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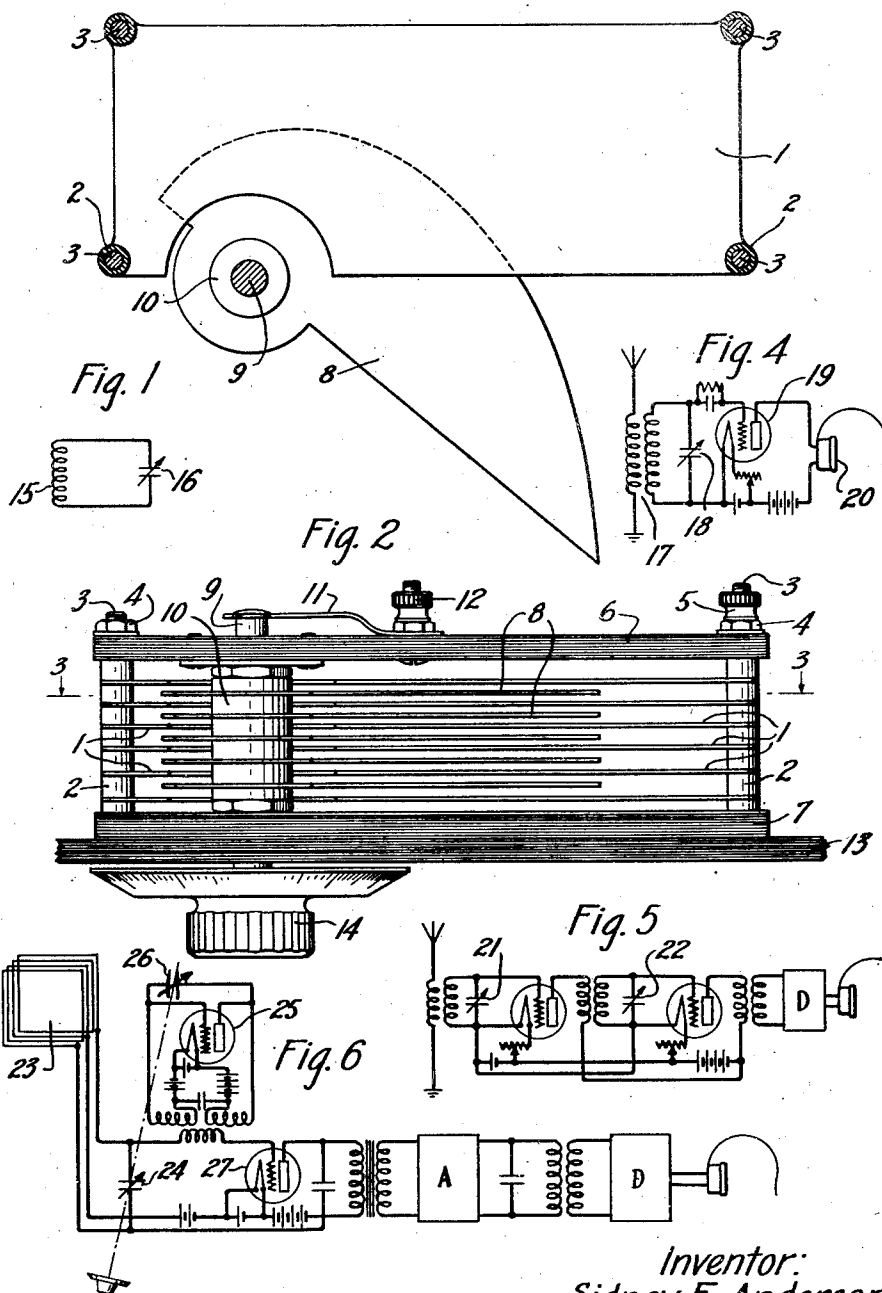
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RADIO APPARATUS

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Fig. 3



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UNITED STATES PATENT OFFICE

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RADIO APPARATUS

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This invention relates to radio receiving systems and more particularly to methods of and apparatus for the tuning of receiving systems.

Prior to the advent of radio broadcasting, stations were assigned wave lengths which varied by a given amount, and it was customary to consider the wave length rather than frequency in tuning and allocation. Because of this tendency, some of the tuning units used at the radio stations were designed to have a linear wave length characteristic, which was advantageous in decreasing to some extent the tendency for the adjustment to become critical at the higher frequency positions.

With the advent of radio broadcasting, however, stations were allocated on a basis of constant frequency difference which greatly increased the difficulty of selectively separating the waves transmitted by different stations, especially at the higher frequencies employed for this purpose.

With the recent widespread development of radio broadcasting, the importance of the frequency difference between various transmitters has been emphasized.

On the basis that a frequency band of 5,000 cycles is satisfactory for the transmission of high quality speech and music, the broadcasting stations have been uniformly spaced at frequency intervals of 10 kilocycles. This means that with reference to wave length the stations are much closer together at the high frequency end of the broadcasting range than at the lower end of the broadcasting range, and hence frequency discrimination between stations using short wave lengths is exceedingly difficult.

In general variable air condensers having semicircular plates are used to control the selective circuits of broadcast receiving sets and, as a consequence, the adjustment of the circuits becomes very critical as the position of minimum capacity of the condenser is approached. This is because the increase in capacity is directly proportional to the condenser setting over a major portion of the scale indicating the relative positions of the condenser plates, and a change in the setting

of one division causes a much larger percentage change in the capacity of the condenser at the lower portion of the scale, where the capacity approaches a maximum, than at the upper portion, where the capacity value is near a minimum.

The difficulty of frequency discrimination, between the waves radiated by different broadcasting stations, can be overcome by using a tuned circuit including a condenser adapted to vary the resonant frequency of the circuit in direct proportion to the condenser setting. For instance, if such a condenser were designed to cover the frequency range from 500 to 1,500 kilocycles, and the scale were divided into 100 divisions; the selective circuit of the receiver would be tuned to a relatively high frequency of say 1,350 kilocycles at 15 divisions on the condenser scale and to the lowest frequency in the broadcast range, namely 550 kilocycles at 95 divisions on the condenser scale.

The availability of condensers having the property mentioned above makes possible the solution of a problem for which there has heretofore been no practical solution. The problem is that of adjusting two resonant circuits simultaneously in such manner that throughout the complete range of adjustment, the two resonance frequencies differ by a fixed constant amount. This problem is encountered in the design of heterodyne receiving systems, and particularly, in the design of double detection or "super-heterodyne" systems, when it is attempted to arrange for tuning by means of a single control. The frequency difference between the received wave and that of the local oscillator is determined by the selective characteristic of the circuit traversed by the detected beat wave. In double-detection systems the beat frequency is usually from 50,000 to 100,000 cycles per second, and the intermediate amplifying apparatus usually includes a fixed circuit selective of this frequency. With the designs heretofore available, the condensers used, respectively, for tuning the input receiving circuit and for tuning the local oscillator, could not be coupled together for operation by a single control. The reason

for this is that the law of the capacity variation was such that a fixed difference between the two resonance frequencies would not result. When it was attempted to secure a single control in this way, the result was that the reception of certain waves, was favored, while other waves normally within the range of the adjustments, were strongly discriminated against.

In accordance with the present invention a double-detection receiving system is adapted to be adjusted by a single control. The feature by means of which the result is secured comprises a tuning unit, the resonant frequency of which varies linearly, and by equal increments, for equal variations in the adjustments of its control element, throughout the operating range for which the unit is designed. The tuning unit comprises a fixed inductance and a variable condenser, having its movable plate so designed that the resonance point of the tuned circuit may be varied as a linear function of the displacement throughout the operating range of the unit.

An object of the invention is to accomplish the tuning of heterodyne receiving systems by means of a single control.

A second object is to permit the simultaneous adjustment of a plurality of tuned circuits so that the resonance frequencies differ constantly by fixed amounts.

Another object of the invention is to cause the frequency to which an adjustable tuned circuit is resonant, herein called its resonant frequency, to vary as a linear function of the position of the adjustable element over the operating range of the circuit.

A feature of the invention, essential to the achievements of the above mentioned objects, is an element, for use in a tuned circuit, which controls the circuit so that its resonant frequency varies as a linear function of the position of the element throughout the operating range of the circuit.

In the specific embodiment of the invention, this element is a variable air condenser, the movable plates of which are so designed that the resonant frequency of the circuit wherein it is used will be a linear function of the angle of rotation of the plate.

Equations for determining the shape and area of the rotary plates of an adjustable condenser adapted to vary the selectivity of a tuned circuit indirectly with frequency and by equal amounts for equal adjustments of the condenser throughout the broadcasting range are given below.

The fundamental equation identifying the relation between the resonant frequency and the angle of rotation in radians of the adjustable element of a resonant circuit, where a linear relation between them is desired is

$$f = a - b\theta \quad (1)$$

where the frequency "f" is highest when the

angle $\theta = 0$ and "a" and "b" are constants to be determined by the conditions to be met.

From the well known equation that

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where "L" represents the inductance, which is constant, and "C" identifies the capacity, which is variable, in the circuit under consideration; we may write

$$f = \sqrt{\frac{k}{A + A_0}} \quad (2)$$

In Equation 2 A denotes the area of the movable blades enclosed between the fixed blades, A_0 denotes an equivalent blade area sufficient to account for the fixed minimum capacity of the condenser, and k is a constant.

Substituting for f the value given in Equation (1), Equation (2) may be written as follows:

$$A = \frac{k}{(a - b\theta)^2} - A_0$$

The above equation defines the law in accordance with which the enmeshed area of the plates must vary in order that the linear relation between frequency and angle of rotation may be secured. This equation is fundamental and is independent of the particular type of plate used or of the mode of adjustment. To develop the detail design of a condenser, it is necessary to determine an exact expression for the geometrical form that will produce the above described variation of the enmeshed area.

The formulæ for the design of a rotating condenser of conventional type will be developed. The rotating plates are in the form of segments, the radius of which measured from the axis of rotation varies with the angle of displacement. The fixed plates are so arranged that the enmeshed area of the moving plates as the angle of rotation is varied, comprises a variable sector limited on one side by the shortest radius of the moving plates.

If "r" represents the variable outside radius of the movable condenser plate and "r₁" is the radius of the segment which must be cut from the stationary plate in order to clear the shaft and spacers supporting the rotary plates, we may write as the area of a small sector:

$$dA = \frac{r^2 d\theta}{2} - \frac{r_1^2 d\theta}{2}$$

whence

$$\frac{dA}{d\theta} = \frac{r^2 - r_1^2}{2}$$

From the previous equation relating the area to the angular rotation, a second equation

tion for the rate of change of the area may be formed, namely:

$$\frac{dA}{d\theta} = \frac{2bk}{(a-b\theta)^3}$$

By combining the two equations for the rate of change of the area, the relationship between the radius r and the angle θ is found, which gives the desired law of capacity variation. This equation is

$$r^2 = \frac{4bk}{(a-b\theta)^3} + r_1^2 \quad (3)$$

The arbitrary constants a , b , and k may be eliminated from Equation (3) as follows: Let f_o and f_π denote, respectively, the maximum and the minimum frequencies corresponding to the extreme condenser settings, 180° or π radians apart, and let " n " be the ratio of f_o to f_π . Further, let r_π be the maximum radius of the rotating blades, then from Equation (1) it follows that:

$$a = f_o$$

$$b = f_\pi \frac{n-1}{\pi}$$

$$\text{and } (a-b\theta) = f_\pi \left[n - \frac{\theta}{\pi}(n-1) \right]$$

Again by substituting the values of a and b in Equation (3) and solving the equation for the value of θ equal to π the value of k is found to be

$$k = \frac{\pi f_\pi^2 (r_\pi^2 - r_1^2)}{4(n-1)}$$

Substituting the values thus found for a , b and k in Equation (3), the equation may be transformed to:

$$r^2 = \frac{r_\pi^2 - r_1^2}{\left[n - \frac{\theta}{\pi}(n-1) \right]^3} + r_1^2 \quad (4)$$

in which the arbitrary constants are now the two radii r_1 and r_π and the ratio n of the extreme frequencies.

A further simplification of the form of Equation (4) may be accomplished by dividing both sides by r_π^2 and denoting the ratios

$$\frac{\theta}{\pi} \text{ and } \frac{r}{r_\pi}$$

by t and u , respectively; then

$$\frac{r}{r_\pi} = \frac{1}{u} \sqrt{\frac{u^2 - 1}{[n - t(n-1)]^3} + 1} \quad (5)$$

If we let $n=3$, which is the ratio most adaptable to the present broadcasting wavelength range with a reasonable overlap, and solve this equation for $r_\pi=1''$, we may obtain a solution which is independent of the exact dimensions of the plates.

The final calculations may be further simplified if we let $s=18t$, i. e., if the equation is solved for $s=1$, we obtain the radius of the plate at an angle of 10° , or, if $s=18$, the radius of the plate is equal to the maximum radius r . Making the substitutions we may write

$$r = \frac{1}{u} \sqrt{\frac{729 \times (u^2 - 1)}{(27 - s)^3} + 1}$$

As a convenient first solution r_π was chosen as $2''$ and r_1 as $\frac{3}{8}''$. This gives $u=16/3$, and our equation becomes

$$r = \frac{3}{16} \sqrt{\frac{20003}{(27 - s)^3} + 1} \quad (A)$$

To determine the capacity of the condenser it is necessary to determine the area of one plate. This may be computed by substituting the value of the radius r given by Equation (4) in the equation for the elemental sector area and integrating the resulting equation with respect to the angle θ between the limits zero and π . The result of such integration gives for the useful area of one side of the plate the value

$$A = \frac{\pi(r_\pi^2 - r_1^2)}{4n^2} (n+1) \quad (B)$$

For a plate having the dimensions given above the area in square inches of the rotary plate will be

$$A = \frac{\pi(4 - 9/64)4}{4 \times 9} = 1.346$$

For spacing of $.025''$ between plates of opposite polarity, constituting a single unit, the capacity thereof would be 12.12 mmf. or with 60 units, corresponding to 30 movable plates, the capacity would be 727 mmf.

By using Equation (A), we can find the radius of the rotary plate of the condenser for as many angles as desired. By plotting these different radii as the function of the angle, the curve of the periphery of the plate may be obtained. By using Equation (B) we may obtain the area of the plate from which we may calculate the capacity of the condenser.

The novel features which are believed to be characteristic of this invention will be pointed out with particularity in the claims appended hereto. The invention itself, however, as to its objects and advantages, the details of its organization and its mode of operation will be better understood by referring to the following description read in conjunction with the attached drawings, in which:

Fig. 1 is a tuned circuit embodying this invention,

Fig. 2 is an elevation of a condenser adapted to be used in connection therewith,

Fig. 3 is a section of the condenser taken on line 3-3 of Fig. 2,

Figs. 4 and 5 are circuits in which the tuning unit may be used to advantage,

Fig. 6 illustrates the application of the invention to a double-detection receiving system for the purpose of providing a single tuning control.

In Fig. 1 is shown a simple tuned circuit consisting of inductance 15 and capacity 16 typifying a circuit such as that employed in a wave trap, wave meter, frequency meter or in a signaling system where a tuned circuit is employed as a unit.

The advantages of a condenser, so designed that the resonant frequency of the circuit is a linear function of the angle of rotation of the movable plates, will be apparent when it is noted that by using such a condenser the same precision and ease of adjustment is obtained over the entire frequency range.

In the condenser shown in Figs. 2 and 3, the stationary plates 1, together with spacing washers 2 and insulating end plates 6 and 7 are assembled on rods 3. The rods are secured at one end to plate 7 while the other ends, projecting through the plate 6, are threaded to receive nuts 4, whereby these elements may be clamped together to constitute a unitary structure. Electrical connection is made to the fixed plates by means of thumb-nut 5.

Rotary plates 8 separated by spacing washers 10 are mounted on shaft 9 which is free to rotate in bearings provided in insulating end plates 6 and 7.

Spring 11 exerts pressure against the end of shaft 9 to produce sufficient friction to prevent the weight of plates 8 from causing rotation and thereby varying the adjustment effected. Binding post 12 is connected to the rotary plates through spring 11.

The condenser is shown mounted on an insulating panel 13 through which shaft 9 extends. Knob 14 is mounted on shaft 9 for the purpose of adjustment and has associated with it a dial for indicating the position of the movable plate.

Fig. 4 shows a typical radio receiver consisting of an antenna coupled to the receiving circuit by a transformer 17, the secondary of which is connected in parallel with a condenser 18 to constitute a circuit selective of the incoming high frequency wave.

The tuned circuit is included in the input circuit of a space discharge device 19, which operates as a detector and a signal indicating device 20, herein shown as a telephone receiver, is included in the output circuit of the device 19.

By using a condenser 18 having the straight line characteristic described above the difficulties attendant upon tuning the receiving circuit to select the waves of different frequencies radiated from the various broadcasting stations will be avoided, since throughout the operating range of the receiv-

ing circuit the frequency to which it is resonant will be varied by equal amounts for equal adjustments of the dial.

In Fig. 5 a plurality of tuned circuits are shown in a radio receiver employing a plurality of stages of radio frequency amplification.

Condensers 21 and 22 are used to control the selective circuits associated with the first and second high frequency amplifiers respectively.

The detector, D together with as many stages of low frequency amplification as are desirable, supplies signal or audio frequency current to the receiving device, herein shown as a telephone receiver.

By use of condensers 21 and 22 of the design described herein to control tuning of the selective circuits, a single control shaft may be employed to accurately adjust both tuned circuits to select any frequency lying within the operating range for which the set is designed.

With other types of condensers heretofore proposed, it would be difficult to maintain both circuits in resonance by varying the two controls an equal amount at the higher frequencies due to the critical adjustment required, which magnifies slight mechanical variation due to manufacturing processes.

Fig. 6 represents a conventional double detection system, consisting of a loop antenna 23 which may be tuned to the frequency of the incoming wave by condenser 24.

Oscillator 25 produces a sustained wave the frequency of which is determined by condenser 26. These oscillations are combined with the incoming wave in detector 27 to produce an intermediate frequency wave which may be used to control an amplifier A, consisting of as many stages as are desirable.

The intermediate frequency wave is detected in the device D, to yield the signal current, which is supplied to the telephone or other receiving devices.

In the circuit just described, condensers 24 and 26 must at all times be adjusted to maintain constant the difference between the frequency selected by the loop circuit and that of the local oscillations, which is largely determined by the tuned circuit associated with the oscillator.

With the types of condensers previously used, as pointed out above, it would be impossible, while controlling the two condensers by a single adjusting means, to maintain the frequency difference constant.

However, if condensers 24 and 26 are built in accordance with this invention, it will be possible by mounting them upon the same shaft and angularly displacing one with respect to the other about the common axis, to operate them by a single control. Condensers so constructed would be operative over 180° minus the angle of displacement.

This is a distinct advantage in receiving sets employing successive detection.

In systems of the double detection type used at the present time, it is essential to adjust two separate controls, the settings of which at certain points in the operating range of the set are critical. Because of this fact these settings can only be accomplished with any degree of accuracy, by a skilled operator. With the arrangement described above a single control element can be used to effect a much more accurate adjustment of the selective circuits than in the system now generally used, and as a result there is provided a receiving set which is especially adapted for use by an unskilled operator.

Although the invention has been shown as embodied in a particular structure and particular circuits, it is to be understood that this invention is not limited thereto, but only in accordance with the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a radio receiving circuit containing a plurality of circuits tuned to different frequencies, variable condensers adapted to control the resonant frequency of said circuits, said variable condensers including movable plates of such shape that the resonant frequency of the tuned circuits varies as a straight line function of the angle of rotation of said plates, and a uni-control means for said movable plates.

2. In a radio receiving system adapted to detect signals by beating the received waves with waves from a local oscillator, a tuned circuit for the received waves, a second tuned circuit for determining the frequency of the local oscillations, variable elements in said tuned circuits adapted for adjusting the resonance frequencies thereof, and means for adjusting the variable elements simultaneously by single control the first tuned circuit to any of a plurality of frequencies in a frequency range of the order of an octave, said elements being so proportioned and disposed with respect to each other that the resonance frequencies of said tuned circuits differ by a constant amount for all positions of the common control.

3. In a heterodyne receiving system, a tuned circuit for received waves, a second tuned circuit for determining the frequency of the heterodyne wave, continuously variable condensers included in said tuned circuits, and a control means adapted to adjust said condensers simultaneously, said condensers being so proportioned and disposed with respect to each other that the resonance frequencies of said tuned circuits differ constantly by fixed amount while the resonant frequency of one of said tuned circuits is varied over a frequency range of the order of an octave.

4. In a heterodyne receiving system, a

tuned circuit for received waves, a second tuned circuit for determining the frequency of the heterodyne wave, continuously variable condensers included in said tuned circuits, and a control means adapted to adjust said condensers simultaneously, said condensers being proportioned to produce linear variations of the resonance frequencies of the respective tuned circuits with respect to the degree of condenser adjustment, and being relatively displaced to provide a fixed difference between the resonance frequencies while the resonant frequency of one of said tuned circuits is varied over a frequency range of the order of an octave.

5. A signal receiving system comprising an input circuit and an oscillator circuit, each of said circuits being provided with requisite tuning means including variable elements adapted to give a straight line frequency variation, and said circuits being tuned to different predetermined frequencies, and means for simultaneously varying the said tuning means so as to maintain constant said frequency difference.

6. A signal receiving system comprising an input circuit and an oscillator circuit, each of said circuits being provided with variable tuning condensers adapted to give a straight line frequency variation, said tuning condensers being relatively so adjusted as to give said circuits a predetermined frequency difference, and means to maintain constant throughout the operating range said frequency difference.

7. A signal receiving system comprising an input circuit and an oscillator circuit, each of said circuits being provided with variable tuning means adapted to give a straight line frequency variation, the said tuning means being mechanically connected in fixed relation and relatively adjusted to maintain a predetermined frequency difference between said circuits, and a tuning control common to the said tuning means.

8. A signal receiving system comprising an input circuit and an oscillator circuit, each of said circuits being provided with variable tuning means adapted to give a straight line frequency variation, the variable elements of the said tuning means being mounted upon a common shaft and fixed thereon in such angular relation as to maintain a predetermined frequency difference between said circuits.

9. In combination, a tuned circuit, a second circuit tuned to a frequency differing from a frequency to which the first circuit is tuned, each of said circuits containing inductance and capacity elements, and movable control means for simultaneously varying the reactance of one of said elements of each tuned circuit, the variable elements being so proportioned that the frequency of the tuned circuits varies as a straight line func-

tion of the movement of said control means, to maintain a constant difference between the frequencies to which said circuits are tuned.

5 10. In combination, a plurality of circuits tuned to different frequencies each of said circuits containing a variable condenser for controlling the frequency to which the circuit is tuned, said variable condensers having
10 movable plates of such shape that the resonant frequency of the tuned circuits varies as a straight line function of the angle of rotation of said plates, and a shaft supporting said movable plates whereby the variable
15 condensers are simultaneously controlled.

11. In a heterodyne signal receiving system employing a super-audible beat frequency, an input circuit and an oscillator circuit, each of said circuits being provided
20 with tuning means including variable elements, said circuits being tunable to different frequencies, the difference of said frequencies being said beat frequency, and means for simultaneously varying the said
25 tuning means, said varying means so relatively connecting said tuning means and said variable elements as to maintain constant said beat frequency.

12. A superheterodyne receiver including
30 a resonant circuit tunable to a signal frequency, an oscillator circuit tunable to a frequency which differs from the signal frequency by a super-audible beat frequency, tuning means for each circuit including an
35 element having a variable electrical value, means for simultaneously varying said tuning means, the said varying means so relatively connecting said tuning means and said variable elements as to maintain said beat
40 frequency a constant.

13. A method of operating a superheterodyne receiver which consists in collecting
45 signal energy of a desired frequency by tuning a resonant circuit to said frequency, producing local energy of a frequency differing from the signal frequency by a super-audible frequency by tuning an oscillation circuit, combining the local and signal energies to produce said difference frequency,
50 and simultaneously varying by equal movements the tuning of the resonant and oscillation circuits to other frequencies, but maintaining the said super-audible difference frequency constant.

55 In witness whereof, I hereunto subscribe my name this 23d day of October, A. D. 1924.
SIDNEY E. ANDERSON.