Oct. 12, 1954 N. M. SMITH, JR 2,691,761

MICROWAVE MEASURING OF PROJECTILE SPEED

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Fig. 1.

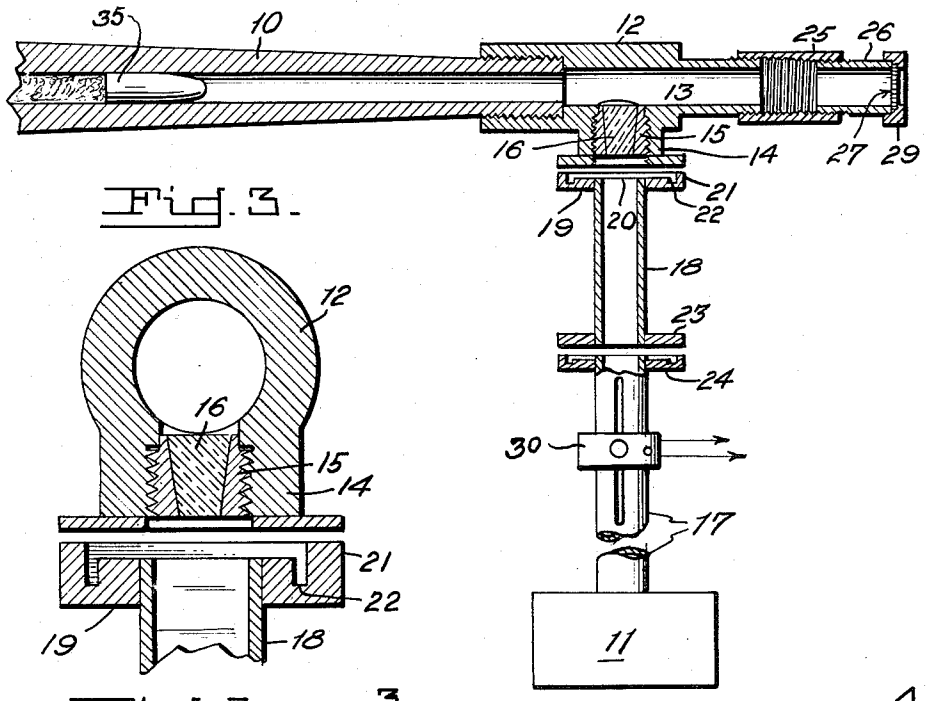


Fig. 3.

Fig. 2.

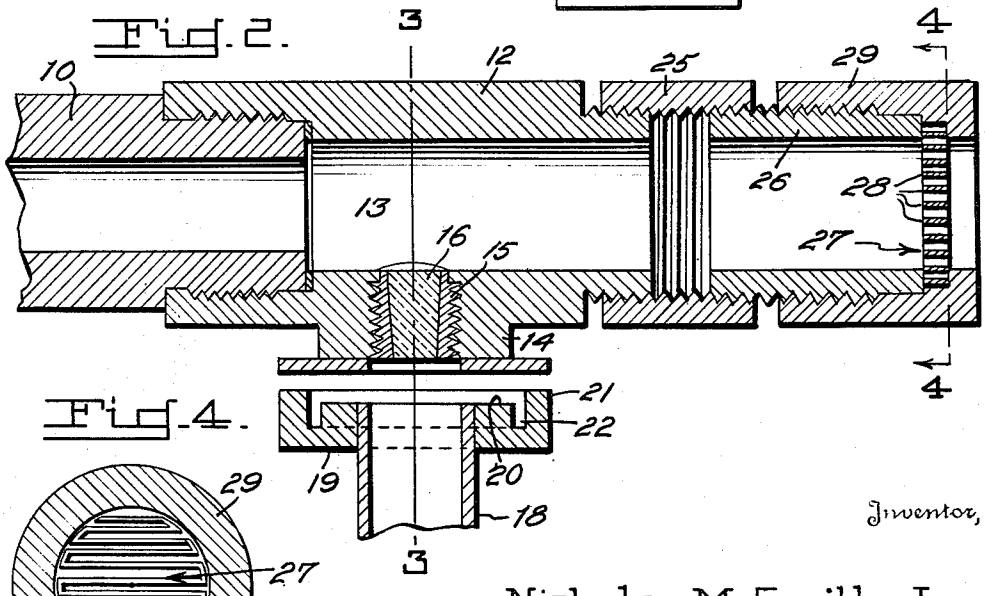


Fig. 4.

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Fig. 5.

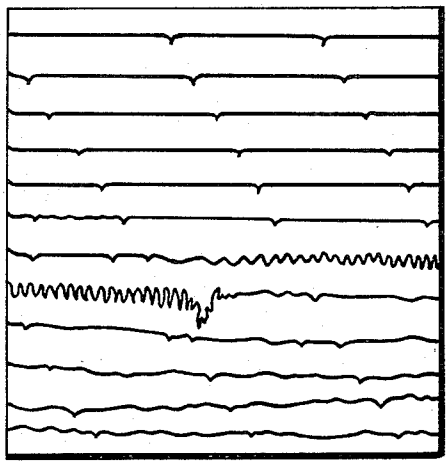


Fig. 6.

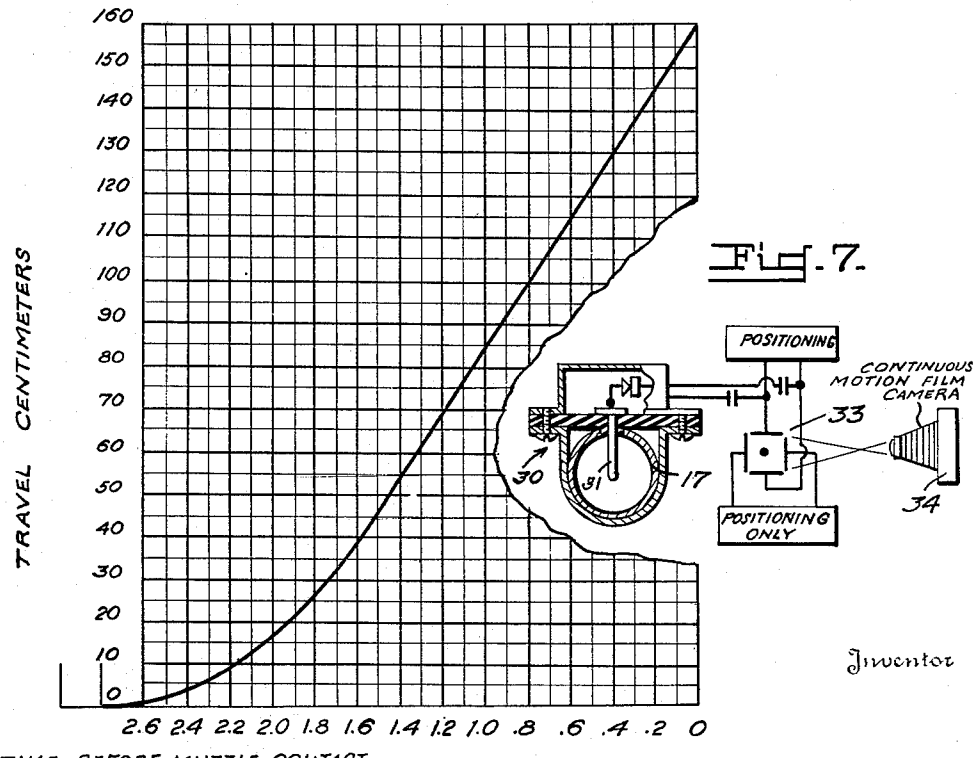


Fig. 7.

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UNITED STATES PATENT OFFICE

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MICROWAVE MEASURING OF PROJECTILE SPEED

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6 Claims. (Cl. 324—70)

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The invention relates to means for measuring the position and velocity of a projectile in the barrel of a gun or mortar incident to its firing, and has for an object to present novel means for perfecting a progressive record of the data named, throughout the movement of the projectile in the barrel.

There are a number of complicating factors in the attainment of the end in view, and it was discovered that the mere transmission of a high frequency wave and the reception and amplification of its echo from within the gun muzzle does not constitute the sole attainment to be accomplished. It was found that a definite correlation of the wave length and the bore diameter of the gun is necessary; and, further that the embodiment of apparatus must be such that a suitable number of detectable signals significant of the positions of the projectile will be derived, in sufficient magnitude and frequency to be readily detected and recorded.

Solution of the last named problems are among the objects of the invention, and in addition the following achievements are also in view: Introduction of H. F. or U. H. F. waves into the gun while at the same time: 1, Sealing, the external wave guide from the powder gases; 2, reducing the effects of vibration of the gun on firing; 3, detection of the combined incident and reflected radiation at a stationary point in the auxiliary wave-guide; 4, obtaining as sharp as possible a signal as the projectile moves from one position to another so that high precision will be enabled in the deduction of its position. This involves the problem of multiple reflections; and 5, recording and interpreting the signal received by the detector.

Additional objects, advantages and features of invention reside in the construction arrangement and combination of parts involved in the embodiment of the invention and in the steps of procedure evolved in the carrying out of the invention, as will be apparent or understood from the following description and accompanying drawings, wherein:

Figure 1 is a schematic horizontal section of the forward part of a gun after firing while the projectile is travelling therein, and of the wave transmitting, standing wave detecting, and resultant signal transmitting means;

Figure 2 is an enlargement of the means for transmitting waves to the barrel, tuning means, and coupling for the transmitter;

Figure 3 is a fragmentary section on the line 3—3 of Figure 2;

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Figure 4 is a cross section of the muzzle assembly on the line 4—4 of Figure 2, showing the reflector grid;

Figure 5 is a graph produced from a photograph of successive sweeps of the beam of an oscilloscope the vertical signal displacement of which was controlled by the output of the detector device of my system during the firing of a gun;

Figure 6 is a graph of displacement in time developed from the record of Figure 5;

Figure 7 is a schematic view of the detecting and recording system.

Referring more particularly to the drawings, there is illustrated a gun barrel 10 of conventional form and construction, the breech and its mechanism being omitted since they comprise no novel part of the invention. The barrel is preferably clamped rigidly, and recoil prevented as much as practicable. A generator of suitable micro-waves is formally indicated at 11, this being a conventional oscillator with means to regulate the wave length as required, of which examples are extant and well known, and therefore it is not described, except to indicate that a guide system of length as short as practicable is extended therefrom to the muzzle assembly on the gun.

The muzzle assembly comprises a coupling T 12, having a bore 13 therethrough of approximately the same diameter or slightly greater as the bore of the barrel 10. The body of the T is of a length suitable to permit tuning of a wave reflected from the outer end of the T to resonance with the bore of the barrel, as will be described, and the inner end of this body of the T is counterbored, interiorly threaded and screwed on to the corresponding threaded muzzle of the barrel 10 so as to bring the bore of the T body close to and coaxial with the end of the barrel bore. The T body has a lateral conduit arm or nipple 14 at right angles thereto, tapped and threaded from its outer end to form an inner seat against which a bushing 15 is screwed having a conical bore therethrough with its larger end inward. Set in this conical opening there is a coned polystyrene plug 16 serving as a wave passing means and also as an obturator to prevent escape of gases from the barrel. The plug may be of other material specially adapted to transmit—that is—pass the micro-waves to the bore of the barrel 10. The outer end of the conduit arm 14 is finished smoothly in a plane normal to the arm. The plug, too, is similarly finished at each end.

The wave conducting system from the source

11 in the present instance includes a first guide section 17 which may be attached to the generator 11, and a separately supported isolated guide 18 mounted independently of the gun, without contact or attachment to either, between the end of the lateral arm 14 and the outer end of the first guide 17. The end of the second guide next the gun assembly has formed thereon an enlarged planiform flange 19 parallel to and of equal area with the outer planiform face of the T arm 14. The end of the guide and the flange 19 are relieved, so as to form a smooth planiform face 20; parallel to the end face of the arm 14, but with a lip 21 surrounding the face 20 extending much closer to the planiform face of the arm 14. The face 20 is also channelled as at 22 beside the lip 21. The opposite end of the second guide is also formed with a simple planiform flange 23 and the first guide section is provided with a relieved flange 24, identical with the one 19 on the second section, and closely opposed to the flange 23. This arrangement between the second guide and its cooperating wave transmitting parts is an expedient known as an M. I. T. choke coupling for micro-wave conduits, and serves to prevent communication of material wave disturbances from the gun assembly to the transmitter, or to the detecting device due to vibrations of the gun incident to its firing.

The outer end of the T-body 12 is exteriorly threaded and has screwed thereon an interiorly threaded sleeve 25, and screwed into this in turn there is an outer tube 26, interiorly bored to the same diameter as the body of the T. The sleeve is adjustable extensibly on the T, and the tube 26 is also extensibly adjustable in the sleeve. Against the outer end of the tube 26 there is firmly held a reflector grid 27 comprising an annular copper body, with a multiplicity of bars 28 closely spaced but with spaces between to permit escape of air being expelled by the advance in the barrel of a projectile being fired from the gun. The grid is clamped against the end of the tube 26 by a cap 29 screwed onto the tube, and overlying the grid sufficiently to hold the latter, as may be understood. The cap is bored in alignment with the bore through the tube 26, or larger. The inner surface of the grid is suitably finished to effectively reflect incident waves passing longitudinally through the T-body, including both those reflected from the inner end of the barrel and those transmitted from the transmitter 11 through the plug 16.

In the first guide section 17 a detector unit 30 is incorporated, which includes a probe 31 extended radially into the guide through a slot 32 formed in the guide, the unit 30 being slidable on the guide to establish coincidence of the probe with a standing wave produced in the guide when output of the transmitter is propagated into the gun as indicated, while the projectile is at its initial loaded position in the gun before firing. The detector unit may conform to known practices for detection of such waves, and in one form may comprise a crystal-cat-whisker device, with amplification if desired, in accordance with prior uses of such appliances. Its output, derived from the peak potentials of standing waves is, after one method (Fig. 7), transmitted to the y axis deflection plates on an oscilloscope 33, the X axis deflection plates of which are used solely as positioning means for the beam, but without a time base sweep. The trace is then photographed by a camera 34 having a clock mechanism operating a film strip horizontally at uniform speed and at a proper rate to give convenient time interval values to linear units of its length. This takes the place of the sweep of the beam in establishing a time base in the record of phenomena manifest in the response of the beam on the y axis. However, by another method of use an oscilloscope (not shown) with stepped sweeps occurring on successive vertically spaced horizontal lines, a record may be produced as shown in Figure 5, of the present drawings.

In the operation of the system as described, a projectile 35 is loaded conventionally with standard or experimental charges to demonstrate the efficiency of the gun, the propellant, or the projectile as to ballistic questions.

The transmitter 11 being in operation, before the firing of the gun the transmitted waves pass through the first and second guides, and pass through the plug 16 to the bore of the T 12. The microwaves then go down the barrel of the gun to the left in Figures 1 and 2, and also to the right, toward the reflector grid. The radiation encountering the grid 27 is reflected back into the muzzle, and by means of the extensible adjustment of the sleeve 25 and grid carrying tube 26, the relation of the reflected waves from the grid and the waves being transmitted directly into the barrel is adjusted or tuned to synchrony, so that the reflected waves from the grid reinforce those proceeding directly from the plug 16 into the muzzle toward the breech of the gun.

After the gun is loaded those directly transmitted waves and their reinforcement from the grid move rearward in the gun until they encounter the projectile and are reflected. This reflection proceeds back along the incoming path of the original, passing outward through the plug 16. The probe of the detector being now properly adjusted so as to establish the coincidence of a standing wave at the probe, the first or initial position of the projectile in the gun is indicated.

When the gun is fired, the projectile is moved forward by the propellant gases, and the standing wave initially manifest will fall and disappear, owing to movement of the system of standing waves outward (carrying the first one beyond the probe) as the projectile advances. But a new similar standing wave will reach or recur at the probe on each unit of linear movement of the projectile equal to one-half the wave length of the output derived from the transmitter 11, and so each new position of the projectile will be made manifest by successive peak potentials of respective advancing standing waves, and these may be registered as definite units of length of the bore or of distance of movement of the projectile by any means responsive to the potentials transmitted by the detector as the waves encounter the probe 31.

When the time elapsing is made manifest and calibrated with the successive positions of the projectile in either of the ways indicated, the displacement vs. time, the velocity vs. time, and the velocity vs. displacement may each be calculated and plotted definitely, as desired.

It will be understood that the reflector grid 27 is expendible, and that as the projectile reaches the grid the latter is sheared and carried away by the projectile without liability of damaging back pressures or impedance of the projectile objectionably.

The principal consideration in the choice of

a suitable wavelength is: it must be one which can be propagated in the barrel of the gun, and at the same time no complication must result from production of more than one mode of wave. From well established theoretical considerations it will be shown that the above two restrictions limit operations to a narrow range of frequencies. This statement will be clarified by the description of some of the general characteristics of electromagnetic wave propagation in conducting tubes. Thus, while the reader is referred to any standard work on micro-waves, the essential ideas are described below.

It has been established by other investigators that electromagnetic radiation may be transmitted down a cylindrical (any shaped) tube having electrically conducting walls. There are two classes of waves which may be transmitted in the tube; first, "H-waves," ones in which the electric vector E has no component in the direction of propagation and, second, "E-waves" ones in which the magnetic vector H, has no component in the direction of propagation. Now the phase velocity of each mode of wave is different from the other in general, and in all cases is greater than the velocity of light in an unbounded vacuum. The phase velocity, and consequently the wave length λ_g, of any mode of propagation in the tube is a function of the shape of the tube and of the wave-length in an unbounded vacuum, λ. There exists for each mode of propagation a critical "unbounded" wavelength, λ_c, such that the wave-length in the guide, λ_g, is infinite. If λ is greater than λ_c then the radiation of that particular mode is rapidly attenuated in the guide.

Because λ_c is different, in general, for each type of propagation, it is possible to choose a range of wave-lengths, λ, such that only one mode of oscillation may be transmitted down the waveguide. For any problem involving standing waves (Doppler effect) this is important, because the interference pattern between the incident and reflected waves is much simplified.

For a tube of circular cross section the easiest mode to excite is the so-called H_{11} mode (see "Micro-Wave Transmissions," by J. C. Slater, McGraw-Hill Book Company, New York, 1942) having a critical cut-off wave-length of 3.412×radius of tube. The next easiest mode to excite is the E_0 mode having a critical wave-length of 2.613×radius of tube. Therefore the λ used should be between these values in order to excite only the H_{11} mode. Now the wave-length in the guide, λ_g, is given by:

$$\lambda_g=\frac{\lambda}{\sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2}}$$

Thus, by a proper choice of wave-length λ, the guide wave-length, λ_g, may be made any desired value between infinity and ($\lambda=2.613\times r$)

$$\lambda_g=\frac{2.613r}{\sqrt{1-\left(\frac{2.613r}{2.412r}\right)^2}}=4.06r$$

Specifically, for the 20 mm. gun, the range of wave-lengths which will allow only one mode of wave in the tube is between the values 3.523 cm. and 2.698. λ_g will then lie between infinity and 4.19 cm. This is calculated from the mean radius of lands and grooves which, experimentally, is 1.0324 cm.

As will be described below, the signal consists

of a negative pulse of rather broad width every time the projectile moves a distance equal to one-half wave-length. Within the range of wave-lengths given above there is a narrower limit of usable wave-lengths which is determined by the following considerations: (1) the largest permissible number of minima is desired as the projectile moves thru the barrel, because each minimum determines one position of the projectile, and (2) the frequencies of the signal must not go above that which can be amplified and recorded.

Restriction (1) makes desirable as short a wave-length as possible, while restriction (2) puts a limit on how short this wave-length may be (this restriction exists together with the possibility of exciting more than one mode—whichever is the more restrictive. It happens that for application to the 20 mm. gun the recorder gives the limitation on the wave-length).

The fundamental frequency at full muzzle velocity is

$$f_0=\frac{2V}{\lambda_g}$$

where V is the muzzle velocity. For recording sharpened pulses the frequency response of the recorder should go up to about ten times f_0.

For a gun having a muzzle velocity of 2820 ft./sec., and a desired limit for f_0 of 20000 cycles, λ_g=8.4 cm., for which λ=3.23 cm.

In my previously constructed apparatus including a 20 mm. gun, a wave-length of 3.200 cm. is used, giving a minimum in the tube for each 3.8225 cm. of travel (each half wave-length), making forty-one minima in all.

It may be noted that if the grid 17 were omitted, there would be established in the operation of the system otherwise disclosed the simple case of one reflected wave beating against the incident wave, and a sinusoidal standing wave pattern would be produced in the tube with a minimum every half-wave-length in the guide. As the projectile moves out this wave pattern also moves out along the guide. Therefore each minimum will correspond to a motion of

$$\frac{\lambda_g}{2}$$

(where λ_g is the wave-length in the guide). If the time Δt is measured between successive minima, then the average velocity between these two times will be

$$\frac{\lambda_g}{2\Delta t}$$

It can easily be shown that there is no difference in the analysis if it is based on the Doppler effect, rather than on the above principle. The two view-points are equivalent.

However, as constructed in the embodiment illustrated, the standing wave pattern will not have the simple sinusoidal shape, but the minima will be sharper, as may be seen in Figure 5. This sharpness depends on the attenuation of the wave as it is propagated; the half-width of a minimum being inversely proportional to the attenuation.

In the use of my invention some details of technique are important and should be observed, among which are the following:

a. The gun must be cleaned after each round with dry swabs.

b. The polystyrene coned plug must be scraped clean.

c. The standing-wave pattern must be probed

with a projectile on a rod, the position of the minima determined and the system tuned up before each round.

d. The wave-length should be checked frequently.

While I have here disclosed the embodiment of my invention in its best form as heretofore practiced, it will nevertheless be understood that this is purely exemplary, and that modifications and changes in construction arrangement and combination of parts in equivalent ways, substitution of elements and materials, may be made without departing from the spirit of the invention as set forth in the appended claims.

I claim:

1. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the outer end of said member, a waveguide adapted to be in connection with said member, a microwave propagator having its output connected to said waveguide and adapted to establish standing waves in said waveguide by reflection from the said reflector and the said projectile, and a detector of standing waves in said waveguide to indicate recurrence of standing waves incident to motion of said projectile after firing.

2. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the end of said member, a waveguide adapted to be connected with said member, an abturator in the said waveguide at the connection thereof with the said member, a microwave propagator having its output connected to said waveguide and adapted to establish standing waves in said waveguide by reflection from the said reflector and the said projectile, and a detector of standing waves in said waveguide to indicate recurrences of standing waves incident to motion of said projectile after firing.

3. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the outer end of said member, a waveguide connected with said member, an obturator in the said waveguide at the connection thereof with the said member, a microwave propagator having its output connected to said arm and arranged to establish standing waves in said waveguide by reflection from the said reflector and the said projectile, and a detector of standing waves in said waveguide to indicate recurrences of standing waves incident to motion of said projectile after firing.

4. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the outer end of said member, a waveguide connected normal to the said member, an obturator in the said waveguide at the connection thereof with the said member, a micro-wave propagator having its output connected to said waveguide and arranged to establish standing waves in said waveguide by reflection from the said reflector and the said projectile, and a detector of standing waves in said waveguide to indicate recurrences of standing waves incident to motion of said projectile after firing.

5. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the outer end of said member, a waveguide connected normal to said member, an obturator in the said waveguide at the connection thereof with said member said obturator being permeable to micro-waves, a micro-wave generator having its output connected to said waveguide and arranged to establish standing waves in said waveguide by reflection from the said reflector and the said projectile, and a detector of standing waves in said waveguide to indicate recurrences of standing waves incident to motion of said projectile after firing.

6. Apparatus for registering displacement of a projectile when fired in a gun comprising a hollow conductive member forming a coaxial extension of the barrel of said gun, a gas pervious microwave reflector at the outer end of said member, a waveguide connected to said member and forming a T therewith, an obturator in the said waveguide at the connection thereof with said member said obturator being permeable to micro-waves, a micro-wave generator having its output connected to said waveguide and arranged to establish standing waves in said waveguide by reflection from said reflector and the front of said projectile, and a detector of standing waves in said waveguide to indicate recurrences of standing waves incident to motion of said projectile after firing.

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