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[45] **Nov. 18, 1975**

[54] **DEVICE FOR OBSERVING WAVEFORM OF MICROWAVE SIGNAL**

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[52] **U.S. Cl.** **315/9;** 313/426; 313/432; 313/433; 315/378; 315/386

[51] **Int. Cl.²** **H01J 29/98;** H01J 29/70; H01J 23/16

[58] **Field of Search** 315/9, 3, 25; 328/228, 328/121; 313/432, 426, 427, 421, 439

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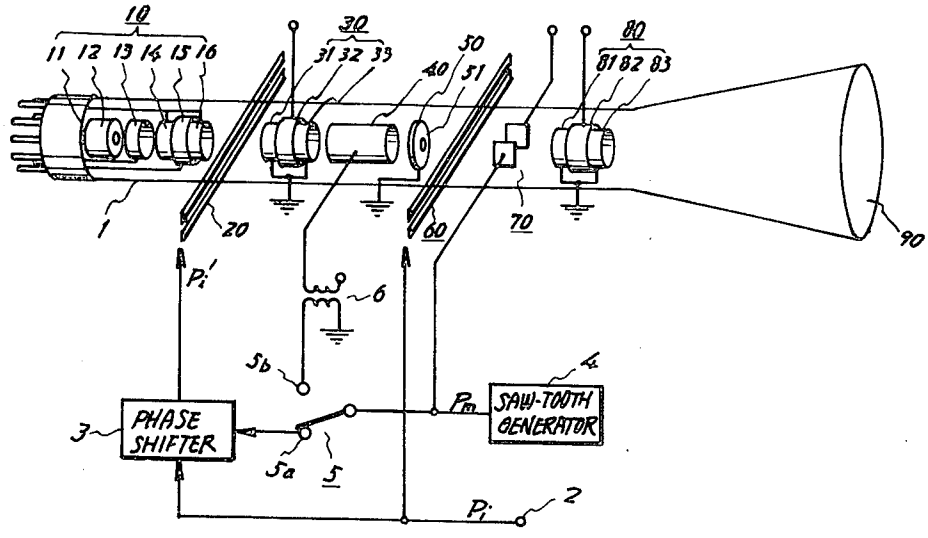
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[57] **ABSTRACT**

Apparatus for displaying the waveform of a microwave signal which embodies means for producing an electron beam, deflecting said beam in synchronism with the microwave signal and permitting transmission of the beam only when it is subjected to a predetermined deflection to form a pulsed beam. Deflecting the pulsed beam by a second deflecting signal synchronized with the microwave signal while varying the phase difference by a third signal and then displaying the effect of deflection by the second signal on one axis of the display means and controlling the sweep of the other axis of the display means by said third signal.

6 Claims, 7 Drawing Figures



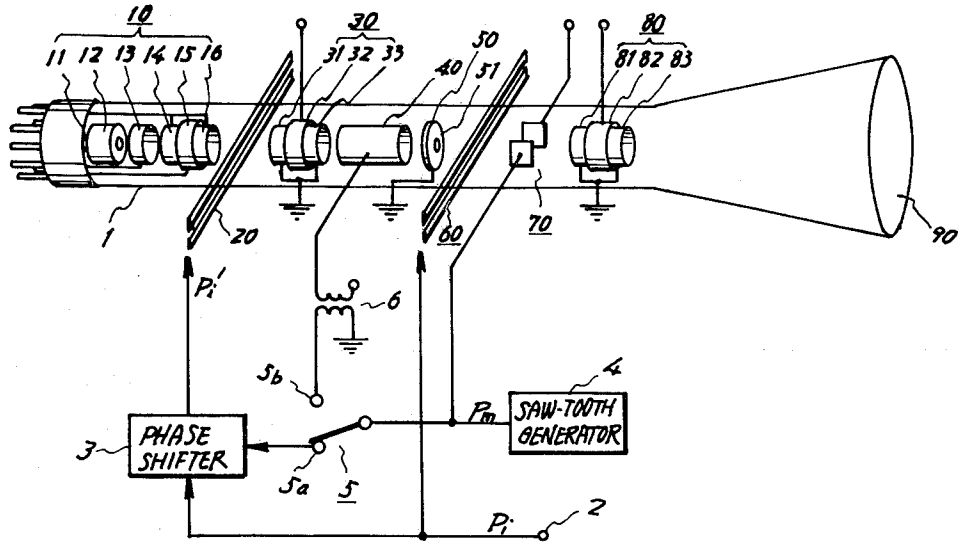

10
11 12 13 14 15 16
30
31 32 33
50
40 51
80
81 82 83
1
20
60
70
90
Pi'
6
5b
4
Pm
SAW-TOOTH GENERATOR
3
PHASE SHIFTER
5a
5
Pi
2

FIG. 1

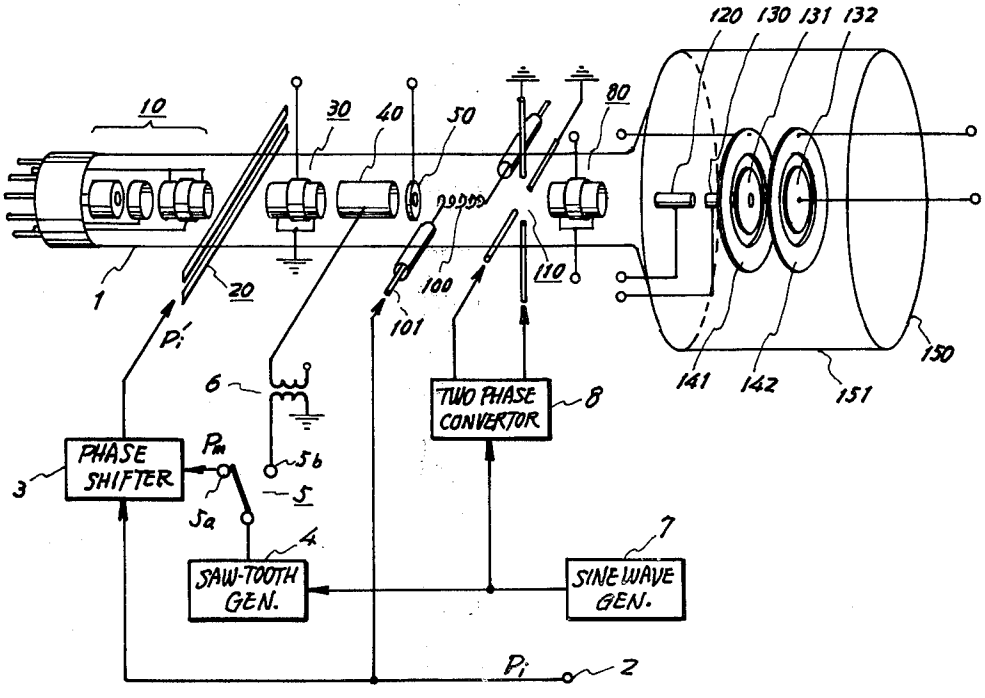

120 130 131 132
10
30
40
50
80
1
20
100
101
110
150
141
142
151
Pi'
6
TWO PHASE CONVERTOR
8
PHASE SHIFTER
3
Pm
5b
5
5a
4
SAW-TOOTH GEN.
7
SINE WAVE GEN.
Pi
2

FIG. 3

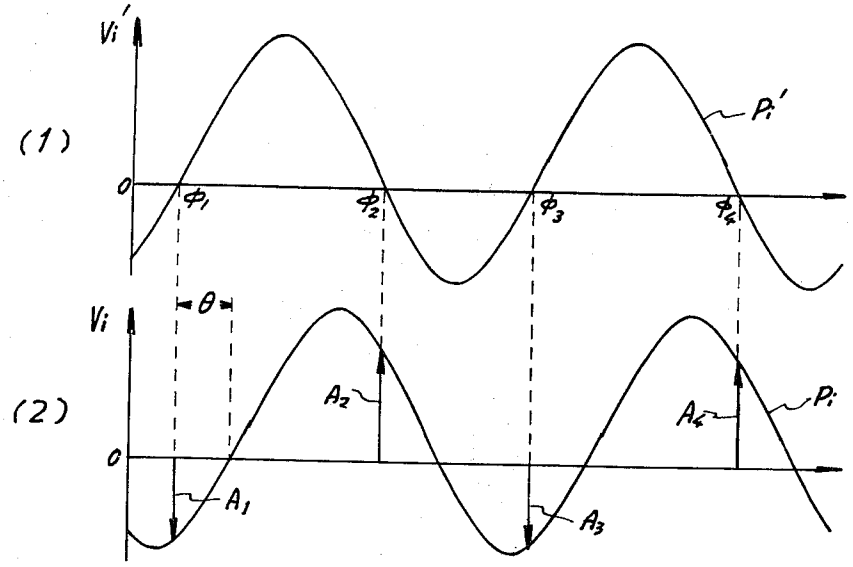


FIG. 2

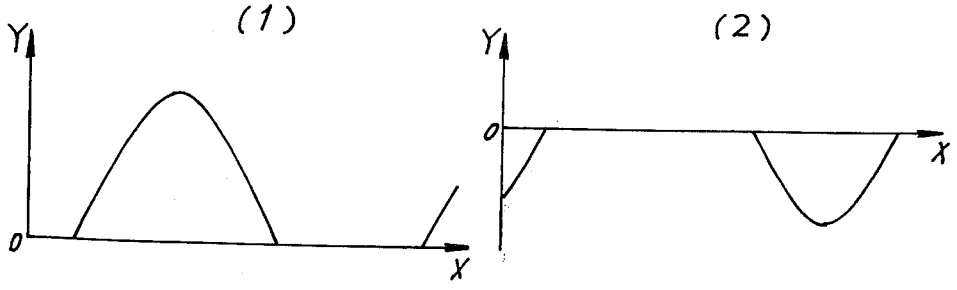


FIG. 5

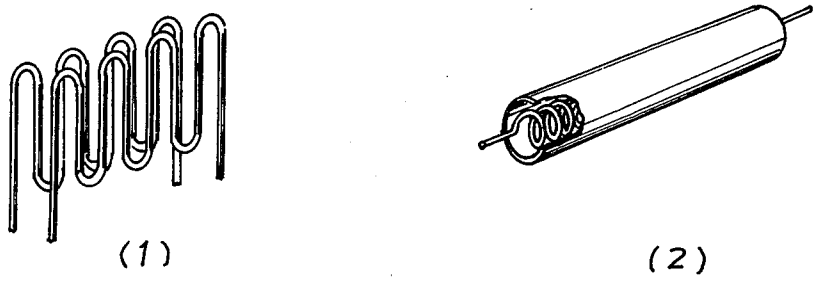


FIG. 7

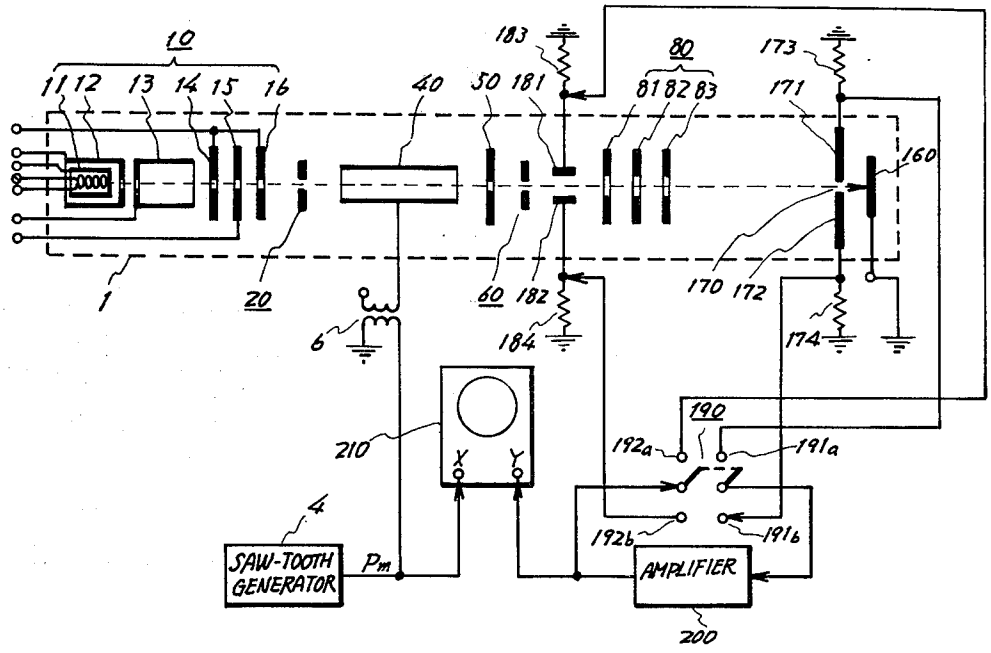

10
11 12 13 14 15 16
40
50 181
183
80
81 82 83
173
171
160
1
20
60
182
184
170 172
174
6
210
X
Y
190
192a
191a
192b
191b
4
SAW-TOOTH GENERATOR
Pm
AMPLIFIER
200

FIG. 4

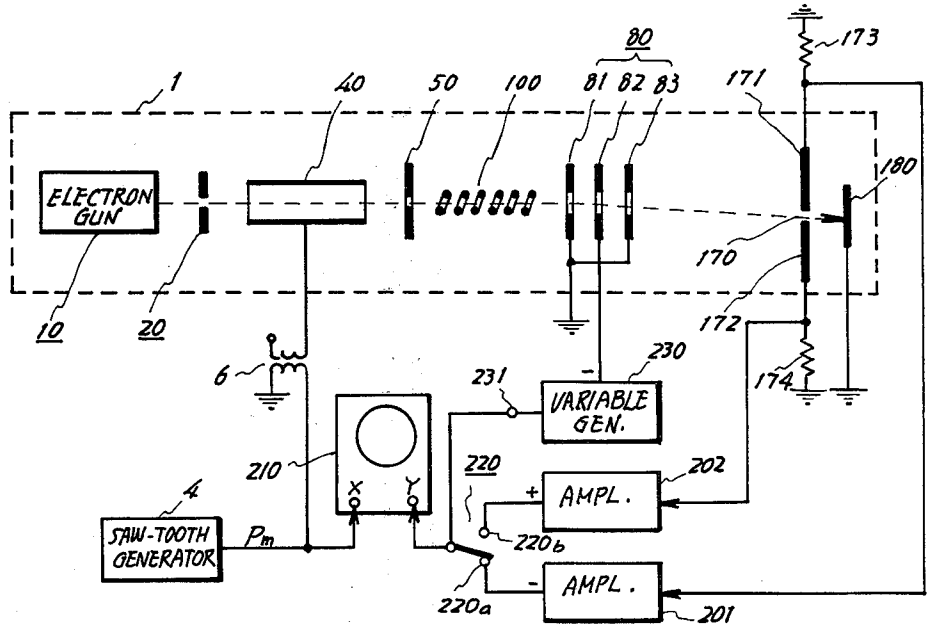

80
173
1
40
50
100
81 82 83
171
180
ELECTRON GUN
10
20
170
172
174
6
231
230
VARIABLE GEN.
210
220
202
AMPL.
4
SAW-TOOTH GENERATOR
Pm
220b
220a
AMPL.
201

FIG. 6

DEVICE FOR OBSERVING WAVEFORM OF MICROWAVE SIGNAL

This invention relates to an improved device for observing the waveform of a microwave signal and other extremely high frequency signals.

In order to observe the waveform of a microwave signal of high frequency, a sampling oscilloscope has been used. In this device, a voltage pulse, which is synchronized with the waveform to be observed and varies its phase bit by bit at every cycle, is produced and the waveform is sampled during the duration of this pulse and amplified for use in waveform display. As the duration of the voltage pulse must be short enough in comparison with the period of the waveform to be observed, the higher the frequency of the waveform becomes, the shorter the required duration of the pulse becomes. Thus, the prior techniques only enable observation of a waveform up to about 18 GHz. In addition, there is little likelihood of this upper limit of observable frequency being raised materially in the near future with known devices.

This invention intends to raise the upper limit of the observable frequency much higher by utilizing an electron beam technique.

The device for observing the waveform of a microwave signal according to this invention comprises a source for producing an electron beam, first deflecting means for deflecting said electron beam under control of a first waveform which is identical to or synchronous with that of said microwave signal, shutter means for letting said electron beam pass therethrough only when predetermined deflection is effected by said first deflecting means, thereby forming a pulsed elctron beam, second deflecting means for deflecting said pulsed electron beam under control of a second waveform which is identical to or synchronous with that of said microwave signal, phase shifting means for varying the phase difference between said first and second waveforms under control of a third waveform, and display means for effecting a display of the deflection effected by said second deflecting means along the phenomenon axis, the time axis sweep of said display means being effected in synchronism with said third waveform.

Other features and operations of this invention will be described in more detail hereinunder with reference to the accompanying drawings. In the drawings:

FIG. 1 is a schematic perspective view, partly in block form, representing an embodiment of a device according to this invention,

FIG. 2 is a waveform diagram to aid in explaining the operation of the device of FIG. 1;

FIG. 3 is a schematic perspective view, partly in block form, representing another embodiment of this invention;

FIG. 4 is a schematic sectional side view, partly in block form, representing a further embodiment of this invention;

FIG. 5 is a display pattern diagram to aid in explaining the operation of the device of FIG. 4;

FIG. 6 is a schematic sectional side view, partly in block form, representing a still further embodiment of this invention; and

FIG. 7 is a schematic perspective view representing two embodiment of a specific component of the device of this invention.

Throughout the drawings, like reference numerals are used to denote corresponding structural components.

Referring now to FIG. 1, an evacuated envelope 1 contains an electron gun assembly 10 comprising a cathode electrode 11, a Wehnelt electrode 12, an anode electrode 13 and an electron lens assembly consisting of three electrodes 14, 15 and 16 at one end thereof and an electron lens assembly 30 consisting of three electrodes 31, 32 and 33, a drift tube 40, a conductor disc 50 having a pin hole 51 in the center, a pair of facing deflection plates 70 and an electron lens assembly 80 consisting of three electrodes 81, 82 and 83 in that order in front of the electron gun assembly 10. A phosphor screen 90 is provided at the other end of the envelope 1. A pair of parrallel conductors 20 are located between the electron gun assembly 10 and the electron lens assembly 30 and a similar pair of parallel conductors 60 are located between the conductor disc 50 and the deflection plates 70, so that the electron beam emitted from the electron gun 10 passes the gaps between the both pairs of parallel conductors.

The parallel conductors 20 are connected to the output of the phase shifter 3 having a control terminal and an input terminal 2, the latter also being connected directly to the parallel conductors 60. The drift tube 40 is connected through a transformer 6 to one fixed contact 5*b* of a single-pole double-throw switch 5, while the other fixed contact 5a is connected to the control terminal of the phase shifter 3. A saw-tooth wave generator 4 is connected to the movable arm of the switch 5 and also to the deflection plates 70. The conductor disc 50 is grounded and the other electrodes are respectively connected as shown and fed with proper operation voltages from conventional voltage sources (not shown).

In operation, a microwave signal Pi to be displayed and observed, which has a waveform as shown in FIG. 2(2) for example, is applied to the input terminal 2. The input signal Pi is directly applied to the parallel conductors 60 and, at the same time, shifted in phase by θ and applied to the parallel conductors 20 as a signal Pi' as shown in FIG. 2(1).

The electron beam emitted from the electron gun 10 is deflected laterally by an electric field produced by the applied signal Pi' between the parallel conductors 20 when it passes the gap between the conductors. When the voltage Vi' of the signal Pi' is zero, the electron beam is not deflected and passes straight through the pin-hole 51 of the disc 50, while, when the voltage Vi' is not zero, it is deflected and collides against the disc 50 and is absorbed thereby. Consequently, the electron beam passes the pin-hole 51 of the disc 50 only at the time points ϕ_1, ϕ_2, ϕ_3, ϕ_4, . . . in FIG. 2(1) and enters the gap between the parallel conductors 60 in an intermittent pulselike form. In the gap of the parallel conductors 60, this electron beam pulse is deflected laterally by an electric field produced by the applied signal Pi as in the case of the parallel conductors 20.

As there is a phase difference of θ between the signals Pi and Pi', the fragments of the electron beam which have passed the pin-hole 51 of the conductor disc 50 at the time points ϕ_1, ϕ_2, ϕ_3, ϕ_4, . . . respectively are deflected by angles which are proportional to the voltages A_1, A_2, A_3, A_4, . . . respectively, as obviously illustrated in FIG. 2.

The saw-tooth wave generator **4** generates a saw-tooth wave signal Pm of relatively low frequency and, when the movable arm of the switch **5** engages the fixed contact **5***a*, this saw-tooth wave signal Pm is applied to the control terminal of the phase shifter **3** to control the phase shift thereof. For example, if the phase shifter **3** is arranged so that the phase difference θ is varied by the signal Pm from zero to 2π, the deflection effected by the parallel conductors **60** traces completely the waveform of the signal Pi. As the saw-tooth wave signal Pm is also applied to the deflection plates **70** and the electron beam is further deflected laterally by an electric field produced by the signal Pm between these plates **70** in the direction perpendicular to the deflection effected by the parallel conductors **60**, the waveform of Pi as shown in FIG. **2**(2) is displayed on the phosphor screen **90**.

The abovementioned phase control can be effected by switching the movable arm of the switch **5** to the fixed contact **5***b* to apply the saw-tooth wave signal Pm to the drift tube **40** instead of controlling the phase shifter **3**. In this case, the phase shift angle θ of the phase shifter **3** is maintained constant. However, as the potential of the drift tube **40** varies linearly in accordance with the slope of the saw-tooth wave Pm it changes the speed of the electrons in the pulsed electron beam passing therethrough. Accordingly, the transit time of the electrons from the parallel contuctors **20** to the parallel conductors **60** varies linearly and this results in the same phase shifting effect as that obtained when the switch **5** is in engagement with contact **5***a*. If the transformer **6** is selected appropriately, the same zero-to-2π phase shift is obtained and the full wave of the signal Pi is traced by the deflection effected by the parallel conductors **60** and similarly displayed on the phosphor screen **90**.

Due to the difference of magnification between the center and the periphery of the phosphor screen **90**, the device of FIG. **1** may produce some distortion of the displayed image. The device of FIG. **3** overcomes this undesired distortion of the displayed image.

In the device of FIG. **3**, an electron gun assembly **10**, a pair of parallel conductors **20**, an electron lens assembly **30**, a drift tube **40**, a pin-hole disc **50** and an electron lens assembly **80** are arranged in the neck portion of an evacuated envelope **1** in same manner as in the device of FIG. **1**. Between the disc **50** and the electron lens **80**, there is disposed a helical travelling wave guide **100** and two pairs of deflection conductors **110** arranged orthogonally with the tips of their inner ends facing each other. As in the device of FIG. **1**, the parallel conductors **20** are connected through a phase shifter **3** to an input terminal **2** and a saw-tooth wave generator **4** is connected through a switch **5** to the control terminal of the phase shifter **3** and further through a transformer **6** to the drift tube **40**. However, the saw-tooth wave generator **4** is coupled with a sine wave generator **7** and is synchronized by a sine wave signal generated thereby. The sine wave signal is also supplied to a two-phase convertor **8** to be converted into a synchronous two-phase a.c. voltage which is applied to the deflection conductors **110** to produce a rotating electric field therebetween.

The envelope **1** has an enlarged cylindrical head portion **150** and a phosphor display screen **151** is formed on the cylindrical side wall thereof. In the head portion **150**, there are located a drift tube **120**, a cylindrical electrode **130** having a flange **131**, a disc electrode **132** facing the flange **131** and two facing annular electrodes **141** and **142** respectively surrounding the flange **131** and disc electrode **132**.

In operation, a microwave signal Pi to be displayed is applied from the input terminal **2** through the phase shifter **3** to the parallel conductors **20** as in the device of FIG. **1** and, at the same time, is applied directly to the input terminal **101** of the helical guide **100**. The electron beam emitted from the electron gun **10** and modulated to form pulses by the parallel conductors **20** and the pin-hole disc **50** is axially velocity-modulated with the applied signal Pi in the helical guide **100** and then radially deflected by the rotating electric field produced by the deflection conductors **110**. The electron beam further passes the drift tube **120** and the cylindrical electrode **130** and enters a retarding electric field produced between the flange **131** and the disc electrode **132**. In this retarding field, the beam is deflected normal to the tube axis and collides with the cylindrical phosphor screen **151** after being focused by the annular electrodes **141** and **142**.

In this case, the deflection angle effected by the retarding field is inversely proportional to the speed of electrons. However, the speed of electrons is related to the voltage Vi of the signal Pi by means of velocity modulation in the helical guide **100** and, therefore, the longitudinal sweep on the phosphor screen **151** corresponds to the level of the signal Pi. Since the phase difference θ between the signal Pi' applied to the parallel conductors **20** and the signal Pi applied to the helical guide **100** is varied with the saw-tooth wave Pm and this phase shift is synchronized with rotation of the electric field produced by the deflection electrodes **110** as abovementioned, the waveform of the signal Pi is displayed on the cylindrical phosphor screen **151** at a period of rotation equal to the period of the sine wave produced by the sine wave generator **7**. As in the case of FIG. **1**, the drift tube **40** may be used for the phase shift by shifting the switch **5** to the other contact **5***b*.

In the embodiments of FIGS. **1** and **3**, the upper limit of the observable frequency is determined based only upon the ability of the parallel conductors or the helical travellings wave guide to provide the electron beam with an effective deflection or velocity modulation, and this is determined by the gap coefficient of the modulation gap. For example, when the accelerating voltage of the electron beam is 10 killovolts and the axial effective length of the gap is 0.2 millimeter, the electron transit angle in the gap is about $2\pi/3$ at 100 GHz of frequency of the wave to be observed, and the gap coefficient is about 0.83. Accordingly, satisfactory operation is obtained.

By designing the device of FIG. **3** such that the travelling speed of the wave, to be observed, in the helical travelling wave guide **100** becomes synchronous with the transit speed of the electrons, it enables more efficient velocity modulation than that afforded by the device of FIG. **1**. In addition, due to a wide band characteristic of the helical travelling wave guide, it becomes possible to observe waveforms over a wide frequency range.

Referring next to FIG. **4**, the arrangement and functions of components **10**, **20**, **40**, **50**, **60** and **80** in the evacuated envelope **1** are exactly same as those of the corresponding components of the device of FIG. **1**. In this embodiment, however, the envelope **1** has no phosphor screen and an electron collector electrode **160** is positioned instead at the end of the envelope **1** remote

from the electron gun **10.** The electrode **160** is grounded. Before the electrode **160,** there are a pair of flat electrodes **171** and **172** arranged in a same plane and define a slit **170** therebetween. The electrodes **171** and **172** are grounded through resistors **173** and **174** respectively. A pair of deflection electrodes **181** and **182** are located between the parallel conductors **60** and the electron lens assembly **80** and grounded respectively through resistors **183** and **184.** The electrodes **171** and **172** are also connected respectively through fixed contacts **191***a* and **191***b* of a double-pole double-throw switch **190** to a high gain amplifier **200** and the output of the amplifier **200** is connected through fixed contacts **192***a* and **192***b* of the switch **190** respectively to the deflection electrodes **181** and **182** and also connected to the phenomenon axis input Y of a cathode-ray tube oscilloscope **210.** The output of a saw-tooth wave generator **4** is connected through a transformer **6** to the drift tube **40** and also connected to the time axis input X of the oscilloscope **210.**

In operation, a microwave signal Pi to be displayed is applied to the parallel conductors **20** and **60** and a saw-tooth wave signal Pm is applied to the drift tube **40** in the same manner as in the operation of the device of FIG. **1** and causes a deflection of the pulsed electron beam, which completely traces the waveform of the signal Pi, at the parallel conductors **60.** In this embodiment, however, the electrons deflected upwardly are absorbed by the electrode **171** and those deflected downwardly are absorbed by the electrode **172,** thereby inducing corresponding voltage drops across the resistors **173** and **174** respectively.

When the movable arm of the switch **190** engages contacts **191***a* and **192***a*, the voltage drop induced across the resistor **173** is applied to the amplifier **200** and the amplified voltage is applied to the deflection electrode **181** to deflect the electron beam downwardly. The such cancelling action continues until the electron beam is aligned with the tube axis and passes the slit **170** and, at that time, the output of the amplifier **200** appears as a d.c. voltage proportional to the corresponding instantaneous value of the voltage Vi of the signal Pi. Therefore, when the output of the amplifier **200** is applied to the phenomenon axis input Y and the saw-tooth wave signal Pm is applied to the time axis input X of the oscilloscope **210,** a waveform pattern as shown in FIG. **5(1)** is displayed on the screen. This pattern is similar to the positive half of the waveform of the signal Pi.

When the movable arm of the switch **190** is turned to the contacts **191***b* and **192***b*, a waveform pattern as shown in FIG. **5(2)**, which is similar to the negative half of the waveform of Pi, is displayed, for the same reason set forth above.

In this embodiment, the electron trajectory is deflected once by the microwave signal Pi on the parallel conductors **60** but it is always forced back to the original straight trajectory by the low frequency deflection effected by the deflection plates **181** and **182.** Therefore, the displayed pattern is not materially affected by distortion of the electron lens system and the low frequency deflection voltage is accurately proportioned to the wave-height of sampled portion of the wave to be displayed.

According to the device of this embodiment of the invention, the waveform display can be effected by an arbitrary separate display device. Although the description involves the use of a cathode-ray tube oscilloscope **210,** a mechanical recording device such as XY-recorder can be used for this purpose if the selected frequency of the saw-tooth wave signal Pm is low enough.

FIG. **6** represents a variation of the device of FIG. **4.** Arrangement and the operation of those components in this device, such as electron gun assembly **10,** parallel conductors **20,** drift tube **40,** conductor disc **50,** electron lens assembly **80,** electrodes **171** and **172** and electron collector electrode **180,** are substantially same as those in the device of FIG. **4.** The output of a saw-tooth wave generator **4** is also connected to the drift tube **40** and the time axis input X of a cathode-ray tube oscilloscope **210.** In this device, however, a helical travelling wave guide **100** which is similar to that of the device of FIG. **3** is located between the disc electrode **50** and the electron lens **80,** instead of the parallel conductors **60** and the deflection electrodes **181** and **182** of the device of FIG. **4.** Moreover, the electrodes **171** and **172** are respectively connected to separate high gain amplifiers **201** and **202** and the outputs of these amplifiers are connected through fixed contacts **220***a* and **220***b* of a single-pole double-throw switch **220** to the phenomenon axis input Y of the oscilloscope **210** and also to the control terminal **231** of a variable voltage generator **230** whose output is connected to the intermediate electrode **82** of the electron lens assembly **80.**

In operation, a microwave signal Pi to be displayed is applied to the parallel conductors **20** and the helical guide **100** and a saw-tooth wave signal Pm is applied to the drift tube **40** in the same manner as in the operation of the device of FIG. **3** and causes a velocity modulation of the pulsed electron beam which completely traces the waveform of the signal Pi, as described in conjunction with FIG. **3.** Due to its own eccentricity and the eccentricity of the electron lens, the electron beam is deflected substantially by the electron lens **80** and collides with the electrode **171** or **172,** as shown in the drawing. The magnitude of deflection imparted by the electron lens **80** to the electron beam relates to the electron speed and the negative potential applied to the electron lens electrode **82** by the variable voltage generator **230.**

When the negative potential of the electrode **82** is at a reference level and the instantaneous voltage of the signal Pi is zero at the helical guide **100,** the electron beam passes through the slit **170** between the electrodes **171** and **172** and is absorbed by the collector electrode **180.** If the instantaneous voltage of the signal Pi is positive, however, the electrons are accelerated to reduce the deflection angle and collide with the electrode **171.** On the contrary, if the voltage of the signal Pi is negative, the electrons are decelerated to increase the deflection angle and collide with the electrode **172.** Consequently, voltage drops corresponding to the electron flow are caused across the resistors **173** and **174** and amplified respectively by the amplifiers **201** and **212.** When the movable arm of the switch **220** is in engagement with the contact **220***a*, the variable voltage generator **230** is controlled by the output of the amplifier **201** and drives the potential of the lens electrode **82** more negative. Therefore, the electrons are decelerated to increase the deflection angle and, when the electrons having collided against the electrode **171** tend to pass the slit **170,** a balance is attained. The output voltage of the amplifier **201** at this time is proportional to the positive voltage of the sampled portion of

the signal Pi. Accordingly, for the same reason as in the device of FIG. **4**, the oscilloscope **210** displays a waveform pattern as shown in FIG. **5**(**1**) which corresponds to the positive half of the waveform of the signal Pi. Similarly, a display pattern as shown in FIG. **5**(**2**) is obtained when the movable arm of the switch **220** is in engagement with contact **220***b*.

As the signal Pi acts on the electron beam by the helical guide **100** for a longer time than by the parallel conductors **60** of the device of FIG. **4**, the device of FIG. **6** exhibits a higher efficiency than the former device. In addition, due to the wide band characteristic of the helical guide, it has a wider observable frequency range.

As above described, waveform sampling can be effected within a time interval which is extremely shorter than that available in the prior sampling devices by utilizing pulse modulation of electron beam, according to this invention, and it becomes possible to observe a waveform of much higher frequency. Moreover, another great advantage of this invention is that the sampling pulse is always synchronous with the wave to be observed and, therefore, it is also possible to observe a waveform of repeated pulse oscillation including jittering which has been impossible to be observed by the prior sampling oscilloscopes.

It should be noted that the above description has been made only in conjunction with certain embodiments and various modifications and changes may be applied without departing from the scope of this invention as defined in the appended claims. For example, the parallel conductors **20** and **60** were shown in the drawings as a pair of parallel straight conductors but they can take other shapes as shown in FIG. **7**. FIG. **7**(**1**) represents a pair of conductors each in the form of a somewhat sinusoidal configuration and disposed in spaced parallel planes. FIG. **7**(**2**) represents a helical conductor surrounded by a cylindrical conductor with both conductors being coaxial or parallel. These parallel conductors are well known by those skilled in the art and are not the subject of this invention.

I claim:

1. A device for observing the waveform of a microwave signal comprising a source of said microwave signal, means producing a continuous electron beam, first beam deflecting means, means producing a first waveform signal synchronous with the microwave signal to be observed, means connecting the last said means with said first deflecting means for deflecting said beam (in one plane), shutter means positioned forwardly of said first deflecting means for permitting said beam to pass when said deflection is within predetermined limits thereby producing a pulsed electron beam, second beam deflecting means following said shutter means for deflecting said beam (in said plane), a second means producing a second waveform signal in the form of and synchronous with said microwave signal, means producing a third waveform signal, phase shifting means for varying the phase between said first and second waveform signals with respect to said electron beam and under control of said third waveform signal, means applying said second waveform signal to said second beam deflecting means, display means in the path of and responsive to said beam for displaying the movement of said beam wherein the deflection produced by said second deflecting means occurs along the phenomenon axis and means for sweeping said beam in synchronism with said third waveform signal.

2. The device according to claim **1**, wherein said first deflecting means comprises a pair of parallel conductors to which said microwave signal is applied, and said shutter means comprises a flat electrode having an orifice therein and located in front of said parallel conductors.

3. The device according to claim **1**, wherein said phase shifting means comprises a tubular electrode positioned between said first deflecting means and said shutter means with said electron beam passing therethrough and said third waveform is applied to said tubular electrode.

4. The device according to claim **1**, wherein said second deflecting means comprises a helical travelling wave conductor to which said second waveform is applied and means for deflecting said pulsed electron beam in a second plane angularly disposed relative to the first said plane, and said display means comprises a cylindrical display screen and means of applying a rotational field to said electron beam in synchronism with said third waveform thereby effecting a circumferential time axis sweep on said screen.

5. The device according to claim **1**, wherein said display means comprises means for producing a voltage corresponding to the deflection effected by said second deflecting means, means interconnected with the last said voltage for cancelling said deflection, and a display device having a phenomenon axis sweep controlled by said voltage and time axis sweep controlled by said third waveform.

6. The device according to claim **5**, wherein said voltage producing means comprises at least one electrode for collecting said electron beam encountering a predetermined deflection and a resistor connected to said electrode, and said deflection cancelling means comprises at least one deflection electrode for deflecting said electron beam opposite to the deflection effected by said second deflecting means under control of a voltage corresponding to a voltage produced across said resistor.

* * * * *