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CRYSTAL HARMONIC OSCILLATOR

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Fig. 1

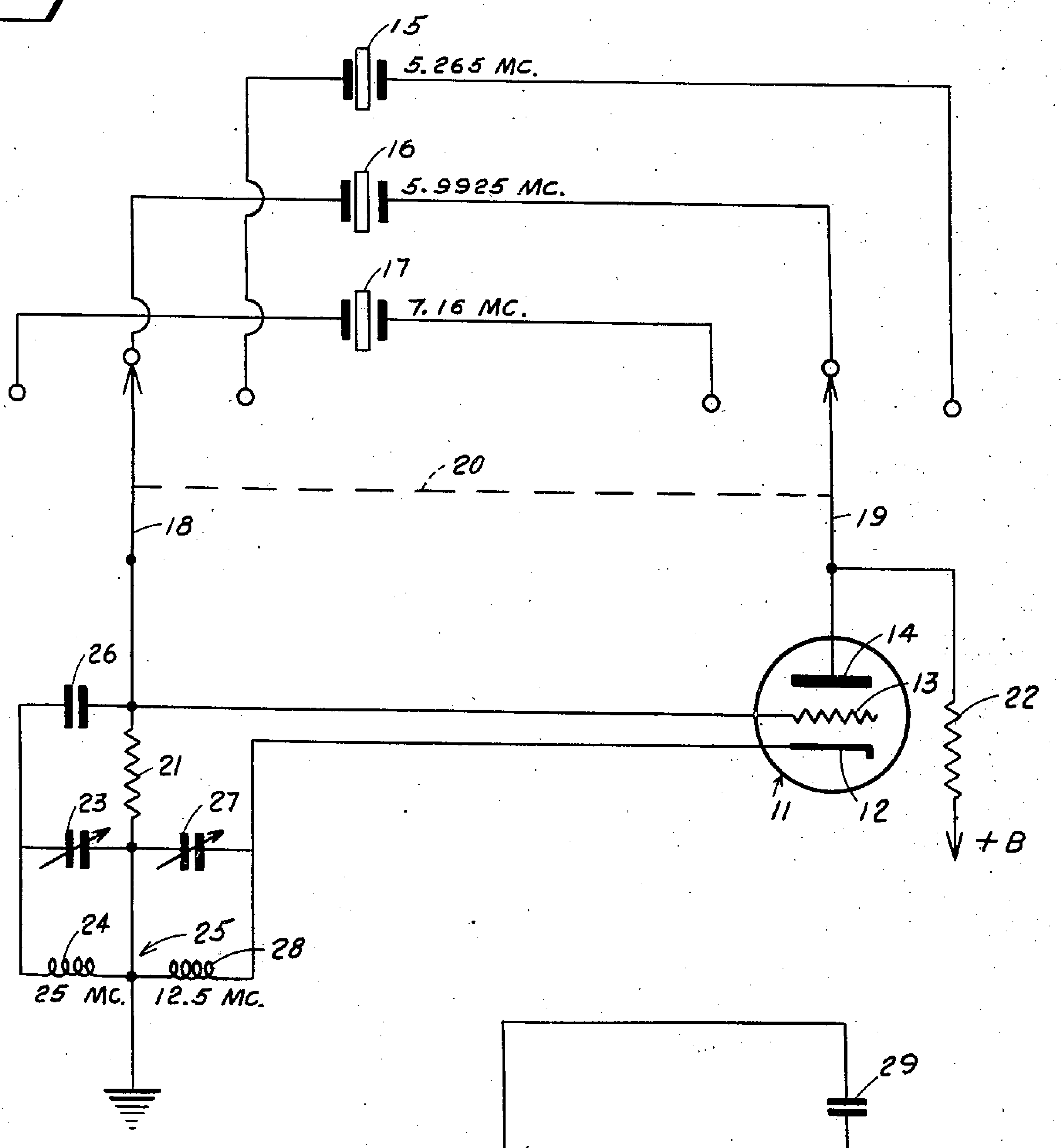
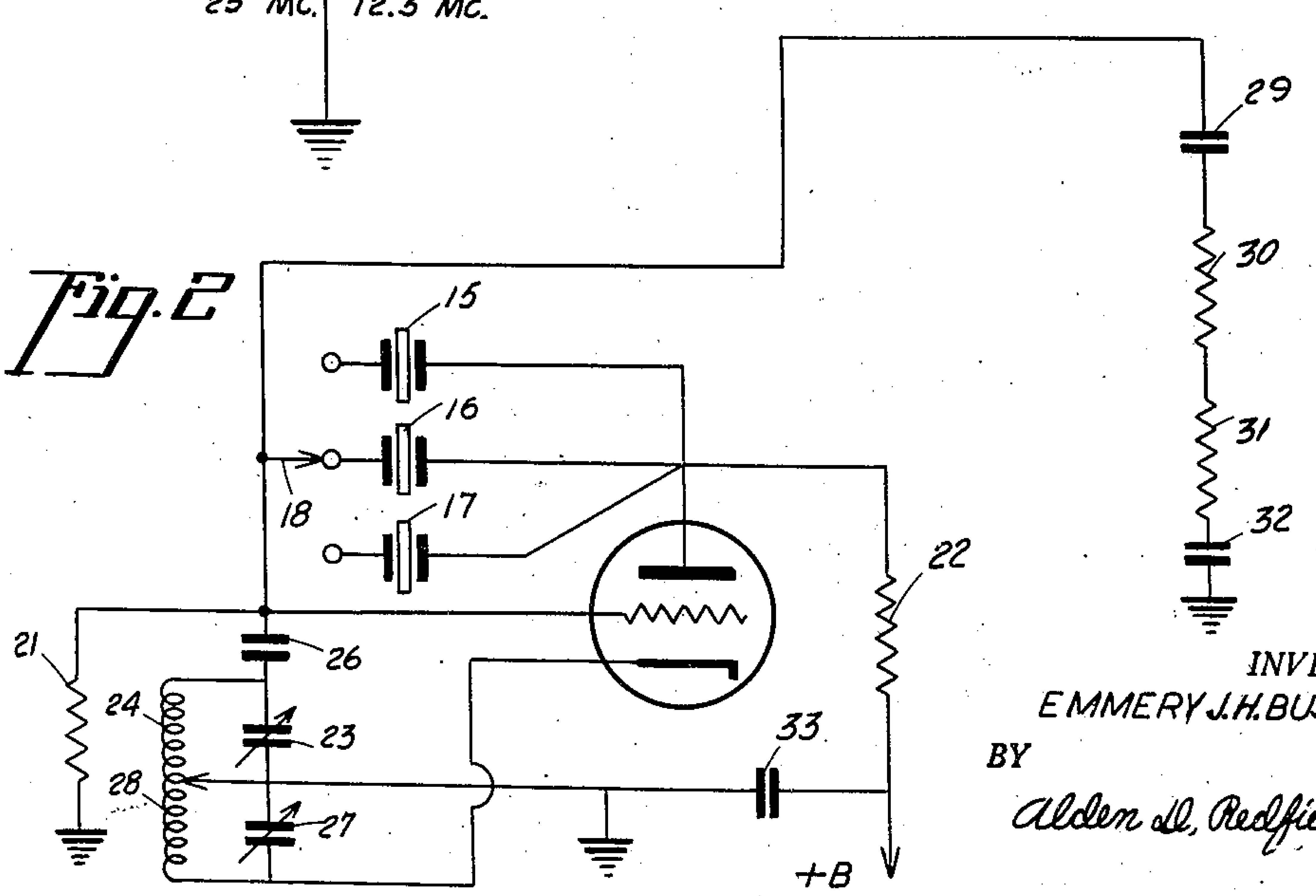


Fig. 2



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CRYSTAL HARMONIC OSCILLATOR

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The present invention relates to radio-frequency oscillators and specifically to a novel crystal-controlled circuit with which any one of a plurality of piezoelectric crystals of different fundamental frequencies may be associated, and which generates harmonic-mode oscillations over an extremely wide band of frequencies. This band has a width equal to the product of an integer representing the order of the harmonics involved and the difference between the fundamental frequencies of the lowest-frequency and highest-frequency crystals involved.

Preset tuning circuits operated by pressing push-buttons or the like have met with widespread popularity. Such preset circuits are presently regarded as representing the best solution to FM tuning problems. This solution requires the prevention of wide oscillator drift by crystal control. It has been suggested that there be provided an FM R. F. input system for incorporation in a double superheterodyne receiver. This system comprises an antenna input circuit having a pass-band from 87.9 to 107.7 megacycles in range, coupled to an oscillator-modulator frequency changer. The first I. F. frequency is variable within the range 72.1 to 73.9 megacycles. These specifications require a crystal-controlled oscillator system which is tunable in steps from 15.8 to 33.8 megacycles. Although this is a typical example, it is but one of many requirements for a crystal-controlled oscillator system which is tunable in steps through a very wide range.

The prior art contemplates that each separate channel or step requires another crystal "tailor-made" for switching into operation in order to produce the desired intermediate frequency. It also contemplates that the same crystal be operated in fundamental and harmonic modes, associated tuning circuits then being switched. However, the last-mentioned expedient is of no utility when the difference between fundamental and harmonic, or between successive-order harmonics, is large with respect to the frequency-difference between steps. Further, at the high frequencies under discussion, harmonic-cut crystals designed for optimum operation on the odd harmonics must be used. When a harmonic-cut crystal is employed, a selective tuned circuit must be provided in the oscillator in order to discriminate against the fundamental frequency or undesired harmonics. Therefore, at such high frequency ranges the prior art suffers not only from the limitation that it requires a separate crystal for each step, but also from the limitation that it further requires separate selective circuits

associated with each individual crystal. The significance of this is that step-by-step tuning with harmonic-mode crystal control has heretofore been understood to require separate complete crystal oscillators or at least separate tuned circuits for each step.

For purposes of illustration, the following description of the present invention shows how one oscillator circuit can be made to cover a 5.68 megacycle range, for example, in three steps. That is, oscillations are produced in steps from 15.8 to 21.48 megacycles by simply switching different harmonic-cut crystals into the same oscillator circuit. There is disclosed a single oscillator circuit which has the ability to provide optimum odd order harmonic operation of a plurality of crystals having different fundamental frequencies. A wide range of oscillation frequencies can be covered by a plurality of harmonic-cut crystals without the necessity of providing and switching in a plurality of selective tuned circuits. The principles of this circuit are not limited to the specific parameters and ranges herein mentioned.

The primary object of this invention is to provide a single oscillator circuit which operates on the harmonic mode for crystals of different fundamental frequencies.

Another object of the invention is to provide a single odd-harmonic mode crystal controlled circuit having a plate-grid crystal feedback circuit, means for discriminating against feedback at the fundamental frequencies of the crystals to be employed, a grid-ground circuit tuned to resonate at a frequency slightly above the largest harmonic to be generated by one of a plurality of crystals, and a cathode-ground circuit tuned to resonate at a frequency slightly below the smallest harmonic to be generated, said circuits being adjusted for optimum operation for the desired harmonic order at substantially the center of the frequency range to be covered, whereby switching into said oscillator of crystals having harmonics of that order within that range adjusts said oscillator in steps within that range.

For a better understanding of the present invention, together with other and further objects, advantages, and capabilities thereof, reference is made to following description of the accompanying drawing. Fig. 1 is a circuit diagram of an illustrative preferred form of crystal oscillator in accordance with the invention; Fig. 2 is a modified form of crystal harmonic oscillator in accordance with the invention.

In Fig. 1 there is shown a triode tube 11 having a cathode 12, control electrode 13, and an anode 14. Any one of a plurality of suitably mounted crystal 15, 16, 17 may be switched between grid and plate by the action of a selector switch comprising two contact arms 18, 19, ganged as by any suitable mechanical expedient indicated by the dashed line 20. Between grid and cathode is provided a grid-bias resistor 21. The anode is connected to a source of space current (indicated by +B) through a resistor 22.

The specific elements so far described are similar in arrangement to the well-known Pierce oscillator, shown in U. S. Patent 2,133,642, a crystal feedback circuit being provided between anode and grid. The basic Pierce oscillator, however, is not suitable for use with harmonic-cut crystals, the only tuned element in the oscillator circuit being the crystal itself. When a harmonic-cut crystal is employed, an additional selective tuned circuit must be provided in order to discriminate against the fundamental frequency or undesired harmonics.

By grinding a crystal specially for harmonic operation, it is possible to enhance its operation as a harmonic oscillator, and BT and AT cut crystals designed for optimum operation on the 3rd, 5th, and 7th harmonics are available. On the illustrative embodiment herein shown, AT cut 3rd harmonic crystals are employed. For 3rd harmonics between 1.5 and 18 megacycles, the AT cut crystal is generally employed. Between 18 megacycles and 36 megacycles the BT cut crystal may be employed, but the AT cut is preferred in the ranges covered by the illustrative embodiment herein described.

It is understood in the art that each crystal herein discussed, together with its mounting, has the characteristics of a series resonant circuit with a very high L/C ratio and Q at the working frequencies herein discussed. Because of the shunt capacitance of the mounting electrodes and associated wiring, the crystal also is capable of anti-resonant operation, but that characteristic is not herein exploited, the series resonant characteristic being employed when the crystal functions as a selective feedback element in such a manner that the phase of the feedback is correct and the amplitude adequate only at or very close to the series resonant working frequency of the crystal. Harmonic-cut crystals used with conventional mountings are excited only on odd harmonics. It will be understood that the harmonic frequency for which each crystal herein shown is designed is the working frequency, such crystal actually oscillating at that frequency.

In accordance with the invention there is provided a single crystal-controlled oscillator, adapted to produce harmonic operation of any one of a plurality of crystals designed for different frequencies. For example, an oscillator with the illustrative parameters herein mentioned covers a range from 15.8 megacycles to 21.48 megacycles by effecting 3rd harmonic operation of any selected one of the three crystals 15, 16, and 17, the fundamental frequencies of which are, respectively, 5.265, 5.9925, and 7.16 megacycles.

This oscillator includes a grid-tank circuit comprising a parallel combination of variable capacitor 23 and portion 24 of inductance 25. This tank circuit is tuned to a frequency slightly above the maximum frequency of the harmonic range to be covered, i. e., 25 megacycles for a range of 15.8 to 21.48 megacycles, so that it is inductive throughout that range. It will be noted that this particular circuit is tuned to a frequency below

the 5th harmonic of crystal 15 and strongly discriminates against higher-order harmonics of each of the crystals. Between the junction of the grid resistor 21 and this tank circuit is interposed a grid capacitor 26.

The oscillator also includes a cathode tank circuit comprising a parallel combination of a variable capacitor 27 and portion 28 of inductance 25. The low potential side of resistor 21, the junction of capacitors 23 and 27, and the tap between portions 24 and 28 of coil 28 are grounded. The cathode tank circuit is tuned to a frequency slightly below the minimum frequency of the harmonic range to be covered, i. e., 12.5 megacycles for the above-mentioned illustrative range, so that it is capacitive throughout that range. This frequency is above the "first harmonic" or fundamental of the highest frequency crystal employed, i. e., the 7.16 megacycle frequency crystal, so that this specific grid tank circuit discriminates against the fundamental frequencies of each of the crystals.

The harmonic oscillator includes means for preventing crystal feedback at the fundamental frequencies of the crystals 15, 16 and 17, and for discriminating against those fundamental frequencies. Specifically, this means comprises elements 26, a capacitor, and 24, an inductance, tuned to series resonance at or near the average frequency of the three fundamentals. This discriminating means effectively short-circuits the grid-cathode input at the fundamental frequencies and therefore discriminates against crystal feedback at those frequencies. Any suitable expedient for accomplishing this result may be employed. In the interest of economy, I have chosen the elements 26 and 24 for the performance of this function. It will be understood that element 26 also functions as a grid capacitor, and that element 24 also functions as a grid circuit tank inductor.

It will be seen that the grid tank circuit is inductively reactive throughout the desired output frequency range. The cathode tank circuit is capacitively reactive throughout the desired output frequency range.

The embodiment of the invention illustrated in Fig. 2 is essentially the same as that shown in Fig. 1, except that only one side of the crystal mountings is switched into circuit when the various crystals are selected. The other sides of the crystal mountings are always in circuit, effectively providing a capacitance between plate and ground. I have found that this capacitance is not objectionable. The parameters and data mentioned herein were obtained with a circuit conforming to Fig. 2. In that circuit there was provided a dummy load network simulating a converter and the coupling network between the harmonic oscillator and the converter. This coupling network comprises capacitor 29, resistor 30, resistor 31, and capacitor 32.

While I do not desire to be limited to any specific circuit parameters, particularly favorable results were obtained in a successful reduction to practice involving the following parameters:

Fundamental frequencies of the crystals: 5.265, 5.9925, and 7.16 megacycles, respectively, for crystals 15, 16, 17

Corresponding range of output working frequencies: 15.8, 17.975, and 21.48 magacycles, respectively, for crystals 15, 16, 17

Plate voltage source: 300 volts

Plate current: .75 milliampere

I in dummy load: 84, 36, and 80 milliamperes for crystals **15**, **16**, **17**
Corresponding values of grid current: 44, 32, 42 milliamperes
Resistor **21**: 82,000 ohms
Resistor **22**: 125,000 ohms
Tube **11**: 6SQ7 or any suitable triode
Capacitor **23**: Appropriate to tune the grid tank to 25 magacycles
Inductor **24**: 4.18 microhenries and 4.5 micromicrofarads distributed capacity
Capacitor **27**: Appropriate to tune the cathode tank to 12.5 magacycles
Inductor **28**: 7.8 microhenries and 2.8 micromicrofarads distributed capacity
Cut of crystals: AT
Q of **24** and **28**: 120 to 150
L_M between **24** and **28**: 1.06 microhenries
Coefficient of coupling k between **24**, **25**: 18.5%
Tuning of **23**, **24**: Resonant at 25 magacycles
Tuning of **27**, **28**: Resonant at 12.5 magacycles
Width of output frequency range covered: 5.68 megacycles
Capacitor **26**: 62 micromicrofarads
Capacitor **33**: 0.001 microfarad
Capacitor **29**: 4 micromicrofarads
Capacitor **32**: 120 micromicrofarads
Resistor **30**: 68 ohms
Resistor **31**: 330 ohms

The inductors **24** and **28** were wound on a form having a diameter of one-half inch, with a pitch of 52. Inductor **24** comprised 25.5 turns, and inductor **28** comprised 29.5 turns. $L_1+L_2+L_M$ was equal to 14.1 microhenries, with 1.2 micromicrofarads distributed capacitance.

It will be observed that an extremely broad frequency range is covered by successively switching crystals **15**, **16**, and **17** into circuit with the single common tube **11** and associated single network system.

The utility of the present invention is not, of course, dependent upon the existence or nonexistence of theories, whether accurate or inaccurate, to account for the observed phenomena. It is sufficient to describe and illustrate the invention as it has been found to work in practice. A tenable theory of operation is, however, as follows: The networks **23**, **24**, and **28**, **27**, being coupled by the fact that inductors **24** and **28** are portions of the same coil **28**, and being located in the grid-input and cathode-output circuits, respectively, cooperate with any of the crystals **15**, **16**, **17** in such a way that the feedback and phase shift conditions between output and input are correct to sustain third harmonic oscillations over a wide band extending, in this particular example, from 15.8 to 21.48 megacycles, and to discriminate against fundamental and fifth order harmonic oscillations of any of the crystals. It is known that detuning of two coupled tuned circuits away from a common frequency has the same effect on the secondary response curve as an increase in coupling in the case of circuits tuned to the same frequency, whereby a double-humped wide-band response curve is obtained and uniform relative phase conditions over a wide band are achieved. The means for discriminating against crystal feedback at the fundamental frequencies has already been described as to construction and operation. In setting up the circuit, a crystal such as **16** having a harmonic oscillation (3rd, for example) near the center of the desired range is switched in, and the tuned circuits are adjusted for optimum operation. The other crystals **15**, **17** are switched in and measured without further circuit adjustment.

The teachings of this invention may be applied to fifth and seventh harmonic operation, and the invention is not confined to the particular parameters herein disclosed.

While there has been shown and described what is at present regarded as the preferred embodiment of the present invention, it will be obvious to those skilled in the art that various modifications and substitutions of equivalents may be made therein without departing from the invention as defined by the appended claims.

Having fully disclosed and described my invention, I claim:

1. A crystal oscillator comprising an electron tube having anode, control and cathode electrodes, a feedback crystal circuit including an odd-harmonic mode crystal and means for coupling it between said anode and grid electrodes, an inductively reactive tank circuit coupled to said control electrode and fixed-tuned to resonate above the output frequency of said crystal, a capacitively reactive tank circuit coupled to said cathode and fixed-tuned to resonate below the output frequency of said crystal, and means for discriminating against crystal feedback at fundamental frequencies.

2. A harmonic-mode crystal oscillator in accordance with claim 1 in which each of said tank circuits includes a portion of a common inductance.

3. A harmonic-mode crystal oscillator in accordance with claim 2 and control electrode biasing means, including a resistor coupled between said control electrode and the junction of said inductance portions and a capacitor interposed between said control electrode and its associated tank circuit, said capacitor and the grid tank inductor portion functioning as a series resonant circuit at fundamental frequencies effectively to short-circuit the grid-cathode input circuit so far as the fundamental frequency feedback is concerned.

4. An odd-order harmonic mode crystal oscillator for generating frequencies of a given order throughout a wide range, on incorporation therein of any one of a plurality of crystals having different fundamental frequencies, said range being equal to the product of an integer representing the harmonic order and the difference between the lowest and highest fundamentals of said crystals, comprising an electron tube having anode, grid and cathode electrodes, selective means for incorporating as a feedback network between anode and grid any one of said crystals, a grid tank circuit that is inductively reactive throughout said wide range and fixed-tuned to a frequency above said odd-order harmonic of the highest-frequency crystal but is capacitively reactive to higher-order harmonics of the lowest frequency one of said crystals, a cathode tank circuit coupled to said grid tank circuit and capacitively reactive throughout said wide range and fixed-tuned to a frequency below said odd-order harmonic of the lowest-frequency crystal but inductively reactive to lower-order harmonics of the highest frequency one of said crystals, said wide band being centered approximately halfway between the resonant frequencies of said tank circuits, and means for preventing crystal feedback at the fundamental frequencies of said crystals.

5. A third order harmonic mode crystal oscillator for generating frequencies of a given order

throughout a wide range, on incorporation therein of any one of a plurality of crystals having different fundamental frequencies, said range being equal to three times the difference between the lowest and highest fundamentals of said crystals, comprising an electron tube having anode, grid and cathode electrodes, selective means for incorporating as a feedback network between anode and grid any one of said crystals, means for biasing said anode and grid electrodes, a grid tank circuit that is inductively reactive throughout said wide range and fixed-tuned to a frequency above the third harmonic of the highest-frequency crystal, a cathode tank circuit coupled to said grid tank circuit and capacitively reactive throughout said wide range, said cathode tank circuit being fixed-tuned to a frequency below the third harmonic of the lowest-frequency crystal, said wide band being centered approximately half-way between the resonant frequencies of said tank circuits, and means for preventing crystal feedback at the fundamental frequencies of said crystals.

6. An odd-order harmonic mode crystal oscillator for generating frequencies of a given order throughout a wide range, on incorporation therein of any one of a plurality of crystals having different fundamental frequencies, said range being equal to the product of an integer representing the harmonic order and the difference between the lowest and highest fundamentals of said crystals, comprising an electron tube having anode, grid and cathode electrodes, selective means for incorporating as a feedback network between anode and grid any one of said crystals, means for biasing said anode and grid electrodes, a grid tank circuit comprising inductance and capacitance that is inductively reactive throughout said wide range and fixed-tuned to a frequency above said odd-order harmonic of the highest-frequency crystal but is capacitively reactive to higher-order harmonics of the lowest frequency one of said crystals, a cathode tank circuit comprising inductance and capacitance coupled to said grid tank circuit and capacitively reactive throughout said wide range but inductively reactive to lower-order harmonics of the highest frequency one of said crystals, said cathode tank circuit being fixed-tuned to a frequency below said odd-order harmonic of the lowest-

frequency crystal, said inductances being portions of a common coil, said wide band being centered approximately half-way between the resonant frequencies of said tank circuits, and means for preventing crystal feedback at the fundamental frequencies of said crystals.

7. An odd-order harmonic mode crystal oscillator for generating frequencies of a given order throughout a wide range, on incorporation therein of any one of a plurality of crystals having different fundamental frequencies, said range being equal to the product of an integer representing the harmonic order and the difference between the lowest and highest fundamentals of said crystals, comprising an electron tube having anode, grid and cathode electrodes, switch means for incorporating as a feedback network between anode and grid any one of said crystals, resistance-capacitance means for biasing said grid electrode, a grid LC tank circuit that is inductively reactive throughout said wide range and fixed-tuned to a frequency above said odd-order harmonic of the highest-frequency crystal but is capacitively reactive to higher-order harmonics of the lowest frequency one of said crystals, and a cathode LC tank circuit coupled to said grid tank circuit and capacitively reactive throughout said wide range but inductively reactive to lower-order harmonics of the highest frequency one of said crystals, said cathode tank circuit being fixed-tuned to a frequency below said odd-order harmonic of the lowest-frequency crystal, said wide band being centered approximately half-way between the resonant frequencies of said tank circuits, the inductances being included in a common coil and having their junction connected to the low-potential side of said grid resistor, and means included in the grid biasing means and grid tank circuit for discriminating against fundamental crystal feedback.

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