

E. L. HÖFFMANN ET AL

STEP-WISE TUNING OF ELECTRICAL CIRCUITS

Filed Dec. 13, 1939

2 Sheets-Sheet 1

Fig. 1.

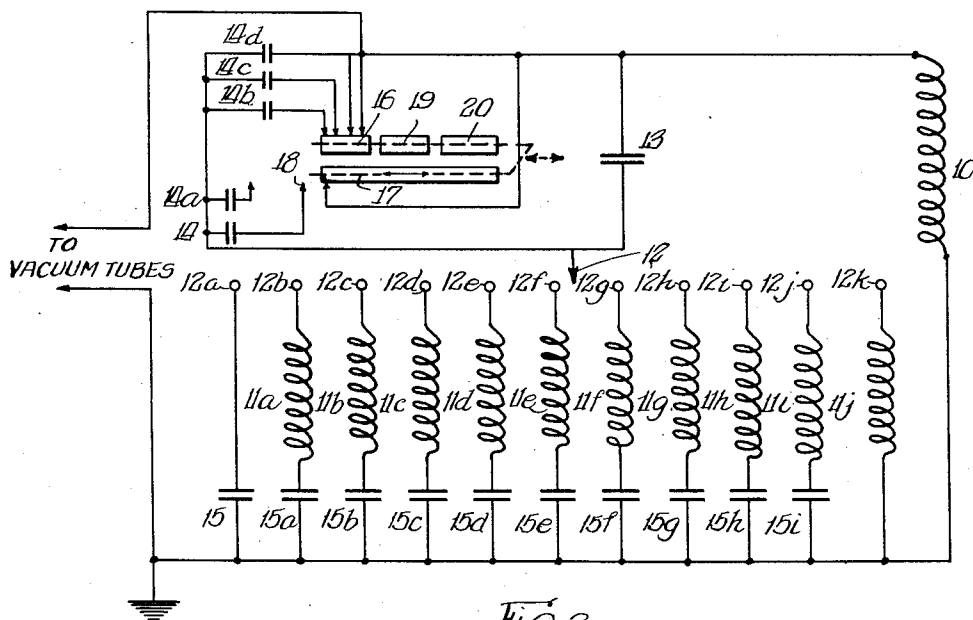
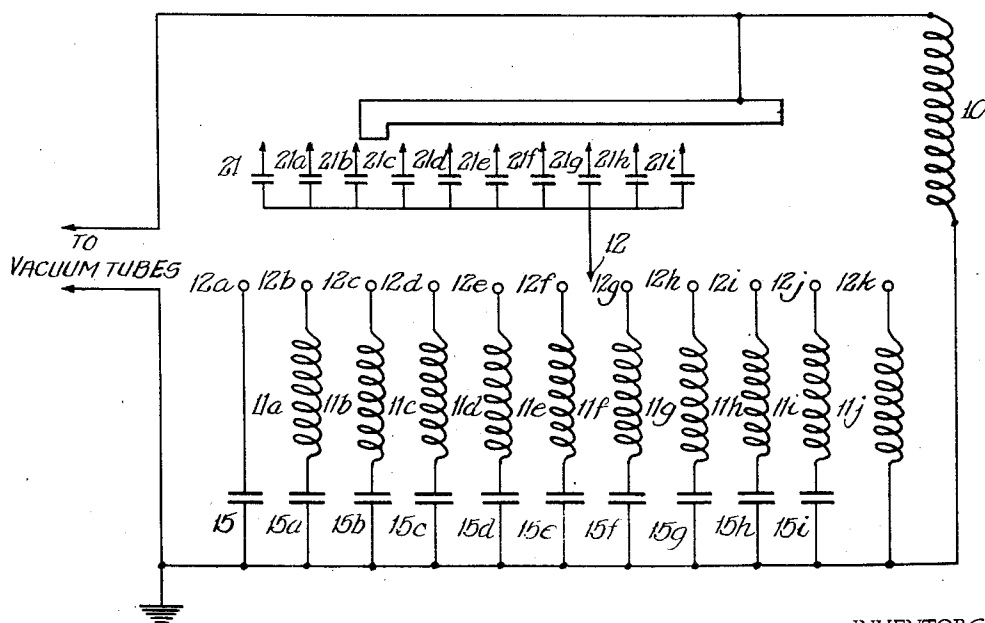


Fig. 2



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2 Sheets-Sheet 2

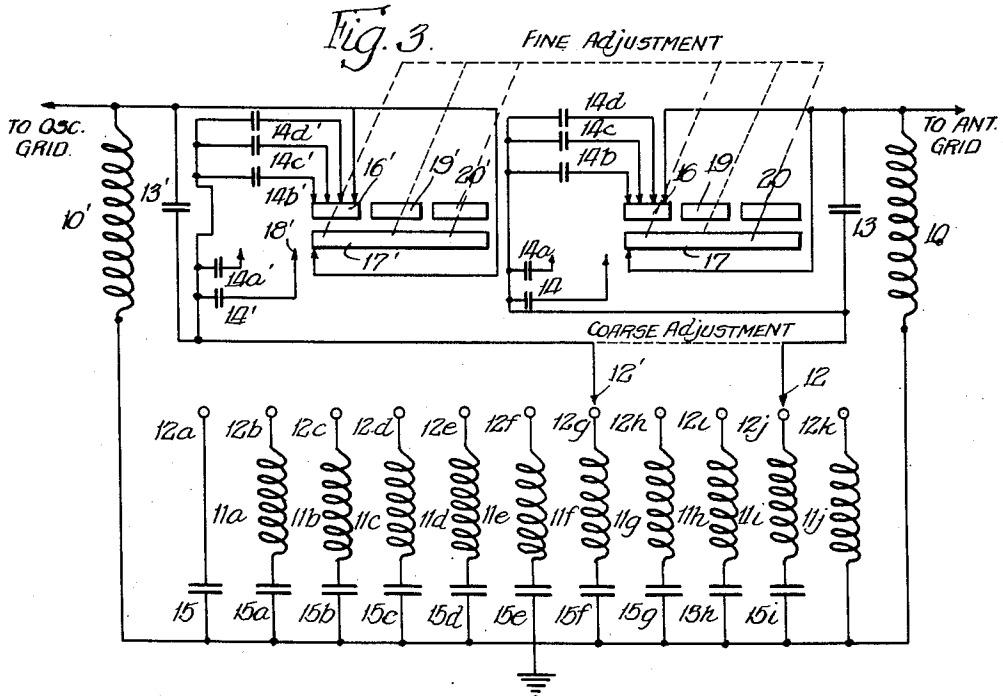
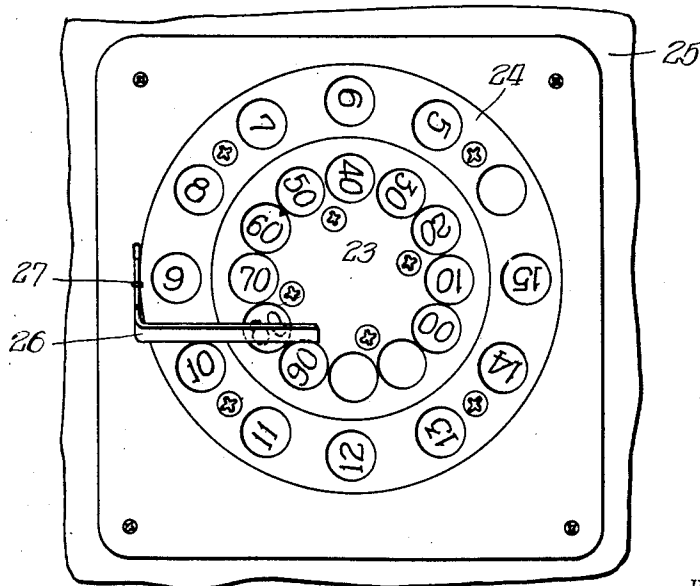


Fig. 4.



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UNITED STATES PATENT OFFICE

2,297,889

STEPWISE TUNING OF ELECTRICAL CIRCUITS

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4 Claims. (Cl. 250—40)

The present invention relates to the step-by-step tuning of electric circuits such as are employed in radio receivers and the like.

The primary object of the invention is the provision of a step-by-step tuning arrangement which is simple, accurate, easy to operate and economical to manufacture. The so-called preferred station selectors embodied in radio receivers have been objectionable in that they are limited to the number of stations which it is practicable to pre-select. Consequently, the user is limited in the extent of station selection which is available to him through the pre-selected means. Furthermore, this equipment has been somewhat expensive and is unhandy in that it must be pre-set or pre-adjusted to the desired stations.

Various expedients have been suggested to overcome these difficulties but they are either so complicated or so expensive as to be impractical from a commercial point of view.

The present invention overcomes the difficulties heretofore referred to by permitting the selection of any desired channel and the apparatus is so arranged that only those channels that are employed in broadcasts will be selected. However, all broadcast frequency channels are available to the user of the apparatus and he is assured of substantial accuracy in tuning. By the particular arrangement hereinafter described, the number of parts and the arrangement is such that there is very little expense involved in manufacture, this fact being primarily due to the tuning of the circuit both by varying the inductance and the capacity thereof.

A further object of the invention is the provision of a step-by-step tuning arrangement in which the coils and condensers employed may be utilized as a portion of the signal and oscillator circuit of a super heterodyne circuit thereby effecting economies in manufacture.

A still further object of the invention is the provision of simplified mechanical control means for tuning said step-by-step arrangement.

Other objects and advantages of the invention will be obvious to those skilled in the art upon an understanding of the embodiment thereof herein illustrated and described. It is to be understood that the forms of the invention herein shown are for purposes of illustration only and are not to be construed as unnecessarily limiting the scope of the invention as defined by the claims.

In the drawings:

Fig. 1 is a schematic circuit diagram showing one form of the invention;

Fig. 2 is also a schematic circuit diagram showing a modified form of the invention;

Fig. 3 is likewise a schematic diagram showing the circuit incorporated in a superheterodyne receiver; and

Fig. 4 shows a simplified tuning dial arrangement for employing said circuits in practice.

As will be apparent from Fig. 1 the circuit includes an inductor 10, a plurality of load inductors 11a to 11j inclusive and capacitors 15 to 15i inclusive. A switch 12 provided with contacts 12a to 12k, respectively, is adapted to select any of the load inductors 11a to 11j and their associated capacitors 15a to 15i for association with the remainder of the circuit hereafter to be described. The switch contact 12a does not include an inductor but does have connected to it a capacitor 15. Connected to the common terminal of the switch 12 in series to the circuit of the inductor 10 are condensers 13—14—14a—14b—14c and 14d. Thus by means of switch 12 and contacts 12a to 12k the load coils 11a to 11j and the capacitors 15 to 15i are placed in series with the inductor to and the capacity element 13.

In the form of the invention shown in Fig. 1 the circuit is tuned in fine steps by shunting capacity element 13 with capacitors 14—14a—14b—14c—and 14d. For purposes of illustration we may assume that when the switch 12 engages contact 12k and there is no condenser shunted across condenser 13 that the circuit may be tuned to 590 kilocycles. It is apparent that by properly calculating the capacity of the condensers 14 to 14d that when capacitor 14d is connected to the circuit in shunted relationship to condenser 13 through means of switching member 16 and when contactor 12 is connected to contact 12k the circuit will be tuned to 500 kilocycles. As switching member 16 is still further adjusted so as to bring the capacitor 14c into the circuit, the will be turned to 570 kilocycles. When 14d is brought into the circuit it will resonate at 560 kilocycles. At this point the switch bars are so arranged that the switch bar 17 will engage the sliding contact 18 and the capacitor 14 will be connected into the circuit and the capacitors 14b, 14c, and 14d will be excluded. The capacitor 14 is of such size that when placed in shunt to 13 the pair will cause this circuit consisting also of inductors 10 and 11j to resonate at 550 kilocycles. Subsequent manipulations of the switch will cause the switch bar 19 to add capacitor 14d to the circuit and then capacitors 14c and 14b will be added. Finally, condenser 14a is added to the circuit and the switch bar 20 then makes contact so that by steps of approximately 10 kilocycles the resonance point of the circuit is adjustable from 590 to 500 kilocycles.

Since the capacity increment required to produce 10 kilocycle steps at the low frequency end of the band are excessive for the high frequencies, their effect must be reduced for the higher frequencies. However, to be sure that the values of these capacitors are sufficiently large to accomplish the 10 kilocycle steps at the low frequency

end, they must be computed from this end of the band. In order to reduce the effect of the capacitors 14 to 14d at the higher frequencies, the capacitors 15 to 15i are incorporated; these condensers being in series reduce the effective capacity of the capacitor 13 and the effect of capacity increments caused by switching capacitors 14 to 14d inclusive, in shunt with capacity 13.

In order to determine the values of all the capacitors in the circuit a choice of inductance is made for the low frequency end. In the interest of practicability, this inductance which is made up of inductors 10 and 11j may be chosen sufficiently large to allow capacitors 14 to 14d inclusive to have a relatively small value. For example, one may choose the value of 200 microhenries. By referring to the table and dividing the L. C. values therein given for the various steps of 10 kilocycles, with the coarse step of lowest frequency, the capacities required to resonate the circuit for each of the 10 kilocycle steps in the instance given are 363.8, 376.5, 389.5, 403.8, 418.7, 434.3, 450.9, 468.9, 486.9 and 506.6 micro-microfarads. The capacitance reached by the grouping of the various capacitors—13, 14, 14a, 14b, 14c and 14d, in the above method, closely approach these values.

value of the inductor 10 since it is the only inductor in the circuit when the circuit is tuned to the high frequency end of the band. Once the value of the inductor 10 has been determined the value of 11a to 11j inclusive can be calculated by determining the total inductance required for each circuit including the inductors and subtracting the value of inductor 10 therefrom. The value of inductor 10 is 70.56 microhenries and the values of 11a to 11j inclusive and in the same order are: 4.9, 10.5, 17.0, 24.7, 32.6, 44.8, 58.4, 75.7, 98.5 and 129 microhenries.

The values for L and Cs computed by the formulae above referred to are not exact since the distributed capacity effects have not been included. Taking these effects in consideration the formulae heretofore referred to are:

$$C_s = -(LC' + LC'') (CaCb + CdCb + CaCd) / 2CaCbCd (\overline{LC'} - \overline{LC''}) + [(LC' + LC'') (CaCb + CdCb + CaCd)^2 - 4(\overline{LC'}(Cb + Cd) - \overline{LC''}(Ca + Cd)) CaCbCd (\overline{LC'} - \overline{LC''})]^{1/2} / 2CaCbCd (\overline{LC'} - \overline{LC''}) \quad (A')$$

$$L = \overline{LC'} (Ca + Cs) / (CaCs + (Ca + Cs)Cd) \quad (B')$$

$$L = \overline{LC''} (Cb + Cs) / (CbCs + (Cb - Cs)Cd) \quad (C')$$

Table of—L. C. ratio constants

[C in mmfds. L in microhenries.]

f	00	10	20	30	40	50	60	70	80	90	
500.....	10, 132.12	97, 386.75	93, 682.64	90, 175.53	86, 866.60	83, 736.50	80, 772.60	77, 963.36	75, 298.10	72, 767.33	I.
600.....	70, 361.97	68, 073.87	65, 895.66	63, 819.85	61, 841.54	59, 953.33	58, 150.38	56, 427.48	54, 780.06	53, 203.71	II.
700.....	51, 694.43	50, 248.56	48, 862.48	47, 532.94	46, 256.95	45, 036.14	43, 854.39	42, 722.70	41, 634.28	40, 586.94	III.
800.....	39, 578.60	38, 607.38	37, 671.47	36, 769.17	35, 898.96	35, 059.23	34, 248.65	33, 465.84	32, 709.58	31, 978.67	IV.
900.....	31, 271.96	30, 588.44	29, 927.10	29, 286.98	28, 687.16	28, 066.80	27, 485.13	26, 921.36	26, 374.73	25, 844.61	V.
1,000.....	25, 330.28	24, 831.17	24, 346.30	23, 876.24	23, 419.28	22, 975.31	22, 543.88	22, 124.45	21, 716.65	21, 320.00	VI.
1,100.....	20, 934.13	20, 558.63	20, 193.15	19, 837.34	19, 490.84	19, 153.34	18, 824.53	18, 504.13	18, 191.83	17, 887.35	VII.
1,200.....	17, 590.48	17, 300.93	17, 018.48	16, 742.88	16, 473.33	16, 211.38	15, 955.10	15, 704.83	15, 460.39	15, 221.61	VIII.
1,300.....	14, 988.35	14, 762.44	14, 537.53	14, 319.81	14, 095.25	13, 898.67	13, 695.01	13, 495.82	13, 300.94	13, 110.23	IX.
1,400.....	12, 923.62	12, 740.95	12, 562.13	12, 387.07	12, 215.62	12, 047.70	11, 883.23	11, 722.11	11, 564.23	11, 409.53	X.
1,500.....	11, 257.91	11, 109.29	10, 963.60	10, 820.74	10, 680.09	10, 543.31	10, 408.57	10, 276.40	10, 146.73	10, 019.49	XI.

Having determined the capacities which accomplish the 10 kilocycle adjustments it is possible to calculate the various remaining circuit constants. In the formulae which are to follow the symbols employed will be used to designate the following circuit constants: Ca, the capacity of the fine step network when adjusted to the low frequency end the the group. Cb, the capacity of the fine step network at the high frequency end of the group. LC', the L. C. ratio for the circuit tuned to the lowest frequency of the group in question. LC'', the L. C. ratio for the highest frequency of the same group. Cs, the value of the series capacitor for the frequency range in question, and L, total inductance in the circuit. The values of 15 to 15i can be computed by the following formula:

$$C_s = CaCb(LC' + LC'') / (LC'Ca + LC''Cb) \quad (A)$$

The calculated values for the capacitors 15 to 15i in the assumed circuit are respectively 132.9, 158.7, 291.2, 332.9, 388.5, 478.1, 482.6, 778.1, 1168 and 2338 micro-microfarads.

The inductance required to resonate the circuit at the proper frequencies may be computed by any of the following formulae:

$$L = LC' (Ca + Cs) / (CaCs) \quad (B)$$

$$L = LC'' (Cb + Cs) / (CbCs) \quad (C)$$

$$L = (1/Ca - 1/Cb) / (1/LC' - 1/LC'') \quad (D)$$

The values of the various inductors in the circuit can be determined by first determining the

$$L = -(LC'Ca(Cb + Cd) - LC''Cb(Ca + Cd)) / 2d^2(Cb - Ca) \pm [(LC'Ca(Cb + Cd) - LC''Cb(Ca + Cd))^2 - 4d^2(Cb - Ca)(LC' - LC'')]^{1/2} / 2d^2(Cb - Ca) \quad (D')$$

These formulae are not completely rigorous but will give a very close approximation where the ratio between distributed capacity and circuit capacity is low. In many cases formulae A, B, C and D will be sufficiently accurate for practical application.

In lieu of employing the inductor 10 with a plurality of load inductors for each 100 kilocycle group, inductors 11a to 11j may have the values computed by Formula D. Furthermore, a load inductance may be employed in the highest frequency group and the other load inductors have values assigned to them that are increased by the value of such inductor. In this arrangement the value of the inductor 10 would be decreased accordingly.

Likewise, a condenser may be put in the low frequency group circuit and the values of the condensers 13, 14, 14a, 14b, 14c and 14d increased. Of course, with such an arrangement the values of the condensers 15 to 15i, inclusive, would be decreased. The formulae heretofore given may be employed for calculating the various modifications above referred to.

A further modification which may be desirable but which involves a more expensive arrangement than that shown in Fig. 1 consists in substituting

for the condenser 13 and the condensers 14 to 14d, inclusive, ten condensers having rather high values. This arrangement is shown in Fig. 2 of the drawings, the condensers referred to being indicated by the reference numerals 21 to 21i, inclusive. The remaining portions of the circuits have been indicated by the same reference characters as employed in Fig. 1. The modification of the invention shown in Fig. 2 is useful in securing more accurate tuning and may be highly desirable in more critical installations.

The fine step network may economically be constructed in several ways. For example, in lieu of the capacitors 13, 14, 14a, 14b, 14c and 14d, ten separate fixed condensers may be selectively added to the circuit, ten fixed condensers may be collectively added to the circuit, and still another alternative is the combination of these methods.

In the event that a fine network is to be made up of ten condensers each having proper capacity to resonate the circuit at the desired point within the coarse step of lowest frequency, selective switching may be employed to connect these condensers in the circuit individually. Neglecting the distributed capacity of the circuit and assuming an inductance value of 200 microhenries the value of these condensers would be 506.6, 486.9, 468.9, 450.9, 434.3, 418.7, 403.8, 389.5, 376.5, and 363.8 micro-farads respectively.

A second method may be employed which incorporates the use of one condenser having the lowest value, e. g., 363.8 mmfd. (13) and adding capacitors to this individually or collectively at the various fine steps within the coarse step. In this case the values which may be required to shunt the condenser 13, are: 12.7, 25.7, 40.0, 54.7, 70.5, 87.1, 105.1, 123.1 and 142.8 mmfds. Each of these smaller values when added to the capacitor 13 will cause the circuit to resonate at one of the fine steps.

Employment of the arrangements just referred to for the fine step network will give the most accurate tuning of the fine steps. However, if greater economy is desired a compromise can be made with accuracy in favor of economy. Some of the errors which are incurred by the method suggested in Fig. 1 may not be intolerable in inexpensive receivers especially if they are sufficiently broad to allow a signal one or two kilocycles off resonance to be received with relatively good quality.

It is also possible with any of these methods to employ automatic frequency control of well known types to compensate for off frequency errors.

In applying the circuit to tuned radio frequency receivers it will be apparent that an entire system is required for each tuned circuit. In connection with superheterodyne receivers, the circuit may be employed in such manner that the inductances of 11a—11j and condensers 15 to 15i may be employed in the oscillator circuit and in the antenna circuit, thereby substantially reducing the cost of producing a superheterodyne receiver.

As is well known, in superheterodyne receivers the difference from the signal frequency to the oscillator frequency is known as the intermediate frequency. The intermediate frequency is generally produced by beating an oscillator of higher or lower frequency against the signal frequency; the intermediate frequency can be the sum or difference. The oscillator frequency may be higher than the signal frequency or it may be

lower by an amount equal to the intermediate frequency. Furthermore, it is practicable to so design the circuit that the oscillator frequency is sometimes greater and sometimes smaller than the signal frequency.

Referring to Fig. 3 it may be noted that in this figure each of the coarse steps employs a separate load coil and pad condenser. Therefore, any two of the coarse networks in the system may be employed if their separate circuits operate at unique frequencies. For illustration, if the signal frequency be 500 kilocycles and pre-selected intermediate frequency be 300 kilocycles the oscillator circuit may use the coarse network which operates at 800 kilocycles. By so selecting the intermediate frequency it is possible for the set to cover a range of from 500 to 1590 kilocycles through use of the coarse network without duplicating the condenser 15 to 15i and the coils 11a to 11j and with an oscillator which has a range from 800 to 1390 kilocycles.

With this arrangement the basic antenna coil and the oscillator coils are of the same size and the buffer condensers and the fine step network condensers must also be of the same size. The foregoing is accomplished by connecting the oscillator coil and antenna coils in the circuit for various frequencies in order to produce at all times the desired intermediate frequency of 300 kilocycles.

In Fig. 3 the circuit is shown in a form such that the coarse step network is employed for the antenna and oscillator coils.

It will be observed that there are two fine step networks, one in the oscillator circuit and one in the antenna circuit. The switching arrangement for these fine step networks act in synchronism as is indicated by the dotted lines. The reference characters are the same as in Fig. 1 through the circuit except that in the fine step network of the oscillator circuit the prime designation has been applied and the switch contact for the oscillator circuit has been indicated as 12'.

The switching arrangement for the switches 12' and 12 is such that when the antenna circuit is connected through the switch 12 to any particular coarse network the oscillator circuit switch 12' is connected to a coarse network three steps away so that the intermediate frequency, assuming that each coarse step represents 100 kilocycles, would be 300 kilocycles. 300 kilocycles is a convenient intermediate frequency although other intermediate frequencies may be employed so long as they are in units of 100 kilocycles. As has heretofore been explained, it makes no difference whether the oscillator frequency is below the antenna frequency or above the antenna frequency so long as the intermediate frequency remains the same throughout the range of operation of the receiver.

It will be apparent that since there are two fine step networks, one in the oscillator circuit and one in the antenna circuit and since these fine step networks operate in unison the fine step adjustments will adjust both circuits at the same time and thereby keep the intermediate frequency constant.

An appropriate set of values for the elements of Fig. 3 is as follows: 10—70.56, 10'—70.56, 11a—4.9, 11b—10.5, 11c—17.0, 11d—24.7, 11e—32.6, 11b—44.8, 11g—58.4, 11h—75.7, 11i—98.5, and 11j—129 microhenries; 13—359.9, 13'—359.9, 14—58.8, 14'—58.8, 14a—228.5, 14a'—228.5, 14b—15.8, 14b'—15.8, 14c—15.8, 14c'—15.8, 14d—15.8,

14d'—15.8, 15—132.9, 15a—158.7, 15b—291.2, 15c—332.9, 15d—338.5, 15e—478.1, 15f—482.6, 15g—778.1, 15h—1168 and 15i—2338 micro-microfarads. It should be noted that the value of capacitors 13 and 13' are listed as 359.9 mmfd., instead of 363.8 mmfd., as given in the text. This change is made in the interest of tuning accuracy. Due to the fact that precise steps of ten kilocycle steps cannot be obtained the slight off resonance variations are reduced by this choice of capacity.

The tuning dial arrangement shown in Fig. 4 consists of a pair of rotatably mounted concentric dials, the center one being designated by the reference character 23 and the outer one being designated by the reference character 24. These dials may be mounted on the exterior of a radio cabinet, a portion of which is indicated by the reference character 25.

Secured to the dial 23 is a shaft, not shown, which controls the contacts of the fine step network and secured to the dial 24 is a rotating member, not shown, which controls the contacts of the coarse step network. It will be apparent from the drawing that the dials are each provided with a series of numbers. In the embodiment shown, the coarse step dial 24 is provided with the numbers 5 to 15 to indicate 500 to 1500 kilocycles. The contacts are so adjusted in relation to the dial that when the dial is rotated by the finger to a stop member indicated by the reference character 26 the particular number opposite the stop member 26 indicates the position of the coarse stage.

The fine step network is similarly adjusted by the dial 23. For example, if the dial 23 is rotated so that the number 70 is adjacent the stop bar 26, then the fine step network is adjusted for 70 kilocycles. In the drawing the dials are shown with the coarse step dial set at 9 and the fine step dial set at 70, thus the receiver is tuned to 970 kilocycles.

The stop member 26 is pivoted at 27 so that it is capable of revolving to the position shown in dotted lines. Thus no matter in which direction the dials are operated, that is to say, whether clockwise or counterclockwise, the stop member will always stop the finger or instrument employed in rotating the dial at the position necessary to tune the set to the frequency selected.

Various expedients may be employed to insure that the dialed numbers will always center on the proper contacts even though the dialing may be slightly off center. For example, spring controlled ratchet members may be secured to the shafts which control the making of the various contacts.

We claim:

1. In a radio receiver, means for tuning a single band of frequencies, including a coarse step network, a fine step network, said coarse step network being tuned to predetermined coarse step frequencies and said fine step network being connected to said coarse step network and being adapted to tune said coarse step network in predetermined fine steps of substantially equal frequency change, said coarse step network consisting of a plurality of inductors, an oscillator circuit and a signal circuit, said signal circuit and said oscillator circuit being connected to said coarse steps, and switching means for connecting said oscillator circuit and signal circuit to different steps of said coarse steps in such manner as to provide a substantially uniform intermediate frequency throughout the tuning range of the coarse step circuit.

2. In a radio receiver, means for tuning a single band of frequencies, comprising a coarse step tuning network, an oscillator circuit, a fine step tuning network connected in said oscillator circuit, means for connecting said fine step tuning network to said coarse step network, said fine step network being so related to said coarse step network as to tune each step of said coarse step network at substantially uniform units of frequency change, a signal circuit, a fine step tuning network associated with said signal circuit, means for connecting said fine step network of said signal circuit to said coarse step tuning network, and means for relating the connections of said oscillator circuit and said signal circuit to different steps of said coarse step tuning network to provide a substantially uniform intermediate frequency throughout the tuning range of said coarse step network.

3. In a radio receiver, means for tuning to frequencies within a single band of frequencies by coarse adjustments and fine adjustments within said coarse adjustments, said means consisting of an inductor and a capacitor connected in series relationship, a plurality of series connected capacitors and inductors selectively connected in series relationship to the first mentioned capacitor and inductor, said capacitors and inductors constituting a coarse adjustment, a plurality of capacitors selectively connectable in shunted relationship to the first mentioned capacitor constituting the fine adjustments, said first mentioned capacitor and inductor and said series connected second mentioned capacitors and inductors having such a ratio of values to one another that when switching the various series connected capacitors and inductors into and out of the circuit the resonance frequency of said circuit is altered in substantially equal coarse steps of frequencies and when switching into and out of the circuit the various fine step capacitors the various coarse step adjustments are substantially equally subdivided into fine steps of frequency.

4. In a radio receiver of the superheterodyne type, a fine step signal selecting network, a fine step oscillator adjusting network, a coarse step network adapted to cooperate with said fine step signal selecting and said fine step oscillator adjusting networks, a ganged means adapted to connect said fine step signal selecting network and said fine step oscillator adjusting network to various different components of said coarse step network, said fine step signal selecting network and its interconnected coarse step component comprising a signal selecting circuit, said fine step oscillator adjusting network and its interconnected coarse step component comprising an oscillator resonating network, said ganged means adapted to simultaneously adjust the frequencies of said signal selecting circuit and said oscillator resonating circuit to frequencies differing by substantially equal amounts throughout the range of selectable frequencies and said ganged means being adapted to adjust said oscillator circuits to frequencies higher than said signal selecting circuit for selected frequencies comprising the lower frequency portion of the selectable band and adapted to adjust said oscillator circuit to frequencies lower than signal selecting circuit for selected frequencies comprising the higher frequency portion of the selectable band.

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DONALD M. FETTERMAN.

CERTIFICATE OF CORRECTION.

Patent No. 2,297,889.

October 6, 1942.

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It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 1, second column, line 19, for the words "inductor to" read --inductor 10--; and same line, for "element" read --element--; line 35, for "circuit, the" read --circuit, the circuit--; line 36, for "turned" read --tuned--; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 10th day of November, A. D. 1942.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.

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