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R. C. RENNICK ET AL

3,756,851

METHOD FOR AUTOMATICALLY ADJUSTING THE FREQUENCY
OF MONOLITHIC CRYSTAL FILTERS

Filed Oct. 8, 1971

4 Sheets-Sheet 1

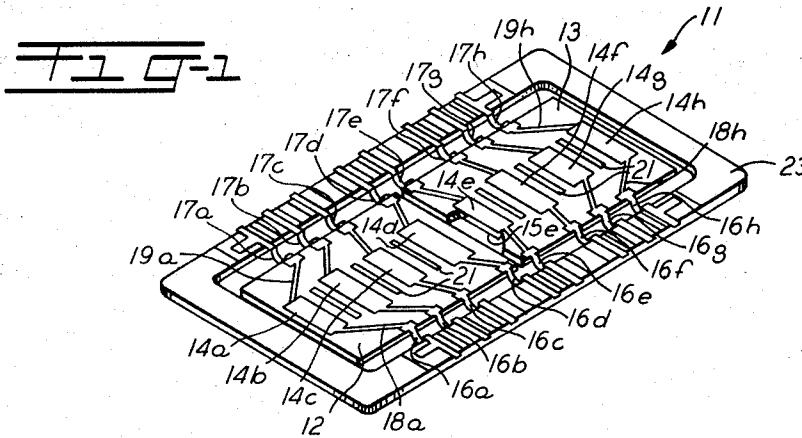
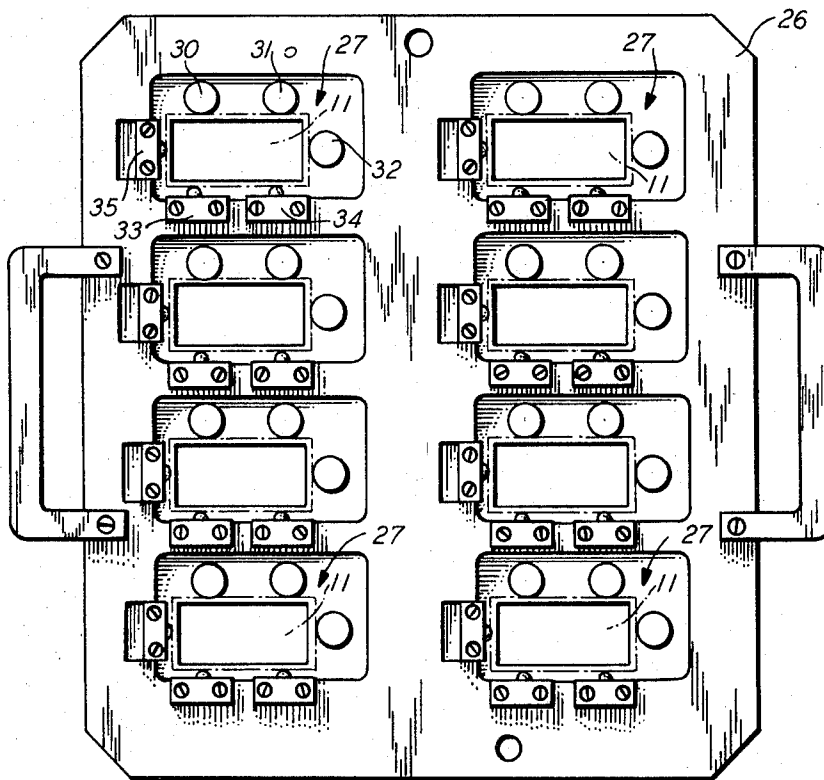


FIG-2

INVENTORS
W. C. MORSE
R. C. RENNICK

BY D. W. Marks
ATTORNEY

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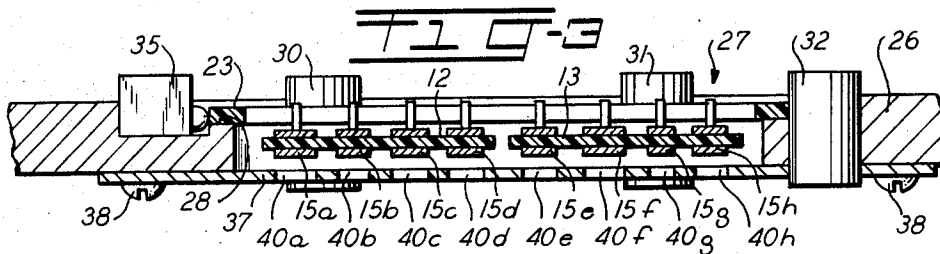
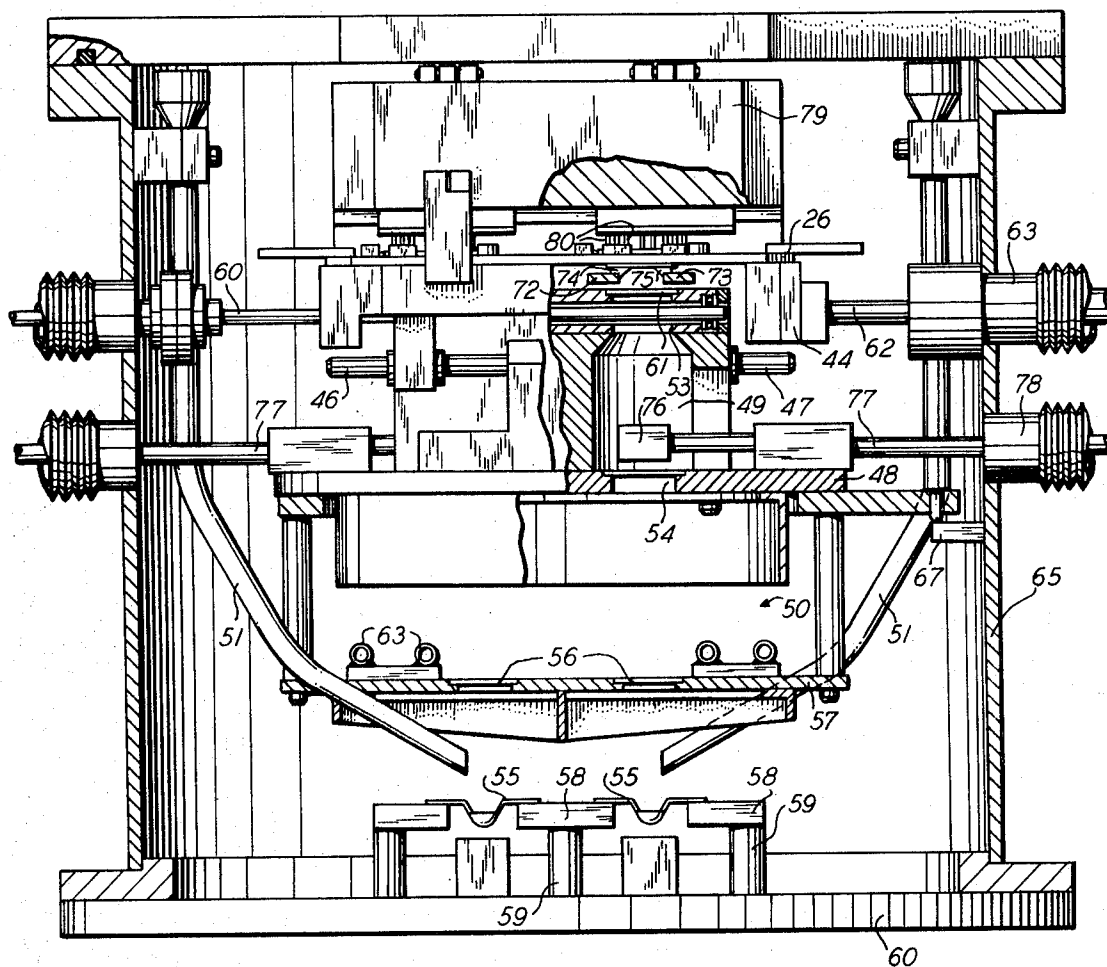


FIG-4

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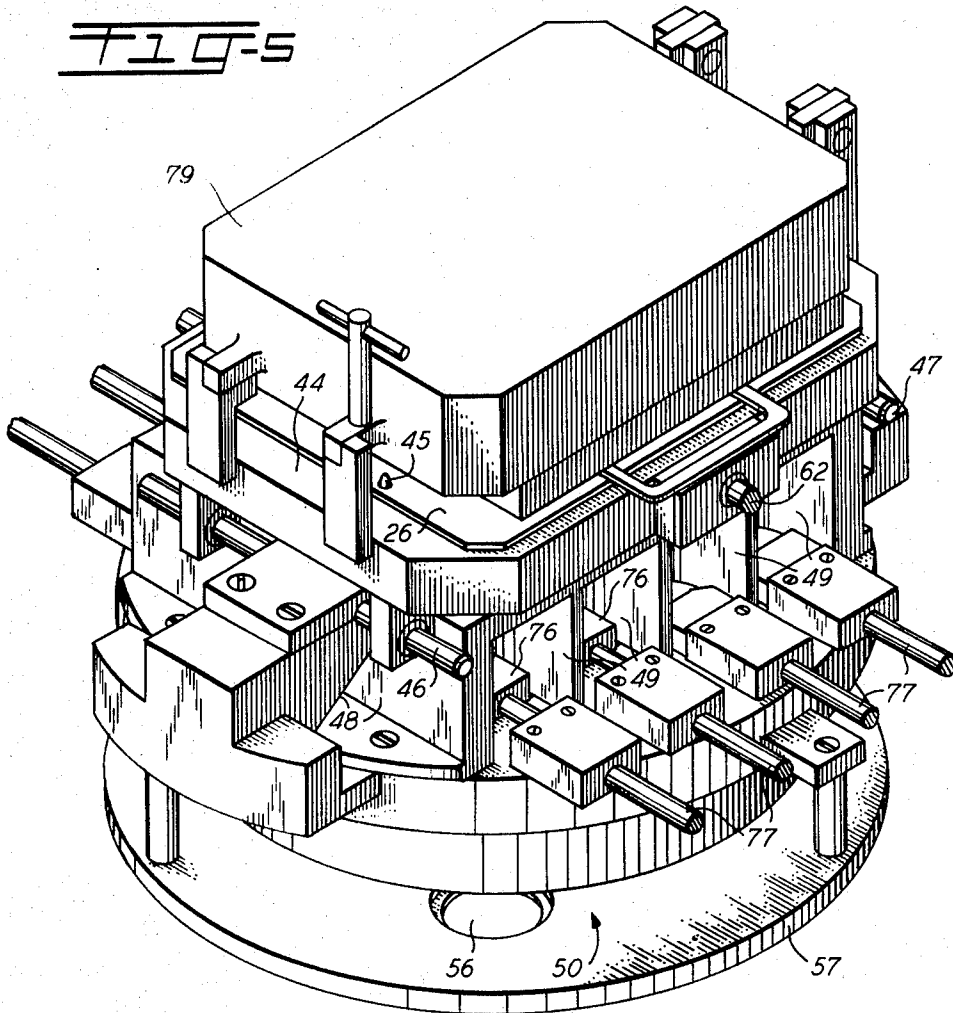
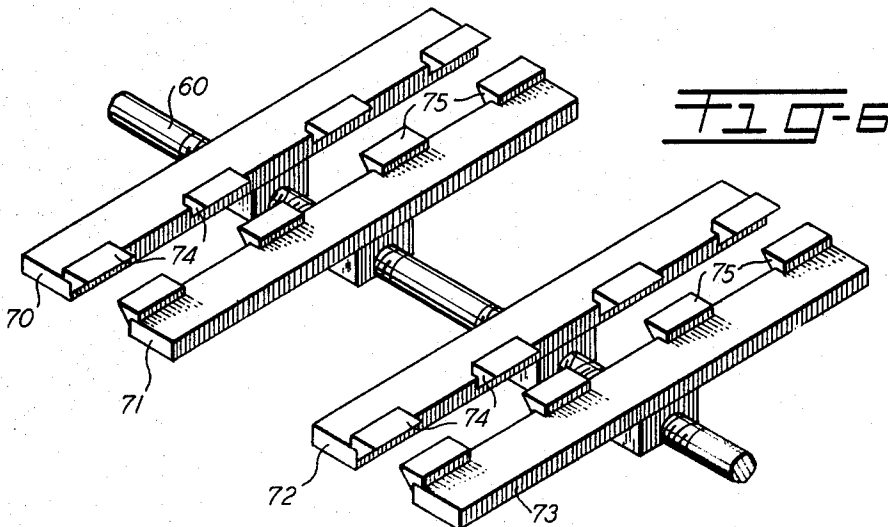
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FIG-5



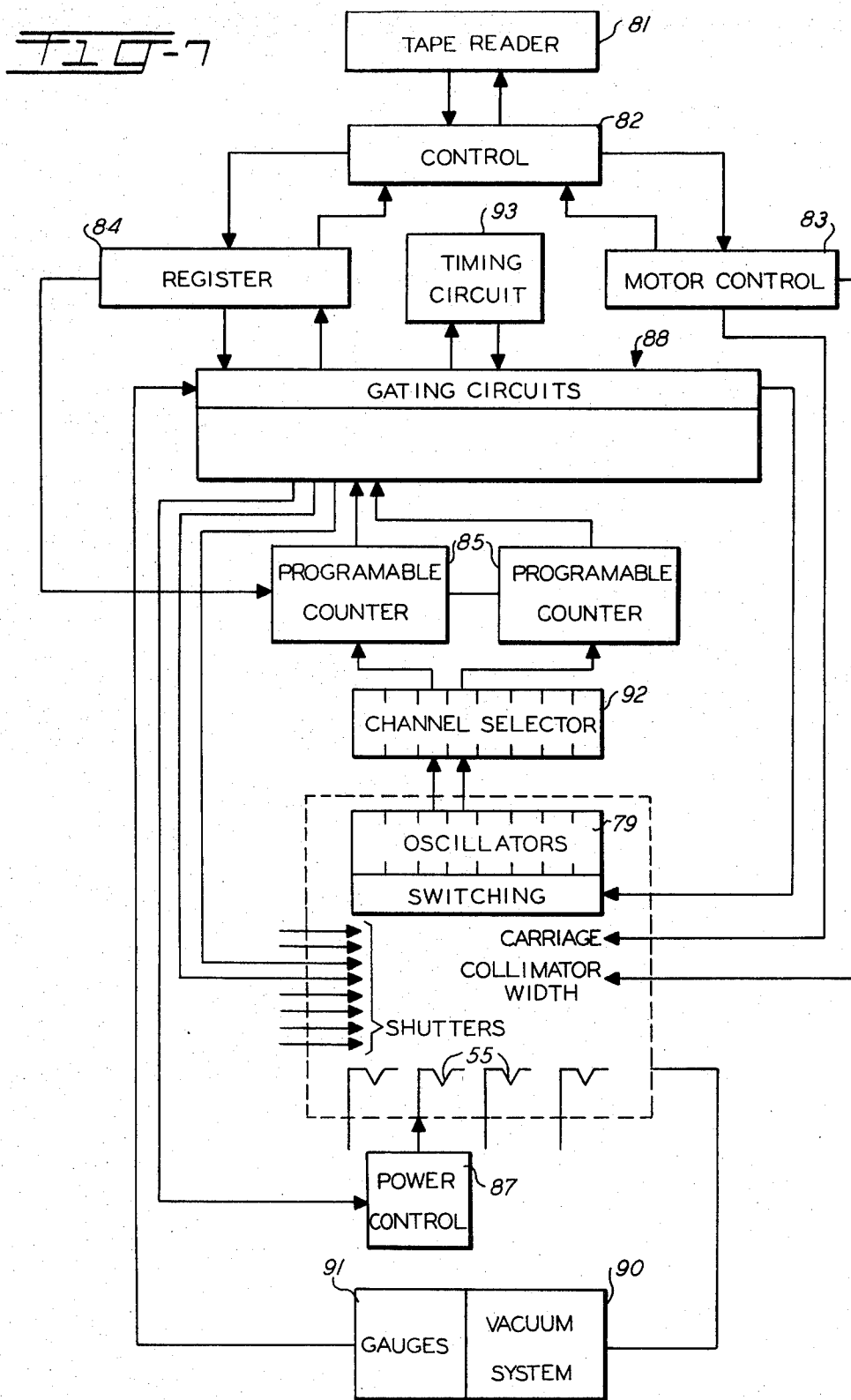
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3,756,851

METHOD FOR AUTOMATICALLY ADJUSTING THE FREQUENCY OF MONOLITHIC CRYSTAL FILTERS

Robert C. Rennick, Center Valley, Pa., and William C. Morse, Newbury, Mass., assignors to Bell Telephone Laboratories, Incorporated, Murray Hill, N.J., and Western Electric Company, Incorporated, New York, N.Y.

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7 Claims

ABSTRACT OF THE DISCLOSURE

Individual resonators on each of a plurality of monolithic crystal filters are adjusted to respective predetermined frequencies. An electrode of a selected resonator on each filter is positioned in the respective path of a substantially non-divergent stream of metal vapor. Each selected resonator, in turn, is excited and its resonant frequency is monitored to interrupt the respective vapor stream when a predetermined value is reached. An electrode of another selected resonator on each filter is positioned in a respective vapor stream and the frequency monitoring facilities are changed to sense a different predetermined value. The width of the vapor streams may be changed to accommodate different widths of electrodes and the density of the vapor stream may be reduced when the resonant frequency approaches the predetermined value. Also, timing facilities advance the cycle if a resonator fails to reach the predetermined value within a predetermined duration. After all the resonators are first adjusted to value, the steps of adjusting are again repeated to change the resonators to still different predetermined values.

BACKGROUND OF THE INVENTION

(1) Field of the invention

A monolithic crystal filter has a crystal plate, such as quartz, with a plurality of resonators which in combination operate as a bandpass filter. The frequency response of the bandpass filter is dependent upon the individual resonant frequency of each of the resonators on the filter. This invention relates to a method and apparatus for adjusting the individual resonators to predetermined resonant values.

(2) Description of the prior art

A crystal having a single resonator on a crystal plate is commonly adjusted to a predetermined resonant frequency by placing it in a vacuum chamber and depositing metal onto one of the electrodes thereof while monitoring its resonant frequency. When the frequency of the crystal reaches a predetermined value, the metal evaporating apparatus is manually stopped or interrupted by a shutter or other suitable means. The vacuum chamber is then opened and another crystal inserted therein. Some prior art crystal adjusting apparatus have a plurality of evaporating stations within a single vacuum chamber so that two or more crystals may be adjusted before opening the chamber. However, these prior art apparatus are not adapted to individually adjust a plurality of crystal resonators on a single crystal plate.

There are also a number of prior art apparatus for evaporating metals, such as gold, etc., on batch quantities of substrates. Some of these employ conveyors for passing a plurality of substrates through an evaporating chamber. However, none of these are capable of adjusting crystal resonators to value.

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SUMMARY OF THE INVENTION

An object of the invention is to automatically adjust a plurality of individual resonators on a monolithic crystal filter to produce a bandpass filter having the desired properties.

Another object of the invention is to adjust the resonators on a plurality of monolithic crystal filters by evaporating metal thereon without opening or exposing the filters to atmospheric pressures until the filters have been completely adjusted.

In accordance with these and other objects, the invention contemplates supporting a monolithic crystal filter with an electrode of a first selected resonator in the path of a substantially non-divergent stream of metal vapor. The first selected resonator is excited and the resonant frequency sensed to interrupt the vapor stream when the first resonator reaches a first predetermined value. An electrode of a second selected resonator is positioned in the path of the vapor stream and the second resonator is adjusted to a second predetermined value.

In one embodiment, the width of the vapor stream is changed before adjusting the second resonator to accommodate for varying size electrodes and spacing between electrodes to prevent the unwanted deposition on non-selected electrodes. Also, the density of the vapor stream may be reduced as the selected resonator approaches its predetermined value to allow for a more accurate adjustment of the selected resonator. In addition, after all resonators have been adjusted once, the resonant frequency of the first resonator is adjusted to a third predetermined value and the resonant frequency of the second resonator is adjusted to a fourth predetermined value.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an isometric view of a monolithic crystal filter;

FIG. 2 is a plan view of a carrier plate for receiving a plurality of monolithic crystal filters;

FIG. 3 is a cross-section of an elevation of the carrier plate shown in FIG. 2;

FIG. 4 is an elevation in cross-section of an apparatus for selectively depositing metal vapor on electrodes of the plurality of crystal filters held by the carrier plate of FIG. 2;

FIG. 5 is an isometric view of the apparatus shown in FIG. 4;

FIG. 6 illustrates adjustable collimator openings of the apparatus shown in FIGS. 4 and 5; and

FIG. 7 is a schematic of an electronic control system for operating the apparatus shown in FIGS. 4, 5, and 6.

DETAILED DESCRIPTION

Several types of monolithic crystal devices for use as bandpass filters are described in Pat. No. 3,564,463 of W. D. Beaver and R. A. Sykes, Pat. No. 3,573,672 of I. E. Fair and E. C. Thompson, Pat. No. 3,576,506 of R. L. Reynolds and R. A. Sykes, and Pat. No. 3,585,537 of R. C. Rennick and W. L. Smith. Referring to FIG. 1, one such bandpass filter 11 has two quartz crystal plates 12 and 13 upon which upper gold electrodes 14a-14h and corresponding lower gold electrodes 15a-15h (only 15e shown in FIG. 1) are deposited. The upper electrodes 14a-14h are connected by suitable conductor paths 18a-18h and conductors 16a-16h to metal pads on a rectangular shaped ceramic ring 23. The lower electrodes 15a-15h are connected by suitable conductor paths 19a-19h and conductors 17a-17h to respective metal pads on the ring 23. The electrodes 14a and 15a make up a resonator. Similarly, the electrode pairs 14b and 15b, 14c and 15c, 14d and 15d, 14e and 15e, 14f and 15f, 14g and 15g, 14h and 15h make respective resonators. The resonators are

so spaced on each plate with the electrodes having sufficient mass that only a predetermined bandwidth of signals is transmitted through the quartz plates between resonators. Metal stripes 21—21 are used to control the coupling and frequency characteristics between resonators on each plate.

In the manufacture of monolithic crystal filters, the individual resonators on each filter are adjusted to individual predetermined resonant frequencies. Then, various resonators may be electrically shorted and interconnected. For the filters 11 shown in FIG. 1, the conductors 16b—16g, 17b, 17c, 17f, and 17g are all shorted together. The conductors 17d and 17e are also shorted together and coupled by a capacitor to the conductors 16b—16g, 17b, 17c, 17f and 17g. Only a predetermined bandwidth of signals will be transmitted from an input across conductors 16a and 17a to an output across conductors 16h and 17h.

Referring to FIGS. 2 and 3, there is shown a carrier plate 26 having a plurality of recesses 27—27 for receiving a plurality of the monolithic crystal filters 11—11. The ceramic ring 23 of each filter is supported on a ledge 28 in each recess 27. Three pins 30, 31, and 32 are mounted on the edge of each recess 27 in the carrier plate 26. Spring members 33, 34, and 35 located opposite to the pins 30, 31, and 32 urge the ring 23 against the respective pins 30, 31, and 32 to accurately position the filter therein. A mask 37 positioned by the pins 30, 31, and 32 is held by screws 38—38 to the bottom of the plate 26 over each recess 27. The mask 37 has openings 40a—40h which correspond to the bottom electrodes 15a—15h of the filter 11. The mask is slightly displaced from the plates 12 and 13 so that the quartz plates 12 and 13 will not engage the mask 37 when they are excited by the application of a voltage to the electrodes of each individual resonator. The openings 40a—40h have dimensions corresponding to about 80% of the respective electrode areas so that metal is deposited on as much of the electrode surface as possible without being deposited on adjacent areas of the plates 12 and 13.

Referring to FIGS. 4 and 5, the carrier plate 26 is positioned on a carriage 44 by suitable pins 45 extending into holes in the carrier plate 26. The carriage 44 is slidably mounted on shafts 46 and 47 which are secured to a housing 48 mounted on supports 67 attached to the inner wall of a vacuum chamber 65. The housing 48 has eight collimator sections or chambers 49—49 which communicate with a lower chamber 50. Four tungsten evaporating boats 55—55 are mounted on conductor bars 58—58 supported by insulated feed-throughs 59—59 of a lower plate 60 of the chamber 65 beneath openings 56—56 on a lower plate 57. The openings 56—56, openings 54—54 between chamber 50 and chambers 49—49, openings 53—53 and 61—61 above chambers 49—49, and edges 74—74 and 75—75 of adjustable collimator members 72 and 73 are in alignment with at least one of the boats 55—55 to produce substantially non-divergent streams of metal vapor impinging on the bottom electrodes of the monolithic filters. The openings 54—54, 56—56 and 61—61 have appropriate recesses in the upper edges thereof for receiving and supporting mask plates with selected dimensioned openings to produce vapor streams having predetermined cross-sections.

Referring to FIGS. 5 and 6, there are shown adjustable collimator members 70—73. A shaft 60 extends by an appropriately sealed bearing through the side wall of the chamber 65 and into the housing 48. The shaft is attached by a righthand thread and nut arrangement to bars 70 and 72 and by lefthand threads to bars 71 and 73. The bars 70—73 have facing edges 74—74 and 75—75 formed thereon to control the width of the vapor stream. The shaft 60 is selectively turned by a stepping motor (not shown) to open or close the bars 70 and 71 and the bars 72 and 73 to selectively determine the width of the vapor stream. This allows the selective plating of in-

dividual electrodes which have different widths and preventing the unwanted deposition of metal on adjacent electrodes.

A selected electrode 15a—15h of each filter 11 is positioned in the path of the vapor stream by a shaft 62 connected through a linear bellows 63 to a rotative to linear motion converter (not shown) driven by a stepping motor (not shown).

Referring back to FIGS. 4 and 5, individual shutters 76—76 extend into the respective chambers 49—49. The shutters 76—76 are connected by shafts 77—77 through bellows couplings 78—78 to air cylinders (not shown) outside of the chamber 65 which control their opening and closing. When a shutter 76 is advanced into the chamber 49, the stream of gold vapor is interrupted and prevented from passing through to the electrode on the filter thereabove.

Tubes 51—51 extending from the upper part of the chamber to the boats 55—55 are used to feed additional gold pellets to the evaporating boats 55 when they are depleted. The lower plate 57 of the chamber 50 has a ring of copper tubes 63—63 attached thereto through which water may be passed to cool the bottom plate 57. Cooling the plate 57 absorbs the heat from the lower evaporating boats 55 and insures that the crystal filters 11—11 are not heated. Heating the filters would change their resonant frequency and produce an erroneous result.

An electronic chassis unit 79 is attached by hinges to the housing 48. The chassis 79 has spring biased connectors 80—80 mounted thereon which engage all of the conductors 16a—16h and 17a—17h on top of the ceramic rings 23. The chassis 79 contains eight oscillators and a plurality of sealed contact relays in a sealed enclosure. The plurality of relays are selectively operated to connect an oscillator to a selected resonator on each filter. Appropriate wiring connects the electronic circuitry through feed-through units to outside electronics hereinafter described. Conventional crystal oscillator circuits are employed with the provision of being able to selectively connect any one of the eight resonators on a filter into the oscillator circuit.

Referring to FIG. 7, there is shown a control system for controlling the automatic operation of the crystal filter adjusting. A tape reader 81 is controlled by a control and decoding circuit 82 for reading and collecting a block of digital information read from a tape. Part of the information is applied to a digital motor control circuit 83 which operates the stepping motors (not shown) to position the carriage 44 (FIGS. 4 and 5) and the collimator members 70—73 (FIG. 6). The rest of the block of information is applied to register circuits 84. The information in the register circuits 84 determine the selected resonator, the frequency at which a lower evaporating rate is employed, and the frequency at which the shutters are operated. The frequency information is supplied to eight programmable counters 85—85 (only two are shown) such as model 5332B counter controllers sold by Hewlett-Packard Corp. Each counter 85 produces appropriate signals when first and second programed signals are sensed thereby.

The power to the four tungsten evaporating boats is controlled by conventional power control or high current switching circuits 87 (only one of four shown) to provide preheat, standby, and four evaporating rates from the boats.

Gating circuitry 88 contains various conventional AND gate circuits, OR gate circuits, delay circuits, etc. to control the sequence of operation. Initially, a vacuum pumping system 90 is operated to produce the proper vacuum in the chamber 65. Appropriate oscillators in the chassis 79 are connected by switching circuitry to the selected resonators which are positioned by the carriage over the opening between edges 74 and 75. Vacuum gauges 91 are sensed by the gating circuitry 88 to operate the power control 87 to preheat the boats and then to begin evaporating at a first selected rate. After a delay, the shutters

76—76 (FIG. 5) are opened, to being plating the selected resonators.

A channel selector circuit 92 provides for a plurality of filters having different frequency bands to be adjusted without changing the control tape. The channel selector 92 heterodynes the output of each of the oscillators 79 with a selected frequency from a plurality of standard oscillators to produce a difference frequency which is applied to the respective counters 85. The selection of the standard oscillator determines the channel of the filter being adjusted. Provision may be made to multiply or heterodyne the difference frequencies to higher frequencies to allow shorter counting times by the counters 85—85.

Each boat 55 supplies vapor to two filters 11—11. When either of the two filters reaches a first limit programmed in the counters 85—85, the power control 87 is operated to reduce the evaporating rate of the respective boat. The slower evaporating rate will continue until the filter passing the first limit reaches a second limit in its respective counter 85. Then the gating circuitry responds only to the remaining filter to evaporate at the faster or slower rate depending upon the value of the remaining filter.

When the gating circuitry 88 senses the second limit from a counter 85, it operates the respective shutter 76—76. When all the counters 85—85 have reached the second limit, signals are applied through the register 84 to the control circuit 82 to read an additional block of information and adjust the next resonator on the filters. In the event a resonator does not reach value within a predetermined duration, a timing circuit 93 signals the apparatus to go on to the next resonator on the filters. With such failure, the affected shutter 76 is disabled and an appropriate indicating device is operated to indicate the defective filter to the operator.

The resonant frequency of any selected resonator is reduced when metal is deposited on any electrode on the same crystal plate as the selected resonator. Consequently, it is necessary to first adjust the resonant frequencies of each resonator to values higher than the respective desired values taking into consideration that the first resonators adjusted will be effected most by the subsequent adjustment of other resonators. After all the resonators on a filter have been adjusted to first respective predetermined values, the adjusting steps are again repeated for the resonators to adjust them to second respective predetermined values. This adjusting may be repeated several times to third, fourth, etc., respective predetermined values to produce the required accuracy of the filter.

The individual resonant frequencies to which the resonators on a filter are adjusted depend upon the design of the filter. The individual resonant frequencies may be the same value, some may be different, or all may be different.

The above-described embodiment of the invention is simply illustrative of the principles of the invention and many embodiments may be devised without departing from the scope and intent of the invention.

What is claimed is:

1. A method of adjusting individual resonators on a monolithic crystal filter to individual resonant frequencies, comprising:

- producing a vacuum in which the following steps are sequentially performed without interrupting the vacuum;
- generating a substantially non-divergent vapor stream of metal having a predetermined width;
- positioning an electrode of a first resonator on the filter in the path of the vapor stream;
- exciting the first resonator at its resonant frequency;
- sensing when the resonant frequency of the first resonator reaches a first predetermined value to interrupt the vapor stream;

positioning an electrode of a second resonator on the filter in the path of the vapor stream without interrupting the vacuum;

exciting the second resonator at its resonant frequency; and

sensing when the resonant frequency of the second resonator reaches a second predetermined value to interrupt the vapor stream.

2. A method as defined in claim 1 which includes the step of changing the width of the vapor stream to accommodate different widths of electrodes.

3. A method as defined in claim 1 which includes the following additional steps:

positioning the electrode of the first resonator on the filter in the path of the vapor stream;

exciting the first resonator at its resonant frequency; and

sensing when the resonant frequency of the first resonator reaches a third predetermined value to interrupt the vapor stream.

4. A method as defined in claim 2 which includes the following additional steps:

repositioning the electrodes of the first resonator on the filter in the path of the vapor stream;

exciting the first resonator at its resonant frequency; and

sensing when the resonant frequency of the first resonator reaches a third predetermined value to interrupt the vapor stream.

5. A method of adjusting individual resonators on a monolithic crystal filter to individual frequencies, comprising:

generating a substantially non-divergent vapor stream of metal having a predetermined width and a first density;

positioning an electrode of a first resonator on the filter in the path of the vapor stream;

exciting the first resonator at its resonant frequency;

sensing when the resonant frequency of the first resonator reaches a first predetermined value to produce a first control signal;

reducing the density of the vapor stream from the first density to a second density in response to the first signal;

sensing when the resonant frequency of the first resonator reaches a second predetermined value to produce a second control signal;

interrupting the vapor stream in response to the second control signal;

positioning an electrode of a second resonator on the filter in the path of the vapor stream;

exciting the second resonator at its resonant frequency;

sensing when the resonant frequency of the second resonator reaches a third predetermined value to produce a third control signal;

reducing the density of the vapor stream from the first density to the second density in response to the third control signal;

sensing when the resonant frequency of the second resonator reaches a fourth predetermined value to produce a fourth control signal; and

interrupting the vapor stream in response to the fourth control signal.

6. A method as defined in claim 5, which includes the step of changing the width of the vapor stream to accommodate different widths of electrodes.

7. A method as defined in claim 5 which includes the following additional steps:

repositioning the electrodes of the first resonator on the filter in the path of the vapor stream;

exciting the first resonator at its resonant frequency;

sensing when the resonant frequency of the first resonator reaches a fifth predetermined value to produce a fifth control signal; and

interrupting the vapor stream in response to the fifth control signal.

References Cited

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ALFRED L. LEAVITT, Primary Examiner

M. F. ESPOSITO, Assistant Examiner

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