

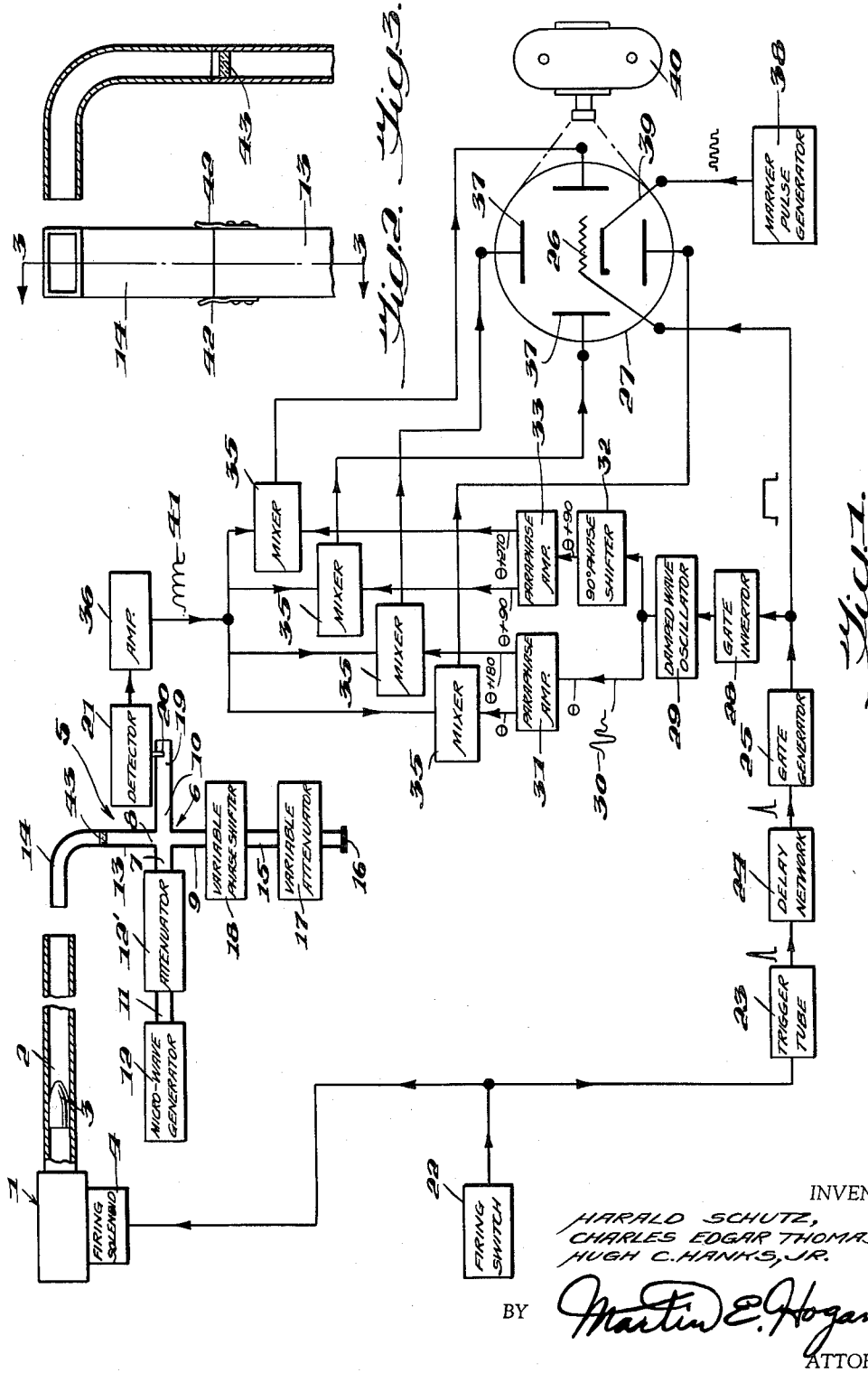
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MICROWAVE INTERFEROMETER

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MICROWAVE INTERFEROMETER

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This invention relates to a microwave interferometer especially intended for use in measuring the velocity of a projectile within a gun barrel.

In the design and testing of fire arms, it is highly desirable to obtain as complete information as is possible concerning the behaviour of projectiles within the gun barrel. For example, it is extremely desirable to be able to measure the acceleration and instantaneous velocity of a projectile from the instant of firing until it has left the gun barrel but heretofore there has been no satisfactory way of obtaining this information easily and economically.

It is therefore an object of this invention to provide a device which will accurately gather this information and display it in a form which permits of ready interpretation.

A further object is to provide a means for projecting microwaves down the barrel of a gun and recording the interference pattern which exists between the waves reflected from the projectile and waves of known phase.

Another object is to provide such a device which requires little or no modification of the gun and which may be readily mounted in operative relationship to the gun.

Still another object is to provide such a device employing an open-ended section of waveguide for projecting the microwaves down the barrel and wherein the portion of the waveguide which extends into the line of fire is releasably secured to the remainder of the waveguide so that when struck by the projectile it will merely be knocked away without damage to the rest of the apparatus.

Further and other objects will be apparent from the following description and claims in view of the appended drawings.

In the drawing:

Fig. 1 is a diagrammatic showing of the interferometer of this invention.

Fig. 2 is a fragmentary view looking toward the open end of the waveguide.

Fig. 3 is a transverse section taken on the line 3—3 of Fig. 2.

Fig. 1 shows somewhat diagrammatically a gun 1 having a barrel 2 within which is a projectile 3. While any suitable means for firing the gun could be employed, we show a firing solenoid 4 adapted to be energized upon closure of a suitable firing switch 22. The interferometer 5 comprises a hybrid waveguide junction 6 (diagrammatically illustrated) having four arms 7, 8, 9 and 10. While many known types of such junctions could be employed, the junction diagrammatically illustrated is of the type commonly referred to as a magic T and is constructed of rectangular waveguide as shown in Patent No. 2,445,896, arms 8 and 9 being co-linear and arm 7 communicating with arms 8 and 9 through one of the wider walls thereof while arm 10 communicates with arms 8 and 9 through one of their narrow walls. Connected to arm 7 of the magic T by a suitable transmission line

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11 is a stable, continuous wave, microwave generator 12 capable of generating electromagnetic waves having a half wave length shorter than the internal diameter of the barrel 2 whereby the latter may act in relation to the energy in the fashion of a waveguide without excessive attenuation. Preferably a suitable attenuator 12' will be interposed in the transmission line 11 to control the amplitude of the waves traveling along the line 11 into the junction 6 and to control the standing wave ratio therein.

One of the co-linear arms 8 of the magic T is connected to a waveguide 13 which terminates in an open ended L-shaped portion 14 which is positioned in spaced relationship to the gun so that its open end faces the open end of the barrel of the gun in substantial axial alignment therewith so as to be electromagnetically coupled thereto. The other co-linear arm 9 of the junction is connected to another section 15 of waveguide having its extreme end shorted as at 16 to form a reflecting line. Preferably a variable attenuator 17 and a variable phase shifter 18 will be interposed in line 15 for reasons to be described hereinafter. The fourth arm 10 of the junction connects to a section of waveguide 19 into which extends the probe 20 of a radio frequency detector 21.

With this arrangement microwave energy generated by generator 12 will be fed into junction 6 and will divide in accordance with the known characteristics of the magic T so that substantially one-half of the energy will pass into arm 8 and the remainder into arm 9. The energy in arm 8 will travel along the waveguide 13 and will be coupled into and travel downwardly along the interior of the gun barrel 2 to the projectile 3. A portion of this energy will be reflected by the projectile and will return along the gun barrel to the waveguide 13 and be returned to the junction 6 through arm 8. As hereinbefore explained, the energy propagated in waveguide 13 has a wavelength such that the gun barrel of the diameter selected for test can cooperate with such energy in a substantially wave guiding relationship.

The other portion of the energy will pass from arm 9 into the delay line 15 and be reflected by the short 16 and likewise returned to the junction 6. The relative phase between the energy returning from the projectile and that returning from the delay line will depend upon the relative lengths of these paths. By proper adjustment of the variable phase shifter 18 in the delay line 15, the effective length of the line 15 may be adjusted so that for any predetermined position of the projectile 3 in the barrel the two sets of returning waves will be exactly 180° out of phase. A characteristic of the magic T type of junction is that when energy of opposite phase is returned through the two opposed co-linear arms 8 and 9, none of it will pass into the arm 10, while if the energy returning through these two arms 8 and 9 is in phase, substantially all of the energy will be coupled into the arm 10. Thus for any particular adjustment of the delay line, as the projectile moves along the barrel, the phase of the energy returning therefrom will alternately be in phase and out of phase with that returning from the delay line 16. Thus there will be produced in the waveguide 19 and at the output of the detector 21 a voltage which fluctuates between a minimum and maximum in accordance with the instantaneous position of the projectile. This voltage will pass through a null point each time the projectile moves a half wave length along the barrel.

In order to make use of the output of the detector 21 in determining the velocity of the projectile, it is desirable that means be provided for displaying this voltage against a predetermined time base. While many systems are obviously adaptable to this end, the following arrangement has been found extremely satisfactory. Controlled

by the same firing switch 22 that actuates the firing solenoid for the gun is a trigger tube 23 adapted to generate a short pulse upon initiation of the firing. This pulse is applied through a suitable delay network 24 to a gate generator 25 which produces at its output a steady D. C. gating voltage for a predetermined time following its triggering by the pulse. The time length of the gate will preferably be at least as long as the anticipated time required for the projectile to leave the gun barrel after firing. This gate is applied to the brightness control grid 26 of a conventional cathode ray tube, diagrammatically represented at 27. The gate is also applied to a gate inverter 28 which converts it into a negative-going gate which is used to initiate the operation of a damped wave oscillator 29. This damped wave oscillator may be of the known type wherein the tube is normally conducting a relatively heavy current and is suddenly blocked by the application of the negative gating voltage to the control grid. Blocking of the oscillator causes damped oscillation to be set up in a suitably loaded resonant network in the oscillator, the frequency of the oscillation depending upon the values of the components and the amplitude being damped at a rate depending upon its loading.

The output from oscillator 29 will be in the form of a damped wave train of phase θ as indicated at 30 which is applied directly to a first paraphase amplifier 31 and indirectly, through a suitable 90° phase shifting network 32, to a second paraphase amplifier 33. Each of the paraphase amplifiers 31 and 33 produces a pair of similar wave trains having a relative phase difference therebetween of 180° . Thus at the outputs of the paraphase amplifiers 31 and 33 there will appear four similar damped waves having phase relationships which may be represented by θ , $\theta+90^\circ$, $\theta+180^\circ$, and $\theta+270^\circ$. Each of these waves is applied to one input terminal of an associated mixer 35. The other input of each of the mixers is connected to the output of the detector 21 through a suitable amplifier 36. The outputs from the mixers 35 are applied as shown in Fig. 1 to the deflection plates 37 of the cathode ray tube 27. A suitable marker pulse generator 38 is adapted to be connected to the cathode 39 of the cathode ray tube so as to periodically blank out the trace on the face of the tube to represent predetermined time intervals. Preferably, a camera 40 will be arranged adjacent the face of the cathode ray tube to photographically record the trace on the face of the tube.

The operation of the display unit is as follows. When the firing switch is energized, the trigger tube will trigger the gate generator so as to apply a positive gate to the brightness control grid of the tube so as to cause a luminous trace to appear on the face thereof. At the same time the damped wave oscillator 29 and paraphase amplifiers 31 and 33 will generate a series of damped sine wave voltages which will be applied through the mixer 35 to the deflection plates 37 of the tube 27. With the phase relationships shown, it can readily be shown that, in the absence of any voltage from detector 21, the resulting trace on the face of the tube will be in the form of a spiral, starting near the periphery of the face and gradually curving in toward the center. At periodic intervals along this trace, blank spaces will occur due to the short marker pulses applied to the cathode 39 by the pulse generator 38. Any voltage from the detector 21 will be superimposed upon the instantaneous voltages fed into the mixers 35 from the paraphase amplifiers so that the trace will be deflected radially in accordance with the amplitude of the detector voltage. As previously set forth when the projectile is traveling along the gun barrel, the output from the detector 21 will be a voltage which periodically rises and falls, each null point representing a movement of the projectile along the gun barrel of $\frac{1}{2}$ of the wave length of the microwave energy. The resulting wave form from the detector will therefore be somewhat as indicated at 41. Thus, the actual trace on

the face of the cathode ray tube will correspond to that which would obtain if the wave form 41 from the detector were superimposed upon the spiral produced by the damped wave oscillator voltages. The time interval required for the projectile to travel a half wave length can readily be determined from the trace itself due to the presence of the marker points represented by the blank spaces in the trace. Since this entire operation occurs in but a fraction of a second, it will of course ordinarily be desirable to photograph the face of the tube by means of camera 40 and to obtain the required information from the resulting photograph.

Since the tip portion 14 of the waveguide 13 extends into alignment with the gun barrel, provisions must be made to prevent damage to the apparatus as the projectile emerges from the barrel. In the instant case, portion 14 is made as a separate, generally L-shaped section which is adapted to be releasably held in place on the fixed portion 13 by means of a pair of spring clips 42 as shown in Fig. 2. Thus when the bullet strikes the portion 14, the latter will be knocked away without injury to the remainder of the structure. To prevent damage to the apparatus due to gun blast, a suitable window of dielectric material 43 will be inserted in the end of the stationary waveguide section 13.

In setting up the apparatus for operation, the guide portion 14 will first be positioned properly relative to the barrel and then the variable phase shifter 18 will be adjusted so as to bring the output from the detector 21 to a minimum with the projectile at rest and in its firing position. Then the attenuator 17 will be adjusted to reduce this output still further to a new minimum, the minimum detector output occurring when the amplitude of the wave reflected by the delay line 15 is substantially equal to that returning from the projectile. The delay network 24 will ordinarily be adjusted so that the gate will not be generated until substantially the same instant that the projectile begins to move, thus compensating for the inherent delay in the firing mechanism.

In the use of this apparatus it has been found to be of considerable importance that the open end of the section 14 be spaced appreciably away from the open end of the barrel. This is necessary since, if the spacing is too small, the energy will tend to travel downwardly along the gun barrel in various modes. Each of these modes will have a different phase velocity along the barrel and the resulting energy returned to the junction 6 will be of several different phases. Instead of the smoothly undulating pattern indicated at 41, the resulting pattern will be a highly complex one having no readily interpreted relationship to the position of the projectile.

While but one form of the invention has been described and shown it is obvious that many changes or substitutions could be made in the specific system illustrated. For example, other hybrid networks could obviously be substituted for the magic T shown herein. Similarly, many different arrangements for displaying the output from the detector for subsequent analysis will be apparent to those skilled in the art. Such substitutions and modifications can be made without departing from the spirit and scope of the invention as defined by the appended claims. Moreover the apparatus is obviously applicable for other uses than for measuring the velocity of a projectile in a gun barrel.

We claim as our invention:

1. Apparatus for determining the instantaneous position of a projectile within a gun barrel comprising means for generating electromagnetic energy having a half wave length substantially shorter than the internal diameter of such barrel, radio-frequency detector means, and means electrically connecting said generator and said detector for transmitting energy from said generator to said detector along two different paths, one of said paths including a transmission line connected to said generator and electromagnetically coupled to but physically sep-

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arated from said gun barrel whereby that portion of the energy traveling along said line from said generator will be coupled into and travel down said barrel and be reflected from the projectile therein and recoupled into said line, said detector means being adapted to produce an output voltage corresponding to the vector sum of the individual radio-frequency voltages of the energy arriving at said detector means along said two paths, and means connected to said detector for indicating said output voltage.

2. Apparatus for determining the instantaneous position of a projectile within a gun barrel comprising means for generating electromagnetic energy having a half wave length substantially shorter than the internal diameter of said barrel, radio-frequency detector means, and means electrically connecting said generator and said detector for transmitting energy from said generator to said detector along two different paths, one of said paths including a transmission line connected to said generator and electromagnetically coupled to said gun barrel whereby that portion of the energy travelling along said line from said generator will be coupled into and travel down said barrel and be reflected from the projectile therein and recoupled into said line, said detector means being adapted to produce an output voltage corresponding to the vector sum of the individual radio-frequency voltages of the energy arriving at said detector means along said two paths, and means included in one of said paths for adjusting the relative phase of energy travelling therealong whereby it will arrive at said detector means in phase opposition to that arriving over the other path when said projectile is at a predetermined position within said barrel, and means connected to said detector for indicating said output voltage.

3. Apparatus for determining the instantaneous position of a projectile within a gun barrel comprising means for generating electromagnetic energy having a half wave length substantially shorter than the internal diameter of said barrel, radio-frequency detector means, and means electrically connecting said generator and said detector for transmitting energy from said generator to said detector along two different paths, one of said paths including a transmission line connected to said generator and electromagnetically coupled to but physically separated from said gun barrel whereby that portion of the energy travelling along said line from said generator will be coupled into and travel down said barrel and be reflected from the projectile therein and recoupled into said line, said detector means being adapted to produce an output voltage corresponding to the vector sum of the individual radio-frequency voltages of the energy arriving at said detector means along said two paths, and means connected to said detector for displaying the output voltage from said detector means against a predetermined time base whereby the movement of said projectile along said barrel per unit time may be readily determined in terms of said wave length.

4. Apparatus for measuring the velocity of a projectile within a gun barrel comprising means for generating electro-magnetic waves having a half wave length substantially shorter than the internal diameter of said barrel whereby they are adapted to travel along the interior of said barrel with the latter acting as a wave guide, detector means, and transmission line means including a delay line and means electromagnetically coupling said generating means to said gun barrel and to said delay line whereby electro-magnetic waves from said generating means will travel therealong, and means electromagnetically coupling said barrel and said delay line to said detector means whereby the latter will produce an output voltage proportional to the vector sum of the instantaneous voltage applied thereto by its coupling with said barrel and said delay line, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

5. Apparatus for measuring the velocity of a projectile

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within a gun barrel comprising means for generating electro-magnetic waves having a half wave length substantially shorter than the internal diameter of said barrel whereby they are adapted to travel along the interior of said barrel with the latter acting as a wave guide, detector means, and transmission line means including a delay line and means electromagnetically coupling said generating means to said gun barrel and to said delay line whereby electro-magnetic waves from said generating means will travel therealong, and means electromagnetically coupling said barrel and said delay line to said detector means whereby the latter will produce an output voltage proportional to the vector sum of the instantaneous voltages applied thereto by its coupling with said barrel and said delay line, said transmission line means including means for adjusting the relative phase of the waves emerging from said delay line and from said gun barrel so that when said projectile is at a predetermined position within said barrel said last mentioned waves will be in phase opposition at said detector means, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

6. Apparatus for measuring the velocity of a projectile within a gun barrel comprising means for generating electro-magnetic waves having a half wave length substantially shorter than the internal diameter of said barrel whereby they are adapted to travel along the interior of said barrel with the latter acting as a waveguide, detector means, and transmission line means including a delay line and means electromagnetically coupling said generating means to said gun barrel and to said delay line whereby electro-magnetic waves from said generating means will travel therealong, and means electromagnetically coupling said barrel and said delay line to said detector means whereby the latter will produce an output voltage proportional to the vector sum of the instantaneous voltages applied thereto by its coupling with said barrel and said delay line, said transmission line means including means for adjusting the relative phase and amplitude of the waves emerging from said delay line and from said gun barrel so that when said projectile is at a predetermined position within said barrel said last mentioned waves will be in phase opposition and of equal amplitude at said detector means, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

7. Apparatus for measuring the velocity of a projectile within a gun barrel comprising means for generating electro-magnetic waves having a half wave length substantially shorter than the internal diameter of said barrel whereby they are adapted to travel along the interior of said barrel with the latter acting as a waveguide, detector means, and transmission line means including a delay line and means electromagnetically coupling said generating means to said gun barrel and to said delay line whereby electro-magnetic waves from said generating means will travel therealong, and means electromagnetically coupling said barrel and said delay line to said detector means whereby the latter will produce an output voltage proportional to the vector sum of the instantaneous voltages applied thereto by its coupling with said barrel and said delay line, a source of sweep voltage and a cathode ray tube connected to said source and responsive to the output from said detector for visually displaying a trace of the output voltage waveform plotted against a predetermined time base upon the face of said tube.

8. Apparatus for measuring the velocity of a projectile within a gun barrel comprising means for generating electro-magnetic waves having a half wave length substantially shorter than the internal diameter of said barrel whereby they are adapted to travel along the interior of said barrel with the latter acting as a waveguide, detector means, and transmission line means including a delay line and means electromagnetically coupling said

generating means to said gun barrel and to said delay line whereby electro-magnetic waves from said generating means will travel therealong, and means electromagnetically coupling said barrel and said delay line to said detector means whereby the latter will produce an output voltage proportional to the vector sum of the instantaneous voltages applied thereto by its coupling with said barrel and said delay line, a source of sweep voltage and a cathode ray tube connected to said source and responsive to the output from said detector for visually displaying a trace of the output voltage waveform plotted against a predetermined time base upon the face of said tube, said source being adapted to cause said trace to have a time length at least equal to the normal time required for a projectile to travel the length of said barrel, means connected to said source and controlled by the firing of said gun for initiating operation of said sweep voltage source, and a camera adjacent said tube for photographically recording said trace.

9. Apparatus for measuring the velocity of a projectile within a gun barrel comprising a waveguide junction having an input section, an output section and a pair of branch sections connected together and so oriented that energy fed into said junction through said input section will be divided between said branch sections, and energy travelling toward said junction within said branch sections will be combined in said output section, a continuous wave high frequency generator for generating electromagnetic waves having a half wave length substantially shorter than the internal diameter of said barrel, said generator being electrically coupled to said input section, a detector electrically coupled to said output section, a reflecting type of delay line electrically coupled to one of said branches, and means for electromagnetically coupling said other branch to the muzzle end of said gun barrel so that energy travelling outwardly along said last mentioned branch will be coupled into and travel down the interior of said barrel and be reflected by a projectile in said barrel and recoupled into and returned along said last mentioned branch to said junction, whereby the output from said detector at any time will correspond to the vector sum of the voltages of the energy reflected by said delay line and that reflected by said projectile, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

10. Apparatus for measuring the velocity of a projectile within a gun barrel comprising a waveguide junction having an input section, an output section and a pair of branch sections connected together and so oriented that energy fed into said junction through said input section will be divided between said branch sections, and energy travelling toward said junction within said branch sections will be combined in said output section, a continuous wave high frequency generator for generating electromagnetic waves having a half wave length substantially shorter than the internal diameter of said barrel, said generator being electrically coupled to said input section, a detector electrically coupled to said output section, a reflecting type of delay line electrically coupled to one of said branches, and means for electromagnetically coupling said other branch to the muzzle end of said gun barrel so that energy travelling outwardly along said last mentioned branch will be coupled into and travel down the interior of said barrel and be reflected by a projectile in said barrel and recoupled into and returned along said last mentioned branch to said junction, whereby the output from said detector at any

time will correspond to the vector sum of the voltages of the energy reflected by said delay line and that reflected by said projectile, said electromagnetic coupling means including a generally L-shaped disposable section of open-ended waveguide having its one leg arranged substantially co-axial with said barrel with its open end directed toward said barrel and spaced therefrom, the other leg of said L-shaped section extending laterally out of alignment with said barrel, and means connecting said other leg to said other branch and releasably supporting said L-section, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

11. Apparatus for measuring the velocity of a projectile within a gun barrel comprising a section of open-ended waveguide adapted to direct electro-magnetic energy into the muzzle end of said gun barrel and to intercept the resulting energy reflected from a projectile within said barrel, a waveguide junction having four branches so oriented that energy moving toward said junction along a first branch will be caused to divide and travel along a second and third of said branches and energy returning along either of said second and third branches will be caused to travel into the fourth branch, means connected to said first branch for generating and feeding into said first branch high frequency continuous wave electromagnetic energy having a half wave length substantially shorter than the internal diameter of said barrel, said second branch being electrically connected to said first mentioned waveguide section, a reflecting type phase delay line electrically connected to the third branch and detector means electrically connected to the fourth branch for detecting the voltage of the energy within said fourth branch, and means connected to said detector for displaying the output voltage from said detector against a predetermined time base.

12. Apparatus for use with a member having an elongate passage bounded by electroconductive material having waveguide properties for electromagnetic energy, and for determining the instantaneous position along said passage of an item travelling lengthwise thereof and consisting of a means capable of effecting an abrupt change in the dielectric properties of said passage, comprising means for generating electromagnetic energy having a half wave length shorter than the diameter of such passage, radio-frequency detector means, and means electrically connecting said generator and said detector for transmitting energy from said generator to said detector along two different paths, one of said paths including a transmission line connected to said generator and electromagnetically coupled to but physically separated from said passage whereby that portion of the energy travelling along said line from said generator will be coupled into and travel down said passage and be reflected from the item therein and recoupled into said line, said detector means being adapted to produce an output voltage corresponding to the vector sum of the individual radio-frequency voltages of the energy arriving at said detector means along said two paths, and means connected to said detector for indicating said output voltage.

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