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MEANS FOR COMMUNICATING THROUGH A LAYER OF IONIZED GASES

Filed April 29, 1964 2 Sheets-Sheet 1

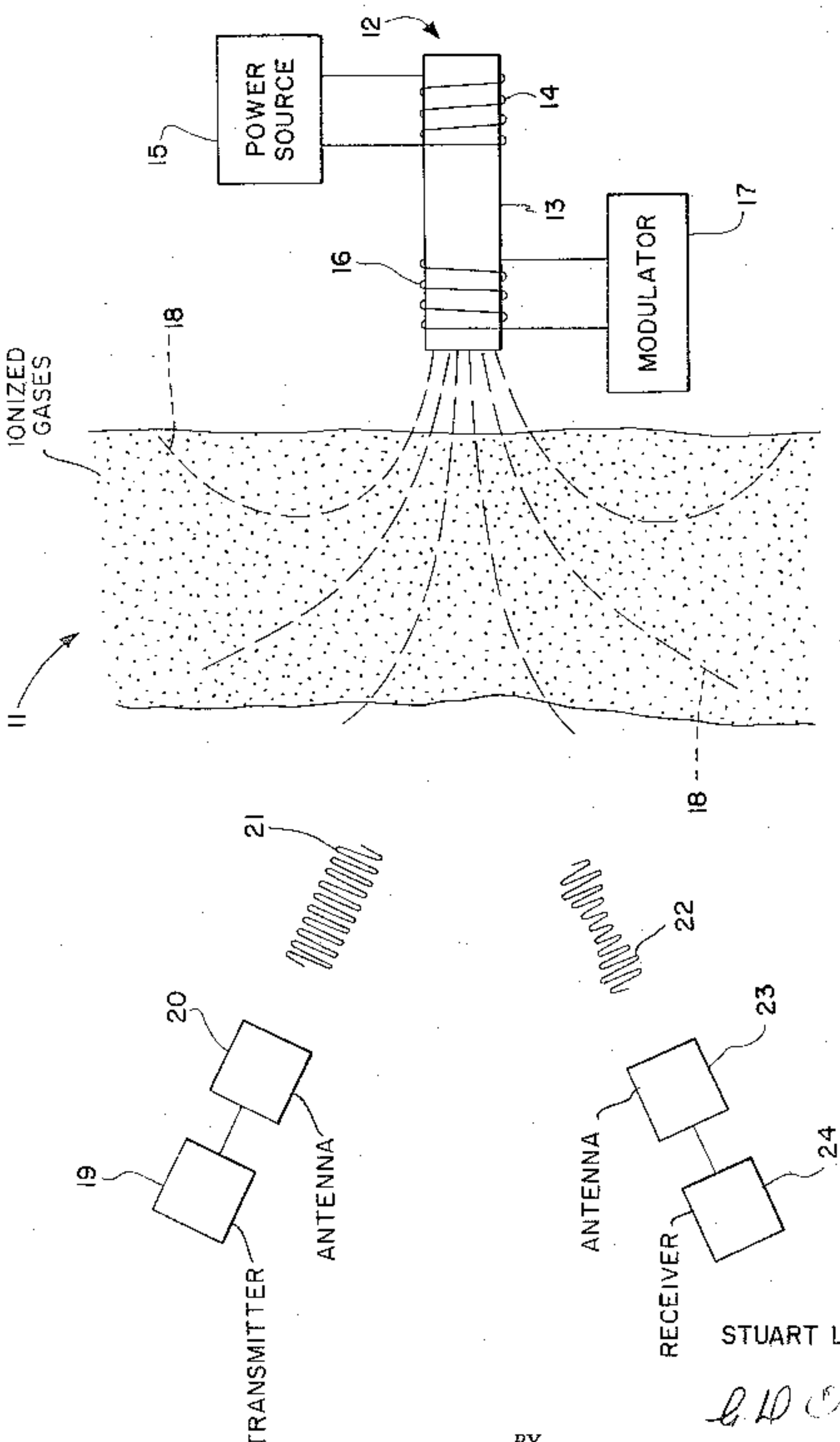

FIG. 1

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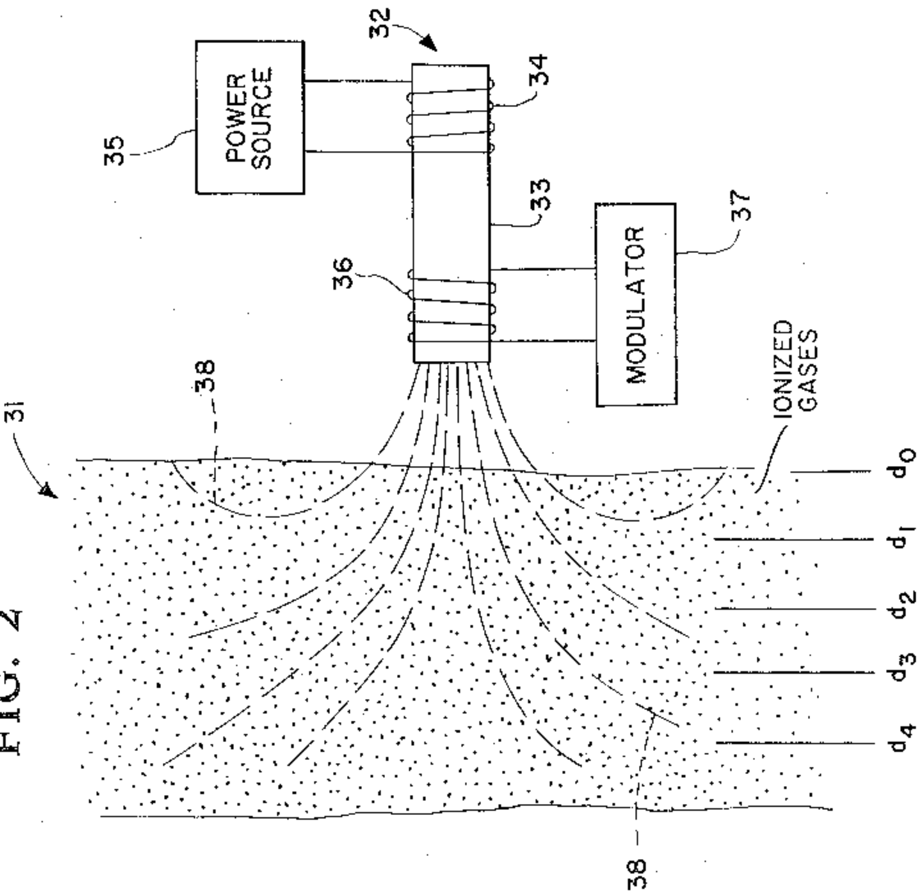
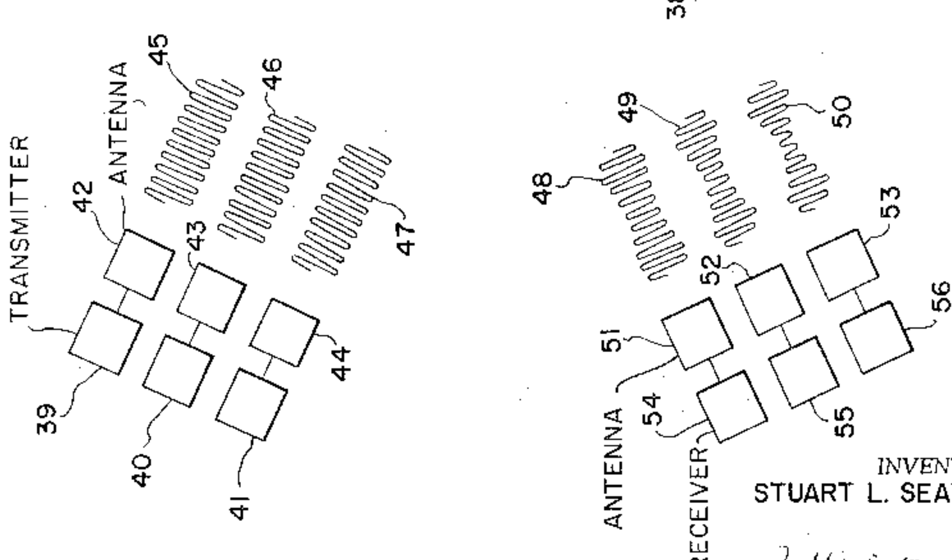


FIG. 2



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MEANS FOR COMMUNICATING THROUGH A LAYER OF IONIZED GASES

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7 Claims. (Cl. 325—65)

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates generally to the modulation of electromagnetic waves and more particularly concerns a method and apparatus for communicating through a layer of ionized gases.

Whenever a space vehicle traveling at a hypersonic speed (Mach 10 or above) enters or leaves a planetary atmosphere, it is surrounded by a shock-induced layer of ionized gases. This energized layer of gases or plasma prevents electromagnetic waves from passing through it. The electromagnetic waves are either reflected or absorbed by the plasma. Consequently, electromagnetic wave communication to and from the space vehicle is either partially or totally obstructed during the times that the space vehicle is surrounded by a layer of plasma. Since a layer of plasma is formed around a vehicle during critical phases of its flights (while leaving or entering a planetary atmosphere), it is desirable to be able to communicate through the plasma.

In the past, there have been several schemes suggested for accomplishing radio wave communication through the layer of plasma surrounding a space vehicle while it is reentering the earth's atmosphere. Among these schemes, is the scheme of selecting for use a signal frequency that will penetrate or pass through the hypersonically generated plasma. Extremely high radio frequencies will pass through the plasma. However, since most communication equipment presently in use is designed for the VHF-UHF bands (30 mc. to 300 mc. and 300 mc. to 3000 mc.) there is an equipment acquisition problem if the extremely high frequencies are used. Also, at the higher frequencies there is an atmospheric absorption problem.

Other schemes suggested for accomplishing radio wave communication through the layer of plasma include aerodynamic shaping, material injection and use of the layer of plasma as an electromagnetic radiator. However, none of these schemes satisfies all foreseeable requirements.

The present invention provides another scheme for communicating through the layer of ionized gases formed around a space vehicle as it enters or leaves a planetary atmosphere. This invention accomplishes its purpose by applying a modulated magnetic field to the layer of plasma whereby when electromagnetic waves are directed into the layer of plasma, the reflected electromagnetic waves contain the same modulation as the modulated magnetic field. The application of the unique principle of this invention also provides a tool for measuring the conditions inside a layer of ionized gases.

It is therefore an object of this invention to provide a new scheme for communicating through the layer of plasma formed around a space vehicle as it either enters or leaves a planetary atmosphere.

Another object of this invention is to provide a new scheme for modulating electromagnetic waves.

A further object of this invention is to provide a tool for measuring the conditions inside a layer of ionized gases.

Other objects and advantages of this invention will further become apparent hereinafter and in the drawings in which:

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FIG. 1 is a schematic drawing of the apparatus used in practicing this invention to communicate through a layer of ionized gases; and

FIG. 2 is a schematic drawing of the apparatus used in practicing this invention to measure the conditions inside a layer of ionized gases.

In disclosing this invention the physics upon which the invention depends will first be discussed, then the apparatus used to carry out the invention will be described.

It is well known that free electrons in an ionized medium, in the presence of a permeating magnetic field, when acted upon by an electromagnetic wave, gyrate about the magnetic lines of force with a frequency f_H given in the equation:

$$f_H = He/2\pi mc \quad (1)$$

where f_H is the gyrofrequency in cycles per second; H is the magnetic field strength in gauss; e/m is the ratio of electronic charge to mass in e.s.u.; and c is the velocity of light in a vacuum.

It is also well known that the mean frequency of collision of free electrons with other particles in a gas is given by the equations:

$$\bar{v} = \bar{V}\Sigma_i P_i Q_i \quad (2)$$

$$\bar{V} = (8kT)^{1/2}/(\pi m) \quad (3)$$

where $\bar{v}$ is the mean collision frequency; $\bar{V}$ is the mean thermic velocity; P_i is the density of the i^{th} species; Q_i is the collision cross section of the i^{th} species; k is Boltzman's constant; T is the temperature in degrees Kelvin; and m is the mean molecular mass.

In terms of the mean free path:

$$v = \bar{V}/L \quad (4)$$

where v is the collision frequency, and L is the electron mean free path.

If n is the number of molecules, or atoms per cubic centimeter, then,

$$L = 1/nA \quad (5)$$

where A is the molecular or atomic cross section.

If the mean thermic velocity of electrons in an ionized medium is augmented by energy from an electric field, the mean work done per collision is:

$$\bar{W} = (\tfrac{1}{2}rZ^2)/(v^2+w^2) \quad (6)$$

where r is equal to e^2/m in e.s.u.; Z is the root-mean-square value of the electric vector in e.s.u.; v is the collision frequency of the electrons; and w is the angular wave frequency of the imposed electric field.

It has been shown by previous authors that an index of interaction,

$$N v \bar{W} \quad (7)$$

where N is the number of electrons per cubic centimeter, exists for electromagnetic wave energies present in an ionized medium permeated by a magnetic field, and that the maximum value of this index of interaction occurs at or near the gyrofrequency. It has also been shown that when the collision frequency is less than the gyrofrequency and the wave frequency varies through the gyrofrequency, then the mean work done per electron collision increases, that is, a notable resonance occurs.

It is further well known that there exists in an ionized medium a "critical" frequency fc such that:

$$N = Bfc^2 \quad (8)$$

where B is a constant equal to 1.24 times 10^4 when the wave frequency f is in megacycles per second.

For wave frequencies f, such that f is less than fc, wave energy of frequency f will be reflected by or refracted in an ionized medium. For f greater than fc wave energy of frequency f will pass through the ionized medium. When f is equal to fc, the dwell time of the wave energy in the ionized medium becomes long and absorption due to collisions dissipates the wave energy. When f is less than or equal to ν, an electron oscillation in response to the wave energy cannot be completed before a collision disrupts the systematic electron motion and hence wave energy is dissipated. For f greater than or equal to ν at least one oscillation can be completed before a collision occurs and so dissipation is reduced.

One of the conditions of the invention for purposes of communication is that the electromagnetic wave frequency, f, lie between the collisional frequency, ν, and the critical frequency, fc, of the ionized medium, that is

$$\nu < f < fc \tag{9}$$

Since in many natural and artificially generated ionized media the natural earth's magnetic field is insufficiently strong to satisfy mathematical expression 9, where f is equal to f_H, it is necessary to produce in the ionized medium a local magnetic field to satisfy mathematical expression 9. If this local magnetic field is modulated, for example at voice frequencies, and if simultaneously the ionized medium is illuminated by an electromagnetic wave of frequency equal to the gyrofrequency associated with the unmodulated magnetic field, then the modulation will vary the local gyrofrequency to and fro across the illuminating wave frequency. By mathematical expression 7, when this condition occurs, wave energy returned from the ionized medium will carry a modulation in intensity consonant with the frequency of modulation of the magnetic field.

Now that the theory of this invention has been discussed, the preferred embodiments of the invention will be described. In describing the preferred embodiments of the invention illustrated in the drawings, specific terminology will be resorted to for the sake of clarity. However, it is not intended to be limited to the specific terms so selected, and it is to be understood that each specific term includes all technical equivalents which operate in a similar manner to accomplish a similar purpose.

Turning now to the specific embodiment of the invention selected for illustration in FIG. 1, the number **11** designates generally a layer of ionized gases. This layer of ionized gases **11** can be the hypersonically generated gases formed around a space vehicle as it enters or leaves a planetary atmosphere or it can be any other natural or manmade layer of ionized gases. The purpose of the embodiment of the invention in FIG. 1 is to communicate through layer **11** with electromagnetic waves or to use layer **11** to modulate electromagnetic waves that strike it. It will be assumed for illustrative purposes that the layer of ionized gases **11** has a free electron density n equal to 10^{10} electrons per cubic centimeter; a critical frequency fc equal to one hundred megacycles per second; and a mean collisional frequency ν equal to one megacycle per second. These values are in no way restrictive, but simply illustrate one set of conditions among many.

Located on one side of and contiguous to layer **11** is an electromagnet **12** consisting of an iron core **13**, a coil **14** wound around core **13**, and a power source **15** connected to coil **14**. Electromagnet **12** generates a magnetic field of H gauss. Also wound on core **13** is a coil **16** which is connected to a conventional modulator **17** having a frequency output of f_m. Core **13**, modulator **17** and coil **16** generate a magnetic field of ΔH gauss. The combined magnetic fields generated by coils **14** and **16** is a magnetic field of $H \pm \Delta H$ gauss. This combined magnetic field consists of magnetic lines of force **18** which pass through layer **11**. The magnetic field $H \pm \Delta H$ gauss resulting from coils **14** and **16** has an associated gyromagnetic frequency $f_H \pm \Delta f_H$ such that f_H is equal to fifty megacycles per second, H is equal to nineteen gauss, and Δf_H is equal to five percent of f_H, all of which is common knowledge in communication engineering.

Located on the other side of layer **11** is a conventional radio transmitter **19** connected to an antenna **20**. Transmitter **19** feeds antenna **20** causing it to emit in the direction of layer **11** a continuous electromagnetic wave **21** having a constant frequency f equal to fifty megacycles per second. Electromagnetic wave **21** is reflected by layer **11** as a continuous electromagnetic wave **22**. By virtue of the magnetic lines of force **18**, the energy of electromagnetic wave **21** is altered by the unique process of having $f_H \pm \Delta f_H$ move to and fro through the frequency of wave **21**. The energy lost by wave **21** in layer **11** is superimposed on the reflected wave **22**. Thereby wave **22** contains a modulation consonant with ΔH caused by the fm produced by modulator **17**. Wave **22** is picked up by antenna **23** and then applied to a conventional receiver **24**. Receiver **24** removes the modulation ΔH from wave **22**.

It can be readily seen that if modulator **17** is used to modulate the magnetic lines of force **18** in accordance with some information, this information is detected by receiver **24**. Consequently, this invention affords a means for communicating through a layer of ionized gases. If the apparatus including electromagnet **12**, coil **16** and modulator **17** is located on a space vehicle and the apparatus including transmitter **19**, receiver **24**, and antennas **20** and **23** is located on earth, then this invention provides a means for communicating through the layer of plasma formed around the space vehicle as it enters or leaves the earth's atmosphere. Also this invention provides a unique means for modulating electromagnetic waves which might be useful for other purposes.

Referring now to FIG. 2 the second preferred embodiment of this invention will be described. The embodiment of this invention shown in FIG. 2 is used for the purpose of measuring the conditions inside a layer of ionized gases **31**. Located on one side of layer **31** is apparatus identical to that shown in FIG. 1. This apparatus consists of an electromagnet **32** including an iron core **33** and a coil **34** supplied by a power source **35**. Also wound on iron core **33** is a coil **36** which is connected to a modulator **37**. The combined magnetic fields generated by coils **34** and **36** is a magnetic field $H \pm \Delta H$ gauss. This combined magnetic field consists of magnetic lines of force **38** which pass through layer **31**.

On the other side of layer **31** there are transmitters **39**, **40**, and **41** associated with antennas **42**, **43**, and **44**, respectively. Antennas **42**, **43**, and **44** emit continuous electromagnetic waves **45**, **46**, and **47**, respectively. Wave **45** has a frequency f_1, wave **46** has a frequency f_2, and wave **47** has a frequency f_3. Any number of these waves can be used. It is only necessary that the frequency of each wave be between ν and fc, that is, the frequencies f_j ($j=1, 2, 3, \ldots$) are such that

$$\nu < fj < fc \tag{10}$$

The waves **45**, **46**, and **47** are directed into the layer **31**. And, as in FIG. 1, these waves are reflected by layer **31** as waves **48**, **49**, and **50**.

A magnetic field falls off in strength inversely as a power of the distance from the origin of the magnetic field. Hence, in layer **31** at each distance dk ($k=0, 1, 2, 3, 4, \ldots$) from the electromagnet **32**, there corresponds a particular gyrofrequency. If, as in FIG. 1, modulator **37** modulates the magnetic lines of force **38** by an amount ΔH, then there will appear on each of the waves **48**, **49**, and **50** a certain percentage of modulation depending upon the distance, dk, to which waves **45**, **46**, and **47** penetrated into layer **31**. Waves **48**, **49**, and **50** are picked up by antennas **51**, **52**, and **53** and then applied to receivers **54**, **55**, and **56** where they are converted into useful form in a conventional manner.

Under the same unique principle as that of the embodiment in FIG. 1, the wave energy (waves **45**, **46**, and **47**) at each of the frequencies fj (f_1, f_2, f_3) upon entering the ionized medium **38** and being acted upon as before described, will emerge as frequencies $f_1 \pm fm$. These waves will each be modulated to an extent that those frequencies which penetrate farthest into the region of action will carry large depths of modulation, while those frequencies not so penetrating will carry lesser depths of modulation. In this way, the internal condition of the ionized medium **38** can be examined. A practical way of measuring the depths of modulation of waves **48**, **49**, and **50** would be to connect the outputs of receivers **54**, **55**, and **56** to an oscilloscope.

It is to be understood that the forms of the invention herewith shown and described are to be taken as preferred embodiments. Various changes may be made in the shape, size, and arrangement of parts. For example, equivalent elements may be substituted for those illustrated and described herein, parts may be reversed, and certain features of the invention may be utilized independently of the use of other features, all without departing from the spirit or scope of the invention as defined in the subjoined claims. This invention could be used to modulate lasers and other such devices which at the present resist being modulated.

What is claimed is:

1. An electromagnetic wave modulator comprising: a layer of ionized gases which reflects a part of any electromagnetic energy that is directed into it; means for applying an unmodulated magnetic field to said layer of ionized gases; means for modulating said magnetic field; means for generating an electromagnetic wave having a constant frequency equal to the gyrofrequency of said unmodulated magnetic field; and means for transmitting said electromagnetic wave into said layer of ionized gases whereby the reflected electromagnetic energy contains the same modulation as said modulated magnetic field.

2. A system for communicating through a layer of ionized gases which reflects a part of any electromagnetic energy that is directed into it comprising: means on one side of said layer for producing an unmodulated magnetic field extending into said layer; means for modulating said magnetic field in accordance with the information to be communicated through said layer; means located on the other side of said layer for generating and transmitting an electromagnetic wave, having a constant frequency equal to the gyrofrequency of said unmodulated magnetic field, into said layer in the region of said magnetic field; and means for receiving and demodulating the reflected electromagnetic energy from said layer whereby the modulation extracted from said reflected electromagnetic energy contains said information.

3. A system in accordance with claim **2** wherein said means for producing an unmodulated magnetic field comprises an iron core, a coil wrapped around the iron core, and a power source connected across said coil.

4. A system in accordance with claim **3** wherein said means for modulating said magnetic field comprises a second coil wrapped around said iron core and a modulator connected across said second coil.

5. A system in accordance with claim **2** wherein said means for generating and transmitting comprises a conventional radio transmitter and an antenna.

6. A system in accordance with claim **2** wherein said means for receiving and demodulating comprises an antenna and a conventional radio receiver.

7. A system for communicating through the layer of ionized gases formed around a spacecraft in an atmosphere wherein said ionized gases reflect a part of any electromagnetic energy that is directed into it comprising: means on said spacecraft for producing a magnetic field extending into said layer which is modulated in accordance with the information to be communicated through said layer of ionized gases; means remote to said spacecraft for generating and transmitting an electromagnetic wave, having a constant frequency equal to the gyrofrequency of said magnetic field, into said layer in the region of said magnetic field; and means for receiving and demodulating the reflected electromagnetic energy from said layer whereby the modulation extracted from said reflected electromagnetic energy contains said information.

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