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ELECTRONIC RESEARCH DIVISION

CLEVITE CORPORATION
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FERROELECTRIC CERAMIC FILTERS, IF TRANSFORMERS, AND NETWORKS

Report No. 25

Fourth Quarterly Report
1 September 1962 through 30 November 1962

Contract No. DA 36-039 SC-87275
DA Task No. 3A99-15-002-05

U. S. Army Electronics Research and Development Laboratory, Fort Monmouth, New Jersey

Signal Corps Technical Requirement Number SCL-7534

The object of the contract is the development of piezoelectric ceramic filters and devices at frequencies above 1 Mc.

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Approved: Hans Jaffe by P.S.D.
Hans Jaffe, Director
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PURPOSE

To perform research and development leading to the design of improved ferroelectric ceramic filters, IF transformers, and networks in the frequency range above 1 Mc. These should include two dimensional filters and networks with a multiplicity of resonators or network elements on a single wafer. Objectives are reliability, miniaturization, and improved performance characteristics over conventional filters in this range.

To fabricate samples illustrating the level of development achieved during this contract and the range of characteristics available as a result of this contract.

ABSTRACT

An introduction discusses the total frequency range for piezoelectric ceramic filters, which at present extends from below 1 kc to above 12 Mc. Modes of vibration suitable for each portion of this range are described. Ceramic Uni-Wafer ladder filters have been developed at 10 Mc using wafers of wedge shaped cross section with 11 and 15 dot-resonators per filter.

The range of action, i.e. the distance within which a disturbance appreciably affects the performance of a dot-resonator, has been shown to be anisotropic in AT-cut quartz wafers. Experiments using mechanical damping indicate ranges of action of the order of 3 wafer thicknesses (3t) and 14t in the z' and x directions respectively; while those concerning interresonator coupling in half-lattice Uni-Wafer filters indicate that range of action should be in excess of 9t in both directions, but somewhat larger in the x direction. Quartz ladder filter measurements are presented and measurement techniques discussed.

CONFERENCES AND REPORTS

Date:	25 October 1962	
Place:	Cleveland, Ohio	
In attendance:	Dr. R. Bechmann,	USAERDL
	Messrs. E. Gikow	USAERDL
	R. Sproat	USAERDL
	D. Curran	ERD
	W. Gerber	ERD
	D. Koneval	ERD

Subject: Progress to date concerning the fabrication of ceramic and quartz Uni-Wafer filters. This included the temperature dependence of ceramic thickness-shear dot-resonators and the asymmetric range of action for quartz thickness-shear dot-resonators.

REPORTS

Tenth Monthly Performance Summary
1 September 1962 through 30 September 1962

Eleventh Monthly Performance Summary
1 October 1962 through 31 October 1962

Twelfth Monthly Performance Summary
1 November 1962 through 30 November 1962

LIST OF ILLUSTRATIONS

FERROELECTRIC CERAMIC FILTERS,
IF TRANSFORMERS, AND NETWORKS

Fourth Quarterly Report
1 September 1962 through 30 November 1962

Contract No. DA 36-039 SC-87275

1. INTRODUCTION

A brief summary of ceramic filters, with emphasis on recommended modes of vibration and the frequency range available with each, is included at the request of the Contracting Officers Technical Representative. Many of the filters to be mentioned here have been discussed previously in greater detail in the literature.(1) Piezoelectric ceramics have been used, in a series of modes, to realize resonators and filters over a frequency range from below 1 kc to above 12 Mc. These modes include the flexural mode, a folded flexural or "tuning fork" mode, the length expander mode, both fundamental and 1st overtone radial modes, the thickness shear mode, and finally the thickness expander mode. Over much of this range and with most of these modes, piezoelectric ceramics offer resonators and filters with good bandpass characteristics and reasonable frequency stability, packaged with substantial reductions in size and weight.

1.1 Flexural Modes

Low frequency filters in the 8 to 60 kc range have been realized using a folded flexural resonator, consisting of a slotted ceramic ring approximately 9/16" diameter. This configuration is versatile in that the one basic element can readily be tuned over the whole frequency range and its characteristics can be altered markedly with the shape and positioning of electrodes.

At present, two types of folded flexural filters are available, Types S and U, which differ only in electrode configuration. Both are balanced

(1) E. Gikow, A. Rand, and J. M. Giannotto, "Functional Circuits through Acoustical Devices," IRE Transactions on Military Electronics, Vol. Mil-4, No. 4, pp. 469-481 (1960).

2 terminal-pair elements, which perform equally well when unbalanced, with bandwidths from 1/2 to 3% of center frequency and about 30 db of stop band rejection. Each has a single pole of attenuation which can be placed on either side of the pass band, or switched from one side to the other by interchanging ground terminals. A pass band response typical of both types is shown in Fig. I-1, and the response for a cascaded pair of elements (with poles located on opposite sides of the pass band) in Fig. I-2.

Both types have strong clean responses with no unwanted responses below their fundamental response, however, the types differ above their fundamental pass band. Type U has no unwanted response below 12 times its center frequency, e.g. a 10 kc filter would have its first unwanted response at about 120 kc. Type S filters, on the other hand, can be operated effectively as overtone units with a strong usable 1st overtone at about 2.3 times its fundamental response. Present units are mounted in HC-6/U crystal closures 3/4" x 3/4" x 3/10".

At lower frequencies, ceramic Bimorph* and Multimorph* bars have been used in the free-free flexural mode (nodally mounted) as low loss filters with frequencies as low as 1 kc (without mass loading) and to below 500 cps with mass loading. However these elements become unwieldy at low frequencies (typically about 4" long for 1 kc) and hence are difficult to package in a convenient form. Larger elements (1" diameter) of the folded flexural design described previously are normally centered at about 3 kc but have been tuned down to 1.3 kc without using external mass loading and to about 1 kc with mass loading. At these lower frequencies cantilever mounted benders, which require only about one sixth the length of a free-free bender for a given resonant frequency, are more

* Reg. U.S. Pat. Off.

desirable dimensionally, but are difficult to mount for efficient operation. Of the cantilever benders, only the double cantilever shows promise for the development of low loss filters.

1.2 Length Expander Mode

Although the flexural modes can be extended in frequency to about 100 kc, the length expander mode in ceramic bars has advantages both in performance and ease of fabrication at frequencies above 60 or 70 kc (about 1 1/2" long for half wave resonance). Length expander mode filter elements and filters have been used at frequencies up to and somewhat beyond 500 kc,[2] and can be used to form well behaved low loss filters. The higher frequency range for use of this mode is often limited more by the versatility of the radial modes of disks than by inherent characteristics of the length expander mode.

1.3 Radial Extensional Modes

Radial modes in ceramic disks form the basis for and are currently being used in a series of filters and filter elements over the frequency range from 170 kc to 6 Mc. A variety of ceramic filters and filter elements are commercially available in production quantities in the 300 to 700 kc range. These include fundamental and 1st overtone radial resonators as 2 and 3 terminal elements, combination filters with capacitance coupled 1st overtone elements, and all-resonator ladder filters. Product engineering prototypes have also been supplied over the remaining portions of the frequency range from 170 kc to 1.2 Mc. The range of characteristics

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(2) S. W. Tehon, "Miniaturized Ceramic Filters," Digest of Papers, Solid State Circuits Conference, pp. 34-35 (1959).

available has been adequately described in the literature[3-5] and hence will not be discussed here. Response curves for two production filters are shown in Figs. I-3 and I-4 as representative examples. The first gives the response for a medium bandwidth combination filter using 4 1st overtone resonators. The second shows the response of a medium bandwidth ladder filter using 17 fundamental resonators.

At frequencies above this, ceramic ladder filters have been fabricated in experimental quantities as developmental samples using fundamental and 1st overtone radial resonators packaged in the micro-module configuration.[6] This configuration is applicable from 1 to 6 Mc. An example of a 20-resonator 1st overtone ladder filter of medium bandwidth is shown in Fig. I-5. This filter was packaged in 4 micro-module sections (5 resonators in each) measuring 0.31" by 0.31" by 0.080". Miniature radial resonators have been fabricated with frequencies as high as 10 Mc. However, the small size (0.22" diameter at 10 Mc) of the higher frequency radial resonators introduces additional fabrication and handling problems, which at this time place an upper frequency limit of about 6 Mc for practical filters of this type.

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(3) A. Lungo and K. W. Henderson, "Application of Piezoelectric Resonators to Modern Band-Pass Amplifiers, "IRE Convention Record Vol. 6 pt 6, pp. 235-242 (1958).

(4) D. R. Curran and W. J. Gerber, "Piezoelectric Ceramic I. F. Filters," Proceedings Electronic Components Conf., pp. 160-165 (1959).

(5) A. Lungo and F. L. Sauerland, "A Ceramic Band Pass Transformer and Filter Element," IRE Convention Record, Vol. 9 pt 6, pp. 189-203 (1961).

(6) D. R. Curran and D. J. Koneval, "Miniature Ceramic Band Pass Filters," Proceedings National Electronics Conference, Vol. 17, pp. 514-520 (1961).

1.4 Thickness Modes in Ceramic Uni-Wafer Filters

Thickness modes in piezoelectric ceramics have a frequency range which broadly overlaps that of the radial modes. Limiting the discussion to Uni-Wafer type filters with more than one resonator per wafer and a maximum spacing between resonators of 1/4", their frequency range should still extend from 4 Mc to above 16 Mc. The lower portion of this range from about 4 to 9 Mc can be covered using the fundamental thickness shear mode with ceramic wafer thicknesses ranging from 12 to 5.3 mils respectively. Similarly, the upper portion of the frequency range, from 8 to 16 Mc, can be covered using the fundamental thickness expander mode in ceramic wafers with thicknesses ranging from 11 to 5.6 mils respectively. Filters using this mode are discussed in a following section.

2. FACTUAL DATA

2.1 Ceramic Thickness Shear Resonators

Initial experiments reported in the Third Quarterly Report indicated that the thickness shear mode in ceramic sheets, poled in the plane of the sheet, had a frequency-temperature dependence comparable to that of the radial extensional mode. However, this conclusion was based on data taken using resonators with air dry silver electrodes, which could somewhat modify the results. Temperature dependence data have now been repeated on three thickness shear resonators made from lapped PZT-6A* sheet stock (8 mils thick) with electroless silver electrodes 80 mils in diameter. From -40° to

* Reg. U.S. Pat. Office

+100°C the average change in resonant frequency f_r for three dot-resonators was -0.4% with comparable variations in f_a. These resonators were then heat treated at 138°C for 16 hours in an attempt to correct this negative frequency-temperature dependence. This heat treatment overcorrected the frequency-temperature dependencies with average variations in f_r of +0.36% for three resonators and in f_a of +0.33% for two resonators (third resonator had spurious response masking f_a). Frequency-temperature curves for one resonator, before and after treatment are shown in Fig. 1. These data show that the frequency-temperature dependence for PZT-6A thickness shear resonators is well within the range which can be corrected by heat treatment and that a less severe treatment than the one used should give satisfactory results.

These resonators were made from PZT-6A sheet stock, which was at that time in short supply. Therefore no attempt could be made to follow through with thickness shear ladder filters. However, some of the small pieces remaining were lapped down to about 4 mils and used to make 10 Mc thickness shear dot-resonators. The response curve for one of these is shown in Fig. 2. Each element had large spurious responses similar to those shown here, which can be attributed at least in part to an improper choice of dot-electrode size. Even with these spurious responses, these elements had resonant and antiresonant impedances of the order of 2 and 1000 ohms respectively which with Δf and C_o of the order of 700 kc and 300 pf gave Q_m values of the order of 150 to 200. However, with the present ceramic sheet stock, 4 mil wafers are rather fragile and occasionally porous, and hence must be considered at present to be somewhat beyond the range of practical applicability.

2.2 Ceramic Thickness Expander Resonators

At this point the investigation of ceramic thickness expander resonators was resumed. Rectangular plates of UP-9698 ceramic were cut from 2" diameter disks and prepared for use as ladder filters. Difficulties were encountered with voids in the resulting thin (8 mils) rectangular wafers first in poling, and then in etching and tuning. With Δf of the order of 500 kc, the tuning by electroplating had to be carried out over a wide frequency range in attempts to produce usable ladder filters. Several attempts failed because of the deterioration of one or more thin electrodes when neighbors were being tuned over large frequency ranges. This situation was improved considerably by using wafers with a wedge shaped cross section with the series dot-resonators located along the thinner portion of the wedge. Considerable care was exercised in the lapping procedures to obtain a uniform, wedge shaped, cross section. For example, in waxing the wafer to the lapping plate, precautions were taken to obtain a very thin and uniform layer of wax. In addition a fixture was used to position the wafer such that the long dimension of the rectangular plate was precisely parallel to a line of constant thickness chosen for the desired frequency. As a result of these efforts, wedge shaped wafers suitable for 11 and 15 resonator ladder filters were obtained. Such a wafer measured 1-3/4" x 3/4" with a cross section varying in thickness from 8.43 ± mils to 7.05 ± .04 mils. To reduce the difficulties encountered in poling resulting from the porosity of the material, these wafers were poled in oil between parallel brass plates, prior to electroding with electroless silver. The desired electrode configuration was then produced by photo-etching and the individual resonators tuned by electroplating with a silver cyanide solution. As a result of the wedge-shaped cross section the frequency separation of series and shunt resonators was well within the limits of tuning by electroplating, and hence the previous difficulties associated with tuning over too large a frequency range, i.e., excessive mass loading and electrode deterioration, were not encountered. The characteristics of the 11 and 15 dot-resonator ladder filters fabricated in this manner are listed in Table I, and shown in Figs. 3 and 4. Ideally, the use of the wedge shape cross section could result in Uni-Wafer filter blanks requiring only fine tuning adjustments.

TABLE I. Ceramic Uni-Wafer Ladder Filters

Center Frequency		12.098 Mc	11.270 Mc
No. of Resonators		11	15
Min. Ins. Loss		8.0 db	8.0 db
Matching Resistance		220 ohms	330 ohms
Bandwidths at			
	3 db	314 kc	261 kc
	6	383	346
	10	410	420
	20	510	520
	30	560	578
	40	---	625
Stopband Rejection (below min. ins. loss)		31 db @ 11.0 Mc	50 db @ 10.4 Mc
		29 db @ 13.6 Mc	53 db @ 12.2 Mc

2.3 Quartz Uni-Wafer Filters

The application of Uni-Wafer techniques to quartz wafers has continued with current emphasis on the evaluation of controlling parameters.

2.3.1 Range of Action for Quartz Uni-Wafer Resonators

Since the introduction of the Uni-Wafer filter, the term "range of action" has been used as the parameter defining the area actively contributing to the response of the dot-resonator. This area, within which a physical disturbance will noticeably affect the dot-resonator, determines both the minimum separation between individual dot-resonators on a Uni-Wafer filter blank and the minimum distance from a dot-resonator to the nearest physical discontinuity, e. g. the edge of the wafer.

The first measurements of range of action were made on ceramic Uni-Wafer, thickness expander, dot-resonators. The results indicated that the magnitude of the range of action was approximately 6 to 10 times the wafer thickness and independent of direction, e.g. circular. For quartz Uni-Wafer dot-resonators, however, the range of action was predicted from Bechmann's criteria(7) on maximum electrode diameter and minimum disk diameter for individual quartz resonators to be approximately 18 times the wafer thickness. The initial Uni-Wafer filter blanks were therefore fabricated assuming this range of action and correspondingly minimum separations between individual dot-resonators and minimum distance to the nearest wafer edge of 2 and 1 times this range of action respectively.

While the range of action for the thickness expander

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(7) R. Bechmann, "Quartz AT-Type Filter Crystals for the Frequency Range 0.7 to 60 Mc," Proceedings of the IRE, Vol. 49, No. 2, pp. 523-524 (1961).

mode in ceramics from symmetry can be expected to describe a circle, this should not be the case for the thickness shear mode in quartz or ceramic. This was first confirmed in the observation of the frequency response of a quartz dot-resonator in which the dot-electrode at one point coincided with the edge of a cracked wafer. With the exception of an increase in the resonant resistance, the response curve was comparable to that obtained for a dot-resonator in which a distance equivalent to the symmetric range of action was maintained completely around the dot-electrode. See Fig. 5. The absence of spurious responses, with the discontinuity this close, suggested that the range of action must be markedly anisotropic.

Since the direction of particle displacement for the thickness shear mode in AT-cut quartz is along the x-axis, it is reasonable to assume that the range of action will be maximum in this (x)-direction and minimum at right angles to it (projection of z-direction). In terms of elastice wave radiation patterns in the plane of the wafer, the edge of the dot-resonator would look like a longitudinal dipole source in the x-direction, and like a shear (transverse) dipole source along the z-projection. The x-axis of several wafers, including the previously mentioned broken wafer, was determined using optical techniques. In the case of the broken wafer the edge was at an angle of 45° with the x-axis rather than parallel with it.

The first visual observations of this anisotropy were made using a nodal dust pattern formed using 15 micron abrasive particles on a 10 Mc AT-cut wafer with a dot-resonator excited at resonance. As shown in Fig. 6, the pattern indicates two wedges of strong activity extending from opposite sides to the dot-resonator along the x-axis. It should be noted however that this technique overemphasizes the degree of anisotropy. An attempt was made to determine the range of action by applying a damping material on the wafer and noting the changes in frequency and impedance. Using the latter technique, the range of action along the x-axis was found to be approximately 4 times that observed in the z′-direction, (perpendicular to x-axis), or of the order of 0.090" (14t) as opposed to 0.020" (3t).

2.3.1.1 Investigation of the Range of Action Using Uni-Wafer Lattice Filters

In an effort to obtain more quantitative measurements of the range of action, the response of quartz Uni-Wafer filters were observed as a function of the dot-resonator separation. Coupling or interaction resulting from insufficient separation between resonators should produce spurious responses in the upper stopband of the filter response. The magnitude of these responses should also be indicative of the degree of coupling, e.g. increasing in the magnitude as the separation between the individual resonators is decreased. Of the two filter configurations, the ladder and the lattice, the latter is preferred to investigate dot-resonator interaction since the coupled response in the stopband produces an effect almost two orders of magnitude greater per resonator than the comparable effect in a ladder filter.

The lattice filters were prepared in the usual manner using standard photo-etching techniques to obtain the desired electrode configuration and electroplating with a silver cyanide solution to accomplish tuning. The electrode pattern consisted of three dot-resonators orientated such that they formed an isosceles triangle whose sides corresponded to the directions of the x and z' axes. By tuning the appropriate resonator as a shunt element and the remaining two units as series resonators, it was possible to obtain two half-lattice filters having the shunt resonator common to both. The response of the half-lattice filter formed by the two resonators in line with the x-direction (3rd resonator shorted) was then compared to that obtained with the two resonators in line with the z'-direction for different values of resonator separation. It should also be noted that the use of a common resonator eliminates one variable and thereby facilitates the comparison of the filter responses corresponding to the two crystal axes.

The first unit fabricated in the above manner, UWQ-110L, had a resonator separation of 18 t in both the x and z' directions. The frequency response of the half-lattice filters corresponding to both the x and z' directions exhibited numerous spurious responses in the upper stopband. While some of these extraneous responses could be attributed to spurious responses observed in the frequency response of the individual dot-resonators, the results were not considered conclusive. A second unit, UWQ-112L, having the same electrode configuration and spacing was therefore fabricated. As shown in Figs. 7 and 8, there is almost a 1:1 correspondence between the spurious responses appearing in the characteristic curves of the individual resonators and those observed in the filter responses associated with the x and z' directions of the crystal. Apparently no measurable interaction between resonators is produced for resonators separated by 18 t in either the x or z' directions. See Table II for the filter characteristics of these and subsequent units.

The first indication of a possible interaction between two dot-resonators was observed for a resonator separation of 9 wafer thicknesses. The filter response of this unit, UWQ-114L, in both the x and z' directions, exhibited numerous spurious responses in the upper stopband. The spurious responses in the x direction, however, are of greater magnitude than those related to the z' axis of the crystal. See Figs. 9 and 10. While some of these can be related to spurious responses of the individual resonators, the remainder appeared to be the result of interaction between the dot-resonators. As in the case of UWQ-112L, the responses of UWQ-114L in the x and z' directions were similar and hence only the data corresponding to the z' direction is given in Table II.

In the fourth unit fabricated for this series, UWQ-115L, the resonators were separated by approximately 3 thicknesses in both the x and z' directions. In both cases large magnitude spurious responses were observed in the upper stopband. See Fig. 11. Since the frequency response of the individual resonators was generally free of spurious responses, the responses occurring in the stopband of UWQ-115L could be attributed to interaction between the individual dot-resonators. This interaction could be electrical or mechanical coupling or a combination of the two. After the initial observation, the resonator in the x direction was removed from the wafer to eliminate any contributions from this resonator to the spurious responses observed in the z' direction. The filter response in the z' direction, however, remained essentially unchanged. The data corresponding to the z' axis is given in Table II.

Prior to deciding upon the 3 resonator configuration for investigating interaction between individual resonators, UWQ-111L was fabricated with only two dot-resonators orientated along the z' axis and separated by 31 t. As in the case of the previous lattice filters, the inductance of the 1:-1 autotransformer was chosen to resonate with the combined shunt capacity of the two resonators. The filter characteristics of this unit are also listed in Table II. Also see Fig. 12. The spurious responses observed in the upper stopband coincide in frequency with those occurring in the responses of the individual resonators.

2.3.2 Quartz Uni-Wafer Ladder Filters

Several Uni-Wafer ladder filters have been fabricated during the past report interval. As with lattice filters, the desired electrode configuration was produced by photoetching, and the resonators appropriately tuned by electroplating with a conventional silver cyanide solution. The first unit was a six resonator ladder filter, UWQ-113, centered around 10 Mc. The resonators were laid out in the regular ladder configuration on a 1" diameter wafer. The initial response curve of the filter had excessive passband ripple. However, with additional fine tuning, the response curve was improved to that shown in Fig. 13. Although this unit now had a respectable response, the passband was not symmetrical and the bandwidth was a factor of 2 less than the expected value. Both conditions are indicative of a misaligned filter section. Additional tuning, however, resulted in either the initial response curve, which had a symmetrical passband and the expected bandwidth but excessive ripple, or the response described above (Fig. 13). Continued efforts to obtain a symmetrical passband having negligible ripple were unsuccessful and eventually 4 of the 6 resonators were lost due to noncontinuous electrodes. As discussed in the following section, it was later found that the passband ripple was caused by reactive matching resulting from the capacitance associated with the measuring instruments and also with the carbon matching resistors themselves.

Table II. Quartz Uni-Wafer Filters

Unit	UWQ-112L	UWQ-114L	UWQ-115L	UWQ-111L	UWQ-113	UWQ-114
Type	Lattice	Lattice	Lattice	Lattice	Ladder	Ladder
Mode	Fund.	Fund.	Fund.	Fund.	Fund.	Fund.
No. of Resonators	3	3	3	2	6	3
Separation of Resonators along x and z' axes	18t	9t	3t	31t	(not aligned)	9t
Response from	z' axis	z' axis	z' axis	z' axis	---------	---------
Center Frequency	9835.44 kc	9762.95 kc	9975 kc	9883.32 kc	9790 kc	9760.52 kc
Min. Ins. Loss	0.8 db	~ 1 db	-------	1.3 db	---------	~ 1 db
Ripple	2.4 db	< 0.5 db	3 db	1.8 db	n o n e	n o n e
Matching Resistance	1.2 K ohms	8.2 K Ohms	8.2 K Ohms	3.3 K Ohms	12.0 K Ohms (input 9.4 K Ohms (output)	27.0 K Ohms
Bandwidths at 1 db	------ kc	------ kc	23 kd	------ kc	8 kc	23.34 kc
3	33.23	28.44	27	30.62	11	27.32
6	38.63	35.75	31	36.82	13	29.68
10	45.56	44.36	35	44.81	16	32.21
15	------	------	------	------	------	34.64
20	67.85	70,90	46	67.99	21	-----
30	91.01	80.54	88	89.67	22	------
40	107.27	86.17	121	103.44	------	------
50	------	89.61	------	-------	------	------
Stopband Rejection	29 db @ 9650 kc 29 db @ 10,070 kc	20 db @ 9400 kc 20 db @ 10,100 kc		33 db@ 9770 kc 33 db @ 10,100 kc	17 db @ 9600 kc 17 db @ 10,000 kc	8 db @ 9700 kc 8 db @ 9800 kc

A second unit was obtained from one of the 3 dot-resonator lattice filters used in the study of range of action. The resulting T-section, designated UWQ-114 as opposed to UWQ-114L for the lattice filter, had a symmetrical passband, less than 0.2 db ripple, close to theoretical rejection, and the expected bandwidths when provided with a purely resistive match. The filter characteristics are listed in Table I, the response curve in Fig. 14.

2.3.3 Improvements in Measurement Techniques

A fixture was fabricated to facilitate measurements of quartz Uni-Wafer dot-resonator characteristics prior to their connection as a filter. In the past, thin wire leads had been soldered to the dot-resonator leads on the wafer. This results in two external leads per resonator and in cases where more than 2 or 3 resonators are involved, the wafer becomes difficult to work with. The present fixture, however, eliminates the need of external soldered leads by using pressure contacts to provide electrical contact to the dot-electrode leads on the wafer. In addition, the fixture provides mechanical support for the wafer. This unit differs from the pressure type contacts used in the past with ceramic dot-resonators in that contact is made to the dot-electrode leads rather than to the dot-electrode. The earlier type of pressure contacts severely damped the response of a quartz resonator and hence, was not satisfactory. The new fixture should be especially useful in fabricating quartz Uni-Wafer filters utilizing 5 or more resonators.

The initial measurements of the characteristic response of UWQ-114L indicated 2-3 db passband ripple, typical of the units fabricated to date. It was found, however, that the ripple observed in the passband was the result of a nonresistive match resulting from the capacitance associated with the measuring device, i.e., voltmeter or compressed gain amplifier. By tuning out the stray capacity of the associated circuitry and measuring devices, UWQ-114L and UWQ-114 were both found to have negligible passband ripple.

3. CONCLUSIONS

The range of action, associated with dot-resonators on 10 Mc AT-cut quartz wafers, has been found to be anisotropic. In direct measurements, using mechanical damping, resonant resistance was observed for a dot-resonator as a function of the separation between the resonator and the applied damping material. In these experiments, increases in resonant resistance by a factor of 2 were observed for separations of 3 times wafer thickness (3t) in the z' direction and 14 t in the x direction. Range of action was also investigated using half-lattice filters by observing the magnitude of spurious responses as a function of dot-resonator spacing. Here, spurious responses not associated with the responses of the individual resonators were observed at resonator separations of 9 t in both the x and z' directions. However, the spurious responses were considerably larger for the filter oriented in the x direction. The importance of proper electrical matching was also observed on both lattice and ladder filters. Pass band ripple attributable to complex or reactive electrical terminations can be eliminated with purely resistive matching.

Temperature dependence measurements on piezoelectric ceramic thickness shear resonators confirm that this frequency-temperature dependence is similar to that for radial resonators of the same composition and that the dependence is within the range which can be corrected by appropriate treatment.

In ceramic Uni-Wafer filters, the use of ceramic plates lapped to a wedge shaped cross-section reduces the problems involved in tuning the individual dot-resonators. Ceramic Uni-Wafer ladder filters consisting of 11 and 15 dot-resonators have been fabricated in this manner.

4. PLANS FOR NEXT INTERVAL

Considerable difficulty has been encountered in fabricating resonators in thin sections of ceramic because of porosity. Resonators will be fabricated from slip-cast ceramic and from ceramic prepared by other techniques in an attempt to reduce this problem. The investigation of ceramic thickness shear resonators and filters will be continued as soon as additional ceramic sheet stock has been received.

The study of the parameters governing the characteristics of quartz dot-resonators will be continued and the development of quartz Uni-Wafer filters will be initiated. An investigation of possible combinations of quartz and ceramic resonators for use in filters will also be initiated.

5. IDENTIFICATION OF KEY TECHNICAL PERSONNEL

The time devoted to this project by principal technical personnel and others during the period of 1 September 1962 through 30 November 1962 follows:

Personnel	Man-Hours
A. Berohn	414
D. Curran	161
D. Koneval	494
Others	60
Total	1129

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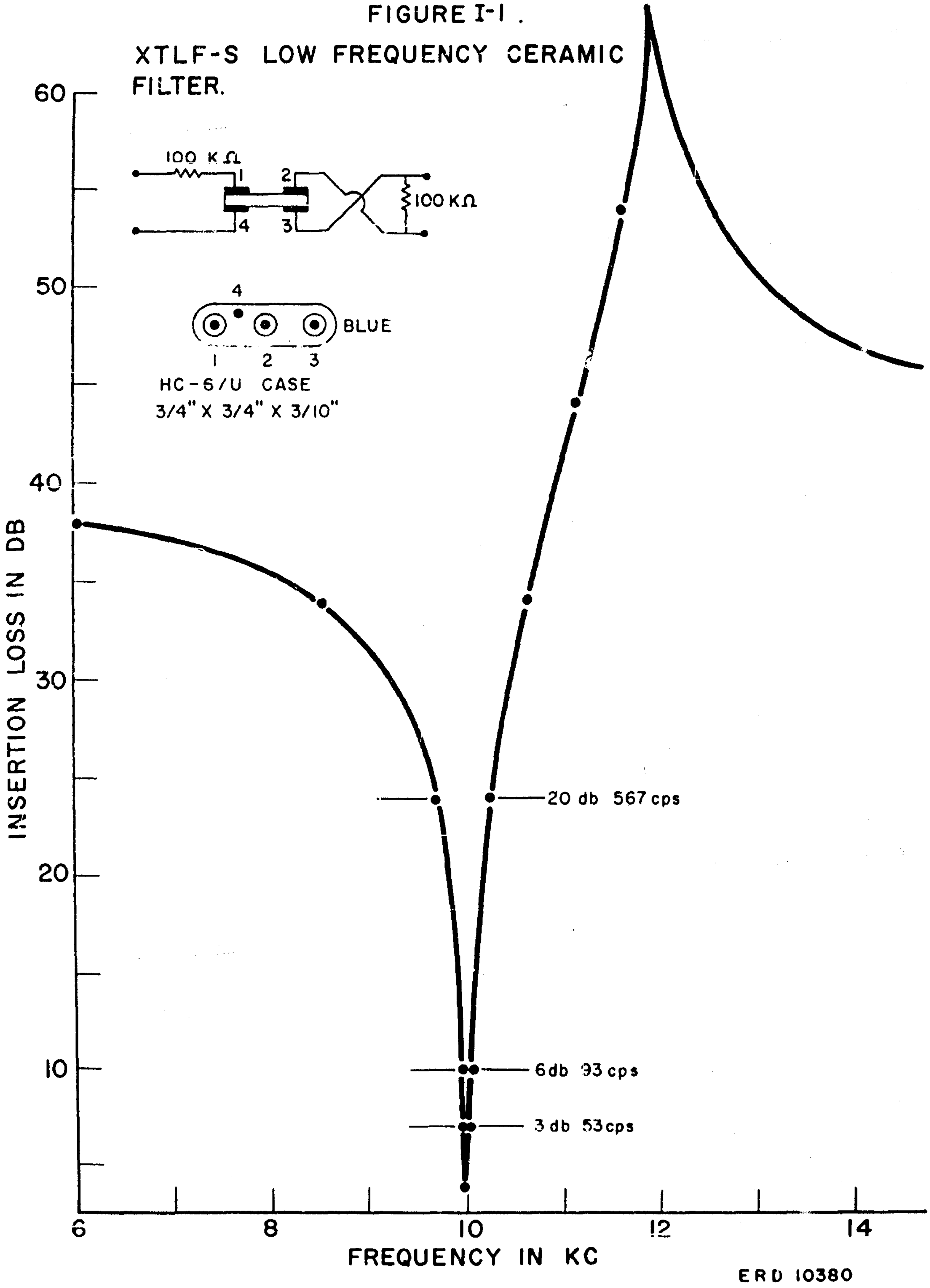
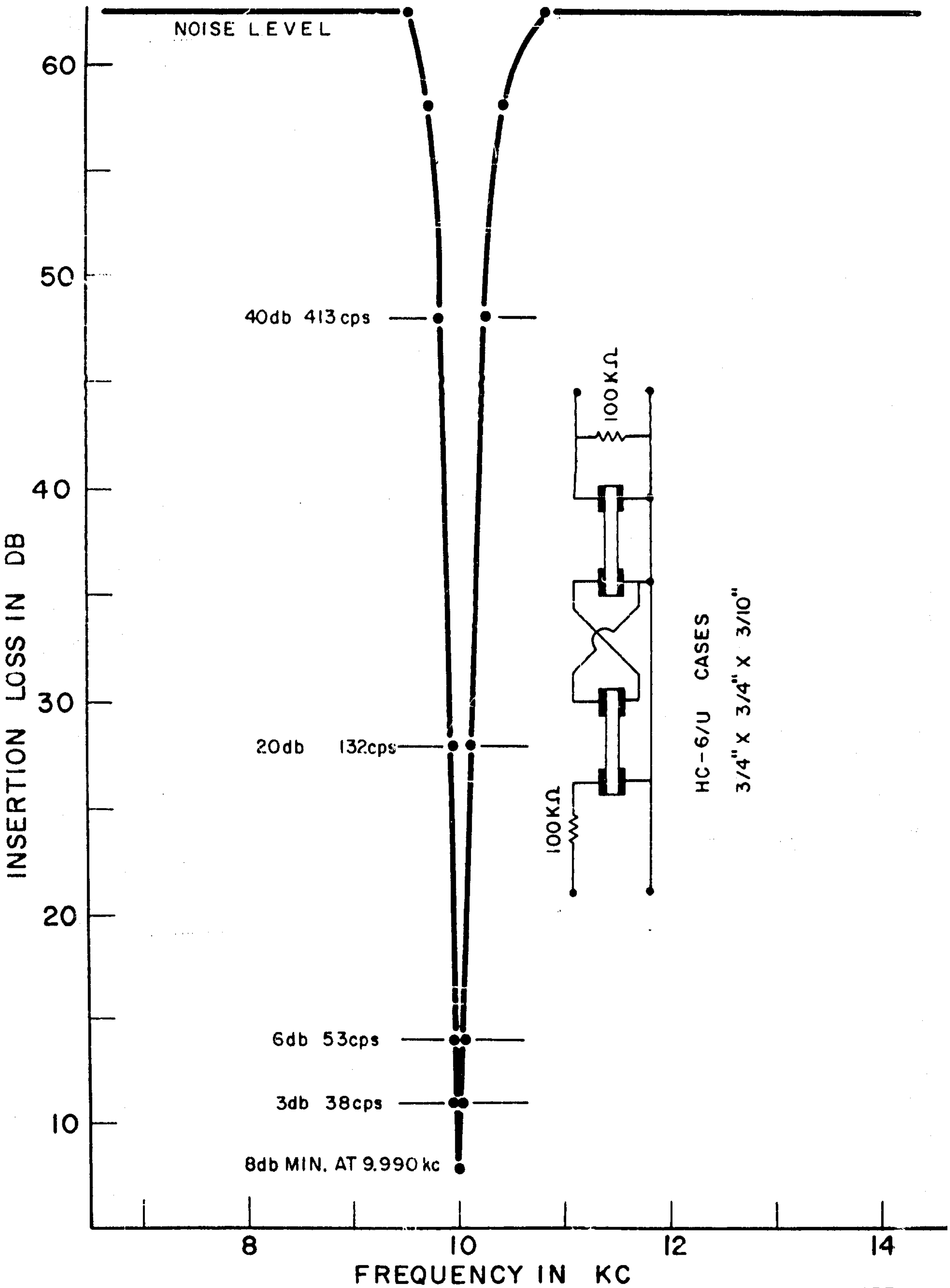


FIGURE I-1.
XTLF-S LOW FREQUENCY CERAMIC FILTER.
100 KΩ
1
2
4
3
100 KΩ
4
BLUE
1 2 3
HC-6/U CASE
3/4" X 3/4" X 3/10"
INSERTION LOSS IN DB
60
50
40
30
20
10
20 db 567 cps
6db 93 cps
3 db 53cps
6
8
10
12
14
FREQUENCY IN KC
ERD 10380

FIGURE I-2.

CASCADED PAIR XTLF-S CERAMIC FILTERS.

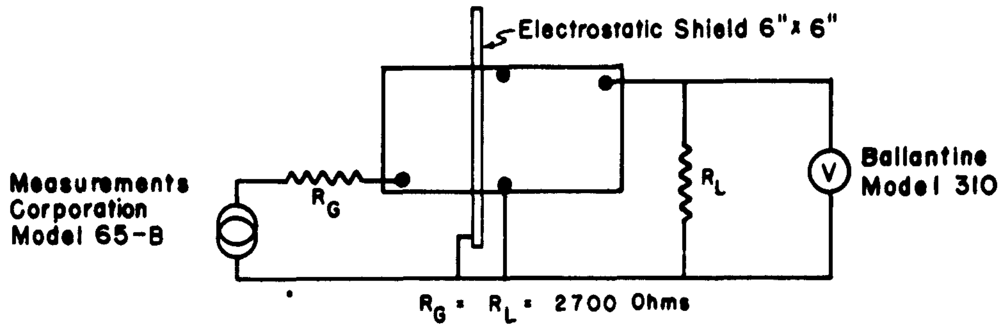


ERD 1037?

FIGURE I-3

TRANSFILTER® COMBINATION TC-04-13A

POWER INSERTION LOSS VS FREQUENCY



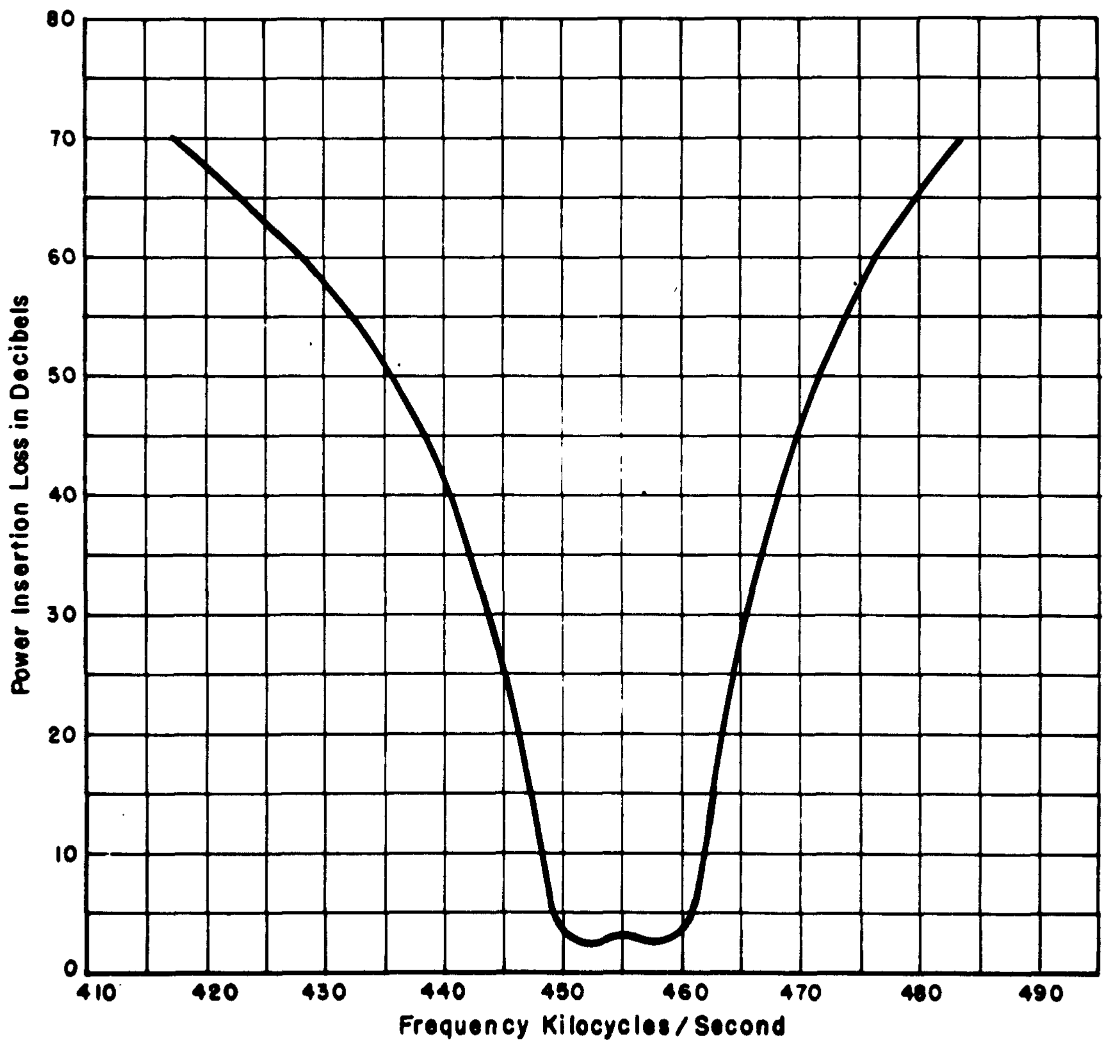


FIGURE I-4

CERAMIC LADDER FILTER TL-10D18A

POWER INSERTION LOSS VS FREQUENCY

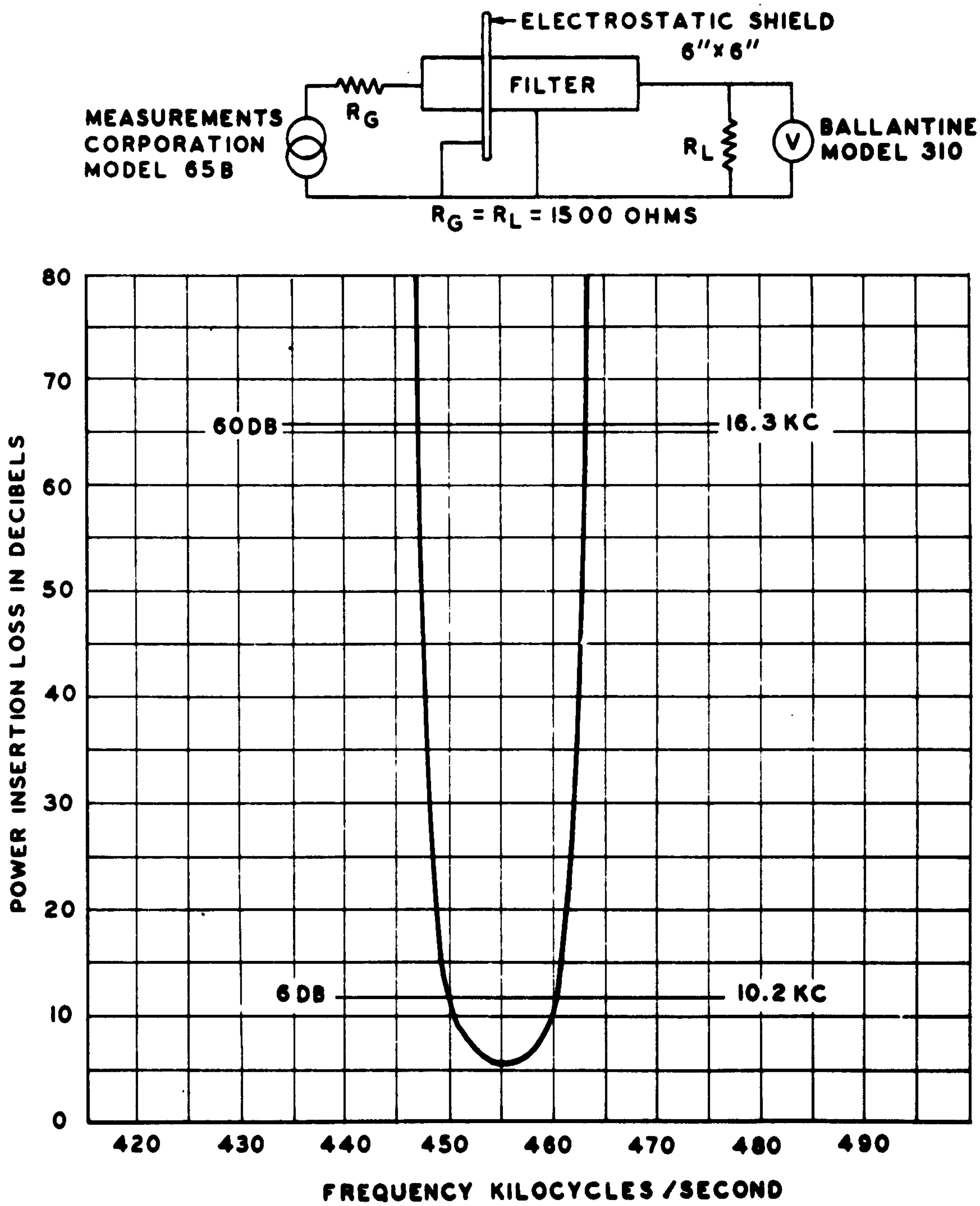
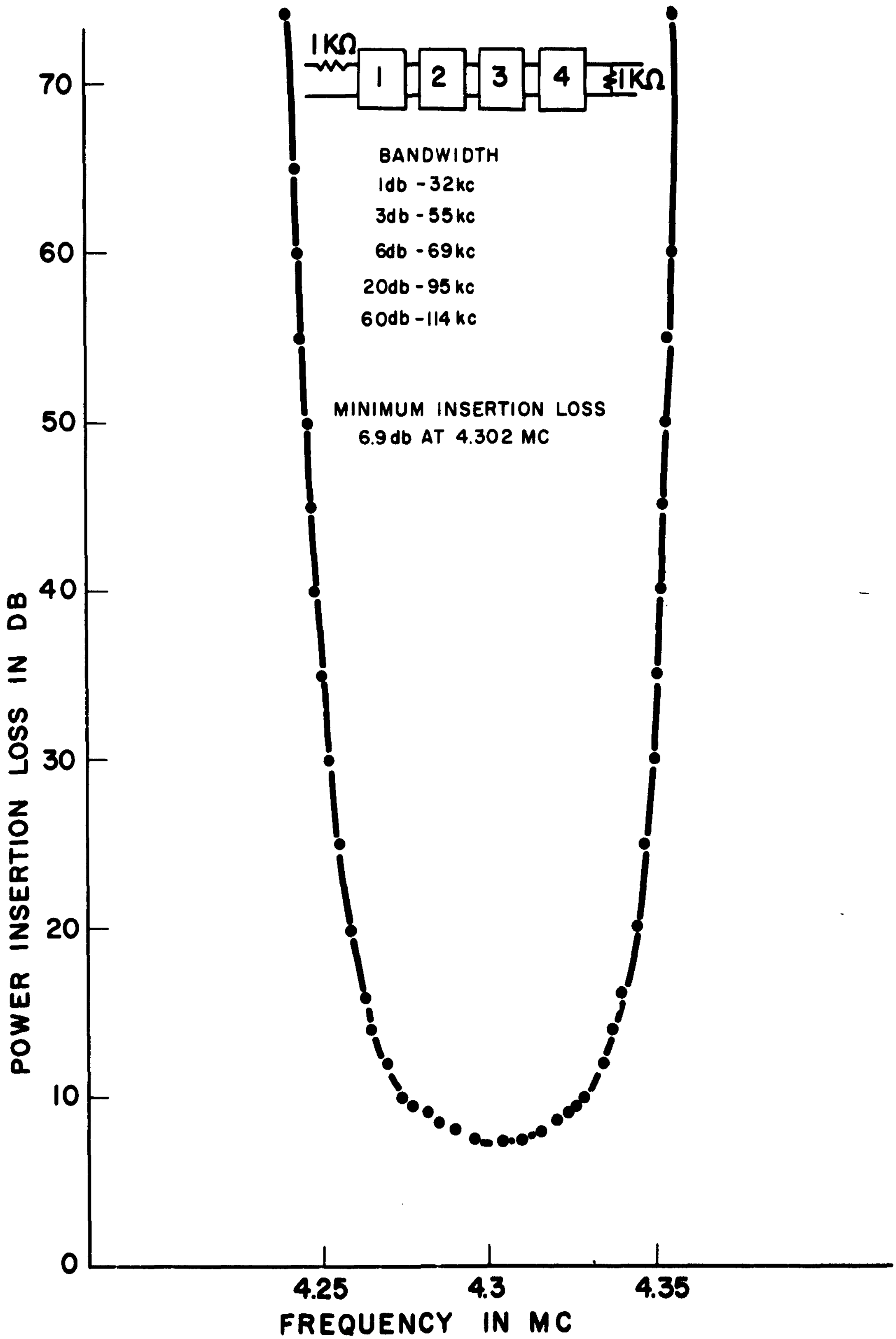


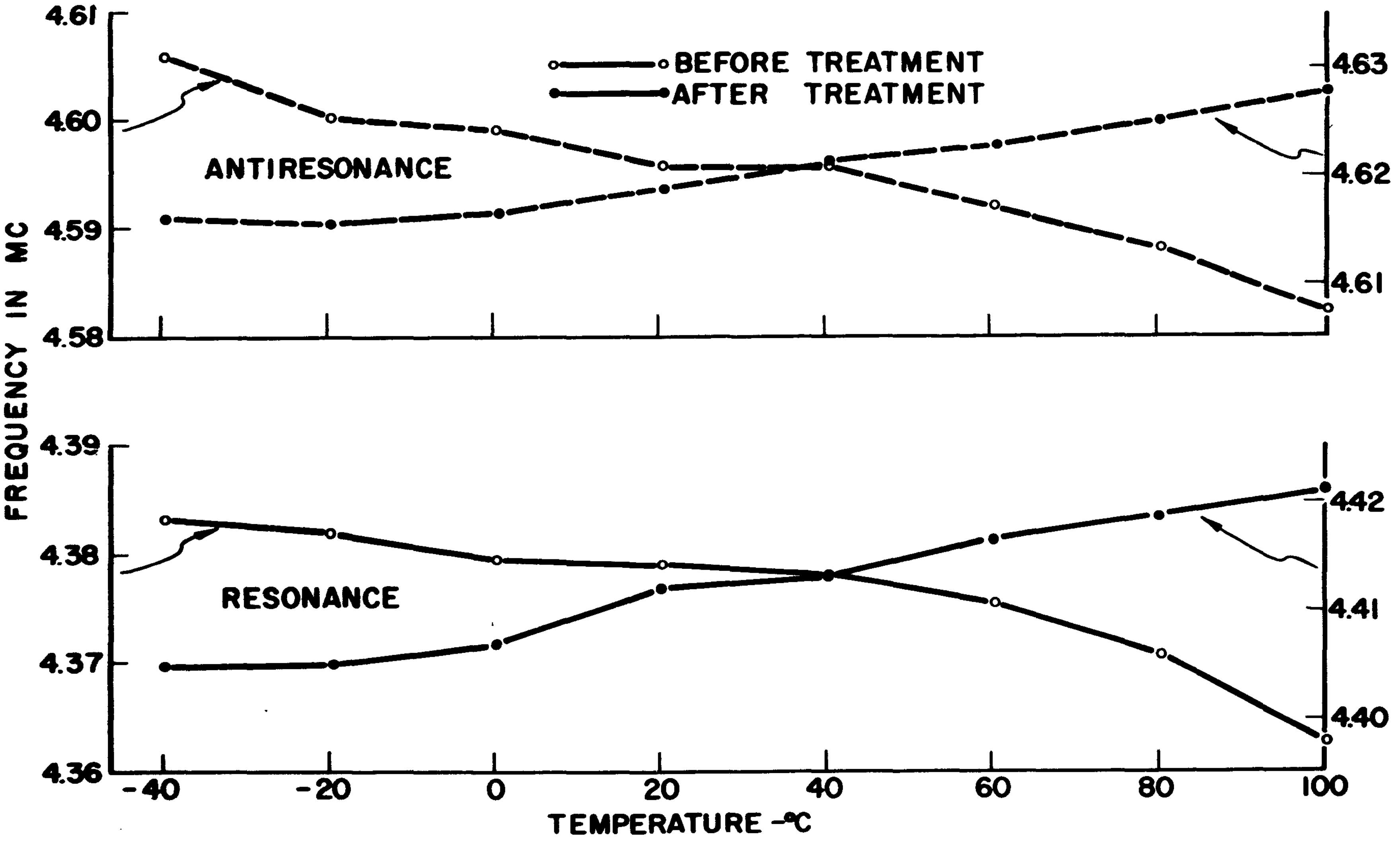
FIGURE I-5. 4.3 MC MEDIUM BANDWIDTH LADDER FILTER.



ERD 10298

FIGURE I

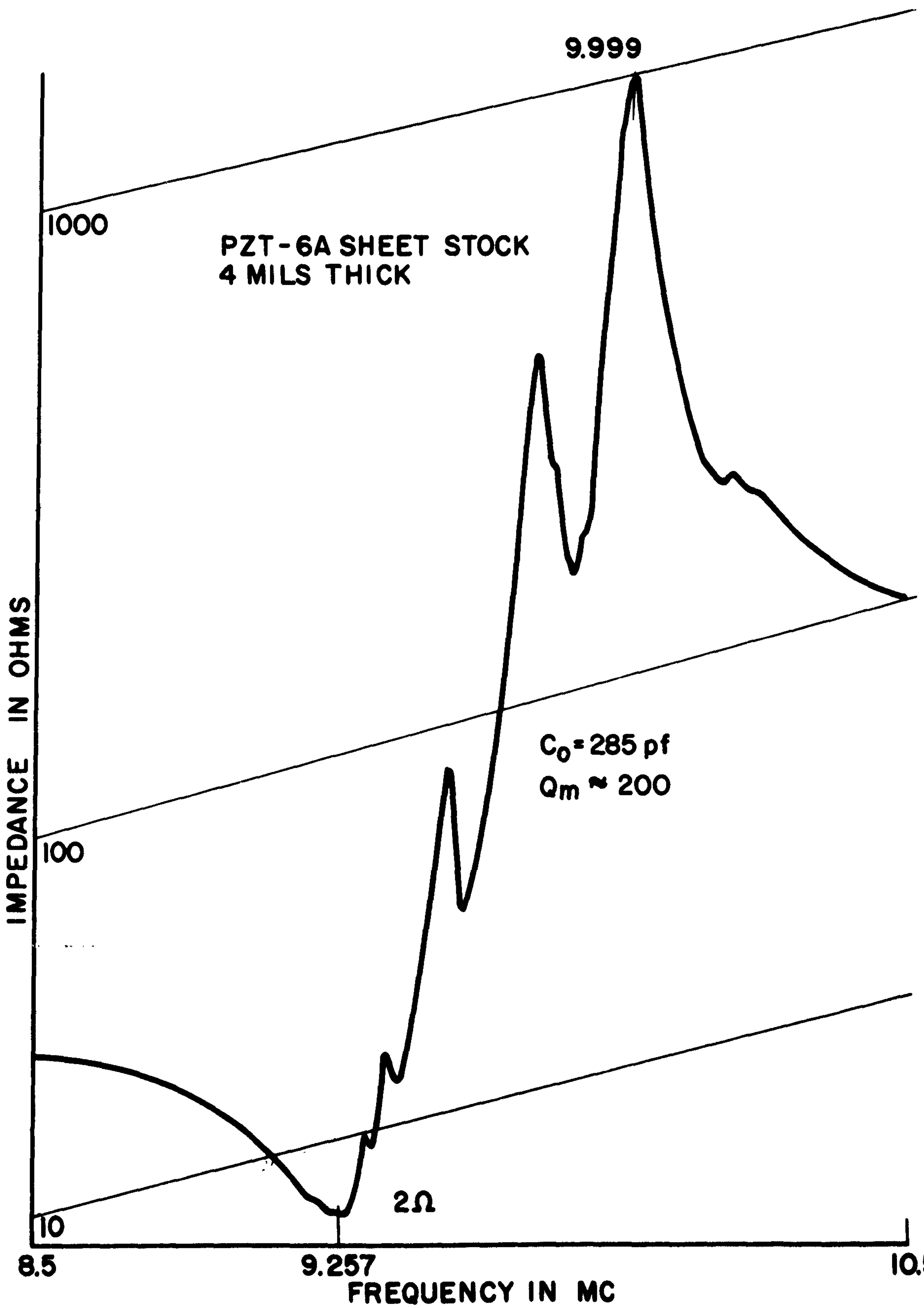
TEMPERATURE DEPENDENCE FOR THICKNESS SHEAR MODE IN PZT-6A SHEET STOCK. (.105" DIA. ELECTROLESS SILVER ELECTRODES)



ERD 10415

FIGURE 2 .

CERAMIC FUNDAMENTAL THICKNESS SHEAR RESONATOR.



ERD 10416

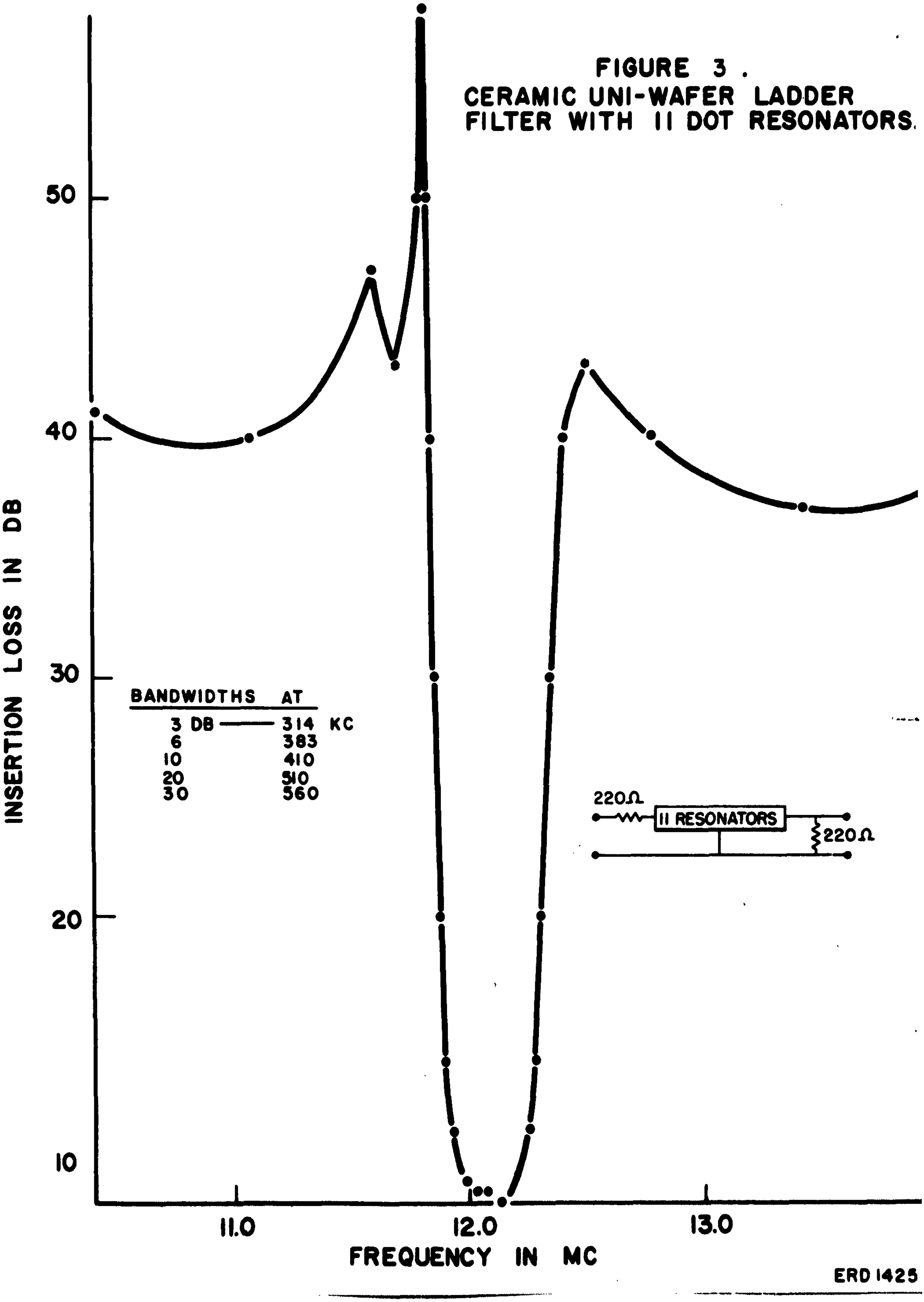
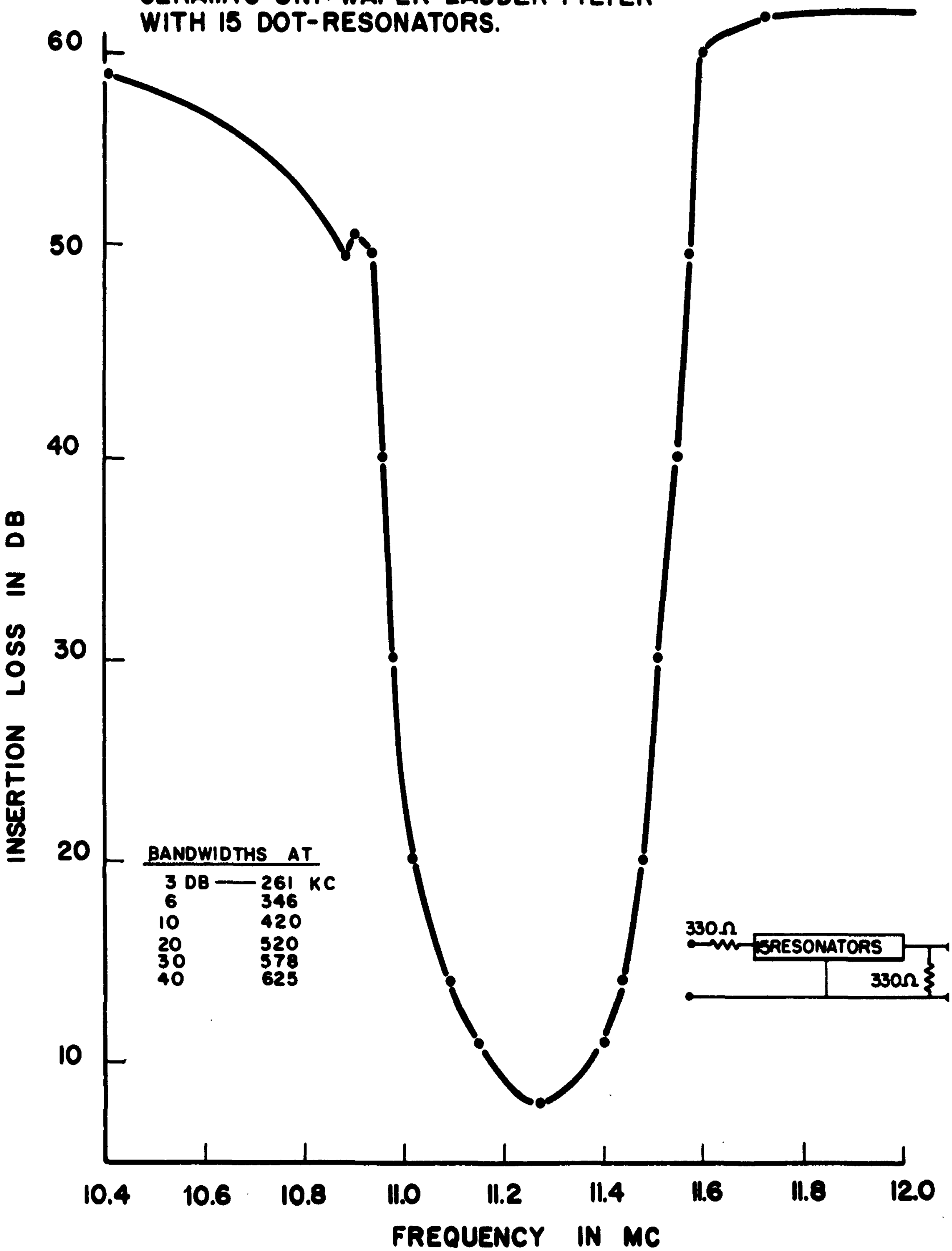


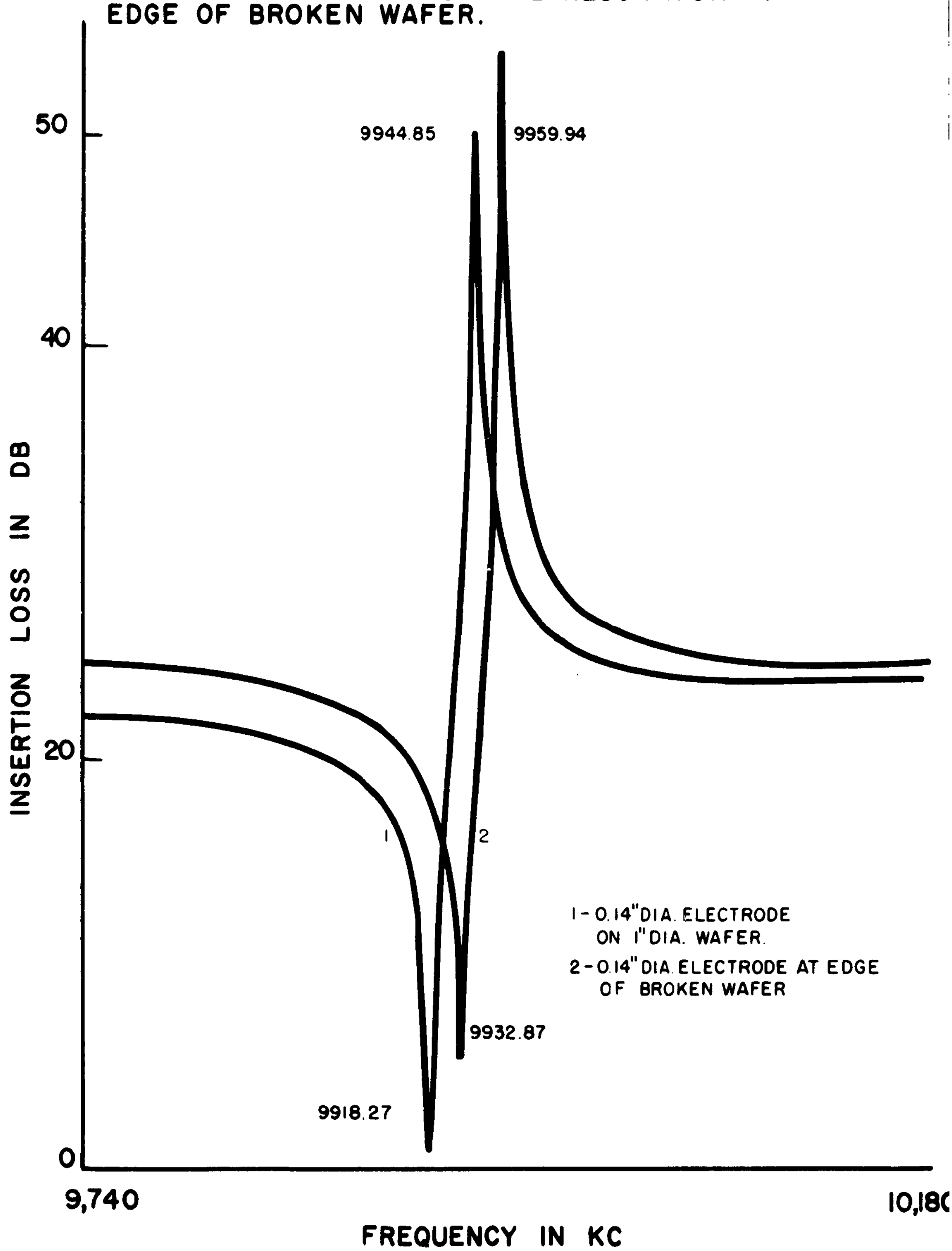
FIGURE 3 .
CERAMIC UNI-WAFER LADDER
FILTER WITH 11 DOT RESONATORS.
50
40
30
20
10
INSERTION LOSS IN DB
BANDWIDTHS AT
3 DB —— 314 KC
6 383
10 410
20 510
30 560
220Ω
11 RESONATORS
220Ω
11.0
12.0
13.0
FREQUENCY IN MC
ERD 1425

FIGURE 4.
CERAMIC UNI-WAFER LADDER FILTER
WITH 15 DOT-RESONATORS.



ERD 1424

FIGURE 5 .
RESPONSE OF AT-CUT QUARTZ RESONATOR AT EDGE OF BROKEN WAFER.



ERD 10423

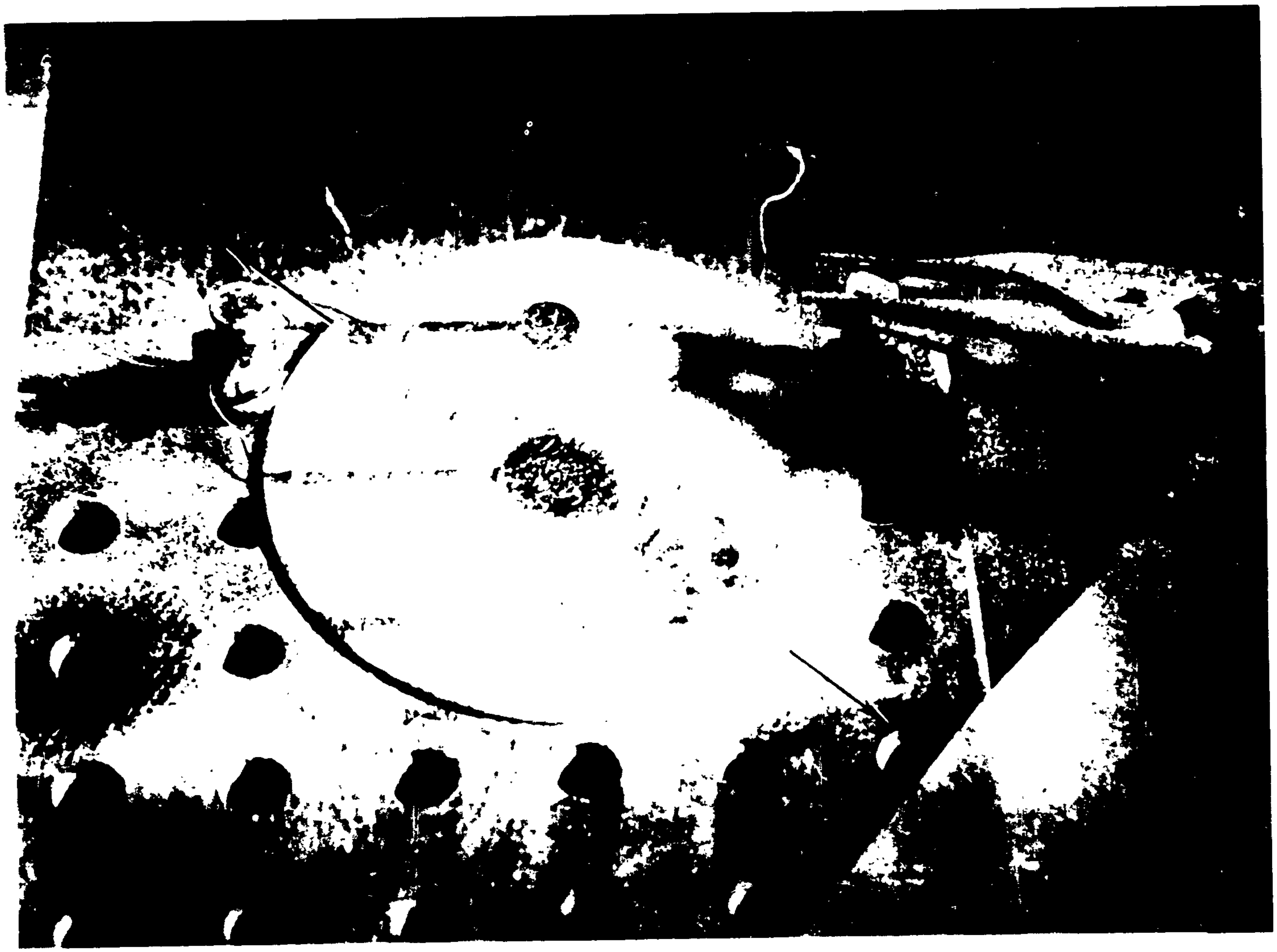
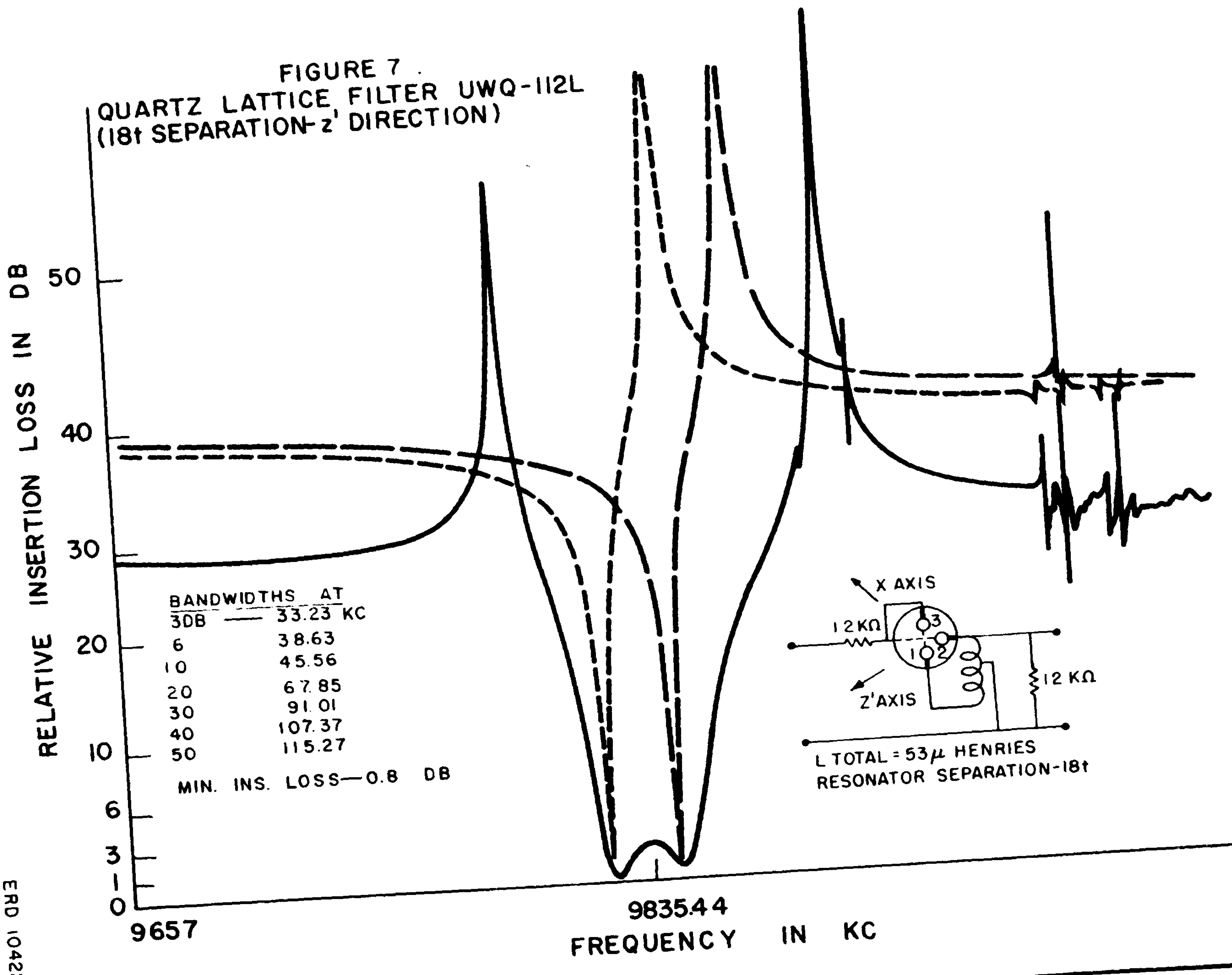


Figure 6. Nodal Dust Pattern on 10 Mc AT-Cut Quartz Wafer

FIGURE 7

QUARTZ LATTICE FILTER UWQ-112L
(18t SEPARATION-z' DIRECTION)



ERD 10422

FIGURE 8.
QUARTZ LATTICE FILTER UWQ-112L
(18t SEPARATION- X-DIRECTION).

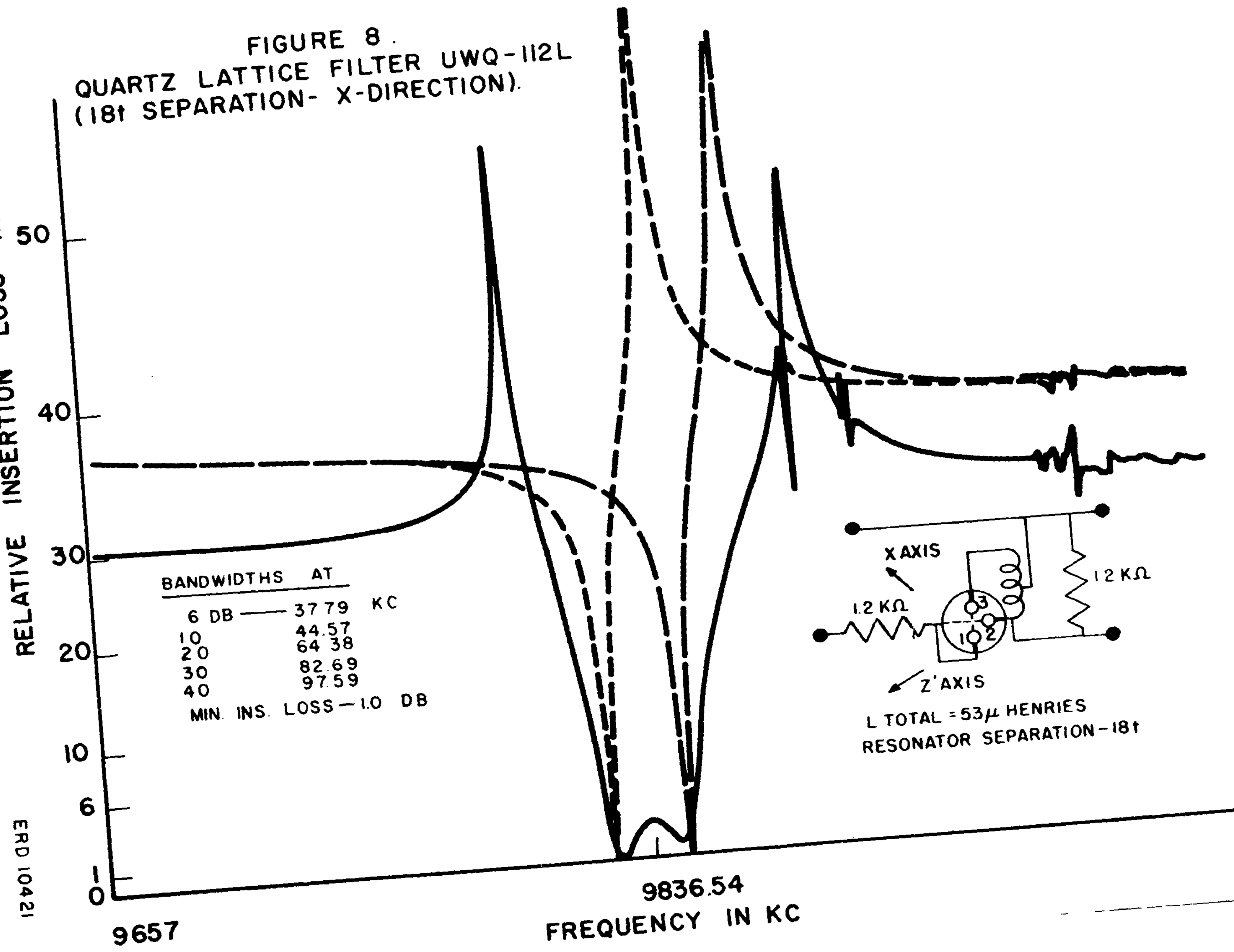
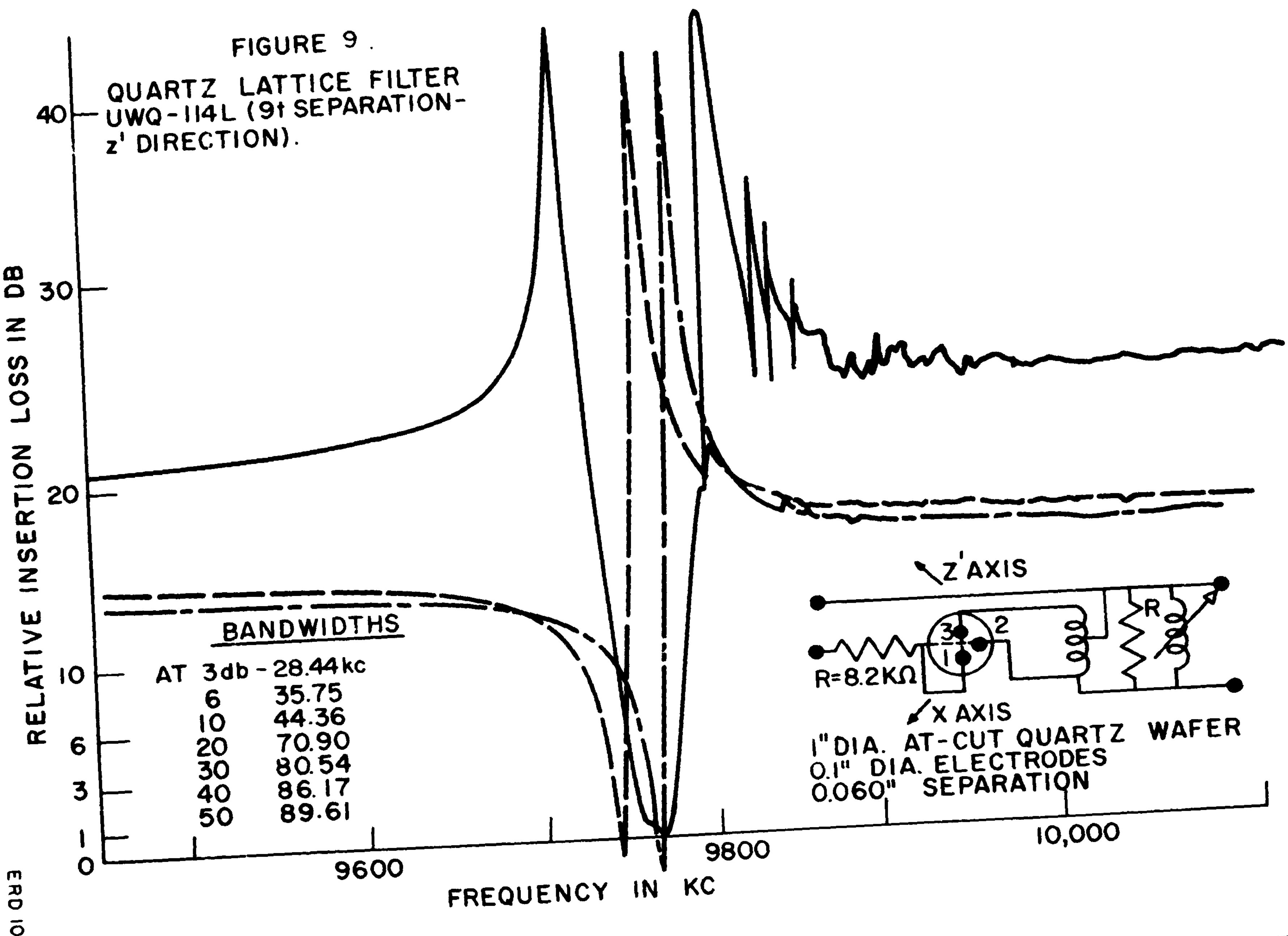


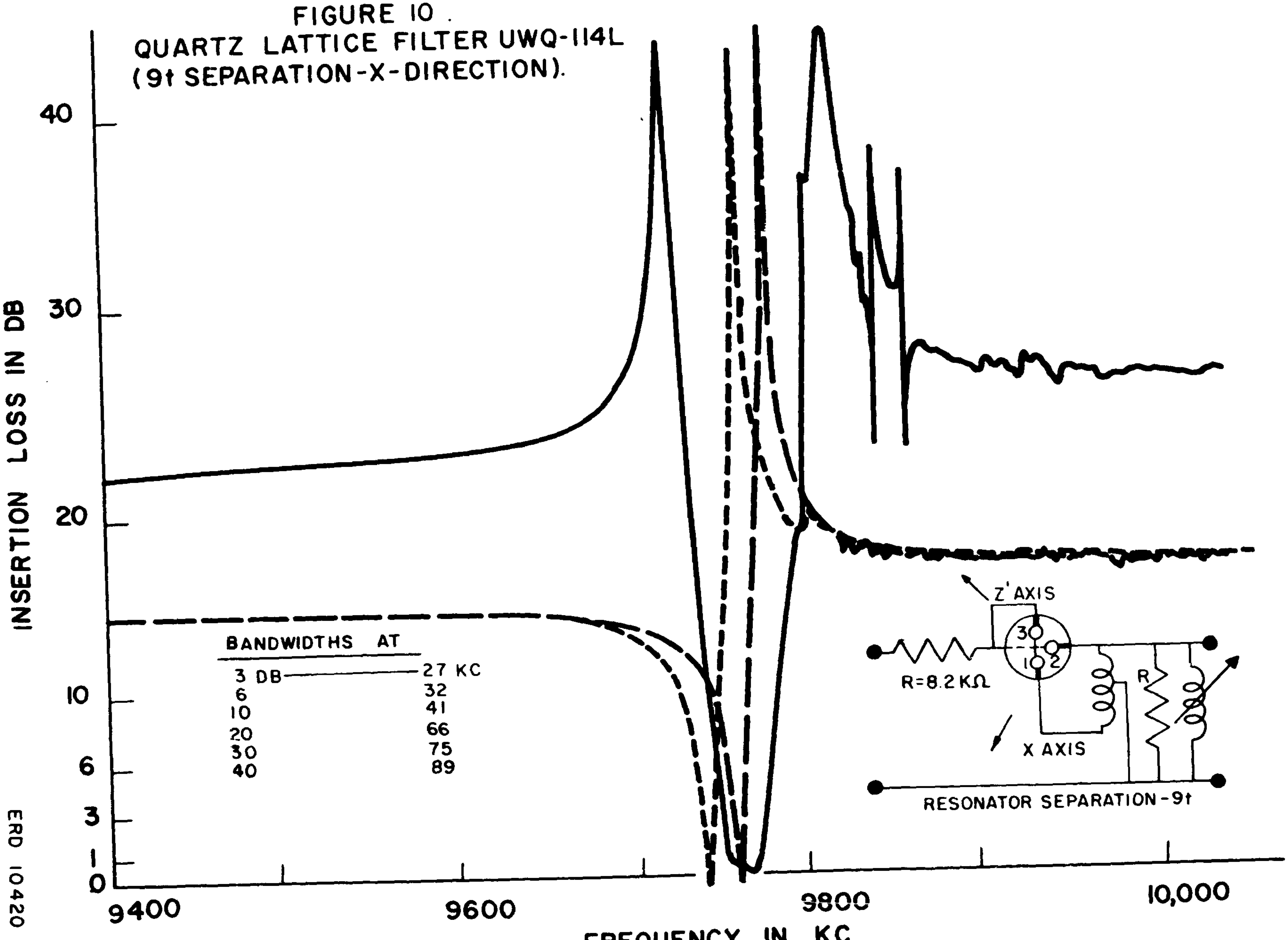
FIGURE 9.

QUARTZ LATTICE FILTER
UWQ-114L (9t SEPARATION-
z' DIRECTION).



ERD 10413

FIGURE 10.
QUARTZ LATTICE FILTER UWQ-114L
(9t SEPARATION-X-DIRECTION).



ERD 10420

FIGURE 11.
QUARTZ LATTICE FILTER - UWQ-115L (3t SEPARATION x AND z' DIRECTIONS).

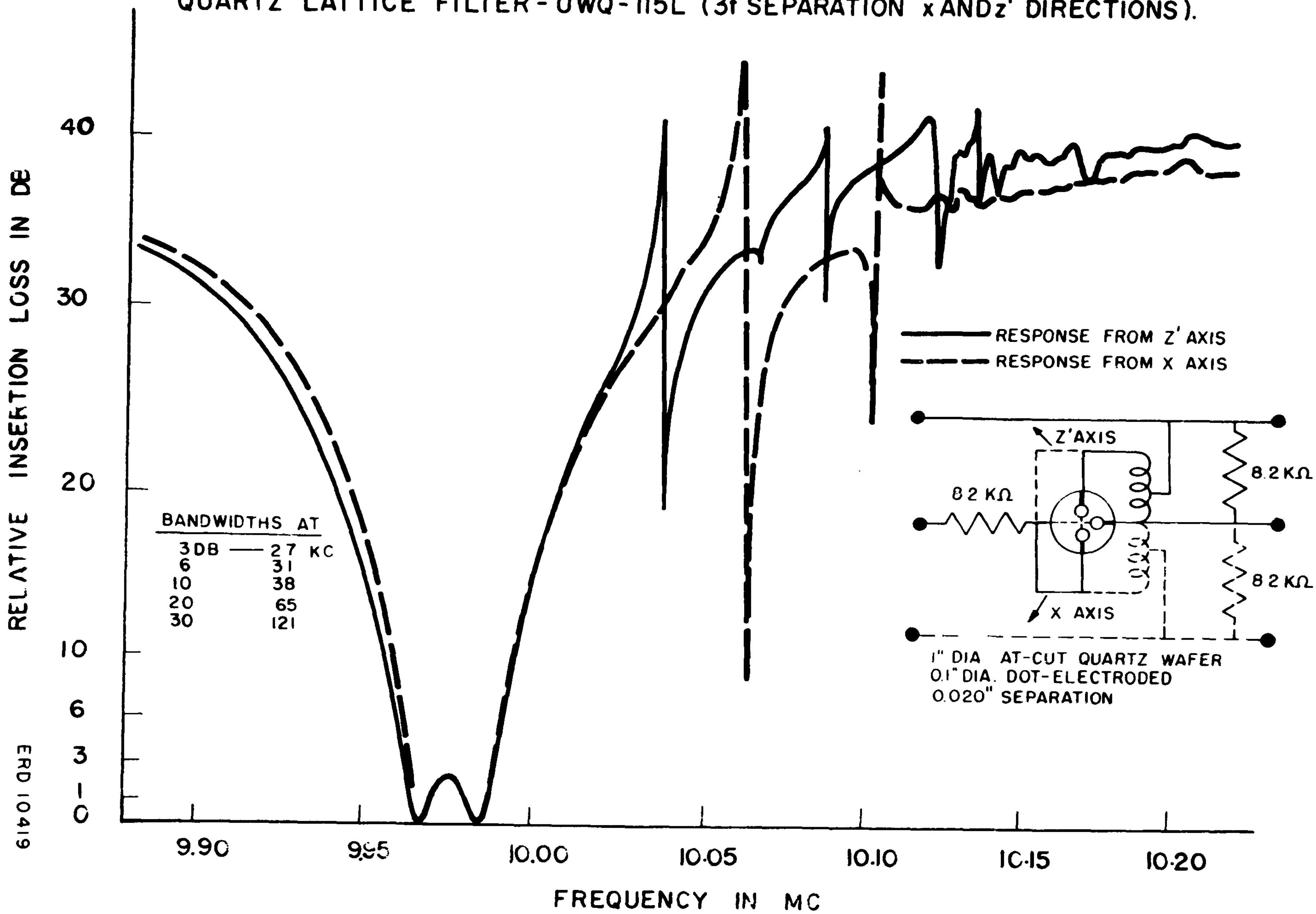
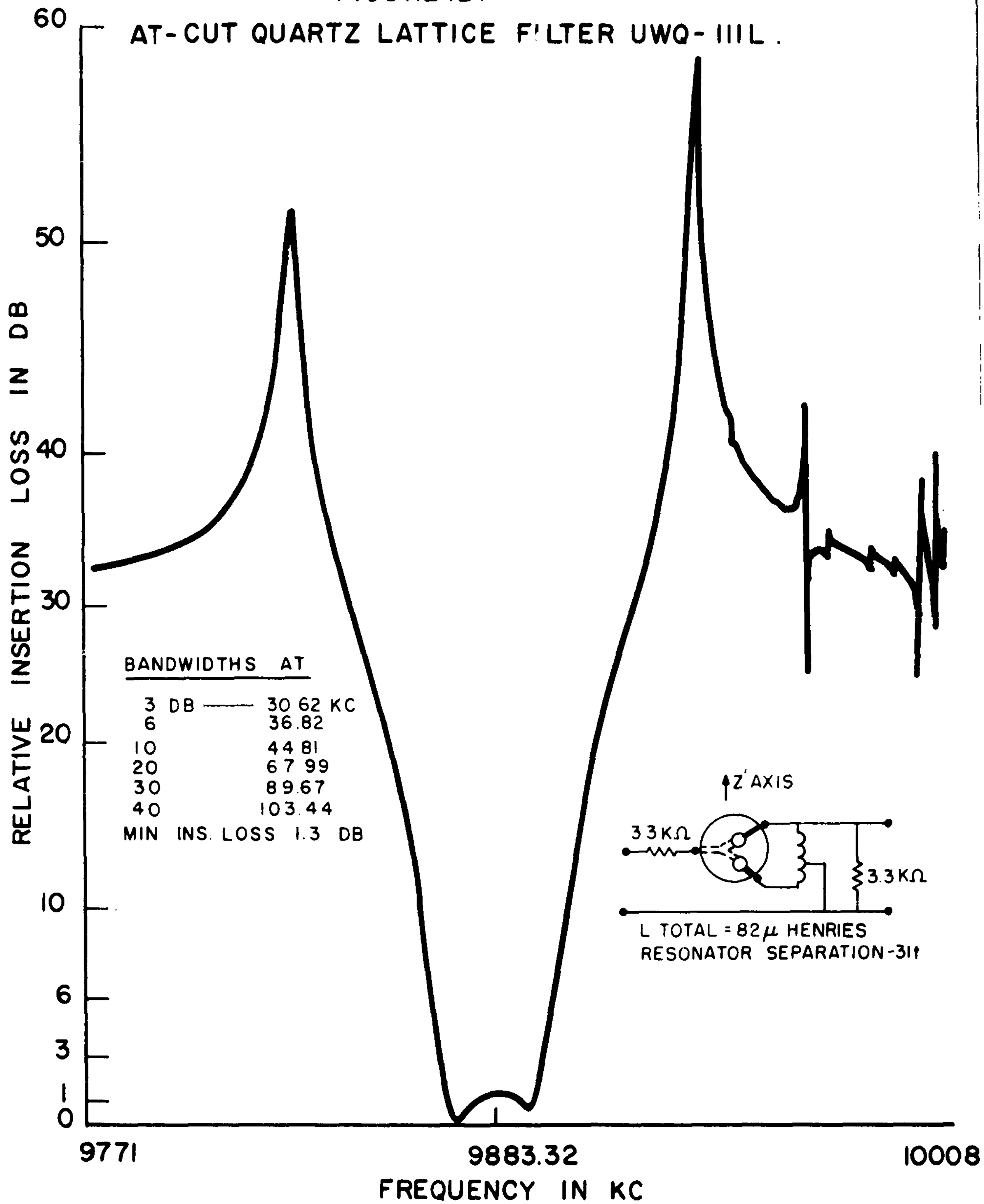


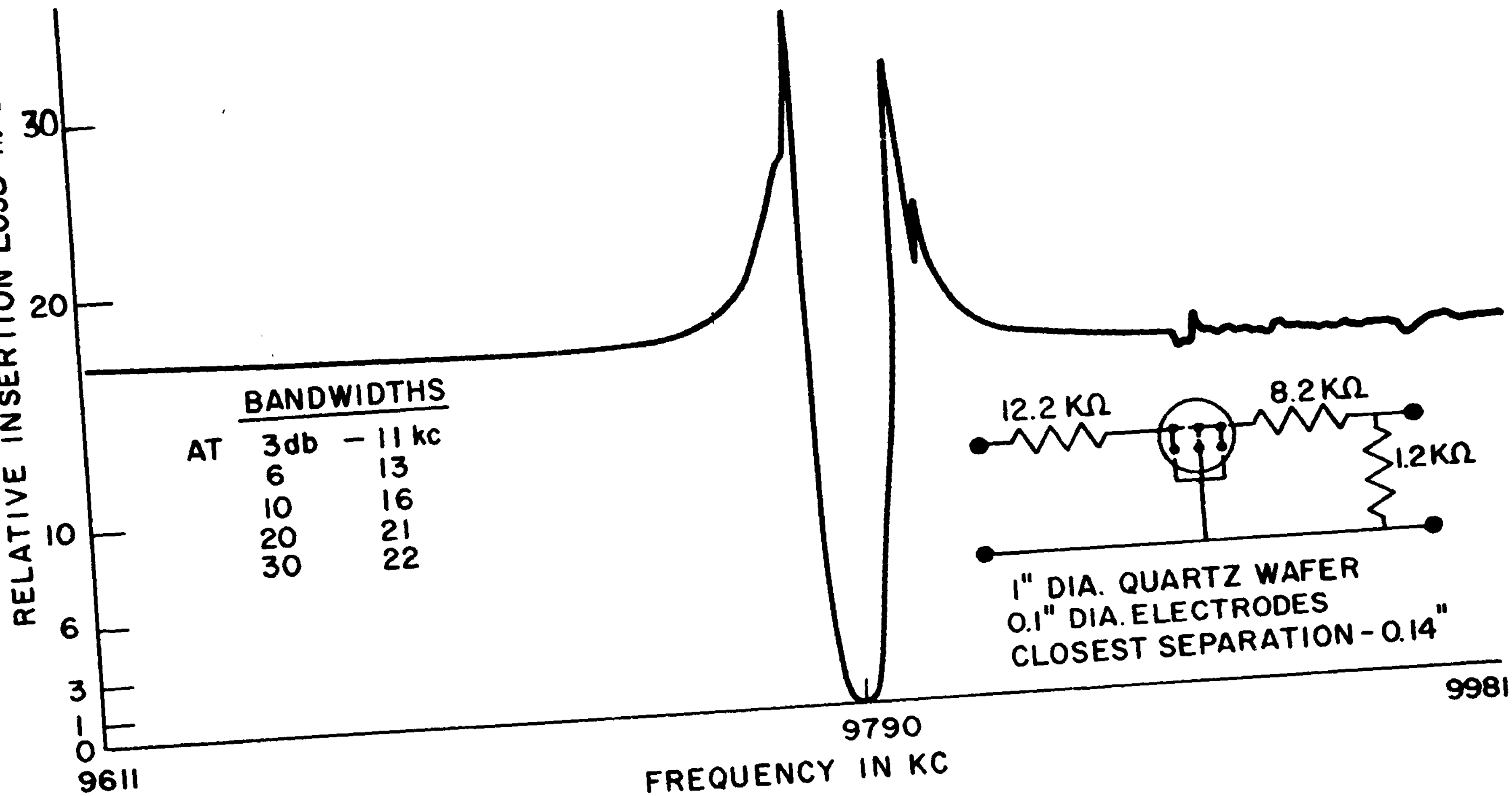
FIGURE 12.

AT-CUT QUARTZ LATTICE FILTER UWQ-111L.



ERD 10418

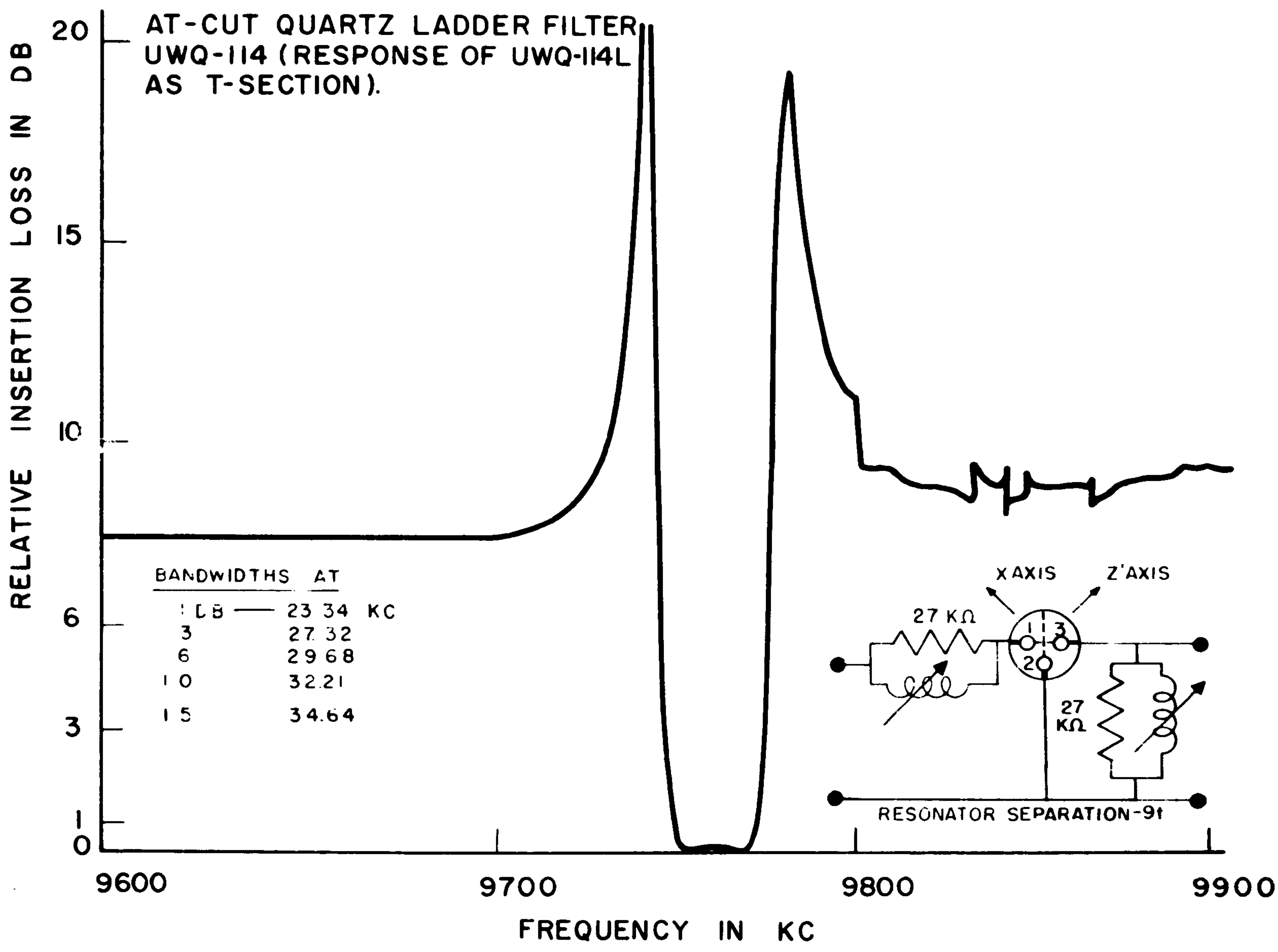
FIGURE 13. SIX RESONATOR LADDER FILTER ON SINGLE AT-CUT QUARTZ WAFER. UWQ-113.



ERD 10412

FIGURE 14.

AT-CUT QUARTZ LADDER FILTER UWQ-114 (RESPONSE OF UWQ-114L AS T-SECTION).



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Contract No. DA 36-039 SC-87275
DA Task No. 3A99-15-002-05
Unclassified Report

An introduction discusses the total frequency range for piezoelectric ceramic filters, which at present extends from below 1 kc to above 12 Mc. Modes of vibration suitable for each portion of this range are described. Ceramic Uni-Wafer ladder filters have been developed at 10 Mc using wafers of wedge shaped cross section with 11 and 15 dot-resonators per filter.

The range of action, i.e. the distance within which a disturbance appreciably affects the performance of a dot-resonator, has been shown to be anisotropic in AT-cut quartz wafers. Experiments using mechanical damping indicate ranges of action of the order of 3 wafer thicknesses (3t) and 14t in the z' and x directions respectively; while those concerning interresonator coupling in half-lattice Uni-Wafer filters indicate that range of action should be in excess of 9t in both directions, but somewhat larger in the x direction. Quartz ladder filter measurements are presented and measurement techniques discussed.

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2. Contract DA-36-039 SC-87275

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