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## FREQUENCY MODULATION MEASUREMENT

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My invention relates to a method and apparatus for measuring frequency modulated waves.

As is well known, frequency modulation is a term applied to modulation effected by varying the frequency of high frequency carrier waves at a rate and in a degree determined respectively by the frequency and amplitude of modulating waves. The amplitude of the carrier waves is preferably maintained constant, as distinguished from amplitude modulation wherein the frequency of the high frequency carrier waves remains constant and the amplitude thereof is varied in accordance with the modulating waves.

In amplitude modulated radio systems the degree of modulation of a modulated carrier wave is commonly measured by means of an oscilloscope or oscillograph having a pair of coordinate deflecting elements to which the modulated carrier waves and modulating waves are respectively applied, thereby causing a projected ray to be deflected in a particular manner. The pattern traced by the ray on a viewing screen or other sensitive surface is determined by the amplitudes of these waves and gives a direct indication of the degree of modulation, as is well understood in the art. However, this method of measurement is unsuitable for the direct measurement of modulation in a frequency modulation system since the amplitude of the modulated waves is not a function of the modulating potentials.

It is accordingly an object of my invention to provide an improved method and means for measuring the frequency characteristics of frequency modulated waves.

It is another object of my invention to provide a method and means for analyzing and indicating directly the degree of modulation of frequency modulated waves.

A further object of my invention is to provide a method and apparatus for producing a wave pattern in accordance with frequency modulated waves and altering the configuration of said pattern in accordance with waves of a known frequency to give a direct indication of the degree of modulation.

Still another object of my invention is to provide a method and apparatus utilizing a cathode ray oscilloscope or oscillograph to give a direct indication of the degree of modulation of frequency modulated waves and for calibrating the same to measure modulation indirectly.

It is a further object of my invention to provide an improved method and means for measuring and indicating the frequency of a carrier or signal wave in terms of the deviation of the fre-

quency of the carrier from a predetermined frequency.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in which Fig. 1 diagrammatically illustrates, partly in conventionalized block form, a frequency modulation transmission system incorporating modulation measuring means embodying my invention; Figs. 2 and 3 represent oscillograms explanatory of the operation of the system of Fig. 1, and Figs. 4 through 6 illustrate various calibration scales which may be employed with the apparatus of Fig. 1.

Referring now to Fig. 1, my invention is illustrated in apparatus for monitoring a frequency modulation transmitter. The transmitter may comprise any suitable apparatus known to the art for supplying an antenna 10 with high frequency energy, the frequency of which is varied in accordance with a source of modulation potentials, for example, a microphone 11. The details of the transmitter form no part of my invention and are therefore not represented. Briefly, modulating potentials supplied from the source 11 are applied to the frequency modulator 12. By means of the modulator 12 the frequency of the oscillations generated by the carrier frequency generator 13 is varied over a frequency band at a rate and in a degree determined respectively by the frequency and amplitude of the potentials supplied from the modulation source 11. The transmitting apparatus may of course include the usual elements for maintaining the amplitude of the modulated waves constant and for amplifying them prior to transmission.

While the modulation source 11 has been illustrated diagrammatically as a microphone 11 it will of course be understood that it may comprise any suitable source. For example, it may be replaced by an audio frequency oscillator generating a tone for test purposes.

The measuring apparatus includes a suitable device for giving an indication of the characteristics of the waves supplied to the antenna 10. This is illustrated as an oscilloscope 14 of the cathode ray type, since this type is particularly suited for use in a practical apparatus embodying my invention. This device is of the usual

construction, comprising an evacuated envelope having a fluorescent screen 15 at one end against which a stream of electrons forming a ray 16 is projected from a cathode 17, illustrated conventionally as of the indirectly heated type. The potential from a source 18, impressed between an anode 19 and the cathode 17 serves to accelerate the ray 16 toward the screen 15. The device is also provided with the usual ray deflecting means, illustrated as the pair of electro-static deflection plates 20 and 21, to which control potentials may be applied. One or both of the ray deflecting means may, of course, be of the magnetic type rather than the electrostatic type, if desired. The device may also include other elements such as means for focusing the ray and controlling the intensity thereof which are not shown since they are non-essential to an understanding of my invention.

While the device 14 has been indicated as a cathode ray oscilloscope, it will be apparent that it may comprise an oscillograph for producing a permanent record. The electro-optical type of instrument may also be used, where the frequency of the waves under investigation permits, in which a light ray rather than an electron ray is utilized to trace a two-dimensional pattern in accordance with the control potentials.

Potentials derived from the modulation source 11 and the transmitter output to the antenna 10 are applied respectively to the horizontal and vertical deflecting plates 20 and 21. As illustrated, waves generated by the source 11 are impressed through conductors 22 upon the primary of the transformer 23. The transformer secondary winding is connected to the extremities of a potentiometer 24. An adjustable tap 25 thereon is connected through a high frequency choke 26 to one of the deflecting plates 20, the other plate 20 being connected to ground through conductor 27. An additional potentiometer 28 connected across a source of constant bias potential, illustrated as a battery 29, is provided for maintaining a controllable amount of direct current bias on the plates 20 for purposes that will be apparent shortly. One terminal of potentiometer 28 and source 29 is grounded through conductor 30, and the adjustable tap 31 is connected to the lower end of potentiometer 24 through conductor 32 as shown. Thus, the complete circuit including the plates 20 extends from ground through conductor 30, an adjustable portion of bias potentiometer 28, tap 31, conductor 32, an adjustable portion of the potentiometer 24 across which potentials derived from modulation source 11 are developed, tap 25, choke 26, plates 20 and through conductor 27 to ground.

The means for deriving potentials from the transmitter output is illustrated as a tertiary winding 33' on the output transformer 33 which couples the transmitter to the antenna 10. One end of winding 33' is grounded and the other end is connected to one of the vertical deflecting plates 21 through the conductor 34. The complete circuit including the plates 21 extends from ground, through winding 33', conductor 34, plates 21, and conductor 27 to ground. If desired, a potentiometer or other suitable means, not shown, may be provided for adjusting the magnitude of the potentials applied to plates 21 from winding 33'.

In accordance with my invention and for reasons to be described presently, an adjustable

frequency oscillator 35 is provided. This oscillator may be of any well-known construction and is therefore indicated only diagrammatically. It is designed to generate oscillations of a predetermined known frequency which can be adjusted to any selected value within a band of frequencies. For reasons that will be set forth below this band is made wide enough to include the band of high frequencies which may be present in the frequency modulated transmitter output to antenna 10. Thus the oscillator 35 is indicated conventionally as having its frequency controlled by the variable capacitor 36' included in the frequency determining circuit 36. The movable element of capacitor 36' may carry a suitable pointer 37 movable over a scale 38 calibrated in terms of the oscillator frequency.

The oscillator output may be applied to a selected pair of the deflection plates 20 or 21 through the three-position switch 39. With the switch 39 in the upper position, as shown, the oscillator 35 is disconnected entirely from the plates. With the switch in the midposition, the output of oscillator 35 is applied to the vertical deflecting plates 21 concurrently with the potentials supplied from the winding 33'. When the switch 39 is in the lower position the output is applied to the horizontal deflecting plates 20 concurrently with the potentials derived from the source 11. The high frequency choke 26 serves to prevent the high frequency oscillations from oscillator 35 from finding a low impedance path to ground through potentiometers 24 and 28 when switch 39 is in the lower position.

Considering now the operation of the apparatus just described, assume first that the switch 39 is in the upper position and that oscillations are being supplied to the antenna 10, these oscillations being frequency modulated in accordance with the modulating potentials supplied by the source 11. A pattern 50 is produced on the screen 15 of the cathode ray oscilloscope of the general configuration as best indicated in Fig. 2. It is seen that this pattern is substantially rectangular. The height thereof depends on the amplitude of the frequency modulated waves applied to the vertical deflecting plates 21. The width depends upon the amplitude of the potentials applied to the horizontal deflecting plates 20 from the modulation source 11. The height of the pattern is therefore substantially constant and independent of the degree of modulation, while the width thereof varies directly with the degree of modulation. Since the instantaneous frequency of the output wave is a function of the instantaneous amplitude of the modulating potentials, each point along the horizontal axis of the pattern represents a definite instantaneous frequency of the output wave.

Assuming that the apparatus is in operation as just described to produce the pattern shown in Fig. 2, if the switch 39 is now moved to the mid position, so that a potential is now applied to the vertical deflecting plates 21 from the oscillator 35, the pattern is changed to one similar to that indicated at 50' in Fig. 3. It is seen that the shape of the pattern is still essentially rectangular except for a pair of diametrically opposite peaks 51. As the frequency of oscillator 35 is varied, it has been found that both these peaks move horizontally along the upper and lower edges of the pattern, always remaining vertically aligned.

The explanation of this phenomenon is thought to be as follows. If the horizontal sweep potentials derived from the source 11 are applied to the plates 20 and if the oscillator 35 alone is connected to the vertical plates 21, a rectangular pattern similar to that of Fig. 2 is produced. However, the waves at all points along the horizontal axis of this pattern are of the same predetermined frequency of oscillator 35. It will be recalled from the previous discussion of Fig. 2 that each point on the horizontal axis of the rectangular pattern produced by the frequency modulated waves corresponds to a different instantaneous frequency. If these two patterns are now combined, by the simultaneous application of oscillations from winding 33' and oscillator 35 upon the deflecting plates 21 and oscillations from modulation source 11 upon plates 20, the pattern of Fig. 3 results. It has been found that the vertical height of the pattern, excluding the peaks 51, is substantially determined by the oscillations of greater amplitude applied to the vertical deflecting plates 21. Preferably, though not necessarily, the oscillations supplied by oscillator 35 are of much less amplitude than those supplied by the winding 33'. Thus, apparently the pattern produced by the oscillations of greater amplitude effectively masks the pattern due to those of lesser amplitude over most of the resultant pattern. However, at one particular point on the horizontal axis the instantaneous frequency of the oscillations supplied from the winding 33' will be exactly equal to the frequency of the oscillations supplied from the oscillator 35. Waves of the same frequency may add vectorially, and the magnitude of their resultant depends on the phase angle between them. The value of this phase angle is a matter of fortuitous occurrence in this system and probably shifts rapidly since the two waves are independently generated. At some instants of time the two waves will combine additively to produce a resultant greater than either one, producing the peaks 51 in the pattern. Due to the persistence of vision and the retentivity of the fluorescent screen 15, these peaks appear to exist continuously.

While logically it might be supposed that the pattern shown in Fig. 3 would be produced only when switch 39 is in the mid position, as a matter of fact it has been observed that it also results when switch 39 is in the lower position, connecting oscillator 35 to the horizontal deflecting plates 20. Although I am not able to explain this effect with certainty, it is believed that electrostatic coupling between the two pairs of deflecting plates 20 and 21 in the cathode ray discharge device 14 is responsible. Apparently, due to the structure and characteristics of this particular type of device, enough energy of the frequency of oscillator 35 is coupled to the vertical deflecting plates 21 under these conditions to produce the effect described.

While I have suggested theories which seem to me to provide reasonable explanations for the occurrence of these phenomena, of course their correctness or incorrectness is immaterial to the practice of my invention. It has been found from actual experiments that these well-defined peaks do occur under the conditions specified.

Since, as previously mentioned, the position of the peaks 51 is indicative of the point at which the instantaneous frequency of the frequency modulated waves equals that of the oscillator 35, a very convenient means for direct frequency

measurement is provided. If the frequency of oscillator 35 is adjusted to the mean carrier frequency of the waves supplied to antenna 10 and if the frequency modulation is symmetrical about this mean carrier frequency, the peaks 51 occur exactly at the center of the pattern as shown in Fig. 3. As the frequency of oscillator 35 is increased the peaks move in a horizontal direction, for example to the right on the pattern. When they reach the dotted positions 52 at the edge of the band the frequency of oscillator 35 corresponds to the upper limit of the frequency swing of the modulated carrier waves and may be read directly from the calibrated scale 38. Similarly, as the frequency of oscillator 35 is decreased until the peaks occupy the dotted positions 53, the lower edge of the modulation band is determined. Reversing the connections to the plates 20 of course reverse the pattern.

Once the apparatus is adjusted for a given set of operating conditions, a scale placed on the screen 15 may be calibrated by means of the oscillator 35 for indirect measurements of frequency modulation. Figs. 4, 5 and 6 illustrate various scales which may be employed. In Fig. 4, for example, the scale is calibrated in terms of per cent modulation above and below the mean carrier frequency. 100 per cent modulation is arbitrarily defined as a certain definite frequency deviation above or below the mean frequency. In Fig. 5 a scale is shown calibrated directly in terms of frequency. As illustrated, the scale is designed for transmission apparatus for which the assigned mean frequency is 42.00 megacycles. If the maximum allowable frequency swing is 60 kilocycles above or below this frequency, the upper and lower ends of the scale will correspond to 42.06 and 41.04 megacycles respectively.

By increasing or decreasing the constant potential bias applied to the horizontal deflecting plates 20 from the potentiometer 28, the entire pattern may be shifted to one side so that only one edge is visible on the screen, and by increasing the magnitude of the modulation potentials applied to these plates from the potentiometer 24, the visible portion of the pattern may be expanded horizontally. By thus shifting and expanding the horizontal scale the position of the edge of the pattern may be measured with much greater accuracy, either directly or indirectly. Thus, for example, Fig. 6 illustrates a scale calibrated in terms of per cent modulation near the upper limit of frequency swing. From this it is a simple matter to determine whether the maximum modulation swing is being maintained within allowable limits.

Oscillations supplied from several oscillators of known frequency may be impressed simultaneously on the deflecting electrodes to give a plurality of peaks each corresponding to the frequency of one of the oscillators. Thus, for example, an oscillator of highly constant frequency may be maintained accurately at the mean carrier frequency, as by crystal or resonant line control. This will produce an accurately located peak corresponding to the frequency of the unmodulated carrier. Other oscillators may be adjusted for the upper and lower limits of the maximum permissible modulation band. Thus, the symmetry or dissymmetry of modulation will be readily apparent and a horizontal shift of the entire pattern will indicate a deviation of the mean carrier frequency from its assigned value.

While I have shown my invention employed

for monitoring a frequency modulation transmitter, it will be apparent that it can equally well be employed with a frequency modulation receiver. In such case additional amplification of the received signals may be necessary to provide sufficient voltage for operating the indicating or recording device.

It will be understood that while my invention is described herein as particularly directed to and as embodied in a system for monitoring a frequency modulation transmitter apparatus, the invention is not to be held limited to use in frequency modulation systems. My invention considered in its broadest aspect is applicable to a system for measuring over a given frequency range the deviation from a predetermined frequency of the frequency of any carrier or like signal wave, whether frequency modulated or unmodulated. It will be evident, for example, to those skilled in the art to which the present invention pertains that if the generator or oscillator 13 be assumed to be arranged as a source of any given carrier or like signal wave whose deviation from a desired frequency it is desired to measure and the oscillator 35 as a source of oscillations frequency modulated about a mean reference frequency, as for example, by a test modulating voltage of fixed lower frequency, the device in accordance with my invention may be utilized for the indication of such deviation. In this case, the mean frequency of the frequency-modulated wave from oscillator 35 is first adjusted to the predetermined desired frequency of the carrier wave from oscillator or generator 13. Assuming that the frequency of the carrier wave produced by oscillator 13 has deviated from its predetermined desired value to an undesired value, then by the combining of this undesired frequency of the carrier wave from oscillator 13 with the corresponding instantaneous frequency within the range of the frequency-modulated wave from oscillator 35, a visible indication, in the form of a deformation or change in the pattern on the oscillograph screen, is produced which shows to what degree the carrier wave has varied in frequency from its predetermined desired mean frequency. It is obvious, therefore, that in operation of the device in accordance with my invention, a visible indication of frequency deviation of a carrier wave from a desired value may readily be obtained by frequency modulating either the wave to be tested or the locally generated wave from the oscillator 35. Of course, if the wave to be tested is already a frequency modulated wave, as a wave modulated in frequency in accordance with a signal, only a constant frequency wave need be generated by the local oscillator 35.

It is further obvious that it may be assumed that the oscillator 35 may be the source of the given carrier or like wave whose deviation from a predetermined frequency it is desired to measure, the oscillator 13 then being an adjustable source of a frequency-modulated wave, either signal modulated or test modulated. In this assumed case the mean frequency of the frequency-modulated wave from oscillator 13 is first adjusted to the predetermined desired frequency of the given carrier wave from oscillator 35. Assuming a deviation of the carrier wave from its predetermined desired frequency to an undesired frequency, then by combining this undesired frequency with the corresponding instantaneous frequency from frequency-modulated oscillator 13, a visible indication is produced as before on the

oscillograph screen showing to what degree the carrier wave has deviated from its desired frequency.

In general, therefore, my invention is applicable to any system including a source of oscillations the frequency of which varies over a predetermined range and further including an indicating means such as an oscillographic device having a sensitive screen upon which a ray or electron beam is adapted to be projected to produce a visible indication thereon, the screen having a calibrated scale associated therewith, and the ray or electron beam being controlled in accordance with the frequency of the oscillations to produce the visible indication at a point of the scale corresponding to the frequency.

Although I have shown a particular system for carrying out the principles of my invention, it will of course be understood that I do not wish to be limited thereto since many modifications may be made therein, and I contemplate by the appended claims to cover any such modifications which fall within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. The method of analyzing electrical oscillations whose frequency is varied over a frequency band at a rate and in a degree determined respectively by the frequency and amplitude of modulating oscillations which comprises the steps of producing an instantaneous two-dimensional pattern, one dimension of which is determined by the oscillations to be analyzed, and the other dimension of which is determined by the modulating oscillations, independently producing oscillations of a predetermined frequency lying within said band and altering the configuration of said pattern in accordance with said last-named oscillations.

2. The method of analyzing electrical oscillations whose frequency is varied at a rate and in a degree determined respectively by the frequency and amplitude of modulating oscillations which comprises the steps of producing an instantaneous electrical pattern in rectangular coordinates, the abscissae of which are proportional to the amplitude of said modulating oscillations and the ordinates of which are proportional to the amplitude of said oscillations to be analyzed, independently producing oscillations of a predetermined known frequency within the range of frequencies of the oscillations to be analyzed, and altering the shape of said pattern in accordance with said predetermined frequency to give an indication of the degree of frequency variations in said oscillations to be analyzed.

3. The method of analyzing oscillations which are frequency modulated over a frequency band in accordance with modulating potentials comprising the steps of producing a two-dimensional patterns whose dimensions are determined by the oscillations to be analyzed and the modulating potentials respectively, independently producing oscillations of a predetermined frequency within said band and altering the configuration of said pattern in accordance with said last-named oscillations.

4. The method of analyzing the frequency characteristics of electrical waves whose frequency is varied over a band of frequencies as a function of modulating potentials comprising the steps of directing an electron beam against a sensitive surface, deflecting said beam in one direction in accordance with said waves to be

analyzed, deflecting said beam in another direction in accordance with said modulating potentials and concurrently deflecting said beam in said first direction in accordance with oscillations of a predetermined known frequency lying within said band, whereby said beam traverses a pattern on said surface whose configuration is a function of said characteristics.

5. The method of analyzing the frequency characteristics of electrical waves whose amplitude is substantially constant and whose frequency is varied over a band of frequencies as a function of modulating potentials comprising the steps of projecting an electron beam against a sensitive screen, deflecting said beam along a first axis in accordance with said waves to be analyzed, deflecting said beam along a second, mutually perpendicular axis in accordance with said modulating potentials, whereby said beam is caused to traverse said screen in a pattern of substantially rectangular outline and whereby each point on said pattern along said second axis corresponds to a definite instantaneous frequency of said waves to be analyzed, and calibrating the positions of said points upon said screen in terms of the corresponding instantaneous frequencies, thereby to determine said frequency variations.

6. The method of analyzing the frequency characteristics of frequency modulated electrical oscillations whose instantaneous frequency is a function of the instantaneous magnitude of modulating oscillations which comprises the steps of projecting an energy-bearing ray against a screen, said ray being effective to produce an indication thereon, deflecting said ray along a first axis in response to said modulated oscillations, deflecting said ray along a second axis in response to said modulating oscillations, whereby said ray is caused to trace a two-dimensional pattern on said screen and whereby each point on said pattern along said second axis corresponds to a definite instantaneous frequency of said modulated oscillations, and calibrating the positions of said points upon said screen in terms of the corresponding instantaneous frequencies, thereby to determine said frequency characteristics.

7. The method of analyzing the frequency characteristics of frequency modulated electrical oscillations whose instantaneous frequency is a function of the instantaneous magnitude of modulating oscillations which comprises the steps of generating other oscillations of a predetermined frequency within the range of frequencies over which said frequency modulated oscillations are varied, projecting an energy-bearing ray against a surface, said ray being effective to produce an indication thereon, deflecting said ray along an axis in accordance with said modulating oscillations, and conjointly and simultaneously deflecting said ray along a mutually perpendicular axis in accordance with said frequency modulated oscillations and said oscillations of predetermined frequency, whereby said ray is caused to traverse said surface in a pattern whose shape is a function of said characteristics.

8. The method of determining the frequency characteristics of frequency modulated high frequency waves whose instantaneous frequency is a function of the instantaneous amplitude of lower frequency modulating waves comprising the steps of independently generating waves of a known frequency which may be adjusted to any frequency within the range of frequencies included by said frequency modulated waves, developing and projecting a stream of electrons against a

surface, deflecting said stream in one direction in response to said modulating waves and conjointly and simultaneously deflecting said stream in another mutually perpendicular direction in response both to said frequency modulated waves and to said known frequency waves, whereby said stream is caused to traverse said surface in a pattern whose shape is a function of said frequency characteristics.

9. The method of determining the degree of modulation of frequency modulated high frequency waves which extend over a continuous frequency band and whose instantaneous frequency is a function of the instantaneous amplitude of modulating waves comprising the steps of producing waves of a predetermined high frequency lying within said band, developing and projecting a stream of electrons against a surface, deflecting said stream in one direction in response to said modulating waves, simultaneously deflecting said stream in another mutually perpendicular direction in response to said frequency modulated waves, whereby a pattern of substantially rectangular outline is traversed by said stream upon said surface whose width in said first direction is proportional to the width of said band, and conjointly and simultaneously further deflecting said stream, in said last named direction in response to said predetermined frequency waves, whereby diametrically opposite deformations are produced in opposite sides of said pattern whose positions correspond to the position of said predetermined frequency within said band.

10. The combination, in apparatus for measuring frequency modulated waves whose instantaneous frequency is a function of the instantaneous magnitude of modulating waves, of a source of waves of known frequency, means to develop and project an energy-bearing ray against a surface, said ray being effective to produce an indication on said surface, a pair of ray deflecting means each adapted to be energized to deflect said ray in one of two different directions, means to energize one of said deflecting means in response to said frequency modulated waves, means to energize the other of said deflecting means in response to said modulating waves, and means to energize one of said deflecting means in response to said known frequency waves.

11. Apparatus for analyzing frequency modulated electrical oscillations whose frequency is varied over a band of frequencies in accordance with modulating potentials comprising, in combination, a source of oscillations of a predetermined known frequency lying within said band, means to project an energy-bearing ray against a surface, said ray being effective to produce an indication on said surface, means to deflect said ray along an axis in response to said oscillations to be analyzed, means to deflect said ray along a second axis in response to said modulating potentials, and means conjointly to deflect said ray along said first axis in response to said oscillations of known frequency.

12. Apparatus for analyzing frequency modulated electrical oscillations whose amplitude is substantially constant and whose frequency is varied over a band of frequencies as a function of modulating potentials comprising, in combination, means to project an electron beam against a sensitive screen, means to deflect said beam along a first axis in response to said oscillations to be analyzed, means to deflect said beam along a second mutually perpendicular axis in response

to said modulating potentials, whereby said beam is caused to traverse said screen in a pattern of substantially rectangular outline and whereby each point on said pattern along said second axis corresponds to a definite instantaneous frequency of said waves to be analyzed, and a scale positioned adjacent said screen and calibrated to indicate the positions of said points upon said screen in terms of the corresponding instantaneous frequencies.

13. Apparatus for analyzing the frequency characteristics of frequency modulated electrical oscillations whose instantaneous frequency is a function of the instantaneous magnitude of modulating oscillations comprising, in combination, means to project an energy-bearing ray against a screen, said ray being effective to produce an indication on said surface, means to deflect said ray along a first axis in response to said modulated oscillations, means to deflect said ray along a second axis in response to said modulating oscillations, whereby said ray is caused to trace a two-dimensional pattern on said screen and whereby each point on said pattern along said second axis corresponds to a definite instantaneous frequency of said modulated oscillations, and a scale positioned adjacent said screen and calibrated to indicate the positions of said points upon said screen in terms of the corresponding instantaneous frequencies.

14. The combination, in apparatus for analyzing frequency modulated wave energy whose instantaneous frequency is a function of the instantaneous magnitude of modulating potentials, of an adjustable source of waves of known frequency, a cathode ray discharge device including a sensitive screen, means to develop a cathode ray therein and to direct it toward said screen and a pair of coordinate ray deflecting means, means to impress said waves to be analyzed on one of said deflecting means, means simultaneously to impress said modulating potentials on said other deflecting means, means conjointly to impress said known frequency waves on one of said deflecting means, and means to adjust the frequency of said known frequency waves.

15. The combination, with a source of modulation frequency waves, a high frequency source of waves of substantially constant amplitude and means for modulating the frequency of said high frequency waves over a frequency band in a degree determined by the instantaneous amplitude of said modulation frequency waves, of an adjustable source of waves of a known frequency lying within said band, a cathode ray discharge device having ray developing means and a pair of coordinate ray deflecting means, means to energize one of said ray deflecting means with said modulation frequency waves, means to energize the other of said ray deflecting means with said frequency modulated high frequency waves, whereby said ray is caused to traverse a pattern of substantially rectangular outline representative of said frequency band, and means conjointly to energize one of said ray deflecting means with said known frequency waves whereby said pattern is locally deformed to give an indication of the position of said known frequency within said band.

16. The combination, with a source of modulation frequency waves, a high frequency source of waves of substantially constant amplitude and means for modulating the frequency of said high frequency waves over a frequency band in a degree determined by the instantaneous ampli-

tude of said modulation frequency waves, of an adjustable source of waves of a known frequency lying within said band, a cathode ray discharge device having ray developing means and a pair of coordinate ray deflecting means, means to energize one of said ray deflecting means with said modulation frequency waves, means to energize the other of said ray deflecting means with said frequency modulated high frequency waves, whereby said ray is caused to traverse a pattern of substantially rectangular outline representative of said frequency band, means conjointly to energize one of said ray deflecting means with said known frequency waves whereby said pattern is locally deformed to give an indication of the position of said known frequency within said band, and means to vary said known frequency over said band to measure the width thereof.

17. A modulation indicator comprising a source of a modulation signal, a source of a carrier signal having its frequency modulated in accordance with said modulation signal, means for modifying the amplitude of said carrier signal at least at one of its modulation frequencies, a cathode-ray tube having a luminescent screen adapted to be scanned by a beam of electrons, means for deflecting said beam in one direction in accordance with said modified frequency-modulated carrier signal, and means for deflecting said beam in another direction in accordance with said modulation signal to produce a pattern on said screen indicative of the frequency excursions of said frequency-modulated carrier signal.

18. A modulation indicator comprising a source of a modulating signal, a source of a carrier signal having its frequency modulated in accordance with said modulation signal, means for modifying the amplitude of said carrier signal at certain frequencies, a cathode-ray tube having a luminescent screen adapted to be scanned by a beam of electrons, means for deflecting said beam in one direction in accordance with said modified frequency-modulated carrier signal, means for deflecting said beam in another direction in accordance with said modulation signal to produce a pattern on said screen indicative of the frequency excursions of said frequency-modulated carrier signal, and indicating means positioned adjacent said pattern calibrated to indicate the carrier-frequency excursion as a function of the amplitude of said modulation signal.

19. The method of analyzing the frequency characteristics of electrical waves whose frequency is varied over a band of frequencies as a function of modulating potentials comprising the steps of directing an electron beam against a sensitive surface, deflecting said beam in one direction in accordance with said waves to be analyzed, deflecting said beam in another direction in accordance with said modulating potentials and modifying the deflection of said beam in said first direction at least at one predetermined known frequency lying within said band, whereby said beam traverses a pattern on said surface whose configuration is a function of said characteristics.

20. A modulation indicator comprising a source of a modulation signal, a source of a carrier signal having its frequency modulated in accordance with said modulation signal, a cathode-ray tube having a luminescent screen adapted to be scanned by a beam of electrons, means for deflecting said beam in one direction in accordance with said modulation signal, means for deflecting said beam in another direction in ac-

cordance with said frequency-modulated carrier signal, and means for modifying the amplitude of deflection of said beam in said second direction at least at one of the frequencies over which said carrier signal is modulated, whereby a pattern is produced on said screen indicative of the frequency excursions of said frequency-modulated carrier signal.

21. A modulation indicator comprising a source of a modulation signal, a source of a carrier signal having its frequency modulated in accordance with said modulation signal, a cathode-ray tube having a luminescent screen adapted to be scanned by a beam of electrons, means for deflecting said beam in one direction in accordance with said modulation signal, means for deflecting said beam in another direction in accordance with said frequency-modulated carrier signal, means for modifying the amplitude of deflection of said beam in said second direction at least at one of the frequencies over which said carrier signal is modulated, whereby a pattern is produced on said screen indicative of the frequency excursions of said frequency-modulated carrier signal, and indicating means positioned adjacent said pattern calibrated to indicate the carrier-frequency excursion as a function of the amplitude of said modulation signal.

22. In combination, a source of oscillations modulated in frequency within a range of frequencies, a second source of unmodulated oscillations having a fixed frequency within said range, a cathode ray discharge device having a sensitive viewing screen, a calibrated scale co-operating with said screen, means for projecting an electron ray upon said screen, means providing a normal path of travel of said ray along said scale in accordance with the instantaneous frequency of said frequency modulated oscillations, and means for controlling said ray in accordance with said modulated and unmodulated oscillations to produce a significant visible indication when the instantaneous frequencies of said oscillations are substantially the same.

23. The method of indicating the frequency deviation of a carrier wave from a predetermined frequency which comprises generating a reference wave at said predetermined frequency, frequency modulating one of said waves, projecting an electron beam against a sensitive screen, causing said beam normally to travel along one coordinate axis of said screen in accordance with the instantaneous frequency of said frequency modulated wave, and controlling said beam in accordance with said oscillations to produce a significant visible indication on said screen whenever said frequency modulated wave is at zero beat with the unmodulated wave.

24. The method of indicating over a predetermined frequency range the deviation of frequency of a carrier wave relative to a predetermined frequency which comprises, generating said carrier wave, independently producing a reference wave adjustable in frequency over a range corresponding to said predetermined range, frequency modulating one of said waves, projecting an energy bearing ray against a sensitive surface, continuously sweeping said ray in a predetermined path in accordance with the instantaneous frequency of said frequency modulated wave to define upon said surface a frequency scale, and causing said ray to produce on said scale a significant visible indication when the frequencies of said carrier wave and said independently produced wave correspond.

25. The combination with a source of high frequency waves having a frequency subject to variation relative to a predetermined frequency over a predetermined range of frequencies, of a source of waves adjustable in frequency over a range of known frequencies corresponding to said predetermined range, means for frequency modulating one of said waves, a cathode ray discharge device including a sensitive screen, means for projecting a cathode ray in said device against said screen, means for continuously sweeping said ray in a predetermined path defining a frequency scale in accordance with instantaneous frequency deviations of said frequency modulated wave from its mean frequency, and means including both said sources of waves for producing on said scale a significant visible indication when said first and second named waves are of the same frequency.

26. Apparatus for indicating over a predetermined range the variation of frequency of a carrier wave relative to a predetermined frequency comprising, in combination a source of carrier waves, a source of waves generated independently of said carrier wave adjustable in frequency over a range corresponding to said predetermined range, means for frequency modulating one of said waves, means for projecting an energy bearing ray against a sensitive surface, means for continuously sweeping said ray in a predetermined path and to an extent proportional to instantaneous deviations of said frequency modulated wave from the mean frequency thereof thereby to define upon said surface a scale of frequencies, and means for causing said ray to produce a significant visible indication upon said scale when the frequencies of said carrier wave and said independently produced wave coincide.

27. The method of indicating the frequency deviation of a carrier wave from a predetermined frequency which comprises generating a reference wave at said predetermined frequency, frequency modulating one of said waves, projecting an electron beam against a sensitive screen, causing said beam normally to travel along one coordinate axis of said screen in accordance with the instantaneous frequency of said frequency modulated wave, and controlling said beam in accordance with said oscillations to produce a significant change in the normal path of travel of said beam whenever said frequency modulated wave is at zero beat with the unmodulated wave.

28. The method of indicating the frequency deviation of received electric oscillations from an assigned frequency which comprises generating oscillations at a reference frequency corresponding to said assigned frequency, modulating the frequency of one of said oscillations, beating the received oscillations with said reference frequency oscillations, and producing a significant change in a predetermined normal path of travel of a space flow of electrons during each modulation cycle at times when the modulated oscillations sweep through the frequency of the unmodulated oscillations.

29. The method of indicating the frequency deviation of a carrier wave from a predetermined frequency which comprises generating a reference wave at said predetermined frequency, frequency modulating one of said waves in accordance with a modulating voltage of lower frequency, projecting an energy-bearing ray against a sensitive surface, controlling said ray in accordance with the instantaneous frequency of said modulated wave to define on said surface a

frequency axis combining said waves to provide oscillations at beat frequency, and controlling said ray in accordance with said beat frequency oscillations to provide upon said scale a significant visible indication at the point of zero beat between said waves.

30. Apparatus for indicating the frequency deviation of a carrier wave from a predetermined frequency comprising a source of carrier waves, a source of reference waves of said predetermined frequency, means for frequency modulating one of said waves in accordance with a modulating voltage of lower frequency, an electron beam discharge device having a sensitive screen, means for continuously sweeping said electron beam in a normal path along one coordinate axis of said screen in accordance with instantaneous frequency deviations of said modulated wave from its mean frequency, and means controlled jointly by said modulated and unmodulated waves for effecting a significant visible change in the normal path of travel of said beam upon the occurrence of zero beat between said waves.

31. Apparatus for indicating the frequency deviation of a carrier wave from a predetermined frequency comprising a source of carrier waves, a source of reference waves at said predetermined frequency, means for frequency modulating one of said waves in accordance with a modulating voltage of lower frequency, an electron beam discharge device having a calibrated scale, means for continuously sweeping said electron beam in

a normal path along said scale in accordance with instantaneous frequency deviations of said frequency modulated wave from its mean frequency, means for beating said modulated and unmodulated waves together to provide beat frequency oscillations, and means responsive to said beat frequency oscillations for effecting a significant deflection of said beam laterally of said scale at instants of zero beat.

10 32. Apparatus for indicating the frequency deviation of the carrier wave from a predetermined frequency comprising a source of carrier waves, a source of reference waves at said predetermined frequency, means for frequency modulating one of said waves in accordance with a  
15 modulating voltage of lower frequency, an electron beam discharge device including a pair of coordinated beam deflecting means and a calibrated scale, means for controlling one of said  
20 deflecting means in accordance with said modulating voltage whereby displacement of said beam along said scale is proportional to the instantaneous frequency deviation of said frequency modulated waves from its mean frequency, means  
25 for beating said waves together to obtain beat frequency oscillations, and means for impressing said beat frequency oscillations upon the other of said coordinate deflecting means thereby to provide a significant lateral deflection of said  
30 beam upon occurrence of zero beat between said waves.

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