

- [54] MICROWAVE APPARATUS USING
MULTIPLE AVALANCHE DIODES
OPERATING IN THE ANOMALOUS
MODE
- [72] Inventor: Hirohisa Kawamoto, Hightstown,
N.J.
- [73] Assignee: RCA Corporation
- [22] Filed: March 31, 1971
- [21] Appl. No.: 129,805

Related U.S. Application Data

- [63] Continuation-in-part of Ser. No. 102,390, Dec.
29, 1970, abandoned.
- [52] U.S. Cl. 331/107 R, 321/69, 330/56,
331/96, 331/101, 333/7, 333/84 M
- [51] Int. Cl. H03b 7/06
- [58] Field of Search 331/96, 101, 107; 321/69;
330/56; 333/7, 84 M

[56] References Cited

OTHER PUBLICATIONS

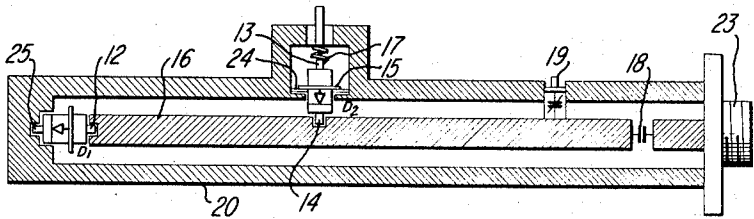
Electronic Engineer, "Diode RF Sources" by Dr. A.
I. Zverev, pages 45- 50, Feb. 1969.

Primary Examiner—John Kominski
Attorney—Edward J. Norton

[57] ABSTRACT

The terminals of a first avalanche diode are shunt cou-
pled to a microwave transmission line. The terminals
of opposite polarity of at least one other avalanche
diode are also shunt coupled to the microwave trans-
mission line. Complementary microwave circuitry and
proper location within a suitable microwave resonant
circuit enables the multiple avalanche diodes to
operate in the anomalous mode in an oscillator, ampli-
fier, or frequency multiplier when reversed biased by
an appropriate signal.

7 Claims, 7 Drawing Figures



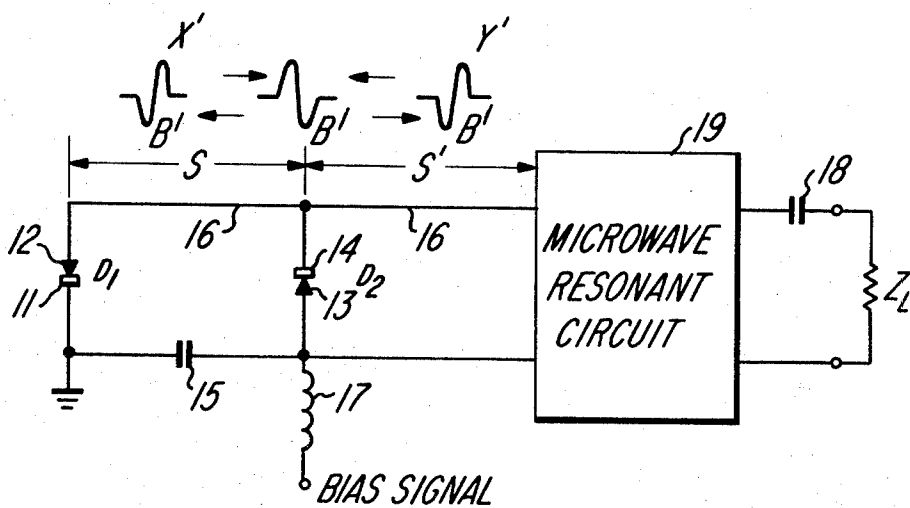


Fig. 1.

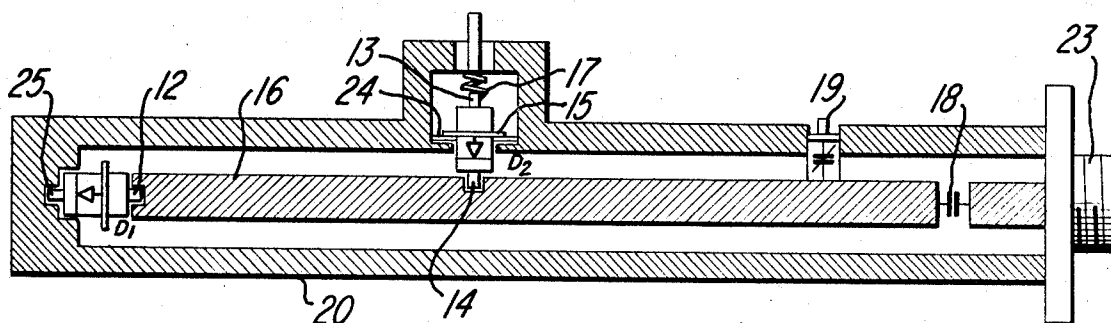
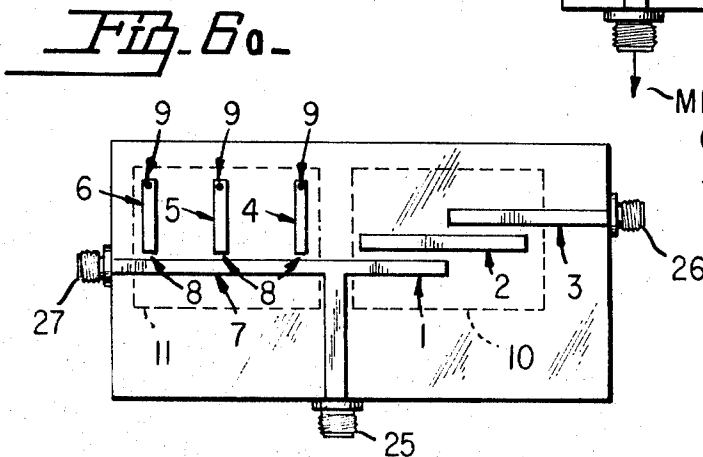
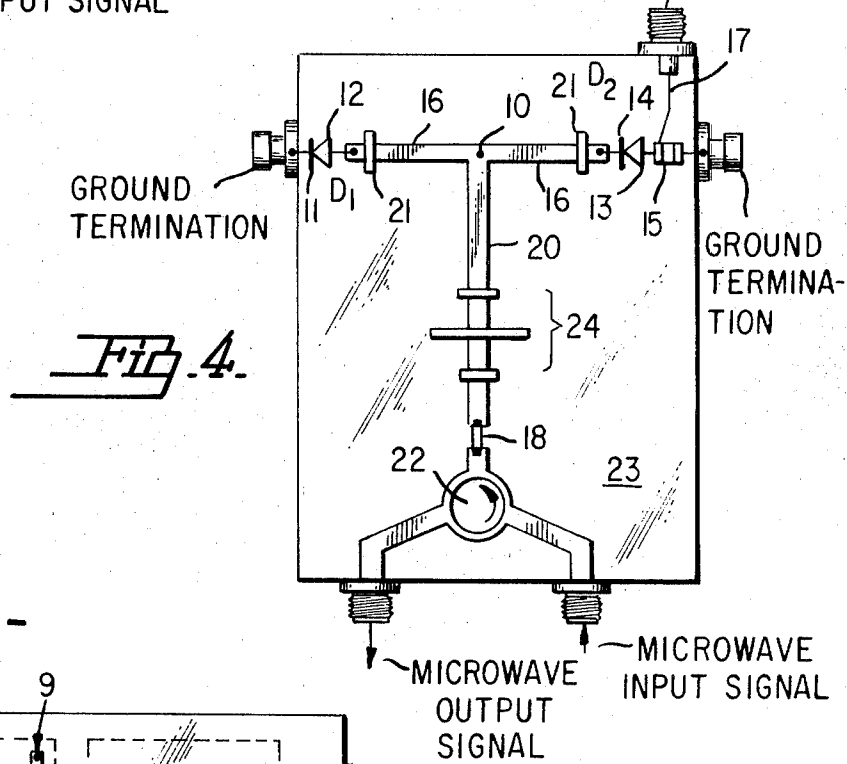
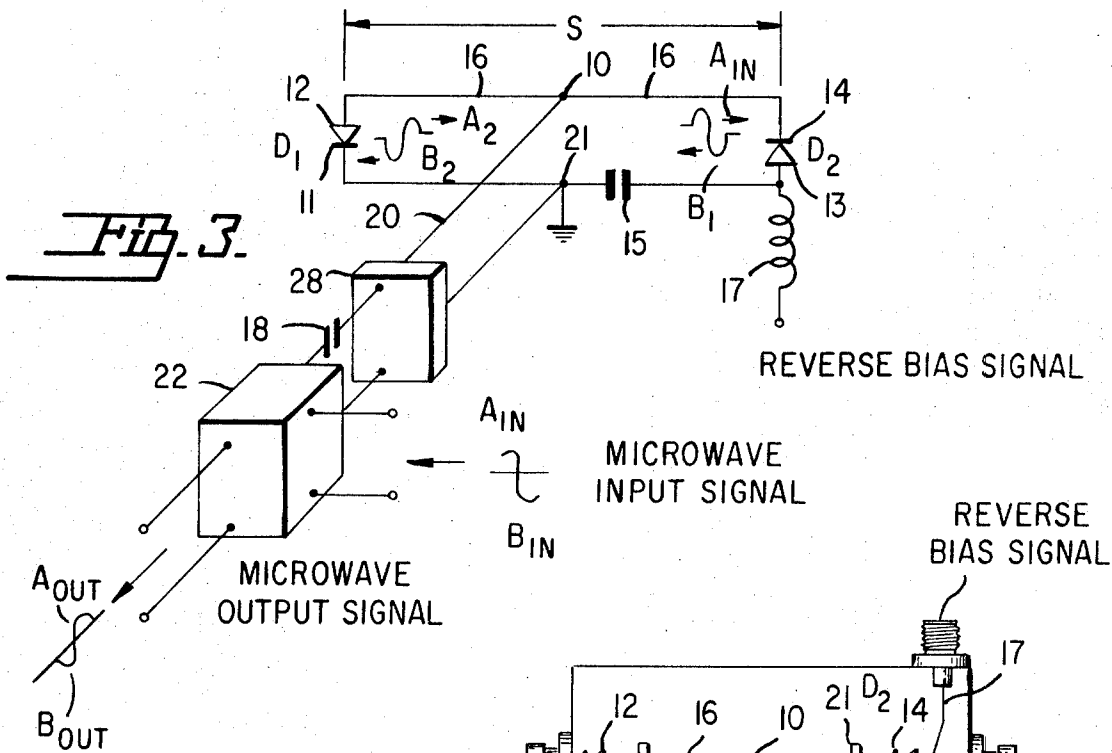
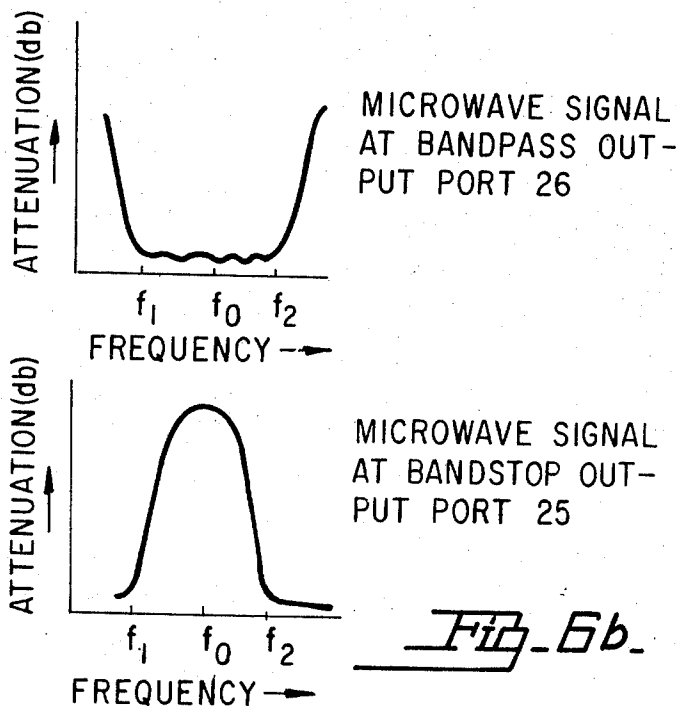
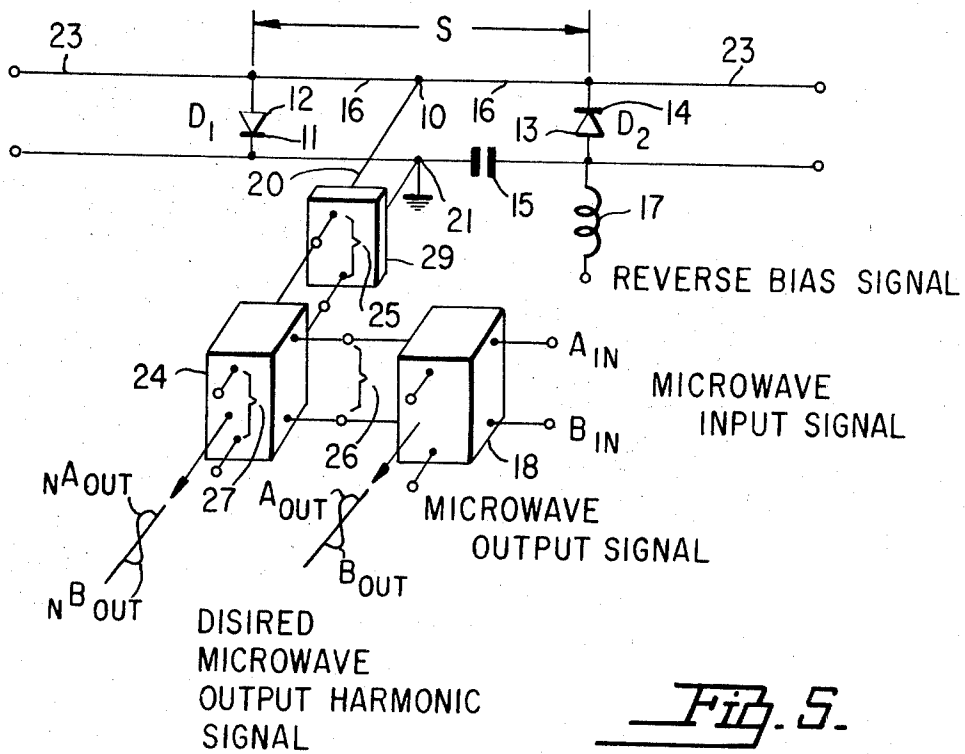


Fig. 2.

INVENTOR.
Hirohisa Kawamoto
 BY
Edward J. Norton
 ATTORNEY



INVENTOR.
HIROHISA KAWAMOTO
BY
Edward J. Norton
ATTORNEY



INVENTOR.
HIROHISA KAWAMOTO
BY
Edward J. Norton
ATTORNEY

MICROWAVE APPARATUS USING MULTIPLE AVALANCHE DIODES OPERATING IN THE ANOMALOUS MODE

The present invention is a continuation-in-part of application Ser. No. 102,390, filed Dec. 29, 1970 and abandoned contemporaneously with the filing of this application.

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

DESCRIPTION OF THE PRIOR ART

The design and successful operation of microwave apparatus using avalanche diodes, operating in the anomalous mode, have been published in many reports. The paper by P. A. Levine and S. G. Liu, entitled "Tunable L-Band High-Power Avalanche Diode Oscillator Circuit," presented at the ISSCC Conference, Philadelphia, February 1969, describes the necessary boundary conditions which must be solved before an avalanche diode can be triggered into generating microwave oscillations in the anomalous mode. However, the demands for increased output power from microwave sources have led to the operation of multiple, shunt-mounted, avalanche diodes in a single microwave oscillator circuit.

The use of microwave hybrids as power summers for individual sources have proved unsatisfactory because they increase the size and complexity of the microwave circuit. A push-pull circuit has been used for operation of two semiconductive devices. However, such an arrangement has the disadvantage of requiring microwave isolation between semiconductive devices, which is sometimes difficult to obtain.

A series coupling of avalanche diodes for a microwave source has the limitation of making it difficult to provide a proper heat sink, causing diode burn out problems if the heat sink is not sufficient. A parallel arrangement of avalanche diodes is more satisfactory, but the simple addition of shunt-mounted avalanche diodes will not solve all the peculiar boundary conditions required of avalanche diodes operating in the anomalous mode.

SUMMARY OF THE INVENTION

The terminals of a first avalanche diode are shunt coupled across a microwave transmission line. The terminals of at least one other avalanche diode are also shunt coupled across the microwave transmission line. The terminal polarity of the other avalanche diode is opposite to the terminal polarity of the first avalanche diode.

A reverse bias signal, exceeding a predetermined threshold level, is coupled across the terminals of each diode for triggering them into operating in the anomalous mode at one or more desired microwave frequencies.

The electrical separation between the first avalanche diode terminals and the other avalanche diode terminals is substantially $\lambda/2$, where λ is the wavelength at a certain desired frequency of operation.

A microwave resonant circuit is coupled to the microwave transmission line containing the avalanche diodes. The resonant circuit will transmit energy at one or more desired frequencies, which may include the fundamental and/or one or more harmonics thereof,

and reflect energy at other undesired harmonics thereof.

The microwave resonant circuit is electrically positioned so that the reflected energy will have the proper phase to aid in triggering the avalanche diodes into the anomalous mode of operation.

Further features and advantages of the invention will become more readily apparent from the following description of specific embodiments, as shown in the accompanying drawings in which:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic representation of a microwave avalanche diode apparatus utilizing concepts of the disclosed invention,

FIG. 2 is a cross-sectional view of a coaxial avalanche diode oscillator using two avalanche diodes reversed biased to operate in the anomalous mode,

FIG. 3 is a schematic representation of a microwave avalanche diode amplifier utilizing concepts of the disclosed invention,

FIG. 4 is a top view of a microstrip avalanche diode amplifier using two avalanche diodes reversed biased to operate in the anomalous mode,

FIG. 5 is a schematic representation of a microwave amplifier multiplier utilizing concepts of the disclosed invention,

FIG. 6(a) is a top view of a microstrip diplexer, FIG. 6(b) is a plot of Attenuation v. Frequency Characteristics of the microwave diplexer.

Referring to FIG. 1, there is shown a schematic representation of a microwave apparatus incorporating the features of the present invention. The diodes D_1 and D_2 are avalanche diodes shunt coupled to a microwave transmission line 16. The terminal polarity of diode D_1 is opposite to the terminal polarity of diode D_2 . The avalanche diodes are separated by an electrical length which is substantially $\lambda/2$, where λ is the wavelength at a desired frequency of oscillation. This is illustrated in FIG. 1, by the microwave coupling of the anode 12 and cathode 11 of diode D_1 to the cathode 14 and the anode 13 of diode D_2 , via the microwave transmission line 16 and the microwave bypass capacitor 15.

The avalanche diode operating in the anomalous mode, within an appropriate microwave circuit, is a two terminal negative resistance semiconductive device. An applied reverse bias signal, slightly greater than the breakdown voltage of the diode, will cause a displacement current or electric field in the depletion layer of the diodes semiconductive material. The diode carriers are ionized at the point of maximum electric field within the depletion layer. The carrier density is increased when the ionized carriers collide with other atoms and create more carriers. The displacement current can also be considered as a wavefront, moving with a specific wave velocity, provided the displacement current has a very fast rise time. If the wave velocity of the displacement current is greater than the saturation velocity of the carriers, a high density of holes and electrons will be left in the wake of this wavefront. As a result of the concentration of holes and electrons, the electric field is reduced and the velocity of the carriers is diminished, leading to the formation of a dense plasma. Microwave energy is obtained from an avalanche diode by extraction of energy from the trapped plasma.

The necessary fast rise time of the displacement current can be achieved by utilizing the high frequency signals created by ionization at low currents. The high frequency signals trigger the avalanche diode into a high efficiency mode of operation, the anomalous mode. The avalanche diode then emits energy at a frequency which is related to the ratio of the depletion layer width to the velocity of the carriers in the plasma, and the design of the complementary microwave circuitry.

A reverse bias signal is applied to the anode 13 of diode D_2 through a biasing circuit that would prevent the leakage of microwave energy into the bias power supply not shown. Such a biasing circuit may be a high inductance lead 17 that will appear as an open circuit at microwave frequencies. The microwave bypass capacitor 15 will allow the applied reverse bias signal to reverse bias both diodes, D_1 and D_2 . The magnitude of the applied bias signal is sufficient to trigger each respective diode, D_1 and D_2 , into generating microwave energy in the anomalous mode of operation. Diode D_2 generates a negative going microwave pulse, B^1 . Part of the negative going pulse, B^1 , is transmitted along the microwave transmission line 16 toward diode D_1 and part toward the microwave resonant circuit 19.

The terminal polarity of diode D_1 is arranged so that the negative going pulse, B^1 , aids the applied reverse bias signal in triggering diode D_1 into operating in the anomalous mode. Diode D_1 generates a positive going microwave pulse X^1 , which is transmitted along the microwave transmission line 16 toward diode D_2 .

The microwave resonant circuit 19 transmits energy at one or more desired frequencies and appears as a microwave short circuit at undesired frequencies harmonically related to the desired frequency or frequencies. Therefore, the microwave resonant circuit 19 reflects the undesired harmonic energy contained in the negative going pulse B^1 , back toward the terminals of diode D_2 . The short circuit effect of the microwave resonant circuit 19 inverts the reflected portion of the negative going pulse B^1 to a positive going pulse Y^1 . It is necessary that the positive going pulse Y^1 and the positive going pulse X^1 be in phase at the terminals of diode D_1 . This is accomplished by making the electrical length between diodes D_1 and D_2 equal to the electrical length between the reflection plane of the microwave resonant circuit 19 and diode D_2 . The combination of the reflected positive going pulse, X^1 , and the generated positive going pulse, Y^1 , aid in triggering the next cycle of microwave oscillation from diode D_2 .

At a particular resonant frequency of interest of the microwave oscillator, the frequency depends on the round trip delay time required for a microwave signal generated by a first diode to aid in triggering a second diode and return to the first diode to repeat the cycle. A way to satisfy this condition is to make the particular resonant frequency dependent on the electrical length between avalanche diodes, D_1 and D_2 , and the electrical length between the reflective plane of the resonant circuit 19 and the closest diode, D_2 . The electrical length, S , between avalanche diodes is

$$S = \lambda/2 - \tau_d V_p$$

where λ is the wavelength in the media of microwave transmission at this frequency of interest. The internal delay time, τ_d , is the time required of an avalanche

diode before it can be triggered into operation. V_p is the phase velocity in the media of microwave transmission. Since the product $\tau_d V_p$ is relatively small, where λ is large at low microwave frequencies such as 800 mhz, the spacing S is substantially $\lambda/2$. The electrical length, S^1 , between the closest diode D_2 and the reflective plane of the resonant circuit 19 is

$$S^1 = \lambda/2 - (\tau_d V_p/2)$$

The product $(\tau_d V_p/2)$ is also negligible in the same frequency range and may be neglected.

Referring to FIG. 2, there is shown a cross section of a coaxial transmission line circuit using the techniques of the present invention. The anode 12 of diode D_1 and the cathode 14 of diode D_2 are both coupled to the center conductor of the same coaxial transmission line 16. The cathode 11 of diode D_1 is connected directly to the outer or ground conductor 20 of the coaxial transmission line. The physical spacing between diodes, D_1 and D_2 , is 12 cm which is equivalent to an electrical spacing of $\lambda/2 - \tau_d V_p$ where λ is the wavelength in free space at 1.0 Ghz, and $\tau_d = 0.1$ nsec. A microwave bypass capacitor 15, with a parallel plate capacitance of approximately 50 pf. at 1.0 Ghz, is formed by inserting a 1 mil thick piece of mica dielectric 24 between the anode 13 of diode D_2 and the ground conductor 20 of the coaxial transmission line.

A variable tuning capacitor 19 suitable for operating at microwave frequencies and having a tuning range from 0.6 to 6.0 pf. is coupled in shunt between the center conductor 16 and the ground conductor 20 of the coaxial transmission line. The tuning capacitor 19 functions as a low pass filter. At the desired frequency of oscillation, which in this case is the fundamental, microwave energy is transmitted to the output connector 23, while at harmonics of the desired frequency of oscillation, the capacitor 19 presents a short circuit plane of reflection. The physical spacing between the tuning capacitor 19 and the cathode 14 of D_2 , is 13.5 cm. This is equivalent to $S^1 = \lambda/2 - (\tau_d V_p/2)$.

In order to prevent the D.C. bias signal from being transmitted to the output connector 23 and yet not impede the propagation of microwave energy, a blocking capacitor 18 with a magnitude of 50 pf. is coupled in series between the center conductor 16 and output connector 23. A negative bias signal, exceeding the breakdown voltage of the diodes, is coupled to one end of 0.25 inch length of 10 mil diameter wire 17. The other end of the wire 17 is coupled to the anode 13 of diode D_1 . The inductive reactance of the wire 17 is sufficient to prevent microwave leakage back to the bias power supply not shown.

An oscillator of the type described in connection with FIG. 2 was built and it was found that the microwave peak output power from this oscillator was 170 watts at 1.0 Ghz, and the maximum efficiency was 27 percent. Each diode used in this oscillator, when operated individually in a conventional oscillator circuit, was found to generate a peak power of 90 watts. The current drawn by each diode was from 2.5 to 3.5 amp., when reversed biased to its breakdown voltage point. Each of the avalanche diodes, used in the circuit of FIG. 2 which was built, was a punch through pnn+silicon mesa structure. The diameter of each of these diodes was approximately 0.020 inch. The junction of

the respective diodes was formed by boron diffusion into n-type silicon epitaxial wafers. The resistivity of the epitaxial layer was approximately 6 ohm-cm. The breakdown voltage of the respective diodes were in range from 120 to 150 volts.

Referring now to FIG. 3, there is shown a schematic diagram of a microwave amplifier. The avalanche diodes, D_1 and D_2 , are reverse biased by a combination of D.C. and microwave signals. FIG. 3 includes all the elements of the microwave oscillator of FIG. 1, which are designated by identical reference numerals. The electrical length, S , separating the terminals of diode D_1 from the terminals of diode D_2 is $S = \lambda/2 - \tau_d V_p$, where, in this case, λ is the wavelength at the frequency of the microwave input signal. The product $\tau_d V_p$ is the same as that required for the microwave oscillator of FIG. 1. The addition of the circulator 22, with one port coupled to the microwave resonant circuit 28, allows an appropriate microwave input signal, applied to a second port of the circulator, to be transmitted to the diode terminals. A D.C. signal applied at one end of the high inductance lead 17 is sufficient, in this case, to reverse bias the diodes, D_1 and D_2 , to slightly below their breakdown voltage levels. The microwave input signal is at a desired frequency of operation and the positive going portion of the microwave input signal, A_{in} , is transmitted through the microwave resonant circuit to the terminals of diode D_2 .

The positive going signal, A_{in} , increases the existing reverse D.C. bias voltage until the breakdown voltage of diode D_2 is exceeded. The positive going microwave signal does not further reverse bias diode D_1 , since the polarity of its terminals is inverted with respect to the terminal polarity of diode D_2 . The magnitude of the microwave voltage triggers diode D_2 into generating a negative going microwave pulse B_1 . The instant the negative going pulse B_1 is generated, the negative going portion of the microwave input signal, B_{in} , is being propagated through the microwave resonant circuit 28. This is accomplished by making S^1 , the electrical length from the reflective plane of the microwave resonant circuit 19 to the terminals of both diodes, D_1 and D_2 ,

$$S^1 = \lambda/2 - (\tau_d V_p/2)$$

The electrical length from the junction point 10 of the microwave transmission lines 16 and 20 to the diode D_2 is substantially equal to the electrical length between the junction point 10 and the reflective plane of the microwave resonant circuit 28. Thus, the negative going portion of the microwave input signal, B_{in} , and the generated signal B_1 are in phase at the junction point 10 and combine as microwave signal B_2 , which triggers diode D_1 into generating a positive going microwave signal A_2 . A portion of the microwave signal, B_1 , is not transmitted toward diode D_1 . This portion is propagated as the amplified microwave output signal through the microwave resonant circuit 28 to the third port of the circulator 22.

A similar analysis is used with the generated positive going pulse A_2 to explain the dependent coupling between diodes, D_1 and D_2 , and their interaction with successive cycles of the applied microwave input signal. The reflected harmonic energy of the pulse B_1 combine with the positive going pulse A_2 and the next positive going cycle of the microwave input signal to

trigger diode D_2 . Diode D_2 contributes the negative going portion of the microwave output signal, B_{out} , and diode D_1 contributes the positive going portion of the microwave output signal, A_{out} .

In FIG. 4, which will now be described, there is shown the top surface of a microstrip amplifier using the techniques of the present invention. The microstrip transmission lines 16 and 20 are conductive strips on one side of a dielectric substrate 23. The bottom surface of the dielectric substrate 23 is covered by a ground planar conductor, not shown. The microwave resonant circuit 24 is a microstrip low pass filter that transmits microwave energy at the frequency of the microwave input signal applied to the first port of the circulator 22. The low pass filter 28 presents a reflective plane at all other higher frequencies generated by the avalanche diodes, D_1 and D_2 . The low pass filter 28 and the tuning stubs 21 match the complex impedance of the multiple configuration of avalanche diodes, D_1 and D_2 , to a load impedance, not shown, terminating the third ground of the circulator 22. The cathode 14 of diode D_2 is coupled to the microstrip transmission line 16. The anode 13 of diode D_2 is coupled to one terminal of a 50 pf. bypass capacitor 15. The remaining terminal of the bypass capacitor 15 is coupled to the ground planar conductor. The bypass capacitor presents a low impedance to ground for energy at microwave frequencies. One end of a 10 mil diameter, high inductance wire 17 is coupled to the anode 13 of diode D_2 . The other end of the high inductance wire 17 is coupled to a D.C. reverse bias signal source, not shown. The high inductance of the 10 mil diameter wire 17 provides effective isolation of microwave leakage to the D.C. reverse bias signal source. The cathode 11 of diode D_1 is coupled to the ground planar conductor, and the anode 12 of diode D_1 is coupled to the microstrip transmission line 16. A 50 pf. D.C. blocking capacitor 18 is coupled between the low pass filter 24 and the second port of the circulator 22. The D.C. blocking capacitor 18 presents little attenuation to microwave signals but prevents leakage of D.C. signals to the circulator 22.

The microstrip amplifier provided a peak microwave output power of 200 watts to a load terminating the third port of the circulator 22. The avalanche diodes used in the microstrip amplifier were similar to those used in the microwave oscillator of FIG. 2. The avalanche diodes were reversed biased by a combination of a peak D.C. voltage of 150 volts across each diode and a microwave signal of 20 watts applied to the first port of the circulator 22.

Referring to FIG. 5, there is shown a schematic diagram of a microwave amplifier multiplier. For certain applications it may be desirable to obtain, from a microwave amplifier, a harmonic multiple of the input frequency. The resulting microwave output power, at this harmonic frequency, should also have gain. The microwave amplifier multiplier illustrated by FIG. 5, uses the same basic design of FIG. 1, but with additional elements. The theory of harmonic generation and amplification of microwave signals by multiple avalanche diodes, operating in the anomalous mode, is unchanged from the microwave oscillator and amplifier. The electrical separation between avalanche diodes is

$$S = \lambda/2 - \tau_d V_p$$

where λ is the wavelength in the media of microwave transmission at the desired harmonic frequency of the microwave input signal. The product $\tau_d V_p$ is the delay time associated with triggering the avalanche diode and the phase velocity in the media of microwave transmission. The electrical separation between each of the avalanche diodes, D_1 and D_2 , and the reflective plane of the microwave resonant circuit 29 is

$$S^1 = \lambda/2 - (\tau_d V/2)$$

The microwave resonant circuit 29 is a bandpass filter that is resonant at the desired harmonic frequency and the frequency of the microwave input signal. However, the bandpass filter 29 is designed to reflect a small amount of microwave energy, at these frequencies, back toward the diode terminals. At all other harmonic frequencies, the bandpass filter presents a reflective plane. Each of the open circuited microwave transmission line stubs 23 have an electrical length of substantially $\lambda/2$, where λ is the wavelength at the desired harmonic frequency. The electrical length of the stubs 23 is measured from the respective diode terminals to the open circuited terminals. The stubs 23 are used to enhance the generation and amplification of microwave energy at the desired harmonic frequency.

The microwave diplexer 24, coupled between the bandpass filter 29 and the circulator 18, is a component that will separate the microwave input signal from the desired microwave output harmonic signal.

Referring to 2 6(a), there is shown, by way of example, a combination of a microstrip bandstop filter 11 and a microstrip bandpass filter 10 that compose the microwave diplexer 24. The microstrip bandpass filter elements 1, 3 and 3 are three open circuited sections of resonant microstrip transmission line. The gaps separating the filter elements 1, 2 and 3 capacitively couple one element to the other. The center section 2 is parallel to the first and third sections and substantially $\lambda/2$ in length, where λ is the wavelength at the microwave input frequency. The first and third sections of the bandpass filter are capacitively coupled to the center section 2 over a parallel length of substantially $\lambda/4$, where λ is the wavelength at the microwave input frequency.

The complementary microstrip bandstop filter 11 is anti-resonant at the microwave input frequency. Each of the bandstop filter sections 4, 5 and 6 are lengths of microstrip transmission line short circuited to ground at one end and capacitively coupled, by a small gap 8, to the main transmission line 7 at the other end. The electrical length of the bandstop filter sections 4, 5 and 6 measured from the short circuit 9 to the capacitive gap 8 is substantially $\lambda/4$, where λ is the wavelength at the frequency of interest. The electrical separation between filter sections 4, 5 and 6 is also $\lambda/4$. The impedances of all the microstrip filter elements are selected to match the source impedance of the microwave input signal.

FIG. 6(b) illustrates the attenuation, db, of a microwave signal, versus the frequency of the microwave signal coupled to the port 25 of a microwave diplexer. The attenuation is measured from the port 25 to the bandpass port 26 and the bandstop

port 27. The microwave diplexer is a bi-directional device. Any microwave signal that is coupled to port 25 will propagate to port 26 with little microwave attenuation and vice versa, provided the signal is in the frequency range between f_1 and f_2 . The high reflective properties of the bandstop filter will prevent any microwave signal in the same frequency range, from propagating to port 27. A harmonic of this frequency band, coupled to port 25, will only propagate to port 27. The reflective properties of the bandpass filter will prevent this harmonic frequency from propagating to port 26.

Referring to FIG. 5, the avalanche diodes D_1 and D_2 are reversed biased by a D.C. signal applied to the anode 13 of diode D_2 through the high inductance wire 17. The magnitude of the applied D.C. signal is below the breakdown voltage level of the avalanche diodes. The magnitude of the microwave input signal applied to the first port of the circulator 22 and transmitted to the diode terminals trigger the diodes, D_1 and D_2 , into operating in the anomalous mode. The enhanced harmonic signal and the amplified microwave input signal are propagated through the bandpass filter 29 toward the port 25 of the microwave diplexer 24. The desired harmonic frequency, being in the pass band of only the bandstop filter, is propagated toward a terminating load impedance, not shown, at the harmonic output port 27. The amplified microwave input signal is within the pass band of only the bandpass filter and is propagated through the bandpass output port 26, toward the circulator 18. The amplified microwave input signal, will propagate toward a load, not shown, terminating the output port of the circulator 18.

A new approach to the generation and amplification of microwave signals by the use of a multiple configuration of avalanche diodes has been demonstrated. The technique does not limit itself to only two avalanche diodes. Any number of diodes may be used as long as the conditions illustrated by the preceding circuits are satisfied. This includes multiple stacks of series connected diodes shunt-mounted across a microwave transmission line in a configuration that satisfies the peculiar boundary conditions associated with using multiple avalanche diodes operating in the anomalous mode.

A preferred embodiment of the invention in microstrip and coaxial transmission line has been shown and described. Various other embodiments and modifications thereof will be apparent to those skilled in the art, and will fall within the scope of invention as defined in the following claims.

What is claimed is:

1. Microwave apparatus operative at a desired frequency, said apparatus comprising:

first and second avalanche diodes each having terminals,

a microwave structure,

the terminals of both said first and second avalanche diodes being shunt coupled to said microwave structure with the terminal polarity of said first avalanche diode being opposite to said second avalanche diode terminal polarity.

means for applying a reverse bias signal, exceeding a predetermined threshold value, across the terminals of each of said diodes, to effect said

avalanche diodes being triggered into their anomalous mode of operation,

said microwave structure and said respective diodes being arranged in cooperative relationship with respect to one another to provide a predetermined delay of a microwave signal propagated through said microwave structure between said respective diodes, said desired frequency being dependent on said predetermined delay,

means for coupling a microwave resonant circuit to said microwave structure, said circuit being resonant at said desired frequency and providing a path of low microwave attenuation for energy at said desired frequency, said circuit being anti-resonant at undesired frequencies harmonically related to said desired frequency to thereby reflect energy at said undesired frequencies, said diodes being positioned with respect to said microwave resonant circuit so that said reflected energy is of proper phase to aid in triggering said avalanche diodes into the anomalous mode of operation.

2. Microwave apparatus according to claim 1, wherein said microwave structure comprises a microwave transmission line, and wherein said diode arrangement comprises spacing said first and second diodes by a given distance of said line, wherein said given distance has an electrical length, S , of substantially,

$$S = \lambda/2 - \tau_d V_p$$

where λ is the wavelength at said desired frequency, τ_d is the response time exhibited by a triggered avalanche diode in achieving operation, and V_p is the phase velocity in the media of microwave transmission.

3. Microwave apparatus according to claim 1, wherein said position of said microwave resonant circuit with respect to the closest of said diodes is determined by an effective electrical separation, S^1 , of substantially,

$$S^1 = \lambda/2 - (\tau_d V_p)/2$$

where λ is the wavelength at said desired frequency and τ_d is the response time exhibited by a triggered avalanche diode in achieving operation, and V_p is the phase velocity in the media of microwave transmission.

4. Microwave apparatus in accordance with claim 1, wherein said reverse bias signal is a D.C. voltage having a magnitude which in and of itself exceeds said predetermined threshold level, whereby said avalanche diodes oscillate at said desired frequency.

5. A microwave apparatus in accordance with claim 1, wherein said reverse bias signal is the sum of a D.C. voltage having a magnitude less than the predetermined threshold value and the amplitude of an applied microwave bias signal at said desired frequency of operation, said sum having a value exceeding said predetermined threshold value, whereby said avalanche diodes are triggered into amplifying said applied microwave bias signal.

6. A microwave apparatus in accordance with claim 3, including a directional circulator having one port coupled to said microwave resonant circuit, said circulator having a second port for applying said microwave bias signal to said avalanche diode terminals through said microwave resonant circuit and a third port for applying said amplified microwave bias signal to a terminating load impedance.

7. A microwave apparatus in accordance with claim 1, wherein said reverse bias signal is the sum of a D.C. voltage having a magnitude less than the predetermined threshold value and the amplitude of an applied microwave bias signal, having a given frequency, said sum having a value exceeding said predetermined threshold value, and said apparatus further including tuning means for enhancing a desired harmonic of said given frequency, said harmonic being said desired frequency of operation, whereby said avalanche diodes are triggered into generating and amplifying said desired harmonic of the given frequency of said microwave bias signal.

* * * * *

45

50

55

60

65

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,683,298

Dated August 8, 1972

Inventor(s) Hirohisa Kawamoto

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 2, correct "nstype" to read --n-type--.

Column 6, line 23, correct "ground" to read --port--.

Column 7, line 12, correct " $S^1 = \lambda/2 - (\tau_d V/2)$ " to read
-- $S^1 = \lambda/2 - (\tau_d V_p/2)$ --.

Column 7, line 33, correct "2 6(a)" to read --Figure 6(a)--.

Column 7, line 37, correct "3" first occurrence to read --2--.

Column 7, line 60, correct "he" to read --the--.

Column 10, line 1, correct " $S^1 = \lambda/2 - (\tau_d V_p/2)$ " to read
-- $S^1 = \lambda/2 - (\tau_d V_p/2)$ --.

Signed and sealed this 9th day of January 1973.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents