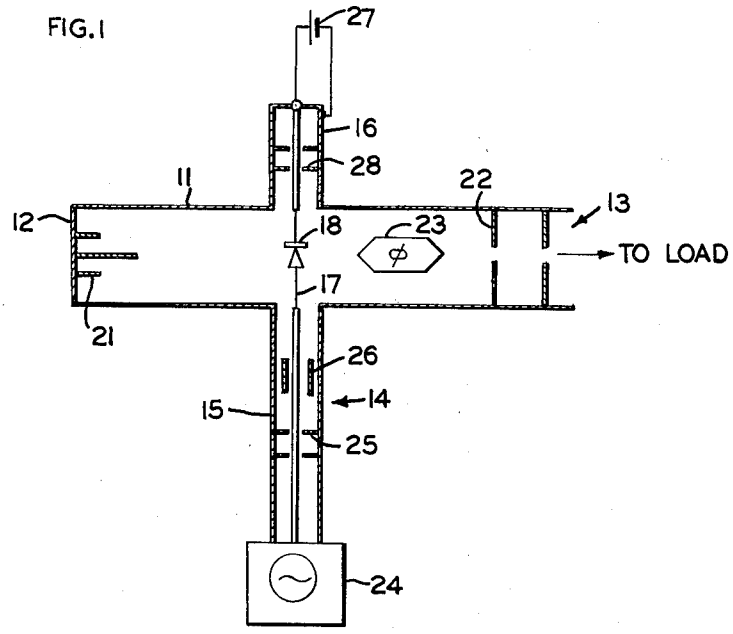
Oct. 23, 1962 P. A. CRANDELL 3,060,365

HARMONIC GENERATOR

Filed Aug. 17, 1959

FIG. 1



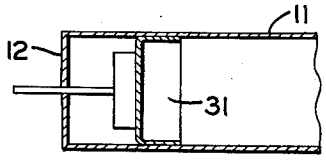


FIG. 2

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3,060,365
HARMONIC GENERATOR

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My invention relates in general to an improved device for generating harmonics of an electrical signal; in particular it relates to harmonic generators employing a non-linear capacitor in order to generate harmonic frequencies in the microwave range.

It is known that a non-linear device generates harmonics when excited by a single-frequency generator. The non-linear resistance of point-contact rectifiers has long been used for this purpose. Similarly, non-linear capacitors have also been used in the past for the purpose of harmonic generation, particularly to provide microwave frequencies by multiplying a low frequency output signal from a standard source. However, all of these techniques were subject to serious limitations because of the low power output available.

A. Uhlir, Jr., in a paper entitled "The Potential of Semiconductor Diodes in High-Frequency Communications," Proceedings of the IRE, June 1958, pp. 1099–1115, points out that high power efficiencies are obtainable in harmonic generators if non-linear capacitors consisting of p-n junction diodes are used. The improved efficiency is the result of the inability of the p-n junction diode to convert any of the incident power into D.C. power, or to dissipate it resistively. The efficiency can be increased further by the proper use of filters. A filter disposed between the diode and the fundamental frequency generator which cuts off below the second harmonic of the fundamental, as well as a bandpass filter preceding the output which permits only the desired harmonic to be applied to the load, can materially increase the output power over that obtainable in more conventional harmonic generators. Despite these expedients, however, insufficient energy is available at the diode for conversion into higher harmonics. The power obtainable at the output remains small enough to place a serious limitation on the utility of equipment using this structure.

Accordingly, it is the primary object of my invention to obtain a material increase in the efficiency as well as in the output power of harmonic generator which employs a non-linear capacitor in the form of a p-n junction diode.

The foregoing object is carried out by placing the diode in a waveguide section or cavity and providing effective means for retaining the energy which is converted into the higher harmonics, except for that at the desired harmonic frequency, within the waveguide section in order to aid its conversion into useful harmonics. The dissipation of all harmonics, other than the desired one, within the cavity is reactive, with no resultant energy loss.

This and other objects of the invention, together with the novel features and advantages thereof, will become apparent from the following detailed specification and from the accompanying drawing, in which:

FIG. 1 illustrates in schematic form a preferred embodiment of the invention herein; and

FIG. 2 illustrates a modification of the apparatus of FIG. 1.

With reference now to the drawing and particularly to FIG. 1 thereof, waveguide envelope or cavity **11** is seen to have a closed end **12** and an open or load end **13**. The waveguide may consist of any desired configuration which provides a resonant cavity between ends **12** and **13**. A coaxial transmission line generally indicated at **14** intersects waveguide **11** transversely thereof,

transmission line portions **15** and **16**, respectively being disposed on opposite sides of the waveguide. The coaxial transmission line includes an inner conductor **17** which passes through the waveguide **11**. A non-linear capacitor consisting of a p-n junction diode **18** is connected in series with the inner conductor and is disposed within the waveguide. The harmonic generator further comprises a septum tuner **21** positioned near closed end **12**, as well as a bandpass filter **22** disposed between diode **18** and load **13**.

The bandpass filter is adjustable to provide a pass band centered about the desired harmonic. A phase shifter **23**, e.g. a ferrite phase shifter, is disposed in the waveguide between diode **18** and pass band filter **22** and is adjusted to load the diode reactively for all frequencies including and below the frequency of the first multiple of the fundamental below the desired harmonic. A low-frequency source **24** such as a crystal-controlled oscillator, supplies energy at the fundamental frequency, e.g. 1800 mc., to the input of coaxial transmission line **14**. A low-pass filter **25** which passes frequencies below the second harmonic only and a matching network in the form of a line stretcher **26** are disposed in the coaxial transmission line between the low frequency source **24** and the diode **18**. A bias source **27** is coupled to the coaxial transmission line **17** and applies a bias potential to diode **18**. A low-pass filter **28** is disposed intermediate bias source **27** and diode **18** and is adapted to pass frequencies below the fundamental frequency only. If required, filter **28** may also be adjustable.

In operation, energy at the fundamental frequency is supplied to the input end of coaxial transmission line **14** for application to p-n junction diode **18**. As previously explained, the diode acts as a non-linear capacitor which can neither convert the incident power into steady state energy, nor can it dissipate it. Substantially all the power supplied to the diode is therefore converted into harmonic frequencies. Inasmuch as low-pass filter **25** passes frequencies below the second harmonic only, no energy, other than that reflected at the fundamental frequency can escape through the coaxial transmission line **15**. Line stretcher **26** matches the impedance of the source and of filter **25** to diode **18**, for optimum power transfer to the diode. The diode is suitably biased from source **27** through coaxial transmission line **16**. The characteristic of low-pass filter **28** prevents the fundamental, as well as any harmonics, from escaping through line **17**. The bandpass characteristic of filter **22**, when properly tuned, prevents the escape of any energy other than energy at the desired harmonic through load end **13** of the waveguide. Accordingly, the energy is retained within the waveguide and is available for the generation of harmonics at the desired frequency. The phase shifter **23**, which is disposed intermediate diode **18** and filter **22**, is importantly reactive at frequencies lower than the desired harmonic frequency and thus mismatches the cavity for these frequencies. Thus, the cavtiy is reactively loaded for these frequencies and energy at these frequencies is retained in the cavity. The overall effect of the phase shifter **23** is to discriminate against the lower harmonics in favor of the desired harmonic frequency. Septum tuner **21**, on the other hand, discriminates against the higher harmonics in favor of the desired harmonic frequency. Any harmonics higher than the desired one for which the waveguide cavity is tuned, produce reactive loading at the diode without any material dissipation of energy. By properly tuning the waveguide by means of the septum tuner, the point of maximum voltage within the waveguide is caused to occur in the vicinity of non-linear diode **18** for the desired harmonic frequency. As a result of the combined action of the phase shifter and of the sep-

tum tuner, higher as well as lower harmonics are discriminated against in favor of the desired one. Consequently, the conversion of the fundamental frequency into the desired harmonic occurs at maximum efficiency inasmuch as the energy is concentrated at the diode and is available for conversion into the desired frequency.

FIG. 2 illustrates an alternative tuning arrangement which can be substituted for the septum tuner **21** of FIG. 1. Here, an adjustable short circuit **31** across closed end **12** of waveguide **11** produces an effect similar to that obtained by the septum tuner. The result achieved is again that of causing the region of maximum voltage for the desired harmonic frequency to occur in the vicinity of non-linear diode **18** for maximum conversion efficiency.

While a preferred embodiment of the invention has been shown and particularly described herein, it will be obvious to those skilled in the art that many modifications, variations, and substitutions may now be made, all of which fall within the scope contemplated by the invention.

I claim:

1. A harmonic generator comprising a waveguide having a pair of ends, one of said ends being adapted to be coupled to a load, a non-linear capacitor consisting of a p-n junction diode disposed intermediate said waveguide ends, means for introducing energy at a fundamental frequency into said waveguide for application to said diode, first filtering means disposed intermediate said energy introducing means and said diode, said first filtering means being adapted to pass only frequencies below the second harmonic of said fundamental frequency, second filtering means disposed intermediate said load end and said diode, said second filtering means being adapted to pass substantially only the desired harmonic frequency, and means for tuning said waveguide to provide a region of maximum voltage in the vicinity of said diode at the desired harmonic, said tuning means including a septum tuner opposite the load end of said cavity, said septum tuner having a plurality of septums to reactively load said diode at frequencies above the desired frequency.

2. A harmonic generator comprising a waveguide having a pair of ends, one of said ends being adapted to be coupled to a load, a non-linear capacitor consisting of a p-n junction diode disposed intermediate said waveguide ends, means for introducing energy at the fundamental frequency into said waveguide for application to said diode, first filtering means disposed intermediate said energy introducing means and said diode, said first filtering means being adapted to pass only frequencies below the second harmonic of said fundamental frequency, second filtering means disposed intermediate said load end and said diode, said second filtering means being adapted to pass substantially only the desired harmonic, and loading means importantly reactive to frequencies below the desired harmonic frequency to reactively load said diode at frequencies below the desired harmonic frequency located between said diode and said second filtering means.

3. The apparatus of claim 2, wherein said reactive loading means comprises an adjustable phase shifter.

4. A harmonic generator comprising a waveguide having a pair of ends, one of said ends being adapted to be coupled to a load, a non-linear capacitor consisting of a p-n junction diode disposed intermediate said waveguide ends, means for introducing energy at the fundamental frequency into said waveguide for application to said diode, first filtering means disposed intermediate said energy introducing means and said diode, said first filtering means being adapted to pass only frequencies below the second harmonic of said fundamental frequency, second filtering means disposed intermediate said load end and said diode, said second filtering means being adapted to pass substantially only the desired harmonic, means for tuning said waveguide to provide a region of maximum voltage in the vicinity of said diode at the desired harmonic, said tuning means including a septum tuner opposite the load end of said cavity, said septum tuner having a plurality of septums to reactively load said diode at frequencies above the desired frequency, and an adjustable phase shifter located between said diode and said second filtering means, said phase shifter being importantly reactive to frequencies below the desired frequency to reactively load said diode at frequencies below the desired frequency.

5. A harmonic generator comprising a waveguide having a closed end opposite the load end thereof, a non-linear p-n junction diode disposed in said waveguide intermediate said ends, means for applying energy at the fundamental frequency to said diode, a first low-pass filter disposed intermediate said last-recited means and said diode, said first low-pass filter being adapted to pass only frequencies below the second harmonic, means disposed intermediate said energy application means and said first low-pass filter to provide an impedance match therebetween, means for applying a bias to said diode, a second low-pass filter disposed intermediate said last-recited means and said diode, said second low-pass filter being adapted to pass only frequencies below the fundamental frequency, a bandpass filter disposed intermediate said diode and said waveguide load end, said bandpass filter having a pass band centered about the desired harmonic frequency, an adjustable septum tuner disposed in the vicinity of said closed waveguide end, said septum tuner being adapted to provide a region of maximum voltage in the vicinity of said diode at the desired harmonic frequency while providing reactive loading at frequencies higher than said desired harmonic, and an adjustable phase shifter disposed intermediate said diode and said second filtering means to provide reactive loading at frequencies lower than said desired harmonic.

6. A microwave frequency harmonic generator, comprising in combination a substantially cylindrical resonant cavity, having a closed end and an open end disposed at opposite extremes, a coaxial transmission line transversely intersecting said cavity intermediate said ends, first and second portions respectively of said transmission line being disposed on opposite sides of said cavity, said coaxial transmission line including an inner conductor passing through said cavity transversely thereof, a non-linear capacitor consisting of a p-n junction diode connected in series with said inner conductor, said diode being disposed within said cavity, means for applying energy at the fundamental frequency to the first portion of said coaxial transmission line, a first low-pass filter disposed in said first transmission line portion intermediate said means for applying energy and said diode, said first low-pass filter being adapted to pass only frequencies below the second harmonic of said fundamental frequency, a line stretcher disposed in said first transmission line portion intermediate said first low-pass filter and said diode, said line stretcher being adjustably adapted to provide an impedance match at said desired harmonic, means coupled to said inner conductor in said second transmission line portion for applying a bias to said diode, a second low-pass filter disposed in said second transmission line portion intermediate said biasing means and said diode, said second low-pass filter being adapted to pass only frequencies below the fundamental, a septum tuner disposed in the vicinity of said closed end for adjustably tuning said cavity, said septum tuner being adapted to provide a region of maximum voltage in the vicinity of said diode at the desired harmonic while providing reactive loading at frequencies higher than said desired harmonic, the open end of said cavity being adapted to be coupled to a load, a tunable bandpass filter disposed in said cavity immediately preceding said open end, said bandpass filter being adapted to provide a pass band centered about the desired harmonic, an adjustable ferrite phase shifter disposed intermediate

said bandpass filter and said diode, said phase shifter being adapted to provide reactive loading at said diode at frequencies below said desired harmonic.

7. The apparatus of claim 6 and further comprising a source of fundamental frequency energy coupled to said one side of said coaxial transmission line, and a D.-C. bias source coupled to the other side of said coaxial transmission line.

8. A harmonic generator for microwave frequencies comprising, in combination, a resonant cavity having an output end, a non-linear reactive element disposed within said cavity, means for introducing energy at a fundamental frequency into said cavity for application to said non-linear reactive element, a bandpass filter whose pass band passes substantially only the desired harmonic frequency, said bandpass filter being disposed intermediate the output end of said cavity and said non-linear reactive element, means which reactively load said non-linear reactive device at harmonic frequencies above and below the desired frequency disposed within said cavity, and means for tuning said cavity to provide a region of maximum voltage in the vicinity of said non-linear reactive means at the desired harmonic.

9. The apparatus of claim 8 wherein said non-linear reactive element comprises a non-linear capacitor consisting of a p-n junction diode.

10. The apparatus of claim 8 wherein said reactive loading means includes a septum tuner disposed in the vicinity of one of said cavity ends opposite said output end for reactively loading said diode at frequencies above said desired harmonic.

11. The apparatus of claim 8 wherein said reactive loading means includes a phase shifter disposed intermediate said non-linear reactive element and said bandpass filter for reactively loading said diode at frequencies below said desired harmonic.

12. The apparatus of claim 8 wherein said reactive loading means includes a septum tuner disposed in the vicinity of one of said cavity ends opposite said output end for reactively loading said diode at frequencies above said desired harmonic and a phase shifter disposed intermediate said non-linear reactive element and said bandpass filter for reactively loading said diode at frequencies below said desired harmonic.

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