United States Patent

Grace et al.

[15] **3,673,510**

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[54] **BROAD BAND HIGH EFFICIENCY AMPLIFIER**

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[73] Assignee: **Sperry Rand Corporation**

[22] Filed: **Oct. 7, 1970**

[21] Appl. No.: **78,720**

[52] **U.S. Cl.**....................................**330/34,** 307/317, 330/56, 333/73

[51] **Int. Cl.**....................................**H03f 3/10**

[58] **Field of Search**..............307/322; 330/34, 56; 333/73 C, 333/80 T

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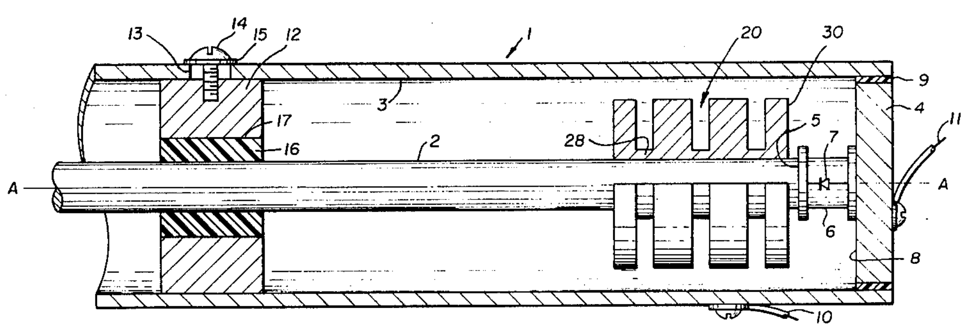
[57] **ABSTRACT**

An active high-efficiency-mode semiconductor device is coupled to oscillating high frequency fields in a transmission line network for amplifying those electromagnetic fields, the apparatus taking the form of a single port high frequency device. The transmission line network provides means for elimination of time delayed triggering of undesired oscillations within the amplifier.

10 Claims, 14 Drawing Figures



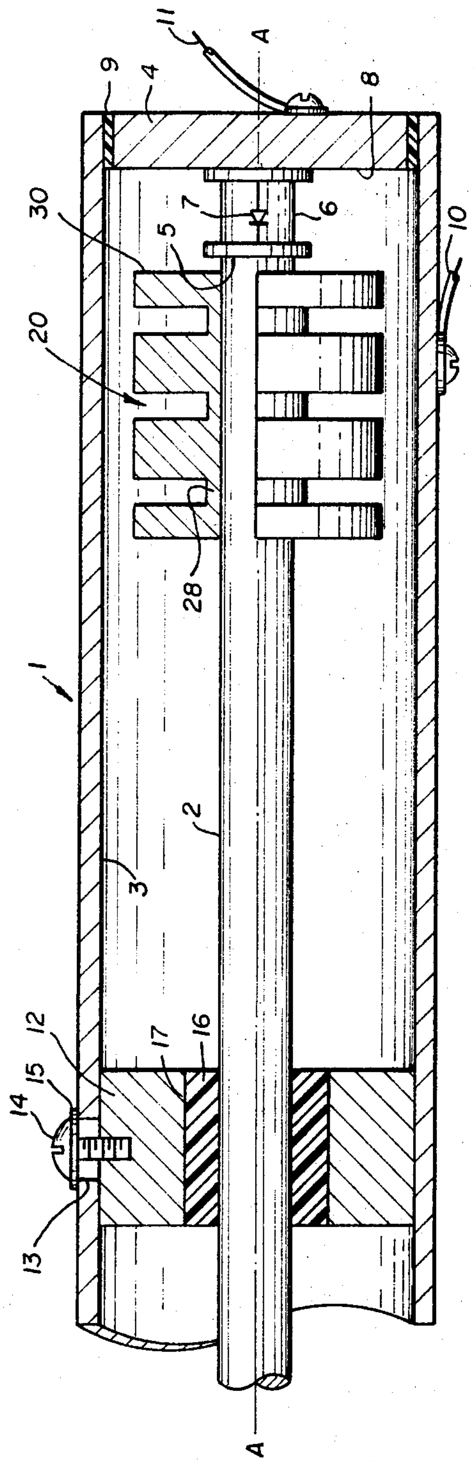


FIG.1

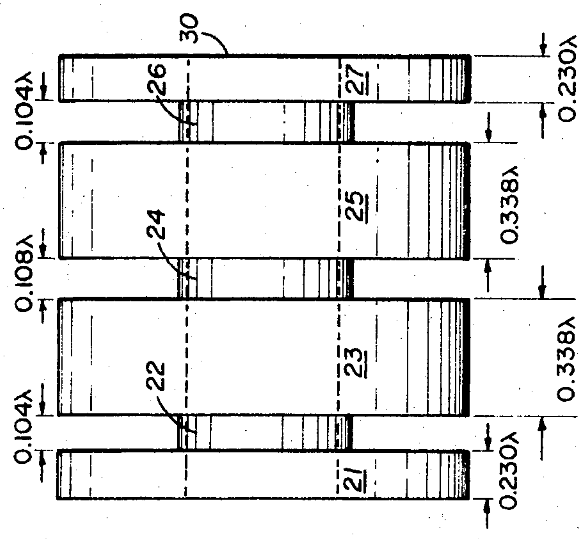


FIG.2

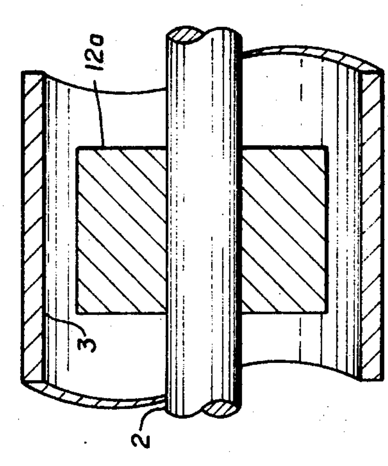


FIG.1a

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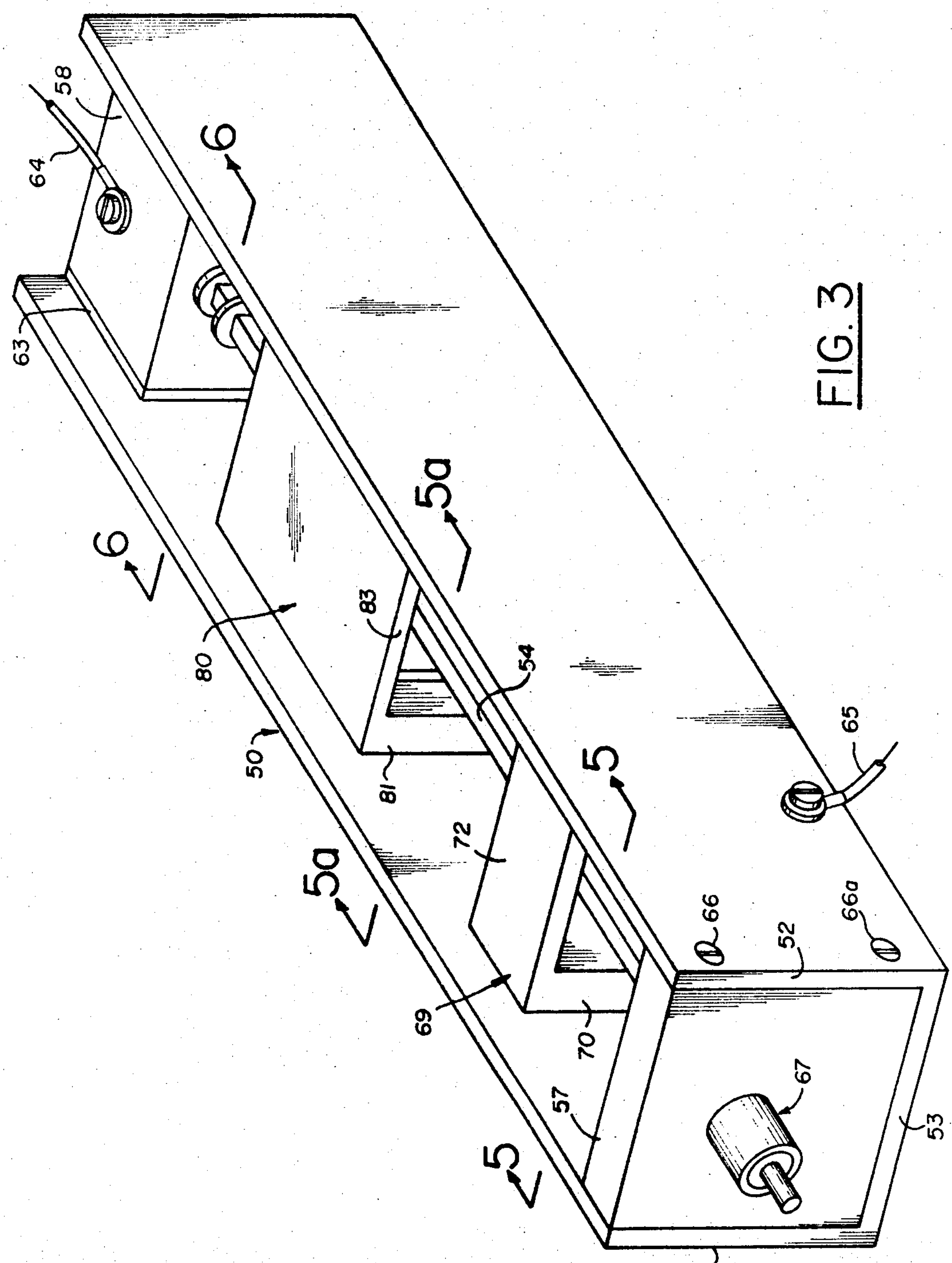

FIG. 3

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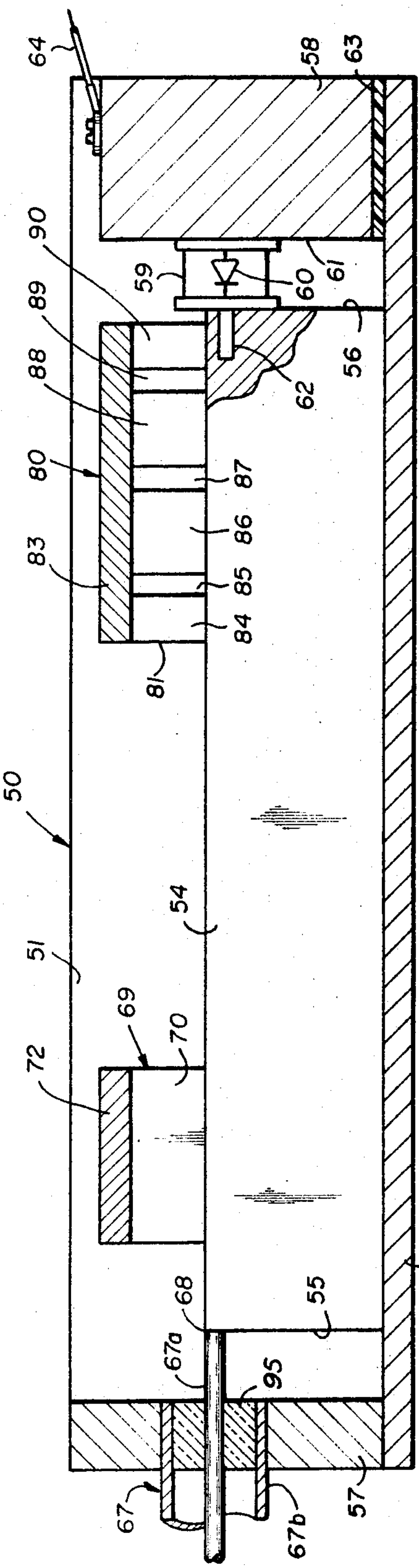

FIG. 4

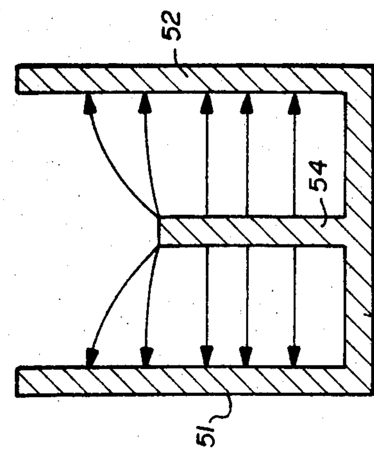

FIG. 7

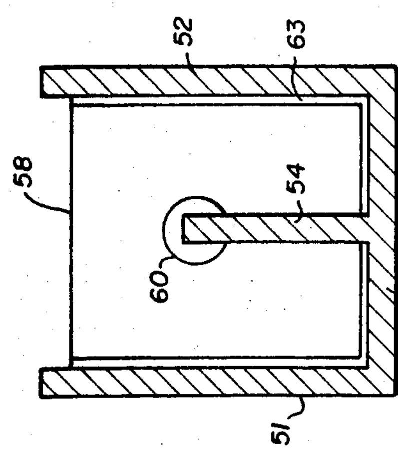

FIG. 6

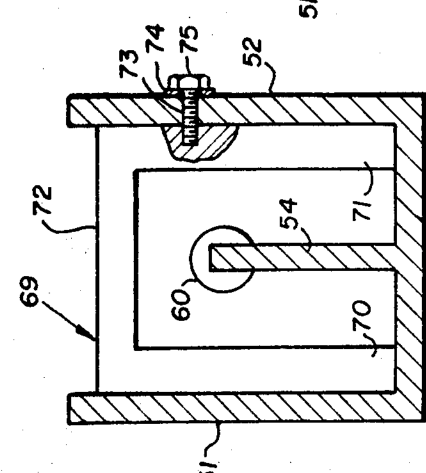

FIG. 5

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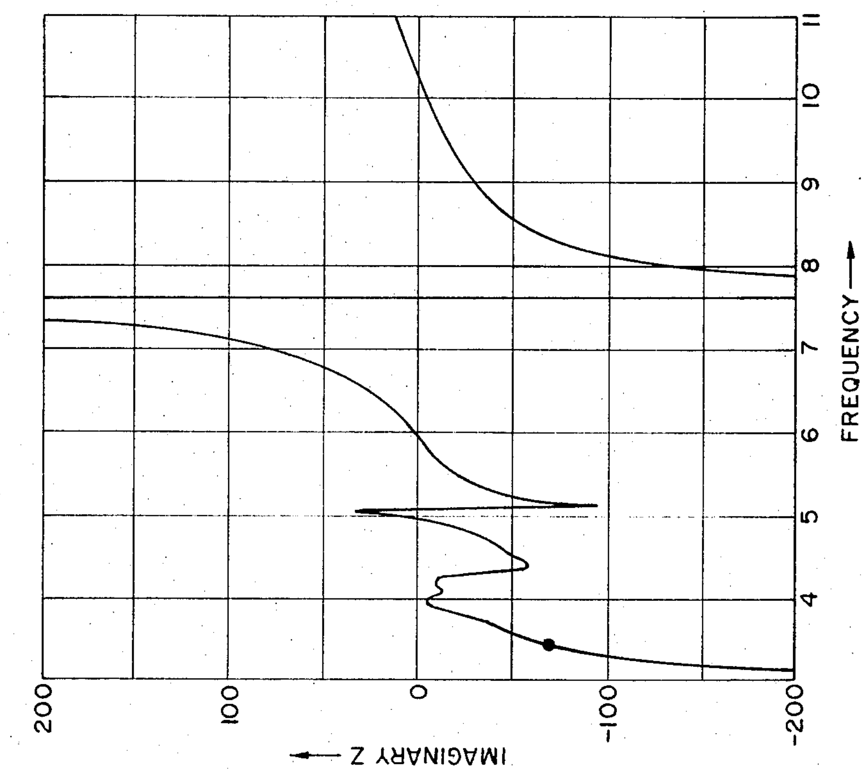

FIG. 9

● OPERATING FREQUENCY f_F

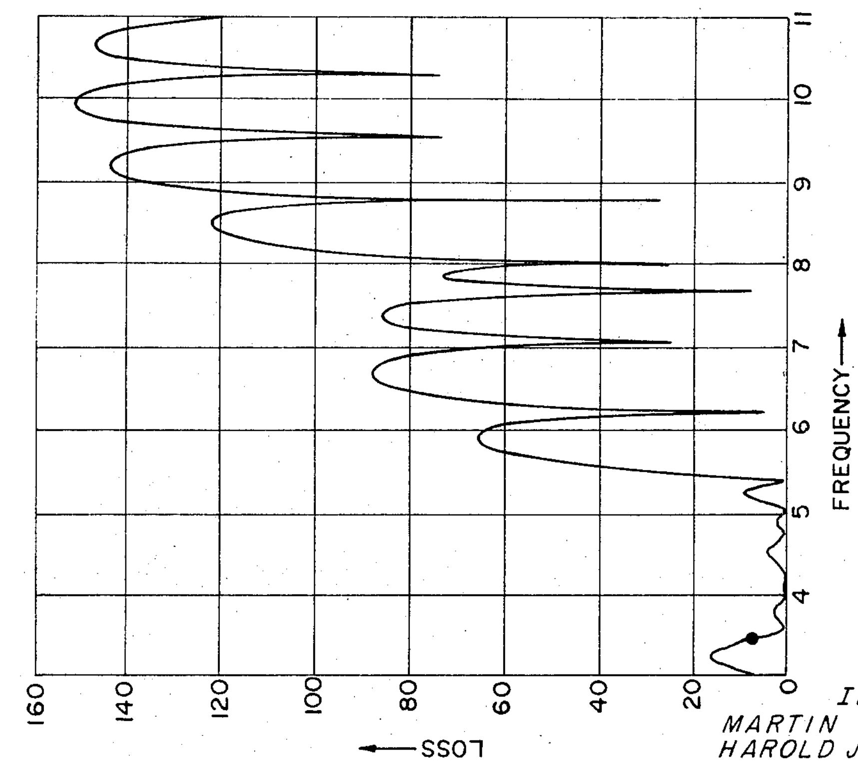

FIG. 8

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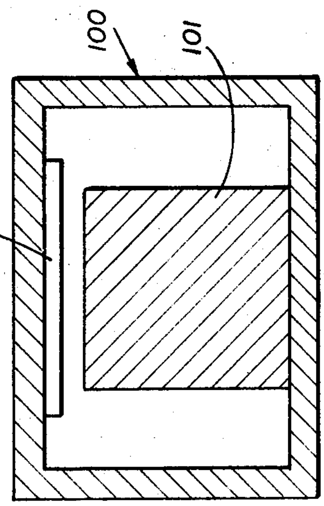

FIG. 12

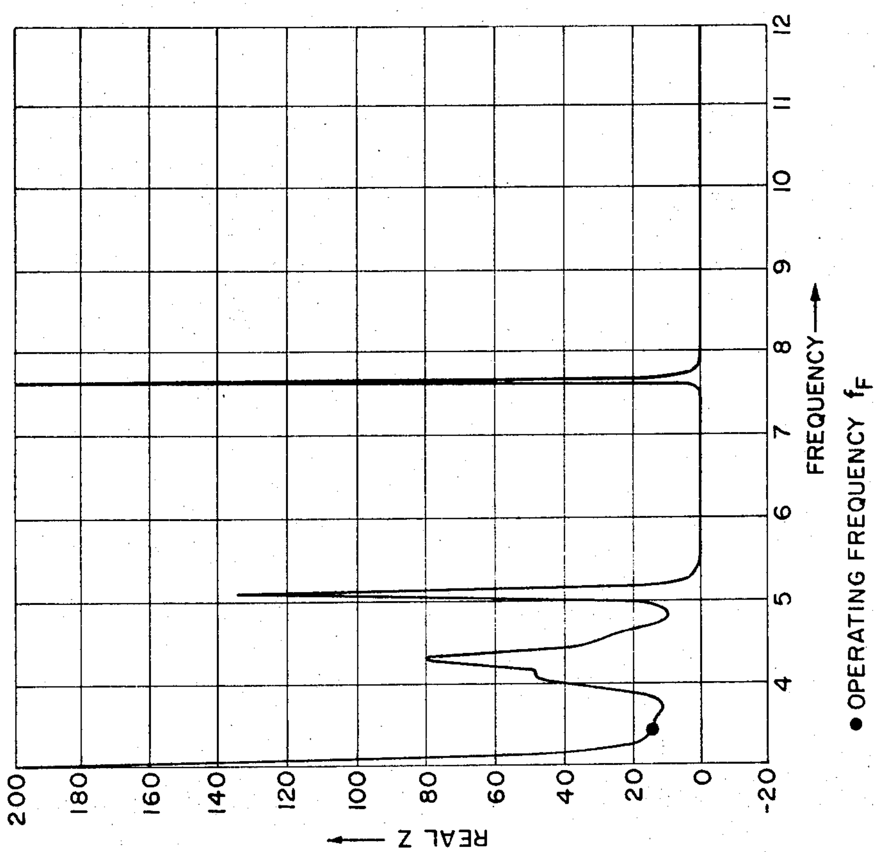

FIG. 10

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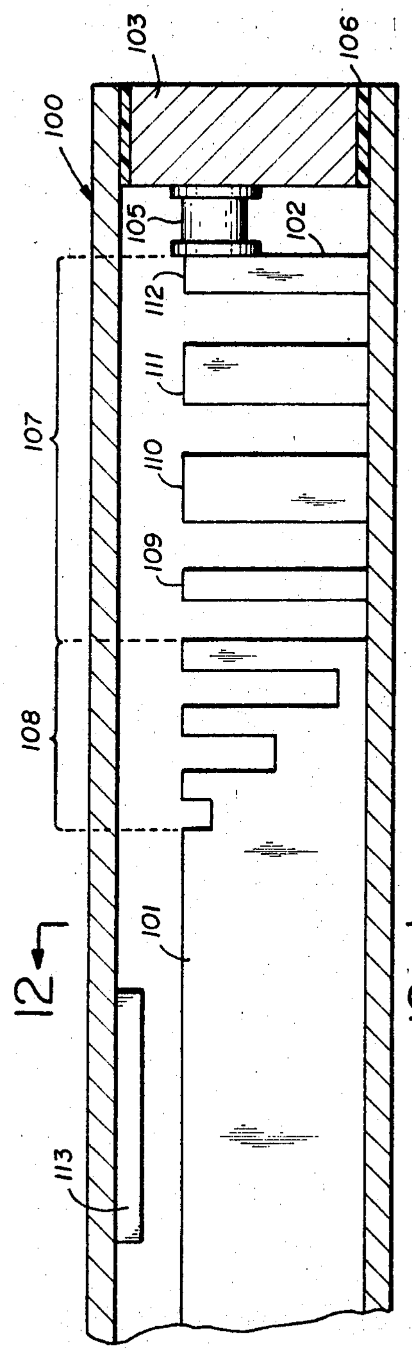

FIG. 11

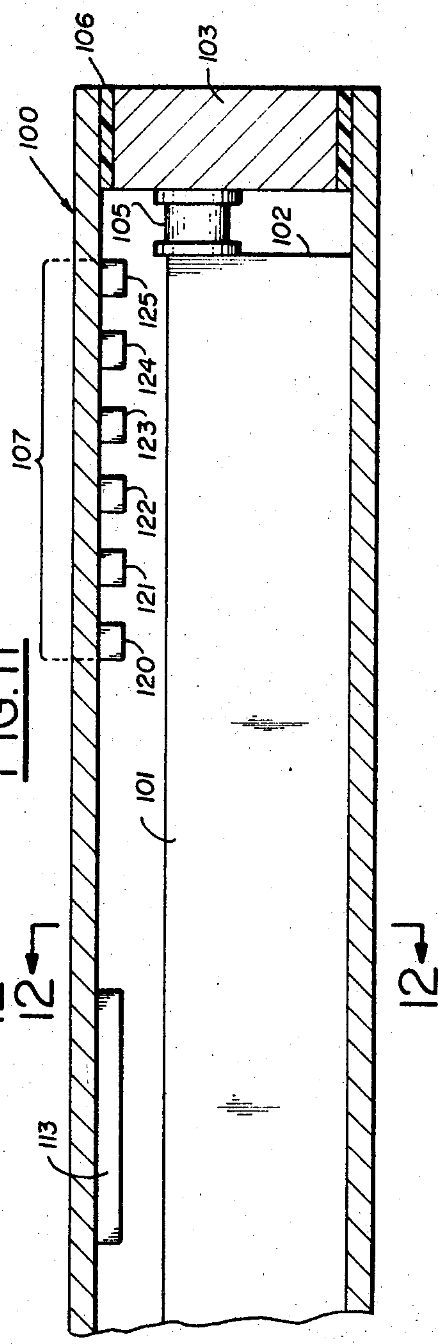

FIG. 13

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BROAD BAND HIGH EFFICIENCY AMPLIFIER

The invention herein described was made in the course of or under a contract or subcontract thereunder with the United States Air Force.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention pertains to high frequency transmission line semiconductor diode amplifiers and more particularly relates to means in such semiconductor energy converter devices for preventing the generation of undesired oscillations.

2. Description of the Prior Art

High frequency amplification often has been observed in systems combining cavity or other resonators or high frequency transmission lines with active semiconductor diodes exhibiting negative resistance effects when placed in suitable electrical bias fields. Furthermore, amplifier circuits suitable for improved operation employing high-efficiency-mode diodes have been devised, both in coaxial line and in other hollow wave guide forms.

It is the function of such circuits as effectively interact with high-efficiency-mode diodes to provide both fundamental and harmonic energy at the location of the high-efficiency-mode diode in the particular relation required by the diode for efficient energy conversion. In other words, the improved circuit must be capable of placing the diode in an oscillating electromagnetic field simultaneously having electric field components at a fundamental frequency f_F and at harmonics f_H thereof.

Such coaxial line and hollow wave guide circuits become difficult to make and to adjust at increasingly high carrier frequencies because of their small size. The problems associated with devising suitable means of independently matching, tuning, and otherwise adjusting the individual parts of the circuit in which fundamental and harmonic signals mutually or separately flow become increasingly difficult. A particular problem associated with known circuits of the subject type is concerned with their highly dispersive characteristics, such circuits having high reactive variation with frequency. Where a device is to be operated as an amplifier, rapid change in circuit reactance as a function of frequency severely limits the possible band width of the amplifier. Accordingly, repeatably attainable band widths with operation free of distorting effects have been quite narrow and are extended to values as high as five per cent only by extreme care in making tuning and other circuit adjustments. It has furthermore been required that the circuit not demonstrate rapid variation in resistance with fundamental carrier frequency.

A second serious problem associated with prior art high-efficiency-mode diode amplifiers is concerned with time delayed triggering of the avalanche shock front within the diode. While of benefit to the operation of high-efficiency-mode oscillators, such a phenomenon produces disturbing effects in a device designed for use as an amplifier.

The action of the time delayed triggering phenomenon which would sustain oscillations in a conventional diode amplifier has been explained as follows. Where a low impedance or short circuit has been placed roughly a half wave at the mid-operating fundamental frequency f_F from the diode, consider that a transient over-voltage sufficient in magnitude to initiate a traveling avalanche zone is placed upon the diode. The over-voltage may be an accidental noise impulse, or may be introduced when a high frequency signal is deliberately coupled into the device for amplification.

While the consequent avalanche zone travels across the depletion region of the diode, the voltage across the diode drops. When the avalanche zone front has completely crossed the diode, the instantaneous voltage on the diode is substantially zero. Accordingly, a step function voltage is generated at the diode whose magnitude is equal to or greater than the diode break-down voltage. This stepped voltage cannot do else than propagate down the transmission line in which the diode is connected.

Upon reaching the effective short circuit placed substantially $\lambda_F/2$ from the diode, the traveling pulse is inverted and is reflected to arrive back at the diode with a total time delay of λ_F/c, where c is the velocity of propagation within the transmission line. The delayed pulse instantaneously drives the voltage across the diode to about twice its break-down voltage, thus triggering another avalanche shock wave within the diode. Such an event permits the entire process repeatedly to cycle.

For high-efficiency-mode oscillators, time delayed triggering may beneficially be a major source of steady state oscillations. However, for wide band amplification, where the desired exciting mechanism for the avalanche shock is the externally applied signal, time delayed triggering is to be avoided. While time delayed triggering can sometimes be avoided in conventional high-efficiency-mode circuits, such can be achieved only by critical adjustment thereof.

SUMMARY OF THE INVENTION

The invention is a microwave or high frequency signal amplifier employing a high-efficiency-mode semiconductor diode as an active negative resistance device in a transmission line network. A filter network located at the diode has a stop band containing certain harmonics f_H of the frequency f_F of the signal to be amplified, while being transparent to the latter signal. The network is tuned to resonate the signal frequency f_F to be amplified. With the special location of the filter, time delayed triggering of the diode is not induced.

In operation, a unidirectional potential is applied across the high-efficiency-mode semiconductor diode such that it is biased near its break-down level. The high frequency signal, when superimposed upon the bias potential, produces large changes in the instantaneous diode voltage and current, which changes are such that a large negative resistance is generated at the same frequency as the fundamental frequency f_F of the applied high frequency signal. The consequent current wave contains many harmonic components f_H which are also coupled to the oscillating harmonic high frequency field to produce amplified harmonic signals, thereby improving the conversion efficiency of the diode.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial cross section view of one embodiment of the invention.

FIG. 1*a* is a similar view of an alternative part for use in the apparatus of FIG. 1.

FIG. 2 is an enlarged view of a portion of FIG. 1.

FIG. 3 is a perspective view of an embodiment alternative to that of FIG. 1.

FIG. 4 is a partial cross section view of the apparatus of FIG. 3.

FIG. 5 is a cross section view taken at line 5 or at line 5*a* of FIG. 3.

FIG. 6 is a cross section view taken at line 6 of FIG. 3.

FIG. 7 is a section of the transmission line similar to FIGS. 5 and 6, showing the nature of the oscillating fields propagating therein.

FIGS. 8, 9, and 10 are explanatory graphs.

FIG. 11 is a partial cross section view of a further alternative form of the invention.

FIG. 12 is a partial cross section view taken at line 8 of FIG. 11.

FIG. 13 is a partial cross section view of an alternative form of FIG. 11.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 illustrate a preferred embodiment of the invention in a form employing a network system circularly symmetric about dot-dash line A—A and using a high frequency or microwave coaxial transmission line 1. Coaxial transmission line 1 consists of an inner conductor 2, which may be in the form of a round rod, and an outer hollow tubular conductor 3. Propagating high frequency energy is confined within the space between conductors 2 and 3, the structure being closed on one end by end wall 4. As is the usual case in high frequency circuit structures, the respective current-carrying surfaces of conductors 2 and 3 and of end wall 4 have good electrical conductivity for high frequency electrical currents. The impedance of line 1 may be, for example, 50 ohms.

Referring especially to FIG. 1, there is placed in series with inner conductor 2 at its end 5 a high-efficiency-mode diode 6 whose particular detailed characteristics remain to be described. Diode 6 is electrically poled as symbolically indicated by the representation 7 shown as if actually drawn on the surface of the diode package. At one of its ends, diode 6 is supported in a conventional manner from the conductive surface 8 of end wall 4, as by being conductively cemented in place thereon or otherwise held in place by conventional means. Opposite the surface 8, diode 6 may be conductively affixed in a similar manner to end 5 of inner conductor 2.

End wall 4, in addition to closing coaxial transmission line 1 and supporting diode 6, is used to provide the required unidirectional bias operating voltage to diode 6, being insulated from outer conductor 3 and supported therein by a thin strip of suitable dielectric material 9. Thus, wall 4 and dielectric strip 9 form a shorting means for high frequency currents, so that energy cannot flow out of line 1 past wall 4. In addition, the arrangement provides means for application of the bias voltage across diode 6, as by a bias source or battery (not shown) connected between lead 11 attached to wall 4 and lead 10 attached to conductor 3.

At a certain location with respect to diode 6, there is provided an adjustable tuning or impedance transforming element 12 whose length is one quarter wave length at the mid-operating value of fundamental frequency f_F. Transformer element 12 comprises a circular ring-shaped element whose outer diameter permits it to be inserted in contact with the inner wall of conductor 3. Where line 1 has a 50-ohm-impedance, transformer 12 may have, for instance a 19 ohm impedance. Like conductor 3, its surfaces exposed to high frequency energy are made of a good, high-frequency-current conducting material. Tuner element 12 may be provided with means permitting it to be translated longitudinally for adjustment purposes within transmission line 1. A short longitudinal slot 13 cut through wall 3 permits tuner element 12 to be adjusted in position and then to be fastened by tightening screw 14 against washer 15, screw 14 being threaded into a mating threaded hole in element 12. Additional matching elements generally of the above described kind may be used in the well known manner to extend the operating band width of the amplifier. Furthermore, a single, quarter wave transformer device 12*a* mounted on the inner conductor 2 of transmission line 1 may be employed where a fixed position device is satisfactory, as shown in FIG. 1*a*.

As in FIG. 1, a dielectric tube 16 may be fastened within tuner 12 at surface 17 by cementing or by other known means. Left free to slide on the surface of inner conductor 2, tube 16 forms a convenient support for conductor 2 within conductor 1. In place of the metallic electrically conducting slug tuner 12, dielectric tuner devices may be substituted and may similarly be used to fix the relative positions of conductors 2 and 3. If such a dielectric means of support is not employed, a conventional dielectric bead (not shown) may be placed to the left of tuner 12 adjacent an input-output connection to the amplifier.

It will be understood by those skilled in the art that a leftward extension of coaxial line 1 may be coupled directly to a conventional high frequency signal circulator. One port of the circulator may be used in the conventional manner to inject signals to be amplified into the apparatus, while a second port of the circulator is used to couple out the amplified signals.

A diode of the type known generally as the avalanche transit time diode is found to have characteristics suitable for use in the invention as diode 6. It may be used in the form known as the trapped plasma avalanche triggered transit diode known as the TRAPATT diode. For example, diode 10 may be an epitaxial silicon or other p-n or step or abrupt junction diode or a p-n-n+ punch-though diode designed such that, with an electric field of suitable amplitude present, the field punches through a substrate at reverse break down. Such diodes have, for example, been described as being successfully formed by diffusing boron from a boron-nitride source into a phosphorous-doped epitaxial material on a heavily doped antimony substrate. The thickness of the epitaxial layer is varied by etching, prior to diffusion, so as to produce either the abrupt p-n structure or the p-n-n+ structure.

A low pass or band pass filter 20 is placed on center conductor 2 at diode 6. It is understood that the distributed filter 20 may be a three or multiple section low-pass filter of the well known Tchebycheff type, though other filters having related properties may be employed. It is further understood that filter 20 may pend from the inner conducting surface of outer coaxial conductor 3. Either kind of filter suspension may be constructed so that the filter is translatable longitudinally for adjustment purposes, for example, in the manner in which impedance transformer 12 is adjustable.

Filter 20 is comprised of alternate disc-shaped elements of a first characteristic impedance, with interposed elements of a second characteristic impedance level. In the form shown in FIGS. 1 and 2, the large diameter discs 21, 23, 25, and 27 are selected to have an impedance of 19 ohms, for example. The intervening small diameter discs 22, 24, and 26 have an impedance close to 50 ohms, depending upon how thin the wall 28 can conveniently be made; i.e., substantially the impedance of inner conductor 2. If filter 20 is fixed permanently to conductor 2, the discs 21, 23, 25, and 27, may be fastened directly to conductor 2 and the respective walls 28 may be omitted.

As seen more clearly in FIG. 2, disc 21 has a 19-ohm impedance and is, in one successful form of the invention, made $0.230\lambda_F$ in length, where λ_F is the wave length corresponding to the mid-operating fundamental frequency f_F. In the same terms, disc 22 may have a 50-ohm impedance and is $0.104\lambda_F$ long. Disc 23 is 50 ohms and may be $0.338\lambda_F$ long and disc 24 is 19 ohms and may be $0.108\lambda_F$ in axial length. The filter is symmetric about disc 24. Thus, disc 25 is 50 ohms and may be $0.338\lambda_F$ in length, disc 26 is 19 ohms and may be $0.104\lambda_F$ in length, and disc 27 is 50 ohms and may be $0.230\lambda_F$ in length.

Filter 20 is placed at diode 6 and is chosen so that:

a. the operating fundamental frequency f_F of the amplifier falls in the pass band of filter 20, and

b. the stop band of filter 20 contains at least the second and third harmonics f_H of frequency f_F.

The latter adjustment retains all harmonic energy in the region about diode 6 and especially, when the input impedance of filter 20 at the third harmonic is that of a short circuit, permits efficient operation of diode 6 without the appearance of harmonic energy in the output of the amplifier. Thus, the band stop properties of filter 20 successfully confine all third harmonic current flow to the diode 6 itself.

Placing the wall 30 of filter 20 at the surface 5 of diode 6 is beneficial, but some separation between wall 30 and surface 5 is tolerable. A separation of $\lambda/10$ may be feasible, and in some cases, this may be increased to substantially $\lambda/2$. However, the separation may properly be chosen to be substantially zero in all circumstances, since such a choice determines that the chance of time delayed triggering of diode 6 is diminished as far as is possible. With finite values of the separation, time delayed triggering has an increasing opportunity to destroy operation of the device as an amplifier, some diodes being more susceptible to this undesired event than others.

The quarter wave tuner 12 is used to resonate diode 6 at the output frequency f_F. At f_F, diode 6 behaves like an inductive reactance because of its avalanche multiplication properties. Representative circuit properties of network 20 and tuner 12 are shown in FIGS. 8, 9, and 10. FIG. 8 represents the transmission loss of filter 20. At the indicated operating frequency f_F, loss is low, while it has increased rapidly at harmonics f_H of f_F.

In one form, filter **20** is a 3-section Tchebycheff low pass structure having a 3.5 GHz cut off frequency and a 3 db. pass band ripple. The imaginary part of the input to the network comprising filter **20** and tuner **12** is shown in FIG. **9**. At an operating frequency f_F of 2.9 GHz, the reactance of the network is −70 ohms. This network reactance is sufficient to resonate with the inductive reactance of diode **6** due to the impact ionization processes. However, at the third harmonic frequency, the network reactance is very small, indicative of the series resonant characteristic of diode **6** at the third harmonic. The real part of the input impedance of the network at the operating frequency f_F is about 20 ohms, which is a reasonable value. At the harmonic frequencies f_H, the real part of the input impedance of the network is very low, so that little harmonic energy is dissipated. Thus, the reactance presented by the network to diode **6** has a desirably small slope as a function of wave length at the second and third harmonic frequencies f_H, a further feature not present in conventional high efficiency mode diode amplifier circuits.

As noted above, the amplifier of FIG. **1** is operated by biasing diode **6** into conduction and by applying a high frequency signal to the amplifier by means of a signal circulator located at the circuit input. When the amplitude of the input high frequency signal attains a sufficient value, an avalanche shock wave is excited in diode **6**, producing amplified output power. In one form, the amplifier exhibits a 3 db. band width of greater than 5 per cent at a 10 db. gain. The peak power output is 10 watts for a 1 microsecond input pulse at a repetition rate of 5,000 pulses per second. The efficiency of the amplifier is greater than 20 per cent. Using a more sophisticated, but conventional, multiple-component tuner in lieu of the single component tuner **12**, a fractional band width of 12 per cent at a 5 db. gain is demonstrated at 1.8 GHz.

FIGS. **3** and **8** show an alternative signal converter or amplifier according to the present invention comprising a section of open-faced transmission line **50**. The preferred form of transmission line **50** is an open-faced first conductor having three connected closed walls **51**, **52**, and **53**, walls **51** and **52** being mutually parallel to each other and mutually perpendicular to wall **53**. The inner surface of wall **53** is provided with a centrally located re-entrant conductor or septum **54**, extending from and along a major portion of wall **54**, as seen particularly in FIG. **4**, and having ends **55** and **56**. The septum **54** is lower in height than walls **51** and **52** and forms a symmetric geometrical structure with walls **51**, **52** and **53** having a cross section generally like the upper-case letter E placed on its side (see FIGS. **5** and **6**). Septum **54** is so constructed and arranged relative to walls **51**, **52**, and **53** that the combination of these conductors supports propagation of traveling high frequency wave energy within the confines of the combination without substantial loss of energy due to radiation.

Propagating energy is largely confined in or bound within the structure in what may be called the TE_{01}-propagation mode illustrated, for convenience, in FIG. **7**. It is seen that the instantaneous electric field lines flow from the opposed conducting surfaces of septum **54** to the respective conductive adjacent inner surfaces of walls **51** and **52**, that they are symmetric about the plane of septum **54**, and that there is very little electric field above the top of septum **54** so that radiation of electromagnetic energy is minimized. The open-faced, box-like structure is completed by end walls **57** and **58**, whose functions will be further discussed. As is usual in high frequency circuits, the respective current carrying surfaces of septum **54** and walls **51** and **52** and their end connecting walls **57** and **58** have good electrical conductivity for high frequency electrical currents.

Referring particularly to FIGS. **3** and **4**, there is placed in series with the septum **54** at its end **56** a high-efficiency-mode diode **59** similar to diode **6** of FIG. **1**. Diode **59** is poled as symbolically indicated by the representation **60** shown as if actually drawn on the surface of the diode package. At one end, diode **59** is supported in any convenient conventional manner from surface **61** of end wall **58**, as by being cemented in place thereon or otherwise held in place by known means. Opposite surface **61**, diode **59** may be equipped with a short lead **62** conductively fitting within a hole drilled in the end **56** of septum **54**.

End wall **58**, in addition to closing transmission line **50** and supporting diode **60**, is used to provide an appropriate bias voltage thereto. As seen in FIGS. **3**, **4**, and **7**, end wall **58** is insulated from the transmission line walls **51**, **52**, and **53** and is also supported therein by a thin strip of suitable dielectric material **63**. Any suitable bonding agent may be used for fixing such a relation of walls **51**, **52**, and **53**, strip **63**, and end wall **58**. Thus, wall **58** and dielectric strip **63** forms a shorting means for high frequency energy, so that such energy cannot flow out of line **50** past wall **58**. In addition, the arrangement operates so that a bias voltage may be supplied by a bias source (not shown) between lead **64** attached to wall **9** and any other part of the apparatus, such as lead **65** in FIG. **3**. It is to be understood that many types of diode packages are available and that the particular package illustrated is merely a representative one selected for ease of illustration.

At the end of transmission line **50** opposite wall **58** is placed a second conductive end wall **57**, held in place by suitable means such as screws **66**, **66*a***. As seen in FIGS. **3** and **4**, wall **57** is supplied with an aperture through which passes coaxial transmission line **67**. Line **67** includes an inner conductor **67a** conductively joined at junction **68** to the end **55** of septum **54** and passing through the aperture in end wall **57**. Coaxial line **67** is further supplied with an outer conductor **67*b***, concentrically surrounding inner conductor **67*a***, and conductively affixed within wall **57**. Conductors **67*a***, **67*b*** may be established permanently in set relation by an insulating bead **95**. Coaxial line **67** and septum **54** are so arranged and so constructed according to established practice as to form a suitable impedance match over the desired operating frequency band. Other known impedance transition elements, such as tapered transitions, may be substituted for the illustrated arrangement in a manner well known in the art. It is also to be understood that coaxial line **67** may be used in a way depending on the manner of operation of the apparatus. For example, the invention may be used as a single port amplifier in the well known manner by coupling a circulator to the coaxial transmission line **67**. Then, one port of the circulator is used to inject signals to be amplified into the apparatus, while a second port of the circulator provides an output.

At an appropriate location with respect to diode **6**, there is provided a tuning or impedance transforming element **69**. The susceptance matching or transforming element **69** may, for instance, comprise as seen in FIG. **3**, **4**, and **6** a symmetric electrically conducting figure shaped generally like an inverted square-cornered letter U with similar arms **70** and **71** and an integral bridging portion **72**. As seen in FIG. **5**, arms **70** and **71** respectively bear against the inner conducting surfaces of walls **51** and **52** and element **72** forms a bridging portion over septum **54** in a region of minimal electric field. The tuning element, as seen in FIG. **5**, may be provided with means permitting it to be moved longitudinally within transmission line **50** in contact with the inner surface thereof. A short longitudinal slot **73** through the wall **53** permits element **69** to be adjusted and then to be fixed in position by tightening a screw **75** against washer **74**, screw **75** being threaded into a mating threaded hole in element **69**. In place of the metallic electrically conducting slug tuning or impedance matching element **69**, a dielectric tuning device may be employed.

A low pass filter **80** analogous to filter **20** of FIG. **2** is placed at diode **59** in the apparatus, as seen in FIGS. **3** and **4**. Filter **80** is constructed generally like tuner **69** in that it is symmetric electrically conducting figure again shaped like an inverted square-cornered letter U with similar arms **81** and **82** (arm **82** is not seen) and an integral bridging portion **83**. The filter **80** has the general appearance of that shown for tuner **69** in FIG. **5**. Filter **80** may be provided with means permitting it to be moved longitudinally similar to the apparatus also shown for that purpose in FIG. **5**. FIG. **4** realistically shows the location of filter **80** with respect to diode **59**. In FIG. **5**, filter **80** has been moved to the left in order to permit ready viewing of diode **59**.

The inner surface of each arm **81** and **82** is provided with alternate vertical ridges of a first characteristic impedance, with interposed depressions of a second characteristic impedance. In the form seen in FIG. **4**, ridges **84**, **86**, **88**, and **90** are selected to have relatively low impedance. The intervening valleys or depressions **85**, **87**, and **89** have an impedance level relatively close to that of the trough transmission line **50**. Filter **80** may alternatively be fixed permanently to the inner surface of wall **51**, so that ridges **84**, **86**, **88**, and **90** may be soldered directly to the inner surface of wall **51**. The successive ridges and depressions may also be arranged to have lengths (parallel to the device axis) in terms of the mid-operating wave length λ_F according to the requirements of the Tchebycheff criteria.

As noted above, the form of the invention used in a coaxial transmission line network has demonstrated many advantages. The trough wave guide form of the apparatus has certain additional advantages, especially for operation at very high frequencies. For example, it is readily fabricated and, having one side open, is relatively easily employed at very high frequencies. While otherwise having certain useful characteristics like those of the coaxial transmission line form of the invention, it has large power handling capabilities, is mechanically simple, has a large pass band, and is readily coupled to coaxial line.

Of significance is its open-faced geometry and the fact that the structure has a relatively large, easily accessible interior. The large effective interior reduces losses, improving the quality factor Q of the circuit. The configuration being open and having no substantial tendency to radiate, permits use of relatively low impedance tuners and permits easy manual adjustment and setting of the impedance matching and other elements. Such manual adjustment may be made with the parts being adjusted in full view, and without substantial confusing effects on the oscillating fields within the apparatus. The tuning elements may after optimum adjustment be easily fixed permanently in position. Since there is substantially no radiation from the open face, a cover sheet (either metallic or dielectric) may be placed over the open face of the apparatus after adjustment is accomplished to prevent any degrading effects of direct exposure to the atmosphere.

It is seen from the discussion of the forgoing embodiments that the invention may be employed in various types of transmission lines. Such versatility is further illustrated in the alternative ridge wave guide transmission line embodiments illustrated in FIGS. **11**, **12**, and **13**. Referring particularly to FIGS. **11** and **12**, apparatus is disclosed employing a closed outer conductor **100** and an enclosed ridge conductor **101** characteristic of conventional ridge wave guide. Ridge conductor **101** ends at wall **102** adjacent high frequency short **103**. Wall **102** is arranged conductively to support diode **105** at one of its ends, the other end of diode **105** being similarly affixed to the inner wall of short **103**. A suitable bias voltage may be applied to short **103** and to conductor **100** and therefore across diode **105** by virtue of the presence of dielectric strip **106**.

Ridge conductor **101** is equipped with a serrated section **107** acting, as before, as a low pass filter and composed of physical parts **109**, **110**, **111**, and **112** of the ridge conductor **101** left standing, for instance, when the intervening parts of ridge are cut away. Filter **107** is analogous in structure and behavior to the filter of FIG. **2** and may be smoothly joined to ridge conductor **101** in a conventional manner by a serrated impedance matching structure **108**. As seen in FIGS. **11** and **12**, quarter wave (at frequency f_0) transformer **113** overlies the ridge conductor **101**, pending from the top wall of conductor **100** and spaced from the top of ridge **101**.

In the alternate form shown in FIG. **13**, corresponding reference numbers indicate parts corresponding to those in FIGS. **11** and **12**. In FIG. **13**, low pass filter **107** is composed of bars **120**, **121**, **122**, **123**, **124**, and **125** pending above the ridge conductor **101** in a manner generally similar to quarter wave transformer **113**.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation, and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

We claim:

1. A high frequency energy converter comprising:
transmission line means having first and second high frequency conducting means adapted for permitting flow of high frequency energy along said transmission line means,
conductive wall means for short circuiting said transmission line means for high frequency currents at one end thereof,
semiconductor means forming a first conductive junction with said conductive wall means and a second conductive junction with said first high frequency conducting means,
circuit means for applying a bias field across said semiconductor means,
distributed filter means conductively mounted on one of said first or second conducting means and providing an impedance step substantially at said second junction for preventing time delayed triggered operation of said semiconductor means
said filter means being adapted to pass high frequency energy of fundamental frequency and to retain in the vicinity of said semiconductor means harmonic energy, and
impedance matching means spaced along said transmission line means with respect to said filter means and conductively mounted on one of said first or second conducting means.

2. Apparatus as described in claim **1** wherein said semiconductor means comprises an avalanche transit time diode having a predetermined impedance characteristic.

3. Apparatus as described in claim **2** wherein said impedance matching means resonates the inductive component of said predetermined impedance characteristic of said diode at said fundamental frequency.

4. Apparatus as described in claim **1** wherein said transmission line means, said conductive wall means, said semiconductor means, said bias circuit means, said impedance matching means, and said distributed filter means are so arranged and constructed as to provide high frequency electric fields with strong fundamental and harmonic frequency components across said semiconductor means.

5. Apparatus as in claim **4** wherein said distributed filter means comprises a physically symmetric filter having a low pass band and an upper stop band.

6. Apparatus as in claim **5** wherein said fundamental frequency falls in said pass band and said harmonic frequency components fall in said stop band.

7. Apparatus as described in claim **4** wherein said transmission line means comprises coaxial means having inner conductor means and outer conductor means.

8. Apparatus as described in claim **7** wherein said distributed filter means is located on said inner conductor means and defines an impedance step located adjacent said semiconductor means.

9. Apparatus as described in claim **4** wherein said transmission line means comprises first conductor means in the form of a 3-sided channel with one open face and second conductor means in the form of septum means symmetrically supported within said channel.

10. Apparatus as described in claim **9** wherein said filter means comprises a conductive element having leg portions in contact with said first conductor means and a bridging portion overlying said septum means.

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