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CONTROLLING TRANSMISSION IN MICROWAVE SYSTEMS

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FIG. 1C

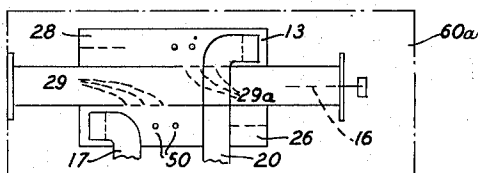
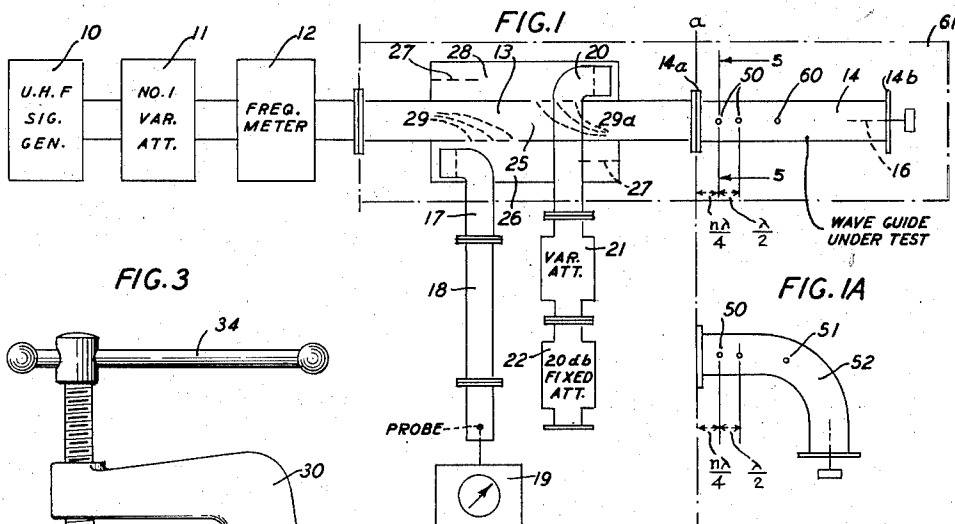


FIG. 3

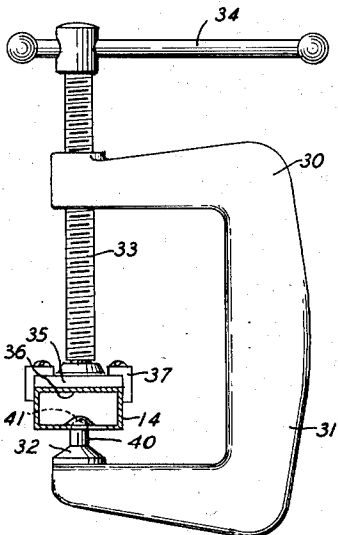


FIG. 4

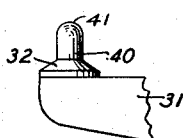


FIG. 1A

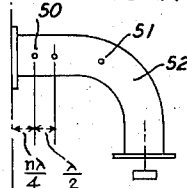


FIG. 1B

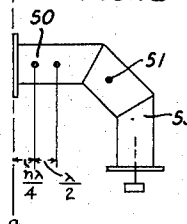
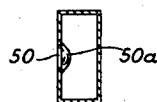
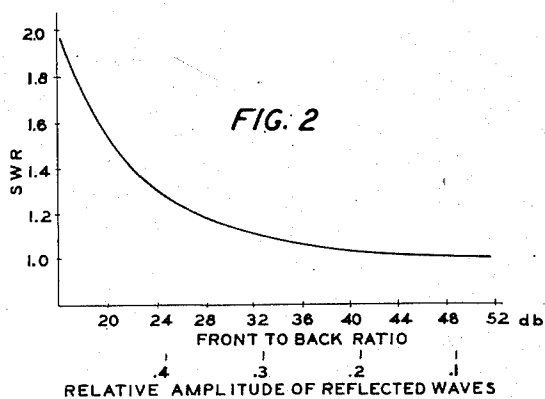


FIG. 5



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CONTROLLING TRANSMISSION IN
MICROWAVE SYSTEMS

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4 Claims. (Cl. 178-44)

1

This invention relates to microwave signal transmission and more specifically to a method of and apparatus for compensating for wave reflections in such transmission systems.

Many microwave signal transmission systems comprise at least one section of rectangular wave guide. This wave guide may extend effectively in a rectilinear direction, and include one or more impedance irregularities due, for example, to coupling misterrinations or variations in cross-section arising during manufacture. The misterrinations may be frequently occasioned by the well-known choke or flange couplings. The variations in cross-section may also be due to the introduction of a bend or a twist into a rectilinear wave guide or to the fabricated corners in curvilinear wave guide which consists of several rectilinear sections of wave guide. Such impedance irregularities tend to cause wave reflections whereby standing waves tend to be produced in the transmission system to impair the efficiency thereof.

The present invention contemplates an arrangement for minimizing reflected waves in a microwave signal transmission system.

The main object of the present invention is to compensate for impedance irregularities inherent in a rectangular wave guide.

Another object is to control wave reflections.

A directional coupler is known in microwave signal transmission systems for separating reflected waves from incident waves for the purpose of their measurement. This coupler is essentially of the type disclosed in the copending application of W. W. Mumford, Serial No. 540,252, filed June 14, 1944. Any alteration of the microwave system that tends to reduce the amplitude of reflected waves indicates a smaller standing wave or a decrease in the reflection coefficient of the impedance irregularities causing the reflected waves in the system. It has been found that the amplitude change in the reflected waves becomes increasingly small as the standing wave tends to approach its ideal value 1.0. Thus, measurements of the amplitude of reflected waves provide highly sensitive indications of improvements in standing waves below a certain limit, say, for example, the value of 1.25.

In accordance with the present invention, the amplitude of the reflected waves that are inherent in a microwave signal transmission system for the above-noted reasons is utilized to determine the amount of correction required to be introduced into such system in order to reduce the standing wave therein to at least a tolerable limit, say, for example, to the value of 1.10 or therebelow so as to

2

approach more closely the ideal value 1.0. This correction involves the introduction into the system of one or more additional reflected waves whose combined amplitude is substantially equal to that of the inherent reflected wave but 180 degrees out of phase therewith whereby the inherent and additional reflected waves tend to cancel each other.

In a specific embodiment of the present invention, the foregoing compensation for reflected waves inherent in a known microwave signal transmission system is effected by producing of one or more preselected deformities in the inside surface of a rectangular wave guide being tested in the system by means of a suitable device employed in a predetermined manner. These deformities, as one illustration, constitute projections formed integral with the surface of the wave guide being tested at the opposite ends thereof and extending interiorly of the wave guide, each projection being spaced from the impedance irregularity to be compensated for and from each other in a sense related to the wavelength of the signal waves being transmitted in the wave guide being tested. As a consequence of these projections additional reflected waves are introduced into the microwave system with such phase and combined amplitude that the additional waves tend to cancel the reflected waves and thereby tend to reduce the standing wave to at least the tolerable value.

The deforming device comprises a familiar type of vise-like apparatus having the usual two opposing jaws, one of which is movable and the other fixed. The movable jaw includes a smooth surface for engaging a small portion of the outer surface on one side of the wave guide, and the fixed jaw includes a pin-like projection for engaging a small portion of the outer surface of the opposite side of the same wave guide along the longitudinal axis thereof. As the movable jaw is gradually brought closer toward the fixed jaw to a predetermined extent, the pin-like projection on the latter jaw forms a dent in the outer surface of the wave guide. This results in a projection formed integrally with the inner surface of the wave guide being tested and extending interiorly thereof. One or more of these dents provided at properly spaced points on the wave guide being tested cause additional reflected waves which tend to cancel the initial reflected waves or to reduce the amplitudes of the latter waves and thereby reduce the standing wave in the microwave signaling system as previously mentioned.

3

For determining the location and number of the dents, a measuring circuit adapted for use with signal waves whose frequencies lie in the ultra-high range is connected alternately to the reflected wave and incident wave outlet taps of the directional coupler. Pursuant to certain readings in the measuring circuit when so connected, the first dent is located at one end of the wave guide being tested a distance of

$$n \frac{\lambda}{4}$$

wavelengths from the impedance irregularity being compensated for, and each additional dent is located a distance of

$$\frac{\lambda}{2}$$

wavelengths from the next previous one, n being an odd integer and λ the wavelength of the signal waves in the interior of the wave guide being tested. This section of wave guide is then reversed end for end in the microwave system, and provided at its other end with one or more dents in a similar manner.

A like procedure is followed for providing one or more dents in one or both ends of a bent and/or a twisted wave guide, of a wave guide having one or more fabricated corners, that is, curvilinear wave guide made up of a plurality of rectilinear sections of wave guide, and in the auxiliary wave guides associated with the reflected and incident wave outlet taps of the directional coupler mentioned previously.

A feature of this invention is that wave guide previously rejected on the ground of causing standing waves lying above a tolerable limit, say for example, the value 1.10 mentioned hereinbefore, may now be rendered satisfactory in the manner aforesaid. This tends to result in an economy of material, time and labor.

The invention will be readily understood from the following detailed description taken together with the accompanying drawing, in which:

Fig. 1 illustrates a known microwave signal transmission system modified in accordance with a specific embodiment of the invention;

Figs. 1A, 1B and 1C show portions of a microwave wave system which may be individually substituted in Fig. 1 and modified in accordance with a specific embodiment of the invention;

Fig. 2 is a curve representing action obtainable in Figs. 1, 1A, 1B and 1C;

Fig. 3 is a side elevational view of a device utilized for practicing the specific embodiment of the invention used in Figs. 1 and 1A, 1B and 1C;

Fig. 4 is an enlarged fragmentary elevational view of Fig. 3; and

Fig. 5 is a cross-sectional view taken along the line 5-5 in Fig. 1.

Referring to Fig. 1, a known circuit for testing a section of tubular wave guide 14 for its standing wave ratio comprises in sequence a signal generator 10, a suitable variable attenuator 11, a suitable frequency meter 12, a directional coupler 13, the section 14 of tubular wave guide, and an adjustable resistive-card load 16. The wave guide 14, for the purpose of this illustration, may be made of copper or aluminum, is $1\frac{1}{4}$ inches by $\frac{5}{8}$ inch in cross-section, has a wall thickness of approximately $\frac{1}{8}$ inch, and will be assumed to include the impedance irregularities which are to be identified later on and to be compensated for in a manner to be explained

4

subsequently. To the directional-coupler tap 17 for reflected waves are serially connected a section 18 of tubular wave guide and a crystal-converter meter 19 of known type including the usual pickup probe. To the directional coupler tap 20 for incident waves are serially connected a variable attenuator 21 and a fixed attenuator 22 of 20 decibels, both of which are of known design. The generator 10 provides signal waves having a frequency within the range at which hollow wave guides are useful in signal transmission systems. The electromagnetic waves being transmitted in the wave guide 14 are of the dominant mode having electric lines normal to the wide sides thereof.

The directional coupler 13 comprises two directional couplers, each of which is essentially of the type disclosed in Fig. 7 of the copending application of W. W. Mumford, supra; and as shown in Fig. 1, includes a main wave guide 25, an auxiliary wave guide 26 provided with a tap 17 at its left-hand end serving as an outlet for reflected power, and a conventional resistive card 27 at its right-hand end; and an auxiliary wave guide 28 supplied with a tap 20 at its right-hand end serving as an outlet for incident power, and the conventional resistive card 27 at its left-hand end. It will be understood that the taps 17 and 20 comprise wave guides formed with suitable configurations for electrically connecting the auxiliary wave guides 26 and 28, respectively, to the apparatus associated therewith. Three openings 29 couple the main wave guide 25 to the auxiliary wave guide 26; and three openings 20a, similar to the openings 29, couple the main wave guide 25 to the auxiliary wave guide 28. These coupling openings provide substantially equal coupling losses for the respective auxiliary wave guides.

In the operation of Fig. 1 to obtain the $\overline{\text{SWR}}^2$ of the wave guide 14, the meter 19 is initially connected as shown in Fig. 1, and the attenuator 11 is adjusted to provide a preselected reading, say for example, ten per cent of the scale of meter 19. Next, the meter 19 is connected to the output terminal of the fixed attenuator 22, and then the attenuator 21 is adjusted to repeat the ten per cent reading on the meter 19. The sum of the reading of the variable attenuator 21 plus the 20-decibel attenuation of the fixed attenuator 22 constitute the front-to-back or F/B ratio of the wave guide 14. This sum is then referred to the curve in Fig. 2 to obtain the value of the $\overline{\text{SWR}}^2$ of the wave guide 14. Assuming, for example, an $\overline{\text{SWR}}^2$ of 1.10 as a tolerable maximum limit for the unknown wave guide 14, then the F/B ratio of this wave guide should be approximately 32.6 decibels; and the relative amplitude of the reflected wave should be approximately 0.3 shown in Fig. 2 for the purpose of this illustration.

In accordance with a specific embodiment of the present invention shown in Figs. 1, 3, 4 and 5, the $\overline{\text{SWR}}^2$ of the wave guide 14 may be reduced in a manner that will now be explained from a value lying outside the tolerable limit of 1.10 to a value lying within this limit, or alternately to a value approaching more closely to the ideal value of 1.10 than the above-identified assumed tolerable limit.

Referring to Fig. 3, a vise-like clamp 30 comprises a U-shaped member 31 provided with a fixed pedestal 32 and a screw 33 adjustable by means of a handle 34 on its uppermost end. At the lowermost end of this screw is positioned a

5

member 35 including a flat under surface 36. On opposite vertical sides of member 35 is a pair of right-angled members 37, 37. The pedestal 32, as shown in Fig. 4, comprises a cylindrical element 40 mounted vertically on the member 31 and whose upper-most end 41 is formed with a substantially semispherical configuration whose diameter is approximately $\frac{1}{8}$ inch. The handle 34 serves to raise and lower the member 35 with reference to the fixed pedestal 32 in the well-known manner.

The operation of Fig. 3 in connection with Figs. 1 and 2 is as follows: Let it be assumed that the wave guide 14 has been found to have a SWR² in excess of the 1.10 tolerable value in the manner explained hereinbefore; and an impedance irregularity is inherent in each of couplings 14a and 14b located at the left-hand and right-hand ends, respectively, of the wave guide 14. Since the adjustable load 16 projects to the left beyond the coupling 14b; the impedance irregularity in this coupling is nullified, and may be disregarded for the moment. Then, with the meter 19 connected in the circuit of Fig. 1, the clamp 30 is positioned on the left-hand end of the wave guide 14 in proximity of the coupling 14a in the manner illustrated in Fig. 3. In this connection it will be observed that the two right-angled members 37, 37 serve to dispose the pedestal end 41 substantially on the center or longitudinal axis of the under-surface of the wave guide 14. Next, the handle 34 of the clamp 30 is so actuated as to increase gradually the pressure of the pedestal end 41 on the under-surface of the wave guide 14, without permitting the pedestal end 41 to make a permanent dent in the under-surface of the latter wave guide. Simultaneously, therewith, the reading on the meter 19 is noted. A reading other than one decreasing below the 10 per cent pointed out previously would tend to indicate that the pedestal end 41 is improperly placed relative to the impedance irregularity in the coupling 14a.

Accordingly, the clamp 30 is shifted along the longitudinal axis of the wave guide 14 until there is found for the pedestal end 41 a position at which the pressure of the pedestal end 41 under control of the handle 34 as previously mentioned provides on the meter 19 a reading which tends to decrease below the initial 10 per cent. This position of the pedestal end 41 would tend to establish a further impedance irregularity in the unknown wave guide 14 whereby a further reflected wave is introduced into the system of Fig. 1. Since the further reflected wave tends to reduce the reading on the meter 19, such further reflected wave tends to be out of phase with the reflected wave caused by the impedance irregularity in the coupling 14a. So long as the meter reading tends to decrease, this procedure of shifting and operating the clamp 30 is repeated until eventually the clamp 30 is located at a point on the wave guide 14 at which the maximum sensitivity of the decreasing meter reading is obtained. The further reflected wave produced at this point is substantially 180 degrees out of phase with the reflected wave caused by the coupling 14a.

In other words, the further impedance irregularity is located substantially

$$n\frac{\lambda}{4}$$

wavelengths from the impedance irregularity in the coupling 14a, n being an odd integer and λ the wavelength of the signal waves in the wave

6

guide 14. It is known that the effects of two impedance irregularities will substantially cancel each other when they are spaced

$$n\frac{\lambda}{4}$$

wavelengths apart, provided their amplitudes are substantially equal. At the point where the pedestal end 41 is located approximately

$$n\frac{\lambda}{4}$$

wavelengths from the impedance irregularity in the coupling 14a, the handle 34 of the clamp 30 is actuated until the pedestal end is driven to its maximum depth into the under-surface of the unknown wave guide 14, whereby a circular dent 50 shown in Figs. 1, 3 and 5 is permanently produced in under-surface or one wide side of the unknown wave guide 14. This dent has a depth of the order of one-sixteenth inch and a diameter of approximately $\frac{1}{8}$ inch for the size of the wave guide 14 previously mentioned, and results in the production of a tapering projection 50a, Fig. 5, formed integral with the inner surface of the lower wide side of the wave guide 14 and extending interiorly thereof. In Fig. 5, the dent and projection are not shown to scale but are somewhat enlarged for the purpose of this illustration; and it will be obvious that the dimensions of the dent and projection may vary for different sizes of wave guide.

Should it happen that the effect of the one dent 50 fails to cancel the effect of the impedance irregularity in the coupling 14a, this means that the amplitude of the further reflected wave caused by the dent 50 is less than the amplitude of the reflected wave caused by the impedance irregularity in the coupling 14a. Additional improvements in the effective cancelation of the reflected wave due to the impedance irregularity in the coupling 14a may be obtained by producing one or more additional dents 50 in the wave guide 14, each dent being spaced

$$\frac{\lambda}{2}$$

wavelengths from adjacent dents. Thus, each dent is located

$$n\lambda \pm \frac{\lambda}{4}$$

wavelengths from the impedance irregularity in the coupling 14a. As a consequence, the amplitudes of the several further reflected waves due to the individual dents 50 effectively add vectorially to cancel substantially the reflected wave caused by the impedance irregularity inherent in the coupling 14a.

The impedance irregularity in the flange 14b of the wave guide 14 may be compensated for by reversing the latter wave guide end for end in Fig. 1 so that the couplings 14a and 14b are interchanged in so far as their relative positions in Fig. 1 are concerned, and thereafter producing one or more dents 50 in the end of the wave guide 14 adjacent the coupling 14b until the effect of the impedance irregularities due to the dents 50 substantially cancel the effect of the impedance irregularity inherent in the coupling 14b as hereinbefore explained.

Over a range of samples of wave guide similar to the wave guide 14 in Fig. 1, it was found that a maximum of four dents 50 introduced a sufficient number of impedance irregularities at each

7

end of the sample wave guides to compensate for the impedance irregularity inherent in the coupling located at each end of the sample wave guides; and further that such number of dents 50 had an adequate factor of safety to prevent a voltage breakdown between the projections 50a, Fig. 5, and the internal surface of the opposite side of the wave guide. In addition, the dent 50 and projection 50a have the advantages of (a) being pressure-tight where the wave guide 14 is operated under gas pressure, and (b) not affecting the band-width characteristic of the wave guide 14.

It has also been found that one or more dents 60, similar to dent 50, may be formed in the wave guide 14 at spaced points along the longitudinal axis thereof to correct for one or more impedance irregularities located elsewhere in the wave guide 14 but not in the couplings thereof and due, for example, to variations in the cross-section thereof. In this connection, it will be understood that one or more dents 60 may be located in the manner previously described relative to the production of dents 50 adjacent the ends of the wave guide 14.

An impedance irregularity in the coupling at each end of wave guide sections 52 and 53 shown in Figs. 1A and 1B, respectively may be compensated for by substituting these individual sections to the right of the line $a-a$ for the section 14 in Fig. 1, and thereafter producing one or more permanent dents 50 and projections 50a in both ends of the respective sections adjacent the couplings thereof in the manner previously explained in connection with wave guide 14 in Fig. 1. Additional dents 51 may be produced in the bends of the sections 52 and 53 in Figs. 1A and 1B to compensate for impedance irregularities inherent in these bends, and may be located in the manner previously described relative to the production of dents 50 in the wave guide section 14.

It will be understood that the aforementioned procedure may be employed to compensate for impedance irregularities in tubular wave guide sections whose initial SWR^2 is above the tolerable value 1.10 so as to reduce the SWR^2 of these samples at least to this tolerable value, or alternately to a value therebelow, if possible. This would tend to reduce the quantity of wave guide rejected on the ground of having a SWR^2 in excess of the tolerable limit of 1.10.

Figs. 1, 1C and 3 comprise an arrangement for compensating for impedance irregularities inherent in the directional coupler 13 and due, for example, to imperfect coupling openings 29 and 29a, the resistive cards 27, and variations in cross-section. To accomplish this compensation, the apparatus included in the box 60a in Fig. 1C is substituted for the apparatus included in the box 61 in Fig. 1. Box 60a comprises the directional coupler 13 and the usual adjustable resistive-card load 16. In the operation of Figs. 1, 1C and 3, the F/B ratio is measured by effecting the 10 per cent readings on the meter 19 in the manner explained hereinbefore regarding the F/B ratio for the wave guide 14 in Fig. 1. This ratio for the directional coupler 13 in Fig. 1C should be approximately 35 decibels for the average sample thereof before the application of the compensating dents 50 and projections 50a thereto.

Then, with the meter 19 connected to the tap 17 in Figs. 1 and 1C, the clamp 30 is disposed on the auxiliary wave guide 26 in Figs. 1 and 1C in

8

proximity of the three coupling openings 29, in a manner similar to that shown in Fig. 3, except one right-angled member 37 is removed from the clamp 30. As the pressure of the pedestal end 41 is gradually increased on the under-surface of auxiliary wave guide 26 without producing a permanent mark therein as pointed out previously concerning wave guide 14, the reading of meter 19 is noted. As this reading tends to decrease, then the clamp 30 is shifted a small distance to the right or left of the initial point and the clamp 30 operated again. So long as the meter reading tends to decrease, this procedure of the shifting and operating the clamp 30 is repeated until eventually the clamp 30 is located on a point of the auxiliary wave guide 26 at which the maximum sensitivity of the decreasing meter reading is obtained. The further reflected wave produced at this point is substantially 180 degrees out-of-phase with the unwanted reflected wave in the directional coupler at the reflected-wave tap. Accordingly, the clamp 30 is operated to produce a permanent dent 50 and projection 50a, Figs. 1C and 5, in the auxiliary wave guide 26 in the manner above described regarding unknown wave guide 14. This dent, as above-mentioned, will be located approximately

$$\frac{\lambda}{4}$$

wavelengths from the impedance irregularity to be corrected for. Additional dents, each spaced a distance

$$\frac{\lambda}{2}$$

wavelength from the next previous one, are produced in the auxiliary wave guide 26 as required, as mentioned hereinbefore concerning unknown wave guide 14. The F/B is then measured by connecting the meter 19 to the directional tap 20, and thereafter adjusting the attenuator 21 until the meter reading substantially equals the meter reading when the meter 19 was last connected to the tap 17. The F/B ratio is the sum of the reading of attenuator 21 plus the fixed 20-decibel attenuation of fixed attenuator 22. The directional coupler 13 is then reversed end for end, and the foregoing correction comprising one or more dents 50 and projections 50a are produced in the auxiliary wave guide 28. Both taps 17 and 20 are suitably corrected for the above-noted impedance irregularities, when the F/B ratio is greater than 50 decibels for each of these taps.

What is claimed is:

1. A tubular uniconductor wave guide for high frequency electromagnetic waves having a plurality of permanent indentations in the wall thereof spaced along the guide in such correlation with the length of said waves in the guide as to have a cumulative reactive effect on said waves, said indentations projecting into the interior of said guide a distance small compared with the cross-sectional dimensions of the interior of said guide.

2. A tubular uniconductor wave guide for high frequency electromagnetic waves including an inherent impedance irregularity in said guide, means for exciting high frequency electromagnetic waves therein, and at least one integral indentation in a wall of said guide in the form of a rounded point-like protuberance extending inwardly of said guide, said indentation being located substantially an integral multiple of one-quarter wavelengths of the mean frequency of

said waves in said guide away from said irregularity.

3. The structure according to claim 2 including a plurality of said indentations spaced apart longitudinally along a wall of said guide substantially an integral multiple of one-half wavelengths of the mean frequency of said waves in said guide as to have a cumulative reactive effect on said waves.

4. A tubular wave guide for transmitting electromagnetic waves and including an inherent impedance irregularity causing wave reflection, an imperforate dent formed in a wall of said guide, said dent forming an integral point-like bulge extending inwardly of said guide of such dimensions and having such location with reference to said impedance irregularity in terms of the wavelength of the waves being transmitted in said guide as to introduce into said guide a further wave reflection in such sense as tends to cancel the first-mentioned wave reflection.

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