July 19, 1966 A. R. SISSON 3,262,119

CAVITY BACKED SLOT ANTENNA WITH ROTATABLE LOOP FEED

Original Filed Aug. 3, 1961 2 Sheets-Sheet 1

FIG. 1

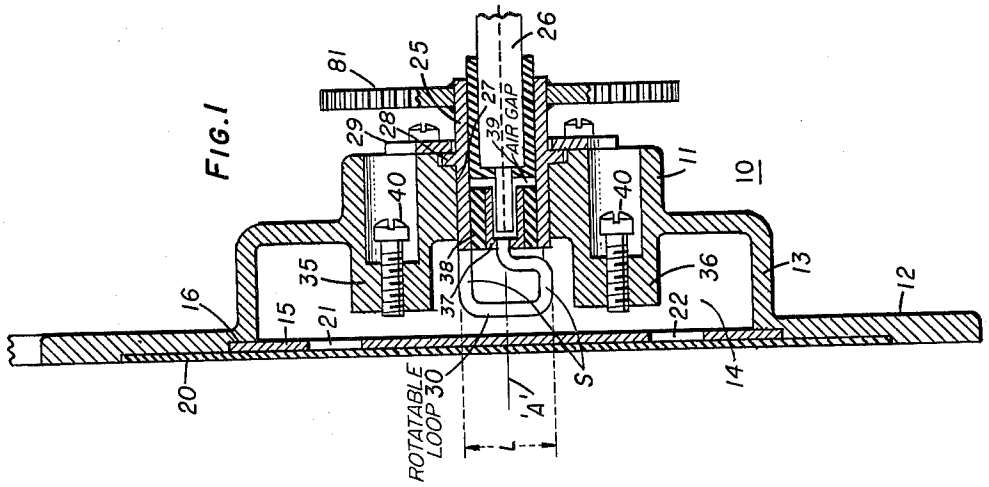
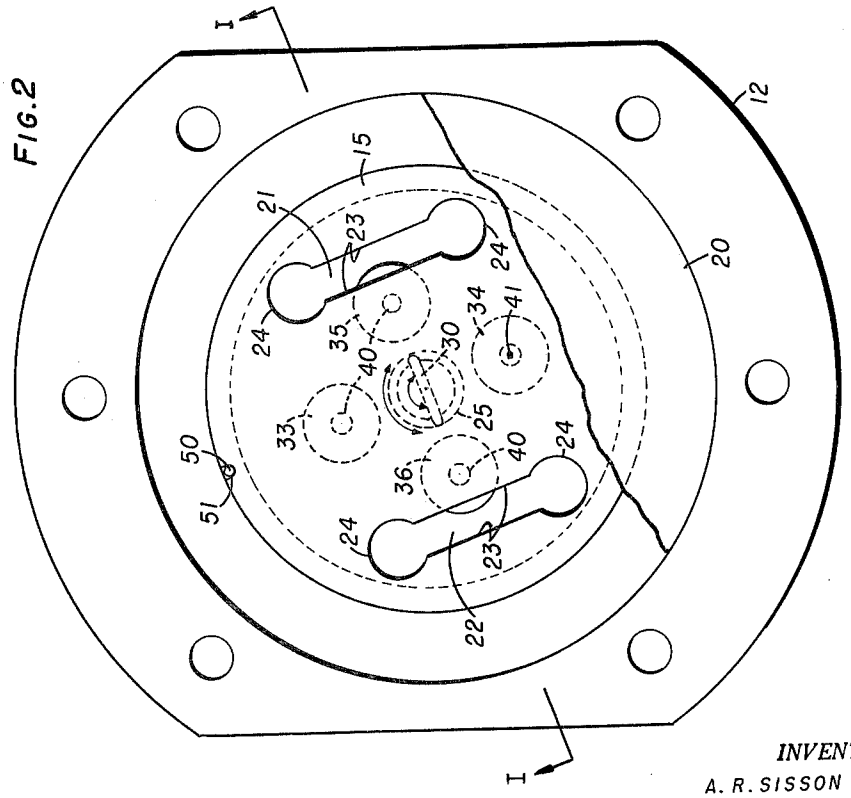


FIG. 2



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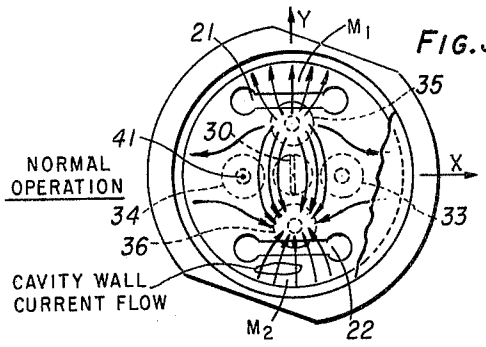


FIG. 3a

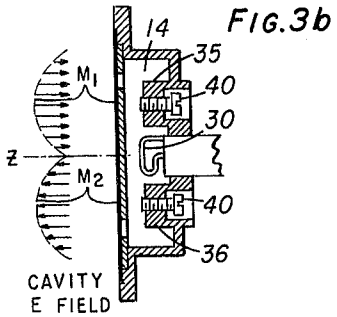


FIG. 3b

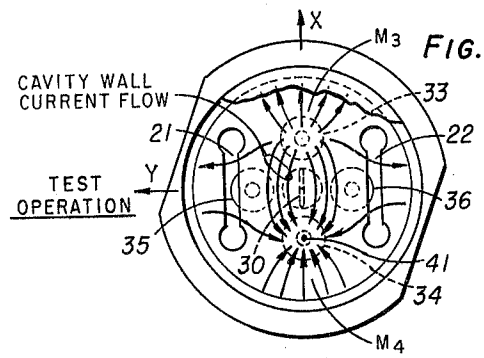


FIG. 4a

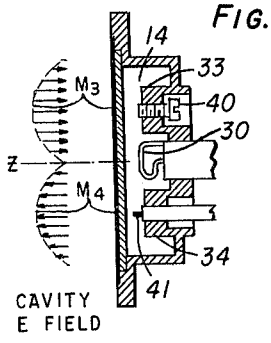


FIG. 4b

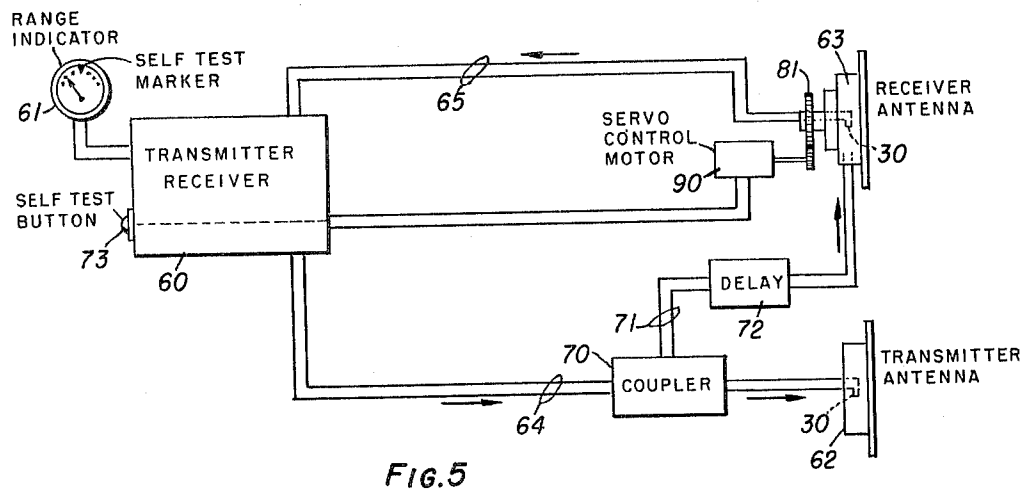


FIG. 5

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CAVITY BACKED SLOT ANTENNA WITH ROTATABLE LOOP FEED

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Continuation of application Ser. No. 129,180, Aug. 3, 1961. This application July 30, 1965, Ser. No. 477,088

12 Claims. (Cl. 343—703)

This invention relates to high-frequency antennas and, more particularly, to slot-type aircraft radar antennas.

The present application is a continuation of my application Serial No. 129,180, filed August 3, 1961, now abandoned.

In the design of antennas for use in radar systems on fast flying aircraft, the merits of the flush-mounted slot antenna are well recognized. Ordinarily they employ a transmission line terminating at a ground plane which in actuality is a continuation of the aircraft skin. The continuous metallic surface made up of the aircraft skin and antenna body is interrupted by at least one substantially rectangular slot constituting the radiating portion of the antenna. In the past, a pair of slots have often been used to obtain a preferred directional pattern. For example, when such slot doublets are spaced at a half-wavelength spacing, a cosine radiation pattern is produced. Typically, slot antennas are fed by a waveguide with the walls defining the slot, or by a coaxial conductor with the center conductor connected to a mid point of the longer side of the radiating slot or slots. One other type of feed for such slot antennas is through a probe positioned in a resonant cavity where the slot or slots are in an end wall of the cavity.

In certain radar applications it is essential that a provision be made for switching the antenna from radiating to nonradiating condition. An example of such a system is one intended for a relatively broad band use employing several slot antennas, each tuned to a selected frequency or oriented in a selected way. Such a system requires one or more antenna switches to energize the proper antenna. An obvious way of accomplishing this effect is to employ a switch in the transmission line between the transmitter and an antenna. However, both coaxial and waveguide switches suffer from the defects of having less than 100% isolation between the antenna and the transmitter when in the open condition, and invariably offer an impedance mismatch with resultant reflections and loss of energy. Moreover, both types of switch structures characteristically are complex mechanically as well, often resulting in short operating lives.

Still another type of radar system in which it is desirable to disable the antenna is one employing a self-testing feature. Such a feature employs a transmission line between the transmitting antenna and the receiver having a predetermined delay. In order to check the operation of the entire system, it is possible to switch from the transmitting antenna to the input connection to the delay line so that pulses generated by the transmitter reach the receiver at a known delay. It is essential in such a system that the antenna be disabled and no RF transmission permitted, since the receiver would otherwise detect both the energy coming through the delay line for test purposes and any reflected energy arriving at its own receiving antenna.

With this understanding of the requirements of the art for aircraft type slot antennas in mind, it is a general object of this invention to provide an efficient, small, slot-type antenna for operation in the 4000-megacycle frequency range.

Another object of this invention is to provide such an antenna with a self-contained switching mechanism to

allow the selective enablement and disablement of the antenna.

Still another object of this invention is to provide a slot-type antenna with an integral switch and including means for sampling energy reaching the antenna during periods of nonradiation.

One further object of this invention is to provide an effective means for feeding a dual slot of an antenna in phase with energy of equal magnitude in order to provide a preferred radiation pattern.

These objects are all achieved in accordance with this invention, one embodiment of which comprises an antenna body including a planar face and defining a cylindrical-shaped cavity with one end wall of the cavity coextensive with the planar face. A pair of substantially rectangular slots in the front face of the antenna body constitute the radiating surfaces of the antenna. An input loop for coupling electromagnetic energy into the cavity is positioned in the center of the body entirely along the longitudinal axis of the cylindrical cavity and mounted for rotation about that axis. A number of pillars, in this case four, extend into the cavity from the rear wall parallel to the cavity axis and at equal distances from the axis to provide capacitative loading. One of the pillars mounts a probe employed for detecting energy within the cavity under test conditions.

One feature of this invention involves the combination of a resonant cavity having a pair of energy-radiating slots in one wall of the cavity and means for introducing electromagnetic energy into the cavity symmetrically with respect to the slots.

Another feature of the invention is the provision for rotating the energy-coupling means so that energy is introduced into the cavity selectively in two modes, one for efficient radiation by the slots and the other for relatively insignificant radiation by the slots.

Still another feature of the invention relates to the presence of symmetrically placed loading means within the chamber and including means for detecting energy in the chamber in the nonradiating mode.

These and other features of this invention may be clearly understood from the following detailed description and by reference to the drawing, in which:

FIGURE 1 is a diametric section through an antenna of this invention.

FIGURE 2 is a front elevational view of the antenna of FIGURE 1, with portions broken away for clarity.

FIGURES 3*a* and 3*b* are simplified elevational and sectional views, respectively, showing the coupling loop in energy-radiating orientation.

FIGURES 4*a* and 4*b* are simplified showings similar to FIGURES 3*a* and 3*b* with the coupling loop shown in nonradiating orientation.

FIGURE 5 is a simplified block diagram of a radar system employing this invention.

Now referring to FIGURE 1, an antenna **10** embodying this invention is made up of a unitary metallic body **11** including a flange portion **12** and a recess portion **13**, the latter of which defines a cylindrical-shaped cavity **14** with the axis A of the cavity extending normal to the plane flange portion **12**. The cavity **14** is closed by an apertured metallic plate **15** resting on a circular step **16** and covered by a circular dielectric disk **20** constituting the front face of the antenna **10** and forming a weather seal for the antenna. The disk **20** is transparent to radiated electromagnetic waves emanating from apertures in the plate **15**.

The apertures in plate **15** are in the form of a pair of parallel-sided slots **21** and **22** positioned equidistant from the longitudinal axis A of the cavity. These slots **21** and **22** are best seen in FIGURE 2 as including straight side portions **23** and circular end-loading regions **24**.

A coaxial conductor **25** extends into the antenna body **11** through an axial aperture so that the central conductor **26** of the coaxial conductor **25** extends along the axis A. The central conductor **26** terminates in a loop **30** having a rectangular configuration with major length L equal to the diameter of the coaxial conductor **25**, and minor sides S effectively extensions of the outer conductor **31** of the coaxial. In a typical application, this loop employed for coupling electromagnetic energy from the coaxial conductor **25** to the cavity **14** is made up of 18-gauge copper wire, or may be formed from a finger which is an integral continuation of the outer conductor **25**. The coaxial outer conductor is mounted for rotation in a cylindrical bore **27** of body **11** constituting a bearing surface. The outer conductor **25** is secured, as by brazing, to a gear **81** used to impart rotational motion to the outer conductor **25** and loop **30**. A ring flange portion **28** constitutes a thrust bearing surface for the rotatable assembly. The flange portion **28** is retained in an annular groove in the body **11** by a retainer plate **29**, the plate **29** and base of the annular groove providing the corresponding nonrotating bearing surfaces for the ring flange **28**.

The loop **30** terminates at its inner end at a cap **37** which is spaced from the outer conductor **25** by an insulating collar **38**. The cap **37** is also spaced from the inner conductor **26** by an air gap **39** providing capacitative coupling between the nonrotating center conductor **26** and the rotating loop **30**.

The above-described arrangement is preferred for providing a simple loop-rotating mechanism. It is basically the well known rotating joint for coaxial lines of the type described and shown in E. G. Bowen, "A Textbook of Radar," copyright 1954, Cambridge University Press, on page 185 and 186 and in FIG. 114. Other types of rotating coaxial joints may be used to fit the particular cavity and antenna requirements in accordance with established practice in the coaxial line art. The essential function of the rotating mechanism is to provide at least 90° of rotation of the cavity by the loop which extends into the cavity from the rear wall coaxially with the cavity axis.

The antenna body **11** includes integral pillars **33**, **34**, **35**, and **36**, two of which are shown in FIGURE 1 extending into the cavity **14**. The pillars **33–36** extend into the cavity in a direction parallel to the longitudinal axis A at the cavity **14** and are all positioned equidistant from the axis and distributed symmetrically at 90° intervals around the axis A. Pillars **33** and **34** form a line parallel to the length of parallel slots **21** and **22**, while pillars **35** and **36** are aligned normal to the length of slots **21** and **22**.

The pillars **33–36** provide capacitative loading of the cavity **14** to reduce its size for any selected frequency in a manner well known in the art. The pillars **35** and **36**, shown by FIG. 1, as well as pillar **33** of FIGURE 2, mount central tuning screws **40** which are used to adjust the resonant frequency of the cavity. The pillar **34**, instead of a tuning screw, mounts a central probe **41** used as hereinafter described to couple energy into the cavity during the test phase of operation.

FIGURE 2 additionally shows the relative position of the apertured plate **15**, and particularly slots **21** and **22**, with respect to the input loop **30** and the loading pillars **33–36** in the cavity **14**. The positioning of the plate **15** is established by an indexing pin **50** in a slot **51**.

The dielectric window **20** forming the front face of the antenna is broken away for clarity, revealing the dumbbell-shaped slots **21** and **22**. The slots **21** and **22** are equidistantly spaced from the axis with the length of the slot approximately equal to one-half of the wavelength of the intended frequency of operation. The circular end regions of the slots **21** and **22** provide additional perimeter length of the slot, allowing a lower frequency of operation than otherwise would be possible, fed by a

cavity of the small diameter possible through the use of capacitative loading pillars **33–36**.

The operation of this invention may be understood from FIGURES 3 and 4 illustrating the normal radiating or detecting mode of operation in FIGURE 3, and test operation in FIGURE 4. In both cases the cavity **14** is excited in the TM_{110} mode in which the magnetic or H field is oriented in the plane of the X and Y axis transversely to the Z axis of the cavity, and the electric or E field is oriented essentially along the Z axis, but varies in the plane of the X and Y axis, as shown in FIGURES 3*b* and 4*b*. The cavity **14** is excited by energy coupled in through the loop termination **30** of the coaxial lines in the second order mode with two maxima, as shown by the E field distribution arrows of FIGURES 3*b* and 4*b*. The voltage maxima points M_1 and M_2 in the cavity wall exist directly opposite the capacitative loading pillars **35** and **36**, and the current distribution in the walls is indicated by the arrows appearing in FIGURES 3*a* and 4*a*. In FIGURE 3*a*, current flow is transverse to the length of slots **21** and **22**, thereby excites the slots **21** and **22**, and produces radiation therefrom or, if the antenna is operating as a receiving device, allows the coupling of properly polarized energy from the slots into the cavity to be detected by the loop **30**. It is noted in FIGURE 3*a* that the direction of current flow through the slots **21** and **22** is the same whereby the slots are fed in phase, resulting in a cosine radiation pattern for the antenna in the transmitting mode. In the normal operation illustrated by FIGURES 3*a* and 3*b*, the probe is positioned along the X axis, which in this case coincides with the zero voltage plane of the Z axis (see FIGURE 3*b*). Therefore, the probe **41** is not excited by energy in the cavity during the normal operation.

FIGURE 4 shows the antenna with the orientation of the coupling loop changed by 90° with respect to the antenna body. For convenience of showing the position of the probe within the cavity in FIGURE 4*b*, the body of the antenna, rather than the loop, is shown rotated 90° from the position of FIGURE 3. It should be noted that the shape of the cavity E field distribution is identical with the case of FIGURE 3*b*. However, the probe as shown in FIGURE 4*b* is now positioned at the point of voltage maximum M_4, whereby energy is efficiently coupled between the cavity **14** and the probe **41**. This is clearly illustrated by the current flow lines of FIGURE 4*a*. The cavity still excited in the TM_{110} mode has the same pattern as in the case of FIGURE 3*a* with current flowing from one point M_3 coinciding with the position of a capacitative loading pillar **33** through the cavity's walls to the second maximum point M_4 opposite the loading pillar **34**. In both cases of FIGURES 3*a* and 4*a*, the direction of current flow is aligned with the direction of the loop **30**. It should be noted in FIGURE 4*a* that there is no net current flow perpendicular to the length of the slots **21** and **22** as the current flowing across one-half of the slots is opposite in direction to, and therefore cancels, that current flowing across the second half of the slot, whereby the slots are not excited significantly, and no radiation therefrom occurs. On the other hand, probe **41** capacitatively coupled to point M_4 of maximum voltage within the cavity is excited.

The operation of this invention may be further understood from FIGURE 5, showing in simplified form an illustrative system employing the antenna of FIGURES 1 and 2 as the receiving antenna and an antenna similar in construction to that of FIGURES 1 and 2 without the provision for rotation of the coupling loop and without any probe as the transmitting antenna. The system of FIGURE 5 is typically a radar-ranging system including a transmitter-receiver **60** having an indicator **61** calibrated to register the time delay between transmission of energy from a transmitting antenna until the detection of return in the receiving antenna as a measure of distance to a reflecting object. Transmitting and receiving antennas **62** and **63**, respectively, are connected to the transmitter-

receiver 60 by suitable transmission lines 64 and 65 which terminate in coupling loops 30. The transmission line 64 to the transmitting antenna 62 includes a coupler 70 for tapping off a small amount of the transmitted energy and introducing it through line 71 and a delay network 72 having a predetermined time delay. The output of the delay network 72 is connected to the probe 41 of FIGURES 2, 3, and 4. The position of the loop 30 in the receiving antenna 63 is determined by a servo control system operated by a button 73 on the transmitter-receiver 60. The servo control system may include a motor 80 driving a gear system 81, as illustrated in FIGURE 5, or simply a solenoid. The function of the servo-control system is to position the loop of the receiving antenna normal to the length of the radiating slots. When the antenna is in its normal operating condition and responsive to the operation of the self-test button 73, the servo control rotates the loop 30 in the receiving antenna 63 90° to orient the loop for test purposes.

During the test operation, a portion of the energy directed to the transmitting antenna 62 and passing through the delay network 72 is coupled back through the internal probe 41, the cavity, and the coupling loop 30 to the receiver portion of the transmitter-receiver 60 where the known delay results in the needle of an indicator 60 moving to a position corresponding to the fixed delay. This position is identified by a test marker on the face of the indicator.

Whenever the operator wishes to determine whether the entire system is operating satisfactorily, he merely depresses the self-test button, and the next transmission to the transmitting antenna results in the needle moving rapidly to the test marker. Any other reading would indicate system malfunction.

The successful operation of the system of FIGURE 5 results from the presence of the antenna of FIGURES 1 and 2, designed for the normal efficient transmission through the dual slots and for test operation in which the slots are not excited.

The two modes of operation are possible because of the simple, effective, noncontacting switching mechanism constituting an integral part of the energy-coupling system within the antenna.

Although for the purpose of describing the invention a particular embodiment thereof has been shown and described, obvious modifications will occur to a person skilled in the art, and I do not desire to be limited to the exact details shown and described.

I claim:

1. A slot antenna comprising:
a conductive body defining a cylindrical cavity,
one portion of said body defining an end wall of the cavity including a pair of substantially parallel slot apertures positioned on opposite sides of the longitudinal axis of the cylindrical cavity for coupling electromagnetic energy between the walls of the cavity and the external medium,
a conductive loop extending through the opposite end wall of said body into the cavity,
said conductive loop extending symmetrically with respect to the said cavity axis, and
means mounting said conductive loop for rotation about the said cavity axis to change the coupling efficiency between the slot apertures and said conductive loop.

2. A slot antenna comprising a body defining a cylindrical cavity, one end wall of the body defining said cavity including a pair of substantially parallel slots positioned symmetrically with respect to the longitudinal axis of the cavity,
loop means positioned in the opposite end wall of said cavity for coupling electromagnetic energy between said loop means and the slots,
said loop means being substantially symmetrical about the longitudinal axis of the cavity, and
means mounting said loop means for selective positioning, either parallel to the length of said slots or at right angles thereto.

3. The combination in accordance with claim 2 wherein said body mounts electromagnetic energy-detecting means in the cavity oriented to be energized when said loop means is oriented at right angles with respect to said slots.

4. The combination in accordance with claim 3 including a plurality of capacitative loading members positioned symmetrically with respect to the longitudinal axis of the cavity and symmetrically with respect to said loop means when said loop means is in both the parallel and right-angle orientation with respect to said slots.

5. The combination in accordance with claim 4 wherein said capacitative loading means comprises four conductive pillars extending into the cavity parallel to the longitudinal axis thereof and symmetrically spaced therefrom.

6. The combination in accordance with claim 5 wherein one of said capacitative loading pillars mounts a probe for coupling energy between said cavity and the exterior of said body.

7. A conductive body defining a substantially cylindrical cavity, one portion of said body defining an end wall of the cavity including a pair of substantially parallel slot apertures positioned on opposite sides of the longitudinal axis of the cylindrical cavity for coupling electromagnetic energy between the walls of the cavity and the external medium,
a conductive loop extending through the opposite end wall of said body into the cavity,
said conductive loop extending symmetrically with respect to the said cavity axis,
said cavity being adapted for excitation in the TM_{110} mode such that its electric field is oriented essentially parallel to said axis.

8. A slot antenna as set forth in claim 7 wherein a pair of capacitive loading pillars are carried on said opposite wall, each of said pillars extending parallel to said longitudinal axis in close proximity to one of said slot apertures.

9. A slot antenna as set forth in claim 7 wherein said loop means is oriented substantially at right angles to said slots.

10. A slot antenna comprising a body defining a cylindrical cavity, one end wall of the body defining said cavity including a pair of substantially parallel slots positioned symmetrically with respect to the longitudinal axis of the cavity,
loop means positioned in the opposite end wall of said cavity for coupling electromagnetic energy between said loop means and the slots,
said loop means being substantially symmetrical about the longitudinal axis of the cavity,
said cavity being constructed and arranged for excitation in the TM_{110} mode in which the magnetic field is oriented in a plane essentially normal to said longitudinal axis and the electric field is oriented essentially parallel to said longitudinal axis.

11. A slot antenna as set forth in claim 10 wherein a pair of capacitive loading pillars are carried on said opposite wall, each of said pillars extending parallel to said longitudinal axis in close proximity to one of said slot apertures.

12. A slot antenna as set forth in claim 10 wherein said loop means is oriented substantially at right angles to said slots.

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ELI LIEBERMAN, *Acting Primary Examiner.*