

July 18, 1967

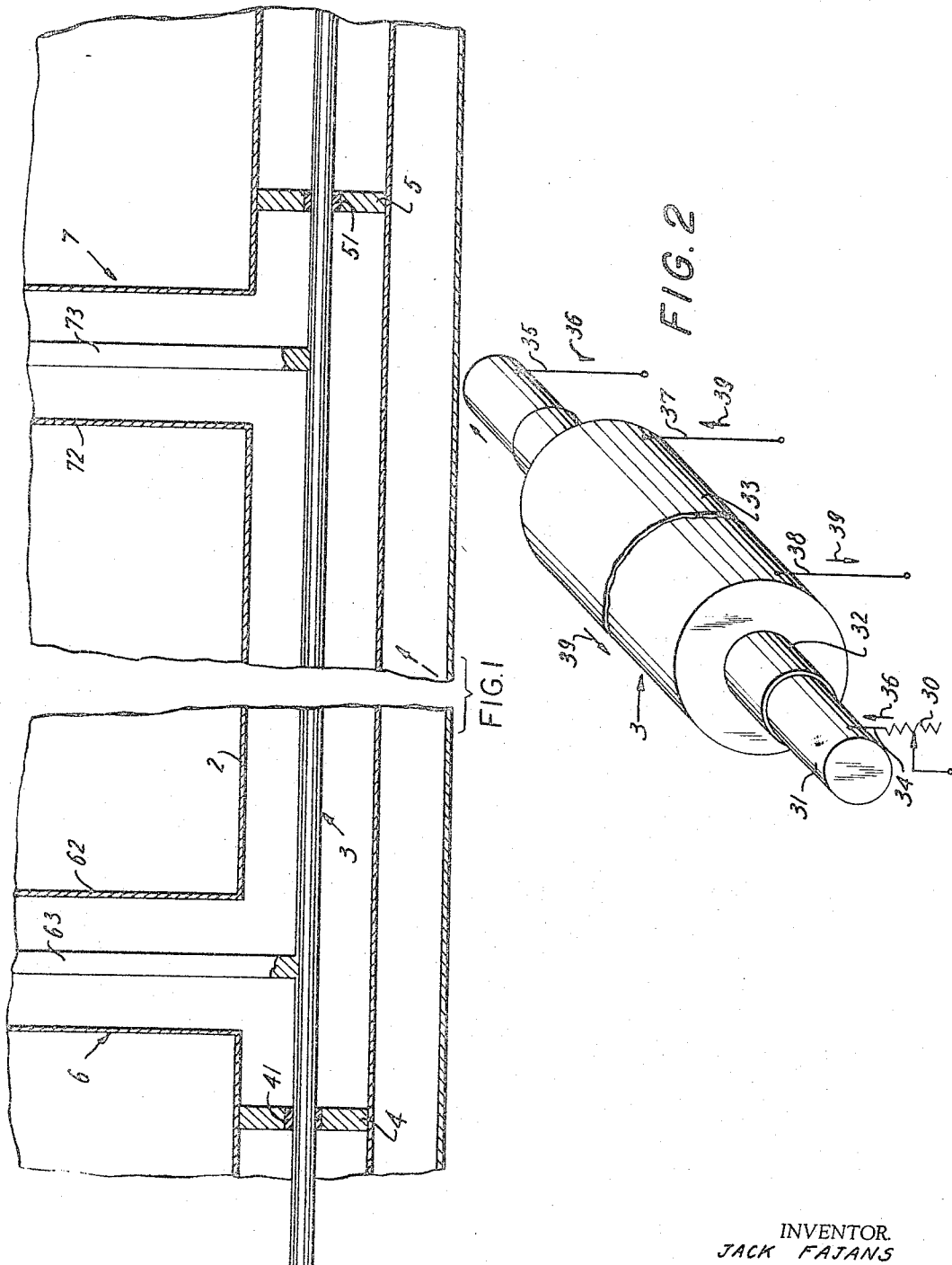
J. FAJANS

3,332,030

TUBULAR WAVEGUIDE USED-AS AN AMPLIFIER

Filed May 16, 1962

2 Sheets-Sheet 1



INVENTOR.
JACK FAJANS

BY

Hans Berman

AGENT

July 18, 1967

J. FAJANS

3,332,030

TUBULAR WAVEGUIDE USED-AS AN AMPLIFIER

Filed May 16, 1962

2 Sheets-Sheet 2

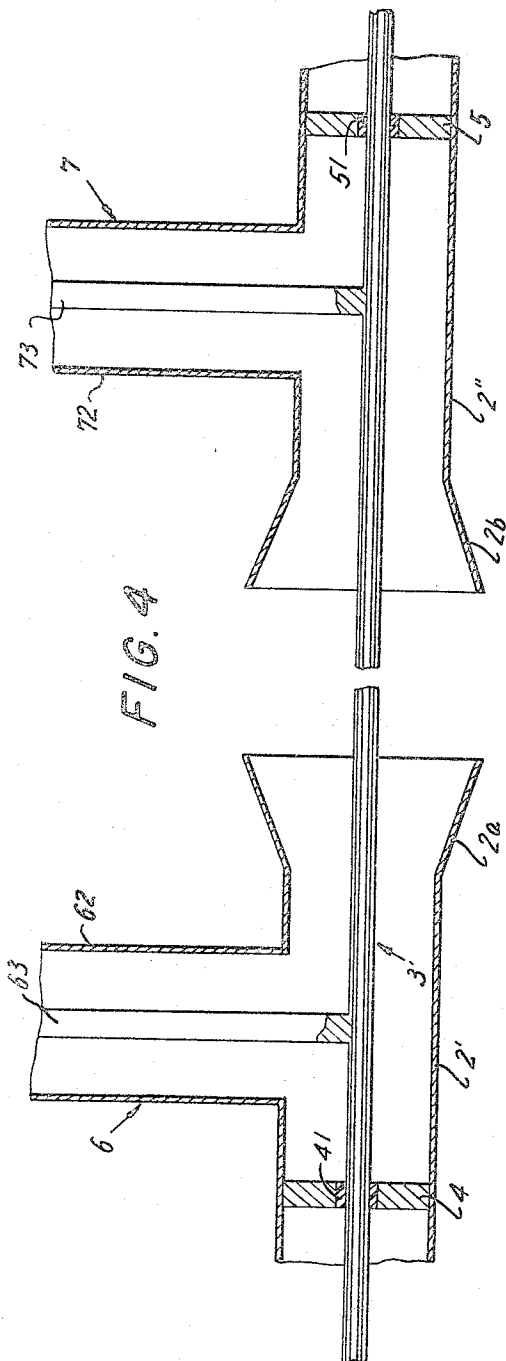


FIG. 4

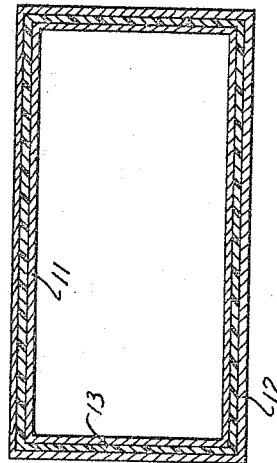


FIG. 3

INVENTOR
JACK FAJANS
BY *Hans Bertram*

AGENT

1

3,332,030

TUBULAR WAVEGUIDE USED AS AN AMPLIFIER

Jack Fajans, Douglaston, N.Y., assignor to Electrokinetics Corporation, Florham Park, N.J., a corporation of New York

Filed May 16, 1962, Ser. No. 195,209

9 Claims. (Cl. 330—62)

This invention relates to tubular waveguides for high-frequency electromagnetic oscillations, and more particularly to waveguide for transmitting, generating, and amplifying oscillations of extremely short wavelengths, including wavelengths of the order of millimeters.

In my copending application Ser. No. 162,457, filed on Dec. 27, 1961, now abandoned, I have disclosed negative resistance devices based on the use of magneto-resistive materials, the term being applied to conductive materials which respond to an applied magnetic field with an increase in their electrical resistance, and to a decrease in the intensity of the applied magnetic field with an increase in electrical conductivity. I have now found that the negative resistance devices of my earlier invention impart highly desirable characteristics to waveguides in which they are employed as structural elements.

Propagation of an electromagnetic wave along a conventional waveguide is ordinarily accompanied by attenuation of the wave in the longitudinal guide direction z . The electric field components may be represented by an equation of the following known type.

$$E = E(x, y) \cdot e^{-\alpha z} \cdot e^{i\omega t} \cdot e^{-i\beta z} \quad (1)$$

wherein

α is the attenuation factor;

ω is the angular frequency of the wave;

β is 2π times the reciprocal of the guide wavelength; and

j is the square root of minus one.

Normally, the attenuation factor α has a positive value because of losses at the walls of the guide, in the guide dielectric, at joints, etc. I have found that these losses can be balanced by making at least a portion of the waveguide of a material having a negative resistance. When a major portion of the waveguide walls is made of negative resistance material the waveguide acts as an amplifier, and may be operated as a generator of electromagnetic waves.

The attenuation factor α for a coaxial line is expressed by the following equation (from Ramo and Whinnery, "Fields and Waves in Radio," 2nd edition, Wiley, 1953, page 39):

$$\alpha = \text{Real} \left\{ \sqrt{(R + j\omega L)(G + j\omega C)} \right\} \quad (2)$$

wherein R , L , and C respectively are the resistance, inductance, and capacitance of the line per meter of length, and G is the conductance per meter due to leakage current.

For the purpose of this discussion, G may be assumed to be negligible. Equation 2 then assumes the form

$$\alpha = \text{Real} \left\{ \sqrt{j\omega RC - \omega^2 LC} \right\} \quad (3)$$

It is evident that α is negative when R is negative.

The general object of this invention is a waveguide having a negative attenuation factor.

The exact nature of this invention as well as other objects and advantages thereof will be readily apparent from consideration of the following specification relating to the annexed drawing in which:

FIG. 1 shows a first embodiment of the waveguide of the invention in an axially sectional fragmentary view;

FIG. 2 is a perspective fragmentary view of an element of the waveguide of FIG. 1 on an enlarged scale;

FIG. 3 shows another embodiment of the waveguide of

2

the invention in cross section transversely of its axis; and FIG. 4 shows a modification of the embodiment illustrated in FIG. 1 in a corresponding view.

Referring now to the drawing in detail, and initially to FIG. 1, there is shown a coaxial line having a straight main portion 1 consisting of a cylindrical tubular outer conductor 2 of tin-plated copper and an inner conductor 3. Plugs 4 and 5 of conducting material are axially slidable in the elongated space or cavity within the outer conductor and have central apertures in which the inner conductor 3 is supported on annular insulators 41, 51 respectively. The impedance of the waveguide illustrated may be matched in a conventional manner by axial movement of the plugs 4, 5.

The structure of the inner conductor 3 is better seen from FIG. 2. The conductor 3 consists of three coaxial layers which are partly broken away in order better to reveal the manner in which they are superimposed. The innermost layer or core 31 is a lead wire of 10 microns diameter. The wire is covered by a layer 32 of silicon monoxide, approximately one micron thick which acts as an insulator separating the core 31 from an outer tubular conductor 33 having an approximate thickness of one micron, and consisting of tin. The exposed face of the outer conductor is parallel to the direction of elongation of the cavity.

Leads 34, 35 are conventionally represented, and are conductively attached to axial end portions of the core 31. They are connected to a source of electric current in such a manner that current flows through the leads 34, 35 and the core 31 in the direction of the arrows 36. A variable resistor 30 in the lead 34 permits the current to be controlled. Leads 37, 38 attached to terminal portions of the outer tubular conductor 33 are connected to a second source of current so that current flows in the leads 37, 38 and the tubular conductor 33 in the direction of the arrows 39. In the binary coaxial conductor constituted by the insulated conductive core 31 and the outer conductor 33, the two currents flow in opposite directions.

The portions of the conductor 3 to which the leads 34, 35, 37, 38 are attached are not seen in FIG. 1 which only illustrates an intermediate portion of the waveguide and adjacent parts of the longitudinally terminal portions thereof. Coaxial lines or waveguides 6, 7 are connected respectively to these terminal portions for coupling the main portion 1 of the coaxial line to a source of electromagnetic oscillations and to a load. An electromagnetic field may thus be generated in one of the terminal portions of the waveguide cavity, and an electromagnetic signal may be transmitted to the load from the other terminal portion. The outer conductors 62, 72 of the lines 6, 7 are connected to the outer tubular conductor 2, and the corresponding inner conductors 63, 73 are conductively joined to the inner conductor 3, and more specifically, to the outer tubular tin layer 33.

The entire apparatus seen in FIG. 1 is held in a cryostat at a temperature of 2.0° K., that is, lower than the transition temperatures of lead and tin which are respectively 7.22° K. and 3.73° K. In the absence of magnetic fields, both the core 31 and the outer conductor 33 of the inner conductor 3 are superconductors since they are held at a temperature lower than their transition temperature.

A current of 0.8 ampere is caused to flow through the lead core 31 in the direction of the arrows 36. The magnetic field generated by the current flow is sufficient to destroy the superconductivity of the outer tin conductor 33, but does not affect the superconductive state of the lead core 31. A small potential applied by means of the leads 37, 38 causes a current of 0.25 ampere to flow through the outer tin conductor 33. The resulting magnetic field reduces the primary magnetic field generated by the current in the lead core 31 sufficiently to restore the super-

3

conductivity of the tin layer 33. The voltage applied to the tin layer may then be reduced to zero without changing the conductive state of the apparatus.

A signal of a frequency for which the waveguides have been matched by means of the plugs 4 and 5 is now admitted through line 6 from an antenna of a conventional type, not further illustrated. The main portion 1 of the waveguide has a length of approximately 20 centimeters. The signal is emitted through the coaxial line 7 at an increased amplitude, and may be fed to a transmitting antenna.

The apparatus shown in FIG. 1 thus constitutes an amplifier in which negative resistance is induced in the outer tin layer 33 by the currents flowing therein and in the core 31. The apparatus may be connected to a source of electromagnetic waves other than the afore-mentioned receiving antenna, and drive a load other than a transmitting antenna. The amplifier is capable of operating at very short wavelengths which are limited only by the performance of the materials of construction employed. When tin is used as the outer layer of the inner conductor, the amplification factor of the device begins to decrease at approximately 10^{10} cycles per second, but other magneto-resistive materials may be substituted for tin, and the apparatus may thereby be adapted to operation as an amplifier for waves having a length of a few millimeters. Lead as a core material may be replaced by a superconductor which is not affected by even strong magnetic fields, such as niobium, and other variations and modifications of the apparatus illustrated will follow from the considerations set forth in more detail in my cited copending application.

FIG. 3 illustrates a rectangular waveguide of conventional outer appearance, the waveguide being shown in section at right angles to its longitudinal axis. The four flat longitudinal walls of the waveguide each consist of three layers, and corresponding layers of the walls are integrally joined to each other.

The innermost layer 11 consists of tin, the outer layer 12 is vanadium, and the interposed layer 13 insulates the layers 11, 12 from each other and consists of silicon monoxide. Conductors and current sources providing currents flowing in opposite longitudinal directions through the two conductive layers of the waveguide walls have not been illustrated since they do not differ materially from those shown in FIG. 2. It will also be understood that the waveguide shown in FIG. 3 is equipped with means for coupling the same to a source of electromagnetic oscillations and to a load. The operation of the apparatus illustrated in FIG. 3 is the same as described above with reference to FIGS. 1 and 2.

The embodiment of the invention shown in FIG. 4 is similar to that illustrated in FIG. 1. It differs from the latter by an interruption in the main portion of the tubular outer conductor 2 of the waveguide. The gap between the two axially separated sections 2', 2'' of the outer tubular member is bridged by impedance matching horns 2a, 2b of substantially conical shape respectively coaxially secured to the tubular sections 2', 2'' and flaring toward each other in a well known manner.

Oscillations are transmitted by a conventional waveguide of the type shown in FIG. 4 when the gap measures a few feet or even one hundred feet. I have found that the permissible length of the gap may be increased substantially under otherwise comparable conditions when the axial conductor of the conventional arrangement is replaced by a conductor 3 which has a negative resistance. This conductor may be identical with the conductor 3 shown in FIG. 1 and in more detail in FIG. 2.

When the gap between the sections 2', 2'' is of the order of a few feet, a signal received by the waveguide arrangement of FIG. 4 over the coaxial line 6 is emitted through the coaxial line 7 with increased amplitude. As this art progresses, the amplification factor of the arrangement

4

and the permissible length of the gap between the tubular sections 2', 2'' may be expected to be increased.

When the conductor 63 is removed from the cylindrical waveguides shown in FIGS. 1 and 4, and the plug 4 is advanced into the main portion of the waveguide, the same capable of operating as a generator or oscillator producing a high-frequency signal emitted over the coaxial cable 7.

It should be understood of course that the foregoing disclosure relates to only a preferred embodiment of the invention, and that it is intended to cover all changes and modifications of the example of the invention herein chosen for the purpose of the disclosure which do not constitute departures from the spirit and scope of the invention set forth in the appended claims.

What I claim is:

1. A waveguide arrangement comprising, in combination:

(a) electrically conductive wall means defining an elongated space,

(1) a face portion of said wall means contiguously adjacent said space being parallel to the direction of elongation of said space;

(b) means for generating an electromagnetic field in a longitudinally terminal portion of said space;

(c) means outside said space for inducing negative resistance to said field in said face portion; and

(d) means for withdrawing an electromagnetic signal from the other longitudinally terminal portion of said space,

(1) said face portion being at least partly interposed between said terminal portions and being elongated in said direction,

(2) said means for inducing negative resistance including a source of a first magnetic field, a source of an electric current, said face portion consisting essentially of electrically conductive magneto-resistive material arranged in said magnetic field and responsive to a decrease in the intensity of said magnetic field to reduce the electrical resistivity of said material, and means for connecting said source of electric current to said face portion for passage of said current through said portion in a direction to generate a second magnetic field opposed to said first magnetic field.

2. An arrangement as set forth in claim 1, wherein said face portion is of superconductor material, said arrangement further comprising means for keeping said face portion at a predetermined temperature lower than the transition temperature thereof, and said first magnetic field being of an intensity sufficient to destroy the superconductivity of said second conductor at said predetermined temperature.

3. An arrangement as set forth in claim 1, wherein said space is of annular cross section and said face portion is convex to define the inner dimension of said space transverse of the direction of elongation thereof.

4. An arrangement as set forth in claim 1, wherein said space is of polygonal cross section, and said face portion defines at least one side of said cross section.

5. An arrangement as set forth in claim 1, wherein said space is of rectangular cross section, the four sides of said cross section being defined by said face portion.

6. A waveguide arrangement comprising, in combination, a first tubular conductive member and a second tubular conductive member, said members having a common axis and being axially spaced from each other, each of said members defining an axial cavity therein; impedance matching horn means axially extending from each of said members in a direction toward the horn means on the other member; and an elongated conductor coaxially arranged in said axial cavities, and longitudinally extending between said cavities, at least a portion of said elongated conductor having negative resistance.

5

7. A waveguide arrangement as set forth in claim 6, wherein said portion of said elongated conductor is outside said axial cavities.

8. A waveguide arrangement as set forth in claim 6, further comprising a source of a first magnetic field; a source of an electric current, said conductor portion consisting essentially of electrically conductive magneto-resistive material arranged in said field and responsive to a decrease in the intensity of said field to reduce the electrical resistivity of said material; and means for connecting said source to said conductor for passage of said current through said portion thereof in a direction to generate a second magnetic field opposed to said first magnetic field.

9. A waveguide arrangement comprising, in combination:

(a) electrically conductive wall means defining an elongated space

(1) a face portion of said wall means contiguously adjacent said space being parallel to the direction of elongation of said space;

(b) means for generating an electromagnetic field in a longitudinally terminal portion of said space;

(c) means outside said space for inducing negative resistance to said field in said face portion; and

(d) means for withdrawing an electromagnetic signal

5

10

15

20

25

6

from the other longitudinally terminal portion of said space.

(1) said face portion being elongated in said direction and extending from one of said terminal portions to the other terminal portion.

References Cited

UNITED STATES PATENTS

2,108,867	2/1938	Mathieu.	
3,048,707	8/1962	Nyberg.	
3,056,092	9/1962	Cook et al.	330—62 X
3,056,889	10/1962	Nyberg.	
3,098,967	7/1963	Keck.	
3,119,076	1/1964	Schlig et al.	330—62

FOREIGN PATENTS

571,100 9/1958 Belgium.

OTHER REFERENCES

"The Negative-Conductance Slot Amplifier," by Pedinoff IRE Transactions on Microwave Theory and Techniques, pp. 557-566, November 1961.

ROY LAKE, *Primary Examiner*.

NATHAN KAUFMAN, *Examiner*.