

May 2, 1967

Filed May 12, 1964

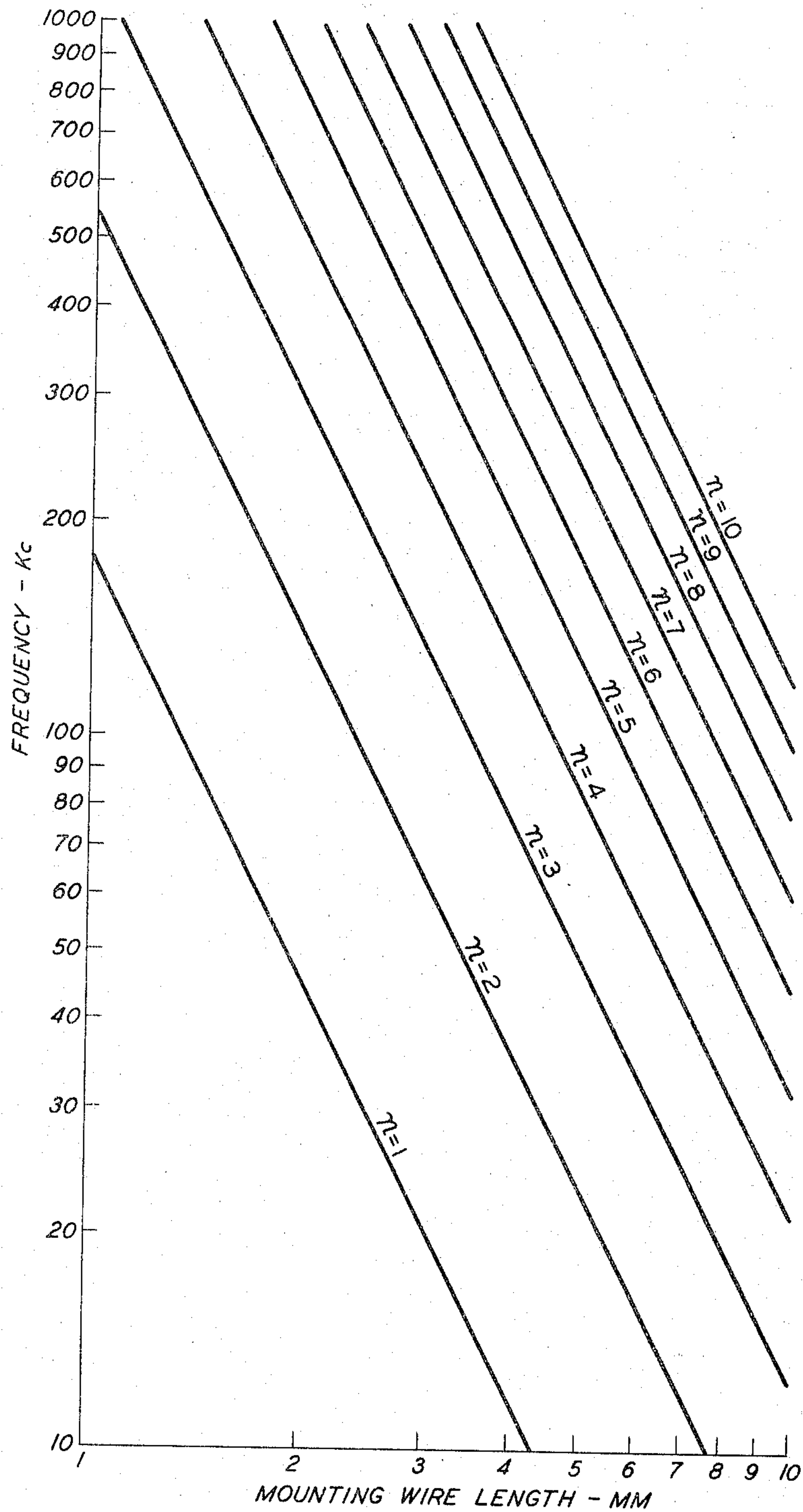
D. M. SPEARS
RESONANT AND ANTIRESONANT VIBRATORY
MEMBERS ATTACHED TO A CRYSTAL

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FIG. 5

WIRE DIAMETER = 3.5 MIL



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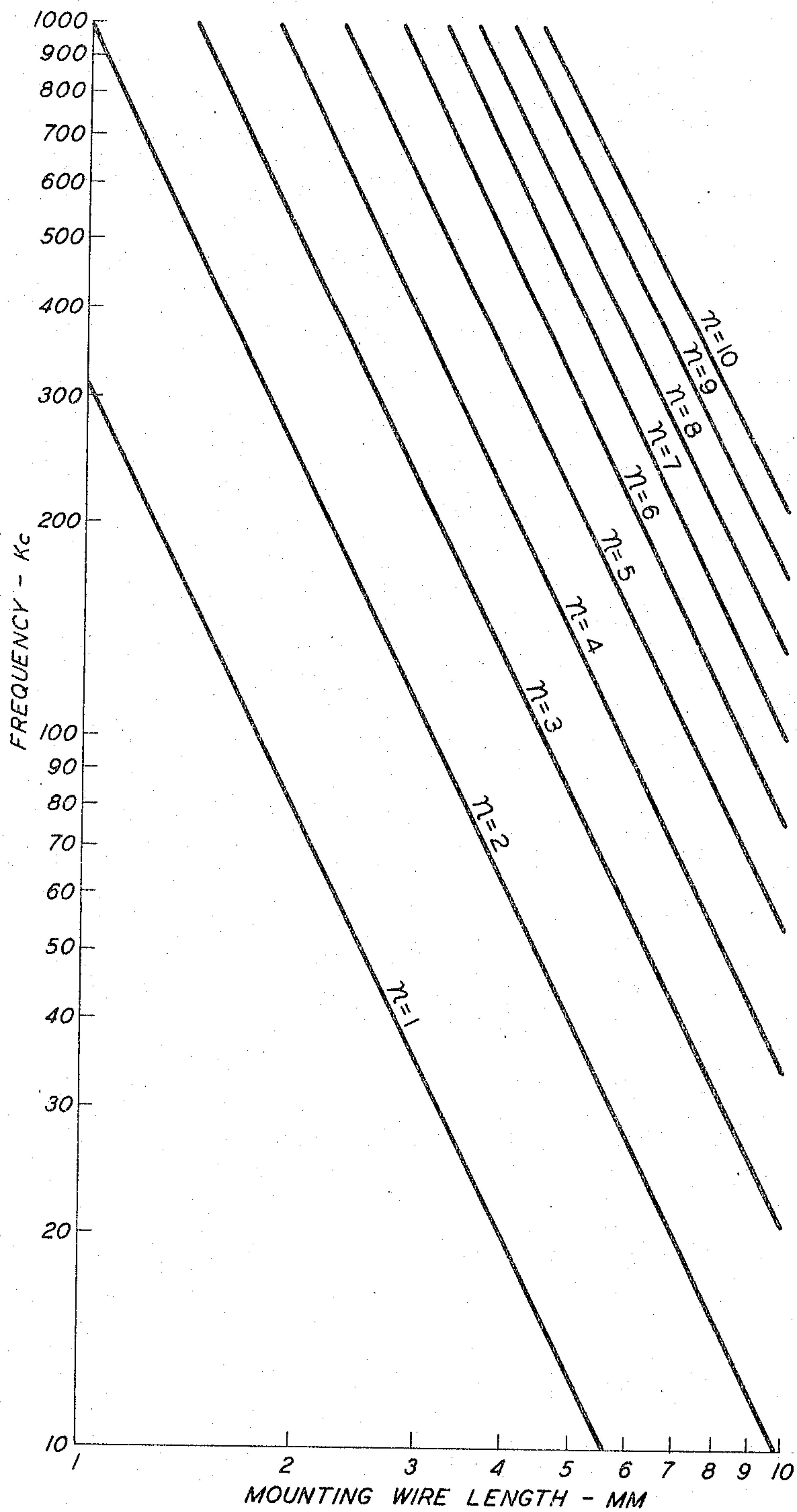
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FIG. 6
WIRE DIAMETER = 6 MIL



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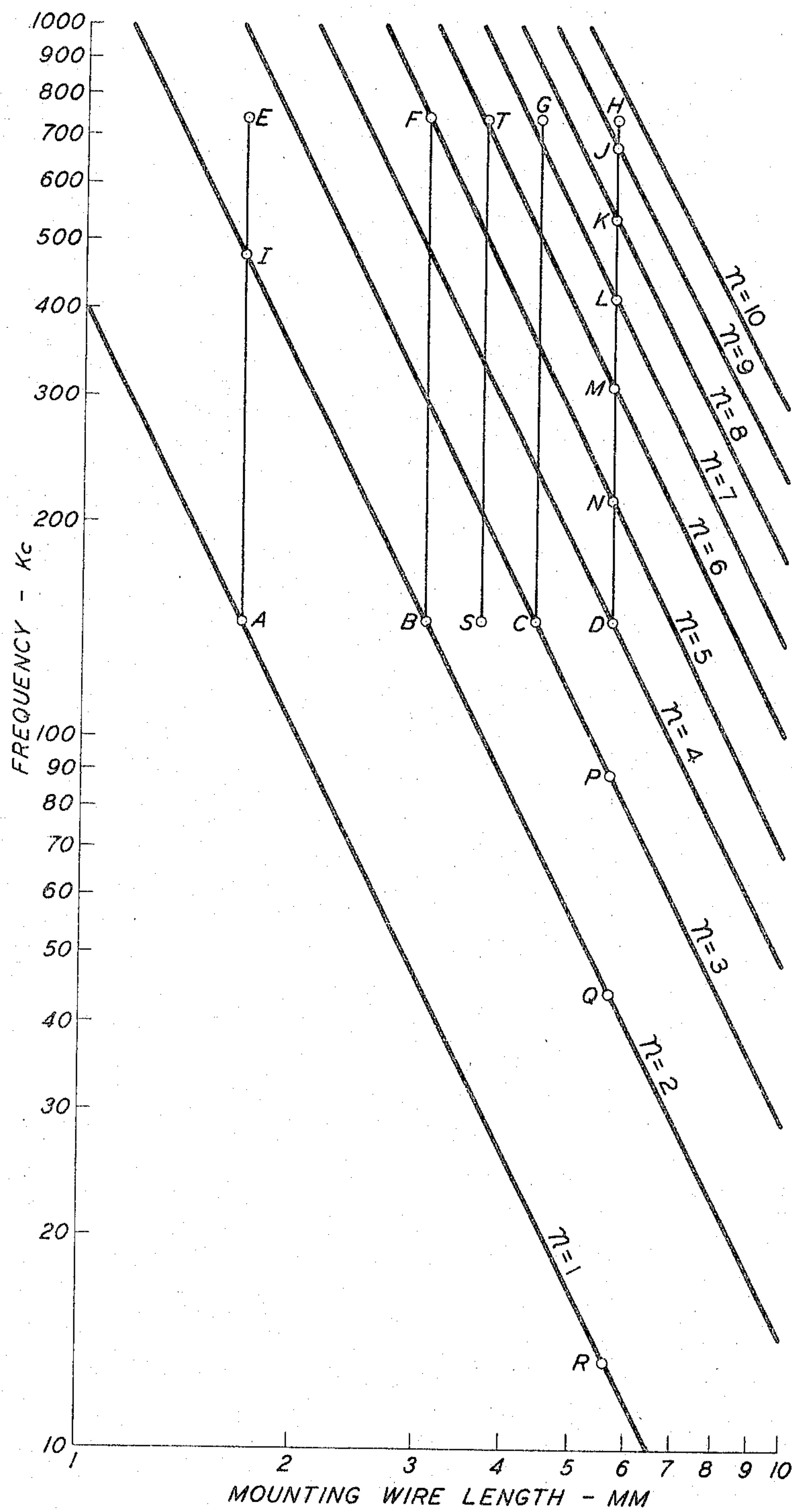
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FIG. 7
WIRE DIAMETER = 8 MIL



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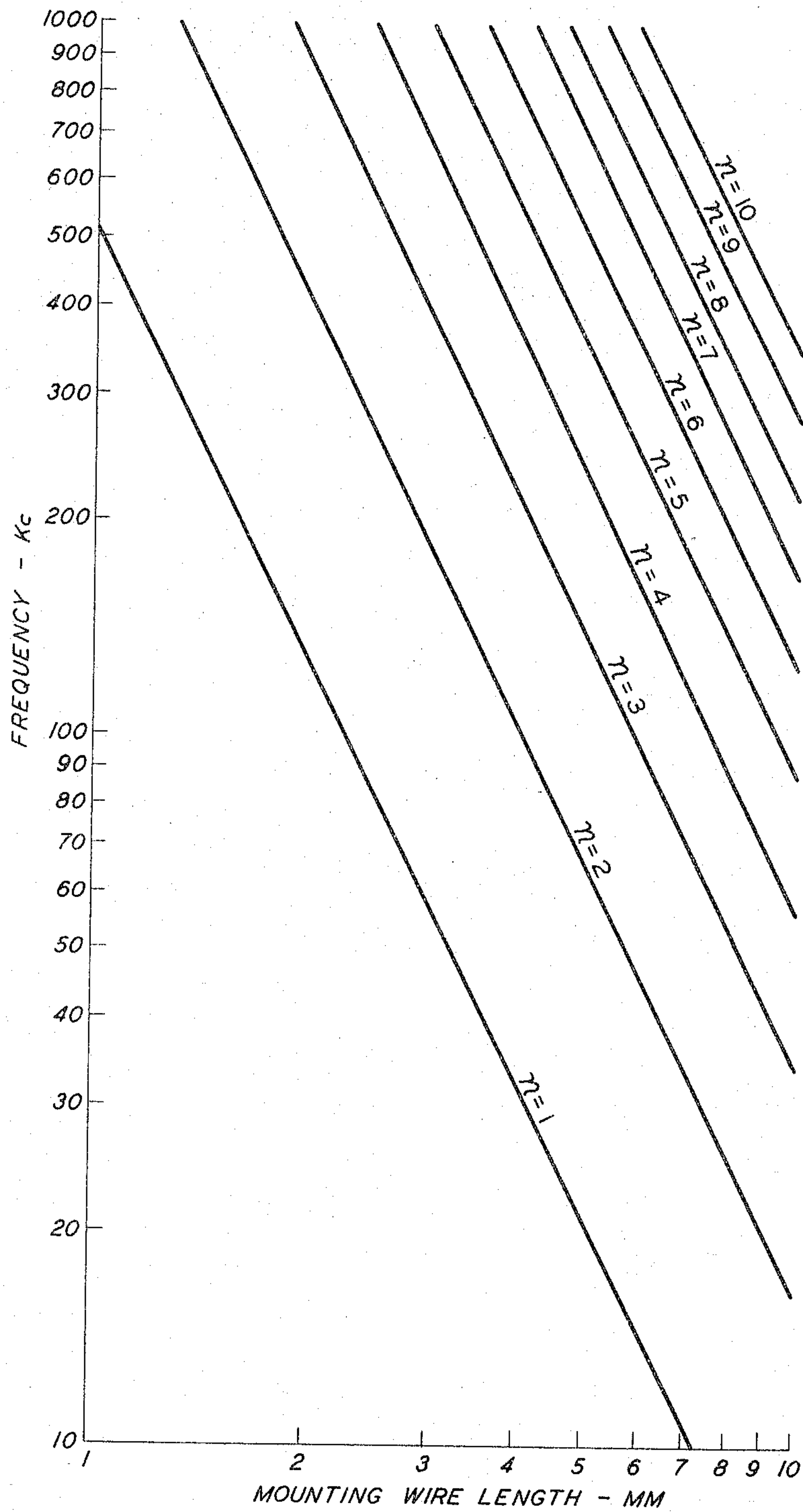
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FIG. 8
WIRE DIAMETER = 10 MIL



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RESONANT AND ANTIRESONANT VIBRATORY MEMBERS ATTACHED TO A CRYSTAL

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6 Claims. (Cl. 310-8.2)

This invention relates to frequency stabilizing vibratory members for use in wave filters, oscillators and the like. More particularly, it relates to piezoelectrically and magnetostrictively driven vibratory members and the like and to improved arrangements for utilizing such members.

It has been common practice for many years to mount vibrating members, such as piezoelectric crystals and the like, on subsidiary supporting members. Usually, but not necessarily, the supporting members are wires, which in many instances also serve to make the necessary electrical connections to the electrical terminals of the vibrating member.

To avoid the absorption of appreciable energy in such subsidiary supporting members or wires, it has further been common practice to employ appropriately positioned weights or substantially rigid mechanical clamping means on the supporting members including the electrical lead wires of piezoelectric crystal units and similar frequency stabilizing vibratory members.

Such weights or clamps are positioned at critical distances along the subsidiary supporting members or wires from the vibrating member such that vibratory energy of the principal, main or wanted resonance frequency of the vibrating member conveyed to the supporting members or wires from the vibrating member will be reflected back to the vibrating member. This avoids an appreciable damping of the principal, main or wanted resonant frequency of the member which is frequently encountered if the effective supporting member or wire lengths do not satisfy specific requirements which are discussed in more detail hereinbelow. This matter is also discussed, for example, in R. A. Heising's book entitled, "Quartz Crystals for Electrical Circuits," published by D. Van Nostrand Company, Inc., New York, 1946, at Chapter VIII (by R. A. Sykes), pages 279 to 284, and in United States Patent No. 2,371,613, granted March 20, 1945, to I. E. Fair.

Neglecting for the moment small but in some circumstances significant modifications which may be required in view of particular terminal conditions which may exist at one or both ends of the wire or other mounting member as noted in Heising's book cited above, it may be stated as a general rule that any supporting member or wire connecting at one end to the vibrating member and clamped or rigidly supported at the other end which has an effective length of substantially an odd number of quarter wavelengths (including one-quarter wavelength) of the principal, main or wanted resonant frequency of the member from the weight or clamping member to the vibrating member will effect a substantially complete reflection of the energy of that frequency which reaches the supporting member or wire back to the vibrating member. As a result, substantially, no loss of energy or damping of the vibration of the vibrating member at that specific frequency is caused by the supporting member or wire. The active portion of the wire or other supporting member may be said in such cases to be resonant at the principal, main or wanted frequency and will present a low mechanical impedance at its point of attachment to the vibrating member at the principal, main or wanted frequency.

In many instances, however, it is found that specific vibratory members, such as piezoelectrically driven crys-

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tals, may have, in addition to the principal, main or "wanted" frequency of resonance, another frequency or even an appreciable number of other frequencies at which resonant vibration, designated for the purposes of the present application as "secondary" or "unwanted" vibration, of significantly large amplitude may tend to take place. This is usually a result of a common tendency of vibrating members to vibrate in several modes, that is, one or more additional modes, rather than solely in the mode which results in vibration at the principal, main or wanted resonant frequency of the vibrating member.

For descriptions of various modes of vibration of a number of vibratory members and of the coupling between the modes, reference may be had to Chapter VI, starting at page 205, and Chapter VII, starting at page 249, by R. A. Sykes and H. J. McSkimin, respectively, of the above-mentioned book by R. A. Heising. It should be noted that substantially all vibrating members tend to vibrate in numerous modes though in most instances the amplitudes of all but a few such modes are sufficiently small or weak that they may be ignored.

Not infrequently, one or more of these unwanted or secondary modes of vibration will, however, occur at a frequency or at frequencies closely adjacent to or actually within the frequency band which is to be utilized and in which only a single principal or wanted frequency is desired. If the supporting member or lead wire length chosen to resonate at the wanted or principal frequency also chances to be approximately an odd number of quarter wavelengths of an unwanted or secondary frequency, the vibrational energy at both frequencies will not be absorbed by the supporting members or wires, but rather at both frequencies it will be reflected back to the vibrating member.

It becomes apparent, therefore, that the supporting member or lead wire length should be chosen so that, where it is essential to suppress a specific unwanted or secondary frequency of vibration, it is substantially an odd number of quarter wavelengths of the wanted or principal frequency and at the same time an even number of quarter wavelengths (that is, one or more half wavelengths) of the unwanted or secondary frequency. The wire may then be said to be substantially resonant or of low impedance at the wanted or principal frequency and antiresonant or of high impedance at the unwanted or secondary frequency.

Accordingly, applicant proposes that the lengths of subsidiary supporting members and/or lead wires be chosen so that not only do they avoid seriously damping the wanted or principal vibration frequency but also they produce a pronounced suppression or damping of one or more other frequencies corresponding to vibrations in unwanted or secondary modes which otherwise might be of troublesome amplitude.

Applicant further proposes the use of additional subsidiary wires or similar appendages attached by one end to the vibrating member, the subsidiary appendages otherwise being free, and having dimensions such that they not only strongly damp or suppress specific unwanted or secondary resonant frequencies but also absorb substantially no energy at the wanted or principal frequency of resonance.

These latter subsidiary wires or appendages will, for the purposes of the present application, be referred to as "discriminator" members since they are not used either as supports or as electrical leads but solely to discriminate against or suppress unwanted or secondary frequencies without appreciably reducing the activity of the vibrating member at the wanted or principal frequency. Such wires may also be said to be substantially resonant (of low impedance) at the wanted or principal frequency

and anti-resonant (of high impedance) at the secondary frequencies they are respectively designed to suppress.

The supporting and/or discriminator members need not, unless of course certain of them are employed to also make electrical connections, be of metal or be in the form of wires but rather may alternatively be members of any shape and made of any resilient material, provided they are designed to have proper resonating characteristics, that is, low mechanical impedance (substantial resonance) at a principal or wanted frequency and a high mechanical impedance (antiresonance) at one or more specific unwanted or secondary frequencies. It should be noted that in many cases the vibrating member, though vibrating in a shear mode or some other complex mode, may cause a quite different mode of vibrations such, for example, as flexural vibrations or longitudinal vibrations in the supporting and/or discriminator members. The vibrating member, of course, may itself, alternatively, be excited in any of numerous modes of vibration, such as longitudinal, torsional, flexural, face shear or thickness shear or the like. The supporting and/or discriminator members must therefore be designed to resonate substantially at the wanted or principal frequency (in the mode the specific member is driven by the vibrating member at that frequency) and to anti-resonate at the unwanted or secondary frequency (in the mode the specific member is driven by the vibrating member at the unwanted or secondary frequency).

Furthermore, if a supporting member is made of a nonconducting material and it is desired that it also serve as an electrical connecting member, then obviously a conducting path can be placed, as by a metallic plating or the like, on the surface of the supporting member to provide an electrical connection to an electrode surface of the vibrating member.

Since the members designated above as "discriminator" members are ordinarily not weighted or attached to anything at one end (the end opposite to that which is attached to the vibrating member), by elementary theory, they will be resonant (low impedance) at lengths which are an integral number of half wavelengths and anti-resonant (high impedance) at lengths which are an odd number of quarter wavelengths of their respective frequencies of vibration.

As is well known to those skilled in the art, mechanically multiply resonant structures analogous to relatively complex electrical circuits can readily be derived by a direct and simple adaptation of the formulas and design techniques employed to determine the electrical circuits.

It is, accordingly, apparent that complex supporting and/or discriminator members can readily be devised by those skilled in the art, each one of which would be capable of providing a plurality of resonant and anti-resonant frequencies (commonly designated "critical frequencies") having any of a large variety of distributions throughout a selected frequency range to meet the requirements of discrimination against particular unwanted or secondary frequencies while having substantially no damping effect with respect to one or more other frequencies within the selected frequency range.

Reference may be had, for example, to the book entitled, "Electromechanical Transducers and Wave Filters," Chapter III, starting at page 80, by W. P. Mason, published by D. Van Nostrand Company, Inc., New York, 1942, and to United States Patents No. 3,064,213, granted Nov. 13, 1962, No. 2,345,491, granted Mar. 28, 1944, and No. 2,342,813, granted Feb. 29, 1944, all three to W. P. Mason. Numerous other similar patents of interest in this connection will be found in Patent Office Class 333, subclasses 71 through 73, inclusive.

For simplicity and clarity of illustration and description, the illustrative embodiments shown in the accompanying drawing and described hereinunder have, how-

ever, employed simple wire-like members as supporting, lead wire, and discriminator members.

Also in connection with the specific illustrative embodiments selected, only one unwanted or secondary frequency is explicitly mentioned as it happens to be the one of greatest amplitude. As is well known to those skilled in the art, a number of other secondary or unwanted frequencies will be generated by the illustrative vibrating members and in general by substantially all vibrating members of the generic type being considered. In general, also, many of the secondary or unwanted frequencies will be of insufficient amplitudes relative to that of the principal or main frequency that they will not introduce any substantial difficulties.

Convenient procedures by which suitable lengths of lead and/or discriminator wires for vibratory members may be chosen to effect both the non-damping of the principal or wanted frequency and the suppression of specific unwanted or secondary resonant frequencies have been developed by applicant and are described in detail hereinbelow.

While the specific illustrative embodiments of the invention described in detail hereinbelow are piezoelectrically driven quartz crystals, it will be obvious to those skilled in the art that the principles of the invention are readily adaptable for use with numerous and varied other types of vibratory members, such, for example, as members of Rochelle salt, barium titanate, magnetostrictively or electrostrictively driven vibrating members, and numerous others. Reference, for a number of such vibratory members and their uses, may be had to the book entitled, "Piezoelectric Crystals and Their Application to Ultrasonics," by W. P. Mason, published by D. Van Nostrand Company, Inc., New York, 1950. A second book by W. P. Mason entitled, "Electromechanical Transducers and Wave Filters," mentioned above, is also of interest in this connection.

Accordingly, a principal object of the invention is to eliminate difficulties resulting from the tendencies of a vibratory member to vibrate in secondary or unwanted modes (or at secondary or unwanted frequencies) without substantially damping the vibration of the member in the principal or wanted mode (or at the principal or wanted frequency).

Other and further objects, features and advantages of the invention will become apparent from a perusal of the following detailed description of specific illustrative embodiments of the principles of the invention and from the appended claims taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates in diagrammatic form a vibrating member of the invention;

FIG. 2 illustrates in diagrammatic form a variation of the arrangement of FIG. 1;

FIG. 3 is a graph indicating the activity at the principal or wanted frequency of vibratory energy of the crystal versus the supporting wire length for a piezoelectric crystal of the type illustrated by FIGS. 1 or 2 with the discriminator members omitted;

FIG. 4 is a graph indicating the activity at a secondary or unwanted frequency of vibratory energy of the crystal versus the supporting wire length for a piezoelectric crystal of the type illustrated by FIGS. 1 or 2 with the discriminator members omitted;

FIG. 5 is a chart indicating the frequencies absorbed by the supporting and/or discriminator wires of various lengths having diameters of 3.5 mils, that is, 3.5 thousandths of an inch;

FIG. 6 is a chart indicating the frequencies absorbed by the supporting and/or discriminator wires of various lengths having diameters of 6.0 mils;

FIG. 7 is a chart indicating the frequencies absorbed by the supporting and/or discriminator wires of various lengths having diameters of 8.0 mils; and

FIG. 8 is a chart indicating the frequencies absorbed by the supporting and/or discriminator wires of various lengths having diameters of 10.0 mils.

In more detail in FIG. 1, a specific piezoelectrically driven member 10, having, for example, a diameter of 30 millimeters and a thickness of substantially 2.5 millimeters such that the member will resonate in the thickness shear mode at a principal frequency of 792 kilocycles per second, assuming the member is cut from a single crystal of quartz oriented with respect to the crystallographic axes of said single crystal of quartz in the manner well known and designated in the art as an AT cut crystal, is illustrated, to a somewhat enlarged scale.

With such crystal members the resonant frequency in the thickness shear mode is determined principally by the thickness of crystal. By way of example, in one communication system requiring nine frequencies separated by 48 kilocycles per second from the next adjacent frequency, or frequencies, the lowest frequency being 648 kilocycles per second and the highest frequency being 1032 kilocycles, all nine crystals were made 30 millimeters in diameter and their respective thicknesses were adjusted so that the above indicated nine frequencies were provided by the nine crystals, respectively.

Such crystals, however, tend also to vibrate in a secondary mode known as the face-shear mode at a resonant frequency determined principally by the dimensions of the crystal faces (or major surfaces) so that each of the above described nine crystals exhibited a tendency to have an unwanted or secondary resonance at a frequency within the range of approximately 140 to 150 kilocycles per second. Since in several instances the amplitude of this second lower frequency "unwanted" or secondary vibration was only approximately 8.5 decibels down from the "wanted" or principal frequency provided by the thickness shear mode of vibration, it became necessary to provide means for further suppressing the unwanted or secondary or face-shear mode of vibration without appreciably damping the principal frequency.

Returning to FIG. 1, member 10 is provided with concentrically positioned, circular, front and rear electrodes 12 and 14 having tab portions 13 and 15, respectively, extending to the right and left edges, respectively, of member 10, as shown.

Wires 16 and 18 may then serve as electrical leads for making electrical connections to tab portions 13 and 15, respectively, and also as mechanical supports for member 10.

The other (or outer) ends of wires 16 and 18 are then rigidly supported by fixed supporting members 20 and 22, respectively, the lengths of wires 16 and 18 being adjusted as indicated above to constitute substantially an odd number of quarter wavelengths of the higher or principal frequency (resulting from vibration in the thickness shear mode) and at the same time to constitute an even number of quarter wavelengths of the lower or unwanted secondary frequency (resulting from vibration in the face-shear mode). By this arrangement the unwanted frequency was suppressed so that its amplitude became 20 or more decibels below that of the wanted principal frequency of vibration.

Members 20 and 22 should, of course, be of sufficient mass and rigidity to reflect substantially all vibration transmitted along the wires 16 and 18 from the member 10. The members 20 and 22 are, further, preferably of electrically conductive material so that connections to an external electrical circuit (not shown) can be more conveniently effected. Adjustment of the lengths of wires 16 and 18 is further facilitated if members 20 and 22 are initially provided with grooves or holes snugly fitting around the extended ends of wires 16 and 18 and are of a material which may be readily swaged or compressed to clamp tightly on wires 16 and 18 at precisely the

correct lengths to satisfy the above-mentioned wavelength relationships.

Although only two support wires are shown in FIGS. 1 and 2, it is entirely feasible with the type of member 10 illustrated to employ three or four support wires equally spaced around the periphery of the member. In accordance with conventional practice in the art, these wires are preferably connected at or near nodal points on the vibrating member (for vibration at the principal frequency) to minimize the transfer of vibration to the wires. A further suppression of a specific unwanted secondary frequency may then be realized by making the lengths of the additional wires such as to suppress the said specific secondary frequency as described at length above.

Alternatively, if several unwanted or secondary frequencies of vibration are encountered, a portion of the total number of wires may be given lengths which will suppress each unwanted or secondary frequency respectively, all wires being further proportioned to avoid suppression or damping of the wanted or principal frequency of vibration.

A further feature of the arrangement of FIG. 1 is the provision of additional wires 24 through 27, inclusive, which are intended as mentioned hereinabove solely for the purpose of increasing the discrimination against particular "unwanted" or secondary frequencies of vibration with respect to the "wanted" or principal frequency. These four wires each have one end only attached to member 10, the other end being free. The length of each of these "discriminator" wires is proportioned to suppress a specific selected unwanted or secondary frequency of vibration while at the same time avoiding any substantial suppression or damping of the wanted or principal frequency of vibration. Several may, of course, be directed to the suppression of one particularly troublesome unwanted secondary frequency or each may be directed to the suppression of a particular different one of several unwanted secondary frequencies by the straightforward application of the principles of the invention as described hereinabove.

In FIG. 2 the vibratory member 10 is shown as supported by downwardly directed vertical wires 16' and 18', which in turn are supported at their lower ends by fixed and rigid supports 20 and 22, respectively, and discriminator wires 26' and 27' are shown as extending vertically upward from member 10. This arrangement is preferable to that of FIG. 1 where encapsulation of the assembly in a container of limited diameter is desired. It has been found to be substantially interchangeable with the arrangement of FIG. 1 where the wires of FIG. 2 having the primed designation numbers have substantially the same lengths as the corresponding wires of FIG. 1 bearing the unprimed designation numbers of like (but unprimed) values, respectively.

The lead and/or discriminator wires of FIGS. 1 and 2 may be attached to member 10 by a "solder cone" or a "headed wire" type of mounting as is well known to those skilled in the art and as is illustrated, for example, in Figs. 8.4 and 8.6 at pages 280 and 282, respectively, of Heising's above-mentioned book. The respective merits and deficiencies of the two types of attachments are discussed in the accompanying pertinent text of Heising's book.

Insofar as it is possible to do so, all wires should be attached, as mentioned above, to the vibrating member at points at or near nodes of its main or wanted principal frequency of vibration and when possible these points of attachment are preferably also chosen so as to be at or near antinodes or "loops" of the unwanted secondary frequency or frequencies of vibration that they are respectively intended to suppress.

One approach toward obtaining a wire length which will not absorb energy at the wanted principal frequency of vibration but will suppress a second unwanted secondary frequency is illustrated by the "activity" charac-

teristics of FIGS. 3 and 4 which were obtained from an AT cut crystal of the general type illustrated in FIG. 1. The "wanted" principal frequency in this specific instance was 792 kilocycles per second, corresponding to vibration in its thickness shear mode, and a troublesome "unwanted" secondary frequency occurred at substantially 150 kilocycles per second, corresponding to vibration in its face-shear mode.

For testing purposes the crystal was electrically connected into a conventional transmission circuit in such manner that an output voltage inversely proportional to the resistance (dissipation), that is, directly proportional to the "activity" of the crystal assembly was obtained.

One lead (and supporting) wire was fixed at a length at which the resistance of the crystal assembly was substantially a minimum and the length of the other lead (and supporting) wire was changed by small increments from a length of approximately one millimeter to a length of substantially six millimeters. Readings of the voltage at the output of the transmission circuit were taken for each wire length, successive runs being made with the crystal first being driven at the principal or wanted frequency of 792 kilocycles per second (FIG. 3) and then at a secondary or unwanted frequency of 150 kilocycles per second (FIG. 4), respectively, for each length.

The results of the run at the higher frequency are shown as indicated above as curve 300 of FIG. 3 and those at the lower frequency are shown as curve 400 of FIG. 4.

Lengths at which the resistance (and energy dissipation) were high are indicated in both curves by the sharp drops in voltage (output). Thus for the higher frequency, wire lengths in millimeters of 1.35, 1.90, 2.5, 3.05, 3.60, 4.20, 4.85, et cetera, produced sharp voltage drops indicating substantial energy absorption by the mounting arrangement. Similarly, for the lower frequency, wire lengths in millimeters of 0.85, 0.95, 1.55, 1.70, 3.00, 4.30, 5.65, et cetera, produced sharp voltage drops.

It is thus apparent that by superimposing the curve of FIG. 3 on that of FIG. 4 suitable wire lengths would be those which are not too near the sharp dips of curve 300 but correspond quite closely to pronounced dips of curve 400. For example, wire lengths of 1.70 and 5.65 millimeters would not damp the higher frequency of vibration but would suppress the lower frequency. Incidentally, it should be noted that a wire length of 3.00 millimeters both frequencies would be strongly damped, so that although the unwanted frequency is strongly damped such a length is unsuitable because it also strongly damps the wanted frequency.

A second approach to the problem is to calculate for each wire length the frequencies which will be suppressed and construct graphs or charts correlating the data thus obtained.

It turns out that when plotted on graph paper using logarithmic scales for both the abscissae (wire lengths) and the ordinates (frequency), the graphs are found to be inclined, substantially straight, lines as shown in FIGS. 5, 6, 7 and 8, inclusive. These are graphs obtained as indicated above, for tinned and headed Phosphor bronze wires having diameters in thousandths of an inch of 3.5, 6, 8 and 10, respectively. Each of the several lines of each graph are labeled with a value of n which indicates the number of half wave or π phase points represented by that line.

The calculation of these graphs is based on the formula designated (8.1) on page 279 of Heising's above-mentioned book, namely;

$$f = \frac{m^2 dv}{8\pi l^2} \quad (1)$$

where

f is the resonant frequency of the wire;

v is the velocity of the energy in the wire in centimeters per second;

d is the diameter of the wire in centimeters;

l is the length of the wire in centimeters;

m is $(n-k)\pi$;

n is the number of half wave or π phase points; and

k is a factor having a value between $\frac{1}{4}$ and $\frac{1}{2}$ which value depends upon whether the "free" end (that is, the end attached to the crystal) is entirely free or is restricted to zero slope.

From the Formula 1 above we obtain for the length l at which the wire is resonant the expression

$$l = (n-k)\pi \sqrt{\frac{dv}{8\pi f}} \text{ centimeter} \quad (2)$$

For maximum suppression (that is, antiresonance) we may therefore write

$$l = (n+k)\pi \sqrt{\frac{dv}{8\pi f}} \text{ centimeter} \quad (3)$$

A reasonably precise value of k may be obtained by the insertion in the above formulae of experimental data such, for example, as that represented by curves 300 and 400 of FIGS. 3 and 4, and for "headed" wires it was found that a value of substantially 0.28 produced good agreement between computed and observed absorption lengths.

As an example of the use of the charts of FIGS. 5 through 8 inclusive, an AT cut crystal of the general type illustrated in FIG. 1 was designed to vibrate in the thickness shear mode at a frequency of 744 kilocycles per second (the wanted or principal frequency) and was found to also vibrate in the face-shear mode at a frequency of 145.4 kilocycles per second (an unwanted or secondary frequency).

Since lead and supported wires of 8 mil inch diameter were being employed, the chart of FIG. 7 is selected and it is found that wire lengths in millimeters of 1.69, 3.05, 4.40 and 5.65 (points A, B, C and D, respectively) will all suppress the lower frequency of 145.4 kilocycles per second.

Drawing vertical lines from each of points A, B, C and D to the horizontal line representing the higher frequency of 744 kilocycles per second (that is, to points E, F, G and H, respectively) however, it is found that the wire length 3.05 millimeters (points B and F) will also suppress the higher frequency and hence is not suitable for use in this instance. Furthermore, the wire length 4.40 millimeters at point G is so close to the $n=7$ suppression line that its use is not to be recommended since reasonable manufacturing tolerances would be precluded.

Accordingly, wire lengths of either 1.69 or 5.65 millimeters may be employed. It should further be noted that for the length 1.69 millimeters the wires would also suppress the frequency 475 kilocycles per second (point I) and for the length 5.65 millimeters the wires would also suppress the frequencies 685, 535, 410, 310, 240, 89, 43.5, and 13.2 kilocycles per second (points J, K, L, M, N, P, Q and R, respectively). From this it is apparent that in appropriate circumstances a single wire length may be employed to suppress several troublesome frequencies while not damping the vibrations at the wanted frequency.

The above is applicable to supporting wires some or all of which may also serve as electrical lead wires making electrical connections to the electrodes of the vibrating member.

Since the discriminator members or wires, such as wires 24 through 27, inclusive, of FIG. 1 are attached to nothing at their outermost ends, the lengths corresponding to maximum suppression of a specific frequency) are at points midway between successive lines $n=1$, $n=2$, et cetera, at the specific frequency. Lengths corresponding to minimum damping of a second specific frequency for such "discriminator" members are points on or near one

of the inclined lines $n=1$, $n=2$, et cetera, at the second specific frequency.

As a specific example, assuming again an AT cut crystal as in the above described example, a wire diameter of 8 mils, a wanted or principal frequency of 744 kilocycles per second and an unwanted or secondary frequency of 145.4 kilocycles per second, then at a discriminator wire length of 3.7 millimeters, point S of FIG. 7, being at 145.4 kilocycles per second midway between lines $n=2$ and $n=3$ will suppress the last mentioned frequency. Extending a vertical line from point S to the wanted frequency 744 kilocycles per second, it is found that point T is closely adjacent to line $n=6$. Accordingly, discriminator wires of 3.7 millimeters in length will suppress the lower frequency (145.4 kilocycles per second) without substantially damping the higher frequency (744 kilocycles per second).

Numerous and varied modifications and rearrangements of the specific illustrative embodiments described and discussed hereinabove can readily be devised by those skilled in the art without departing from the spirit and scope of the invention disclosed. Accordingly, it is to be understood that the invention is illustrated but in no way restricted by the above disclosure.

What is claimed is:

1. A piezoelectric device comprising a piezoelectric crystal adapted for resonance at a given principal frequency and which also exhibits at least one significant resonance at an unwanted frequency, at least one resilient support member for supporting at least a portion of said crystal at the periphery, the length of said resilient support member being substantially an odd number of quarter wavelengths of said principal frequency, and an even number of quarter wavelengths of said unwanted frequency.

2. A device of claim 1 in which the crystal exhibits more than one significant resonance at an unwanted frequency and includes more than one resilient support member of which two have different lengths respectively cor-

responding to an even number of quarter wavelengths of different unwanted frequencies so that the overall structure suppresses more than one unwanted frequency.

3. A piezoelectric device comprising a piezoelectric crystal adapted for resonance at a given principal frequency and which also exhibits at least one significant resonance at an unwanted frequency, support means for supporting said crystal, the improvement comprising at least one resilient elongated member having one end attached to said crystal at the periphery and being independent of the support means for suppressing said unwanted frequency, said resilient member having a length substantially equal to an even number of quarter wavelengths of said unwanted frequency.

4. The device of claim 3 having more than one resilient member.

5. The device of claim 4 in which at least two of the resilient members have different lengths corresponding to an even number of wavelengths of different unwanted frequencies so that the structure suppresses more than one unwanted frequency.

6. The device of claim 3 in which the crystal and the resilient member resonate in different modes.

References Cited by the Examiner

UNITED STATES PATENTS

2,392,429	1/1946	Sykes	333—72
2,441,139	5/1948	Fair	310—8.2
2,546,321	3/1951	Ruggles	310—8.2
3,069,572	12/1962	Dick	310—8.2
3,091,708	5/1963	Harris	310—8.3
3,114,848	12/1963	Kritz	310—8.3

FOREIGN PATENTS

414,764	8/1935	Great Britain.
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MILTON O. HIRSHFIELD, *Primary Examiner*.

J. D. MILLER, *Assistant Examiner*.