loop. In lines 118 and 120, the parallel or series resonance is required depending upon which loop is calculated. These frequencies are estimated from a priori knowledge. The more confident one is of these points(f), the smaller the frequency step size can be taken (line 125).

Lines 138-163 is a section of code that allows the user to perform a frequency sweep. This is executed only if, for some reason, the circular approximation method does not apply. The portion of code that includes lines 176-215 is the location where the conductance and susceptance (resistance and reactance) for the three initial points(f) are determined. The ARRAY variable contains the coefficients of Eq. 4. In line 216, the subroutine SIMEQ solves the three simultaneous equations, which ultimately results in the center and radius of the circle given in lines 218-220.

The code from lines 221-237 is used to solve Eq. (2) for ω_i and $1/L$, which are used to calculate the frequencies at two initial points(i) and the motional inductance value L (lines 241-250). Line 252 is a decision statement that determines if the difference between two successive series

(parallel) resonant frequencies is within a desired tolerance. If the frequency is within tolerance, the program has determined the best fit ω_i and L for Eq. (1). If the tolerance is not met, a new and hopefully better-fit circle will be computed using the frequencies at the two 120-degree points(c) (lines 261-283). These 120-degree frequency points(f) are found by solving Eq. (3) and substituting the recently computed values for ω_i and L. This entire procedure repeats until the tolerance condition is met in line 252.

The second major computational portion of the MICAM program is found in lines 294-321. This portion uses the ω_i and L that meet the tolerance specifications and Eq. (3) to calculate the quasi-equally spaced points(i). The remaining portion of the program determines the critical frequencies described earlier in this report. The RSORT subroutine sorts the data from the largest to the smallest value. In line 322, the conductance (resistance) is sorted so that the first value in the array will be the f_s (f_p). The RSORT subroutine is called again in line 327 where frequency is the variable sorted. The remaining critical frequencies are determined by exercising a maze technique. This technique is found in lines 337-384 and is based on previous knowledge on all immittance loops, shown in Fig. 5. The criteria used are:

$$f_m < f_s < f_r < f_a < f_p < f_n. \quad [B1]$$

A critical frequency point(f) is searched only in the region wherein it could occur; i.e, it satisfies the inequalities of Eq. (B1). All of the critical frequencies are chosen from the points(i&f) of the immittance loop except for f_p (f_s). The points(f) f_p (f_s) require that more points(f) be calculated in order to have relatively accurate data. For example, when an admittance loop has been run, f_p is determined by switching the HP analyzer to the impedance mode, spotting the point(f) f_{1a} , and sweeping the frequency until the frequency at maximum impedance is found. On the other hand, when an impedance loop has been run, f_s is determined by switching the analyzer to the admittance mode, spotting the point(f) f_{h1} , and then sweeping the frequency in reverse until the frequency of maximum admittance is found. This technique is illustrated in lines 408-431.

The remaining portion of the program can be considered a formatted output section that prints a table of all critical frequencies described and files the data points(i) for plotting. The plots that can be created include a graph of magnitude of immittance verses frequency and a graph of the imaginary part of immittance verses the real part of immittance. Also the critical frequencies are stored so they may be overlaid on the immittance plot as shown in Figs. B1 and B2, which are examples of admittance loops obtained on a USRD Type F42A transducer in air and in the USRD Lake Facility by MICAM.

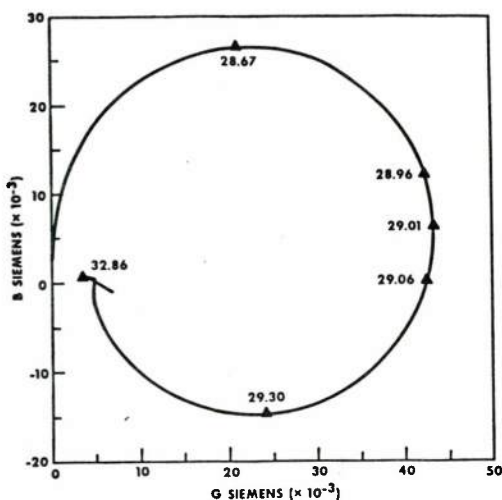


Fig. B1 - Admittance loop obtained on an F42A transducer in air.

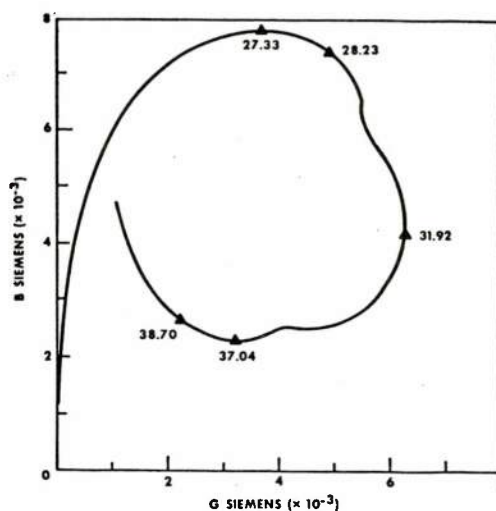


Fig. B2 - Admittance loop obtained on an F42A transducer in the USRD Lake Facility.

There are several differences in MICAM for impedance or admittance loops. The first difference, of course, is that the HP analyzer is in the proper mode for the desired measurements (lines 171 and 172). Secondly, there is a difference in the motional resistance (R) found in Eqs.(1) through (3) for the two loops. In the admittance mode, R is approximated by the reciprocal of the diameter, and in the impedance mode, R is approximated by simply using the diameter of the circle. Two interactive runs of the program MICAM are included in Appendix B, which illustrate how

the user can obtain results in either immittance mode.

LISTING

```

0001
0002
0003 C      MICAM PROGRAM
0004
0005 C      WRITTEN BY TINA RUGGIERO
0006 C      FEBRUARY, 1983
0007
0008 C THIS PROGRAM DETERMINES A FREQUENCY SWEEPING FUNCTION BY APPROXIMATING
0009 C      AN ADMITTANCE LOOP WITH A PERFECT CIRCLE.  ALSO FN, FM,
0010 C      FA, FR, AND ADMITTANCE LOOPS ARE STORED AND ARE AVAILABLE
0011 C      FOR PLOTTING.
0012
0013
0014      DOUBLE PRECISION DEF(3), CONS(3), ARRAY(3,3), COEFF(3,3), COLUMN(3), ANS(3)
0015      REAL RES(1000), XES(1000), FREQ(1000), X(6), Y(6), F(6), FR(3), FRE(1000)
0016      REAL K33, CE, CP, C0B, CAP, XCOF(5), COF(5), ROOTR(5), ROOTI(5), ADM(1000)
0017      REAL CRX(8), CRY(9), MAG(1000)
0018      COMMON FR, AMR, RR, XR, FA, AMA, RA, XA, FM, AMM, RM, XM, FN, AMN, RN, XN, XH, XL
0019      COMMON RH, RL, FH, FL
0020      COMMON /LENGTH/LEN
0021
0022
0023      BYTE ANSWER(80)
0024
0025      BYTE A(13)                                I VOLTS
0026      DATA A /'O', 'L', 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 'E', 'N'/
0027
0028      BYTE B(12)                                ! START
0029      DATA B /'T', 'F', 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 'E', 'N'/
0030
0031      BYTE C(13)                                I STOP
0032      DATA C /'P', 'F', 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 'E', 'N'/
0033
0034      BYTE D(12)                                I STEP
0035      DATA D /'S', 'F', 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 'E', 'N'/
0036
0037      BYTE E(13)                                I SPOT
0038      DATA E /'F', 'R', 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 'E', 'N'/
0039      BYTE IDSP(4)
0040      DATA IDSP /'F', '1', 'A', '4'/          IDISPLAY CAP  DIS
0041
0042      BYTE IADV(2)                              ISTEP UP
0043      DATA IADV /'W', '2'/
0044
0045      BYTE IREV(2)                              ISTEP DOWN
0046      DATA IREV /'W', '4'/
0047
0048      BYTE IAD1(2)
0049      DATA IAD1 /'D', '1'/          IDATA READY ON
0050
0051      BYTE IAD0(2)

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0052      DATA IADO /'D','0'/                IDATA READY OFF
0053
0054      BYTE IADM(4)
0055      DATA IADM/'F','1','A','2'/          IDISPLAY G      B
0056
0057      BYTE IAV1(2)                          I AVERAGE ON
0058      DATA IAV1/'V','1'/
0059
0060      BYTE IAH1(2)                          I HIGH SPEED ON
0061      DATA IAH1/'H','1'/
0062
0063      BYTE IAH0(2)                          I HIGH SPEED OFF
0064      DATA IAH0/'H','0'/
0065
0066      BYTE IAMM(2)                          I MANUAL SWEEP
0067      DATA IAMM/'W','0'/
0068
0069      BYTE IAC3(2)                          I PARALLEL CIRCUIT (ADMITTANCE)
0070      DATA IAC3/'C','3'/
0071
0072      BYTE IAC2(2)                          I SERIES CIRCUIT (IMPEDANCE)
0073      DATA IAC2/'C','2'/
0074
0075      BYTE IAEX(2)                          I TRIGGER THE READING
0076      DATA IAEX/'E','X'/
0077
0078      IADDR=1
0079      ITIMO=30
0080      LUN=1
0081      CALL BTAKEC(LUN,ISTAT)                I TAKE CHARGE OF GPIB
0082      CALL BDEVCL(IADDR,ISTAT)             I CLEAR SELECTED DEVICE
0083
0084      CALL ERRSET(64,,.FALSE.,,.FALSE.,,)  I IGNORE ERROR MESSAGE 64
0085
0086      CALL BWRITE(IADDR,IADM,4,ISTAT)       I DISPLAY MODE
0087
0088      AMM=10000.
0089      LENGTH1=35
0090      LENGTH2=21
0091      LENGTH3=80
0092      1053  FORMAT(F9.5)
0093      AMN=0.
0094      WRITE(5,888)
0095      888   FORMAT('$DO YOU WANT 1)IMPEDANCE 2)ADMITTANCE ')
0096      READ(5,889)ILOOP
0097      889   FORMAT(I2)
0098      WRITE(5,900)
0099      900   FORMAT('$, 'DO YOU WANT 1)LOW, 2)MED. 3)HIGH SPEED ')
0100      READ(5,950) IAVE
0101      950   FORMAT(I2)
0102

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0103 10 WRITE(5,1000)
0104 1000 FORMAT(/'$','ENTER THE VOLTAGE LEVEL (IN VOLTS): ')
0105 READ(5,1060,ERR=10) VOLTS
0106 ENCODE(9,1070,A(3)) VOLTS
0107 CALL BWRITE(IADDR,A,13,ISTAT)
0108 1060 FORMAT(F10.0)
0109 1070 FORMAT(F9.4)
0110 NTIMES=1
0111
0112 WRITE(5,1111)
0113 1111 FORMAT(' $ ENTER # OF POINTS ')
0114 READ(5,1020)NPTS
0115 1020 FORMAT(I4)
0116 20 NTIMES=NTIMES+1
0117
0118 IF (ILOOP .EQ. 1)WRITE(5,1010)
0119 1010 FORMAT(/'$','ENTER FREQUENCY(PARALLEL RESONANCE) (IN KHZ): ')
0120 IF (ILOOP .EQ. 2)WRITE(5,1011)
0121 1011 FORMAT(/'$','ENTER FREQUENCY(SERIES RESONANCE) (IN KHZ): ')
0122 READ(5,1060,ERR=20) START_FREQ
0123 ITIME=1
0124
0125 WRITE(5,1030)
0126 1030 FORMAT('$ENTER STEP FREQ (IN KHZ): ')
0127 READ(5,1060)STEP_FREQ
0128 IF(NTIMES .LT. 5)THEN
0129 GOTO 3000
0130 ELSE
0131 TYPE *,'DO YOU WANT TO SWEEP FREQ?'
0132 READ(5,1035)ISWEEP
0133 1035 FORMAT(A2)
0134 IF(ISWEEP .EQ. 'N')THEN
0135 NTIMES=-10
0136 GO TO 3000
0137 END IF
0138 I=1
0139 ENCODE(8,1066,D(3))STEP_FREQ
0140 CALL BWRITE(IADDR,D,12,ISTAT)
0141 WRITE(5,1040)
0142 1040 FORMAT(/,'$ENTER THE STOPPING FREQ (KHZ) ')
0143 READ(5,1060)STOP
0144 ENCODE (9,1070,C(3))STOP
0145 1066 FORMAT(F8.4)
0146 CALL BWRITE(IADDR,C,13,ISTAT)
0147 ENCODE(9,1070,E(3))START_FREQ !SPOT FREQUENCY
0148 CALL BWRITE(IADDR,E,13,ISTAT)
0149
0150 CALL BWRITE(IADDR,IAMM,2,ISTAT) !MANUAL MODE
0151 1044 CALL BWRITE(IADDR,IAEX,2,ISTAT) !TRIGGER
0152 DO J=1,80
0153 ANSWER(J)=0

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0154      END DO
0155      CALL BREAD(IADDR, ANSWER, LENGTH3, ISTAT)
0156      DECODE(12, 1050, ANSWER(5))RES(I)
0157      DECODE(12, 1050, ANSWER(21))XES(I)
0158      DECODE(9, 1053, ANSWER(35))FREQ(I)
0159      IF (FREQ(I) .GE. STOP)GOTO 88
0160      CALL BWRITE(IADDR, IADV, 2, ISTAT)          IADVANCE FREQ.
0161      I=I+1
0162      GO TO 1044
0163      END IF
0164 3000      STEPI=STEP_FREQ
0165
0166      IF (IAVE.EQ. 1) CALL BWRITE(IADDR, IAV1, 2, ISTAT)  I AVERAGE SPEED
0167      IF (IAVE .EQ. 3)CALL BWRITE(IADDR, IAH1, 2, ISTAT)  I HIGH SPEED
0168      IF (IAVE .EQ. 2)CALL BWRITE(IADDR, IAHO, 2, ISTAT)  I NORMAL SPEED
0169
0170      CALL BWRITE(IADDR, IAMM, 2, ISTAT)          I MANUAL MODE
0171      IF (ILOOP .EQ. 2)CALL BWRITE(IADDR, IAC3, 2, ISTAT)  I CIRCUIT TYPE 3
0172      IF (ILOOP .EQ. 1)CALL BWRITE(IADDR, IAC2, 2, ISTAT)  I CIRCUIT TYPE 2
0173
0174 48      IF (IT .GT. 1)CONTINUE
0175
0176 49      DO I=1, 3
0177      IF (ITIME .GE. 2)THEN
0178          IF (I .EQ. 2)GOTO 85
0179          FREQUENCY=ABS(FR(I)/(1000.*2*3.14159))
0180          ENCODE(9, 1070, E(3)) FREQUENCY  I SPOT STARTING POINT
0181          CALL BWRITE(IADDR, E, 13, ISTAT)
0182          FREQ(I)=FREQUENCY
0183      ELSE
0184          ENCODE(9, 1070, E(3)) START_FREQ  I SPOT STARTING POINT
0185          CALL BWRITE(IADDR, E, 13, ISTAT)
0186          FREQ(I)=START_FREQ
0187      END IF
0188
0189      CALL BWRITE(IADDR, IAEX, 2, ISTAT)          I TRIGGER THE READING
0190      DO J=1, 80
0191          ANSWER(J)=0
0192      END DO
0193      K=0
0194      CALL BREAD(IADDR, ANSWER, LENGTH1, ISTAT)
0195      DECODE(12, 1050, ANSWER(5))RES(I)
0196      DECODE(12, 1050, ANSWER(21))XES(I)
0197 1050      FORMAT(E12.2)
0198      IF (ITIME.EQ. 1.AND.I.EQ. 1)THEN
0199          FREQA=FREQ(1)
0200          XESA=XES(1)
0201          RESA=RES(1)
0202      ELSE
0203      END IF
0204      FREQ(I)=FREQ(I)*1000

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0205 85      ARRAY(I,1)=RES(I)
0206      ARRAY(I,2)=XES(I)
0207      ARRAY(I,3)=1.
0208      CONS(I)=- (RES(I)*RES(I)+XES(I)*XES(I))
0209      IF (ITIME.EQ.1)START_FREQ=START_FREQ+STEP_FREQ
0210      END DO
0211
0212 C      SIMEQ IS A SUBROUTINE THAT SOLVES SIMELTANEOUS EQUATIONS
0213 C      USED TO FIND COEFICIENTS OF A GENERALIZED CIRCLE
0214
0215      N=3                                !NUMBER OF PARAMETERS
0216      CALL SIMEQ(N,ARRAY,CONS,DEF)
0217      IF(N .EQ. 0)GO TO 20
0218      CENTERX=-DEF(1)/2.                  !X VALUE OF CENTER
0219      CENTERY=-DEF(2)/2.                  !Y VALUE OF CENTER
0220      RADIUS=.5*SQRT(DEF(1)*DEF(1)+DEF(2)*DEF(2)-4*DEF(3))
0221      IF(ILOOP .EQ. 2)RESIS=1./(2*RADIUS) !RESISTANCE (ADMITTANCE)
0222      IF(ILOOP .EQ. 1)RESIS=2*RADIUS     !RESISTANCE (IMPEDANCE)
0223
0224 C      SLOPE IS THE TAN(THETA) IN EQUATION 1
0225
0226      SLOPE1=((XES(1)-CENTERY)/(RES(1)-CENTERX+RADIUS))
0227      SLOPE2=((XES(2)-CENTERY)/(RES(2)-CENTERX+RADIUS))
0228      SLOPE3=((XES(3)-CENTERY)/(RES(3)-CENTERX+RADIUS))
0229
0230      COEFF(1,1)=SLOPE1*RESIS*6.283185*FREQ(1)
0231      COEFF(2,1)=SLOPE2*RESIS*6.283185*FREQ(2)
0232      COEFF(1,2)=1.
0233      COEFF(2,2)=1.
0234      COLUMN(1)=(2*3.14159*FREQ(1))**2
0235      COLUMN(2)=(2*3.14159*FREQ(2))**2
0236
0237      N=2
0238      CALL SIMEQ(N,COEFF,COLUMN,ANS)
0239      IF(N .EQ. 0)GOTO 20
0240
0241 C      ANS(1) is the Inductor
0242 C      ANS(2) is the Resonant Freq.
0243      IF(ANS(2) .LT. 0)GOTO 20
0244
0245      ANS(1)=1/ANS(1)
0246      ANS(2)=SQRT(ANS(2))
0247      IF(ANS(2) .EQ. 0)GOTO 20
0248      RESONANCE=ANS(2)/6283.185
0249      WRITE(5,77)ANS(2)/6283.185
0250 77      FORMAT(' FREQ= ',F10.3)
0251
0252      IF(ABS(ANS(2)-OMEGA)/6283.LE.(.0005*FREQA) .OR. ITIME .GE. 25)THEN
0253          ANS(2)=(OMEGA+ANS(2))/2.
0254          ANS(1)=(RINDUCTOR+ANS(1))/2.
0255          GOTO 50

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0256     ELSE
0257         OMEGA=ANS(2)
0258         RINDUCTOR=ANS(1)
0259     END IF
0260
0261 C     ANGLES OF OTHER 2 POINTS
0262
0263     TRANSX1=RES(2)-CENTERX
0264     TRANSY1=XES(2)-CENTERY
0265     TRANSA1=ATAN2(TRANSY1, TRANSX1)
0266     X2=COS(TRANSA1+2.094395)*RADIUS+CENTERX
0267     X3=COS(TRANSA1-2.094395)*RADIUS+CENTERX
0268     Y2=SIN(TRANSA1+2.094395)*RADIUS+CENTERY
0269     Y3=SIN(TRANSA1-2.094395)*RADIUS+CENTERY
0270
0271     SLOPE1=(Y2-CENTERY)/(X2-CENTERX+RADIUS)
0272     SLOPE3=(Y3-CENTERY)/(X3-CENTERX+RADIUS)
0273     B1=-SLOPE1*RESIS
0274     B2=-SLOPE2*RESIS
0275     B3=-SLOPE3*RESIS
0276
0277     FR(1)=-B1-SQRT(B1*B1+4.*ANS(1)**2*(ANS(2)*ANS(2)))
0278     FR(1)=FR(1)/(2*ANS(1))
0279     FR(2)=FREQ(2)*2*3.14159
0280     FR(3)=-B3-SQRT(B3*B3+4.*ANS(1)**2*(ANS(2)*ANS(2)))
0281     FR(3)=FR(3)/(2*ANS(1))
0282     ITIME=ITIME+1
0283     IF(ITIME .GE. 2)GOTO 49
0284 50     R=SQRT(RESA*RESA+XESA*XESA)
0285     THETA=ATAN2(XESA, RESA)
0286     A0=SQRT((CENTERX-RESA)**2 + (CENTERY-XESA)**2)
0287     CONVERT=1.74532E-02
0288     TIM=359./NPTS
0289     PI=3.14159
0290     TRANSX=RESA-CENTERX
0291     TRANSY=XESA-CENTERY
0292     THETA=ATAN2(TRANSY, TRANSX)
0293     I=1
0294     DO IT=1, NPTS
0295     DELTA2=IT*TIM*CONVERT+THETA
0296     X3=(COS(DELTA2)*RADIUS)+CENTERX
0297     Y3=(SIN(DELTA2)*RADIUS)+CENTERY
0298     SLOPE3=(Y3-CENTERY)/(X3-CENTERX+RADIUS)
0299
0300     B3=-SLOPE3*RESIS
0301
0302     FRE(I)=-B3+SQRT(B3*B3+4.*ANS(1)**2*(ANS(2)*ANS(2)))
0303     FRE(I)=FRE(I)/(2.*ANS(1))
0304     FREQUENCY=ABS(FRE(I))/(1000.*2*3.14159)
0305 9     TOLERANCE1=2.5*RESONANCE
0306     IF ( FREQUENCY .GT. TOLERANCE1)GOTO 70

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0307          ENCODE(9,1070,E(3)) FREQUENCY  I SPOT STARTING POINT
0308          CALL BWRITE(IADDR,E,13,ISTAT)
0308          CALL BWRITE(IADDR,IAEX,2,ISTAT)          ITRIGGER THE READING
0310          DO J=1,80
0311              ANSWER(J)=0
0312          END DO
0313          K=0
0314          CALL BREAD(IADDR,ANSWER,LENGTH1,ISTAT)
0315          DECODE(12,1050,ANSWER(5))RES(I)
0316          DECODE(12,1050,ANSWER(21))XES(I)
0317          IF(RES(I) .GT. 1.3E6 .OR. XES(IT) .GT. 1.3E6)GO TO 70
0318          FREQ(I)=FREQUENCY
0319          MAG(I)=SQRT(RES(I)*RES(I)+XES(I)*XES(I))
0320          I=I+1
0321          70      END DO
0322          88      CALL RSORT(RES,FREQ,XES,I-1,1)
0323          GS=RES(1)
0324          BS=XES(1)
0325          FS=FREQ(1)
0326          TAN0=ATAN2(BS,GS)
0327          CALL RSORT(FREQ,RES,XES,I-1,1)
0328          FLAG=0
0329          IT=2
0330          XESMAX=-1E12
0331          RESMAX=-1E12
0332          XESMIN=1E12
0333          RESMIN=1E12
0334          ADMMIN=1E12
0335          ADMMAX=0
0336          TANMIN=1E12
0337          DO J=2,I-1
0338              IF(XES(J) .GT. BS .AND. FLAG .EQ.0 .AND. XES(J) .GT. 0)THEN
0339                  FREQ(1)=FREQ(J)
0340                  RES(1)=RES(J)
0341                  XES(1)=XES(J)
0342                  GO TO 500
0343              ELSE
0344                  FREQ(IT)=FREQ(J)
0345                  RES(IT)=RES(J)
0346                  XES(IT)=XES(J)
0347                  TAN1=ATAN2(XES(IT),RES(IT))
0348                  FLAG=1
0349                  ADM(IT)=SQRT(RES(IT)**2 +XES(IT)**2)
0350                  IF(FREQ(IT) .LE. FS .AND. IT .GT. 1)THEN
0351                      IF(XES(IT) .GE. XESMAX)THEN
0352                          XESMAX=XES(IT)
0353                          FH=FREQ(IT)
0354                          GH=RES(IT)
0355                          BH=XES(IT)
0356                      END IF
0357                  IF(ADM(IT) .GT. ADMMAX .AND. ILOOP .EQ. 2)THEN

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0358         ADMMAX=ADM(IT)
0359         FM=FREQ(IT)
0360         GM=RES(IT)
0361         BM=XES(IT)
0362     END IF
0363     IF(XES(IT-1) .LT. 0 .AND. XES(IT) .GT. 0)THEN
0364         FRES=FREQ(IT)
0365         GR=RES(IT)
0366         BR=XES(IT)
0367     END IF
0368 END IF
0369 IF(FREQ(IT) .GE. FS .AND. IT .GT. 1)THEN
0370     IF(XES(IT) .LE. XESMIN)THEN
0371         XESMIN=XES(IT)
0372         FL=FREQ(IT)
0373         GL=RES(IT)
0374         BL=XES(IT)
0375     END IF
0376     IF(XES(IT-1) .LT. 0 .AND. XES(IT) .GT. 0)THEN
0377         FRES=FREQ(IT)
0378         GR=RES(IT)
0379         BR=XES(IT)
0380     END IF
0381     IF(ADM(IT) .GT. ADMMAX .AND. ILOOP .EQ. 1)THEN
0382         ADMMAX=ADM(IT)
0383         FN=FREQ(IT)
0384         GN=RES(IT)
0385         BN=XES(IT)
0386     ENDIF
0387 END IF
0388     IT=IT+1
0389 END IF
0390 500     END DO
0391 IF(ILOOP.EQ.1)THEN
0392     WRITE(5,1109)
0393 1109     FORMAT(///,9X,'TYPE',11X,'FREQUENCY(KHZ)',2X,'RESISTANCE',2X,
0394     1'REACTANCE')
0395     ELSE
0396     WRITE(5,1110)
0397 1110     FORMAT(///,9X,'TYPE',11X,'FREQUENCY(KHZ)',2X,'CONDUCTANCE',2X,
0398     1'SUSCEPTANCE')
0399     END IF
0400     WRITE(5,1112)
0401 1112     FORMAT(9X,'-----',11X,'-----',2X,'-----',
0402     12X,'-----',/)
0403     IF(FRES .EQ. 0)THEN
0404         IF(BL .LT. 0)THEN
0405             FRES=FS
0406             GR=GS
0407             BR=BS
0408         WRITE(5,1130)FRES,GR,BR

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0409         ELSE
0410         WRITE(5,1120)
0411 1120     FORMAT(1X,'RESONANCE',17X,' DOES NOT EXIST')
0412         END IF
0413     ELSE
0414         IF(ILOOP .EQ. 2)WRITE(5,1130)FRES,GR,BR
0415 1130     FORMAT(1X,'RESONANCE',16X,F8.3,7X,E8.3,5X,E9.3)
0416         IF(ILOOP .EQ. 1)WRITE(5,1131)FRES,GR,BR
0417 1131     FORMAT(1X,'ANTIRESONANCE',12X,F8.3,7X,E8.3,5X,E9.3)
0418         END IF
0419     CALL BWRITE(IADDR,IAMM,2,ISTAT)                !MANUAL MODE
0420     FLAG1=0
0421     ENCODE(8,1066,D(3)).1                          !STEP SIZE
0422     CALL BWRITE(IADDR,D,12,ISTAT)
0423     IF(ILOOP .EQ. 1)CALL BWRITE(IADDR,IAC3,2,ISTAT)
0424     IF(ILOOP .EQ. 2)CALL BWRITE(IADDR,IAC2,2,ISTAT)
0425     IF(ILOOP .EQ. 2)ENCODE(9,1070,E(3))FL
0426     IF(ILOOP .EQ. 1)ENCODE(9,1070,E(3))FH
0427     CALL BWRITE(IADDR,E,13,ISTAT)                  !SPOT
0428     GP=0
0429 1270     CALL BWRITE(IADDR,IAEX,2,ISTAT)
0430     DO J=1,80
0431         ANSWER(J)=0
0432     END DO
0433     CALL BREAD(IADDR,ANSWER,LENGTH3,ISTAT)
0434     DECODE(12,1050,ANSWER(5))A1
0435     DECODE(12,1050,ANSWER(21))B1
0436     DECODE(9,1053,ANSWER(35))F1
0437     IF(A1 .GE. GP )THEN
0438         FP=F1
0439         GP=A1
0440         BP=B1
0441         IF(ILOOP .EQ. 2)CALL BWRITE(IADDR,IADV,2,ISTAT)    !ADVANCE
0442         IF(ILOOP .EQ. 1)CALL BWRITE(IADDR,IREV,2,ISTAT)    !REVERSE
0443     GO TO 1270
0444     ELSE
0445         FLAG1=FLAG1+1
0446         IF(FLAG1 .EQ. 1) THEN
0447             IF(ILOOP.EQ.2)CALL BWRITE(IADDR,IADV,2,ISTAT)
0448             IF(ILOOP.EQ.1)CALL BWRITE(IADDR,IREV,2,ISTAT)
0449             FP=F1
0450             GP=A1
0451             BP=B1
0452             GOTO 1270
0453         END IF
0454     END IF
0455     NUM=8
0456     CRX(1)=GS
0457     CRY(1)=BS
0458     CRX(2)=GP
0459     CRY(2)=BP

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0460      CRX(3)=GM
0461      CRY(3)=BM
0462      CRX(4)=GN
0463      CRY(4)=BN
0464      CRX(5)=GH
0465      CRY(5)=BH
0466      CRX(6)=GL
0467      CRY(6)=BL
0468      IF(FRES .EQ. 0)THEN
0469          NUM=NUM-1
0470      ELSE
0471          CRX(7)=GR
0472          CRY(7)=BR
0473      END IF
0474      IF(FA .EQ. 0)THEN
0475          NUM=NUM-1
0476      ELSE
0477          CRX(8)=GA
0478          CRY(8)=BA
0479      END IF
0480      IF(ILOOP .EQ. 2)WRITE(5,1160)FS,GS,BS
0481      IF(ILOOP .EQ. 1)WRITE(5,1160)FP,GP,BP
0482 1160      FORMAT(1X,'SERIES RESONANCE',9X,F8.3,7X,E8.3,5X,E9.3)
0483      IF(ILOOP .EQ. 2)WRITE(5,1170)FP,GP,BP
0484      IF(ILOOP .EQ. 1)WRITE(5,1170)FS,GS,BS
0485 1170      FORMAT(1X,'PARALLEL RESONANCE',7X,F8.3,7X,E8.3,5X,E9.3)
0486      IF(ILOOP .EQ. 2)WRITE(5,1180)FM,GM,BM
0487 1180      FORMAT(1X,'MAXIMUM ADMITTANCE',7X,F8.3,7X,E8.3,5X,E9.3)
0488      IF(ILOOP .EQ. 1)WRITE(5,1280)FN,GN,BN
0489 1280      FORMAT(1X,'MAXIMUM IMPEDANCE',8X,F8.3,7X,E8.3,5X,E9.3)
0490      WRITE(5,1190)FH,GH,BH
0491 1190      FORMAT(1X,'HIGH POINT',15X,F8.3,7X,E8.3,5X,E9.3)
0492      WRITE(5,1200)FL,GL,BL
0493 1200      FORMAT(1X,'LOW POINT',16X,F8.3,7X,E8.3,5X,E9.3)
0494      WRITE(5,1300)7
0495 1300      FORMAT(//,' ',A1)
0496      IF(ILOOP .EQ. 2)TYPE *,'ADMITTANCE LOOP'
0497      IF(ILOOP .EQ. 1)TYPE *,'IMPEDANCE LOOP'
0498      CALL FILE(IT-1,RES,XES)
0499      TYPE *,' '
0500      TYPE *,'CRITICAL FREQUENCIES'
0501      CALL FILE(NUM,CRX,CRY)
0502      TYPE *,' '
0503      TYPE *,'FREQ VS. MAG.'
0504      CALL FILE(IT-1,FREQ,MAG)
0505      CALL BDEVCL(IADDR,ISTAT)
0506      END

```

ICLEAR SELECTED

APPENDIX C

Running MICAM

RUN SUPER

DO YOU WANT 1) IMPEDANCE 2) ADMITTANCE 1

DO YOU WANT 1) LOW, 2) MED, 3) HIGH SPEED 3

ENTER THE VOLTAGE LEVEL (IN VOLTS): .1

ENTER # OF POINTS 100

ENTER FREQUENCY (PARALLEL RESONANCE) (IN KHZ): 15

ENTER STEP FREQ (IN KHZ): .5

FREQ= 15.304

FREQ= 15.293

FREQ= 15.291

<u>TYPE</u>	<u>FREQUENCY(KHZ)</u>	<u>RESISTANCE</u>	<u>REACTANCE</u>
ANTIRESONANCE	15.291	.107E+07	0.100E+05
SERIES RESONANCE	14.384	.485E-02	-.288E-02
PARALLEL RESONANCE	15.291	.107E+07	0.100E+05
MAXIMUM IMPEDANCE	15.291	.107E+07	0.100E+05
HIGH POINT	15.284	.530E+06	0.530E+06
LOW POINT	15.297	.630E+06	-.540E+06

IMPEDANCE LOOP

FILE NAME FOR X,Y DATA: DATA1

CRITICAL FREQUENCIES

FILE NAME FOR X,Y DATA: DATA2

FREQ VS. MAG.

FILE NAME FOR X,Y DATA: DATA3

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RUGGIERO AND HENRIQUEZ

RUN SUPER

DO YOU WANT 1) IMPEDANCE 2) ADMITTANCE 2

DO YOU WANT 1) LOW, 2) MED, 3) HIGH SPEED 3

ENTER THE VOLTAGE LEVEL (IN VOLTS): .1

ENTER # OF POINTS 100

ENTER FREQUENCY(SERIES RESONANCE) (IN KHZ): 14

ENTER STEP FREQ (IN KHZ): .5

FREQ= 14.390

FREQ= 14.372

FREQ= 14.372

<u>TYPE</u>	<u>FREQUENCY(KHZ)</u>	<u>CONDUCTANCE</u>	<u>SUSCEPTANCE</u>
RESONANCE	14.375	.678E-02	0.300E-04
SERIES RESONANCE	14.373	.679E-02	0.540E-03
PARALLEL RESONANCE	15.291	.107E+07	0.000E+00
MAXIMUM ADMITTANCE	14.373	.677E-02	0.790E-03
HIGH POINT	14.357	.311E-02	0.379E-02
LOW POINT	14.391	.327E-02	-.316E-02

ADMITTANCE LOOP

FILE NAME FOR X,Y DATA: DATA1

CRITICAL FREQUENCIES

FILE NAME FOR X,Y DATA: DATA2

FREQ VS. MAG.

FILE NAME FOR X,Y DATA: DATA3

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