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[54] GENERATION OF MICROWAVE FREQUENCY COMBS WITH NARROW LINE SPACING

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[51] Int. Cl. H01b 19/00
[58] Field of Search 328/14–16; 331/56, 37, 53, 76; 321/69; 307/281; 332/17, 16, 22

[56] References Cited

UNITED STATES PATENTS

2,028,212	1/1936	Heising	331/76
3,448,401	6/1969	Welch	331/53
2,500,945	3/1950	Hansen	332/17
2,459,822	1/1949	Lalande	331/53
3,059,187	10/1962	Jaffe	328/16
3,054,969	9/1962	Harrison	331/76
3,164,802	1/1965	Kleist	331/37
3,379,995	4/1968	Koontz	331/53
3,576,499	4/1971	Axford	331/76
2,402,385	6/1946	Eaton	331/53
3,199,047	8/1965	Cushman	331/76
3,296,549	1/1967	Johnson	331/53
3,312,909	4/1967	Bryant	331/76
3,401,355	9/1968	Kafitz	331/53

FOREIGN PATENTS OR APPLICATIONS

645,706	11/1950	Great Britain	331/37
599,133	11/1957	Canada	331/37
642,253	11/1960	Italy	331/37

OTHER PUBLICATIONS

Moll "Physical Modeling of the Step Recovery Diode" Proceeding of IEEE Vol. 57 No. 7 July 1969 Pages 1250–1259

Berry "Variable–Width Fractional–Nanosecond Pulse Generators" 1962 International Solid State Circuits Conference Pages 80–81

Gottlieb "Harmonic Generation With the Step Recovery Diode" Book Frequency Changers 1st Edition Jan. 65 Pages 87–96

Krakauer "Harmonic Generation, Rectification ..." Proceeding of IEEE July 1962 Pages 1665–1676

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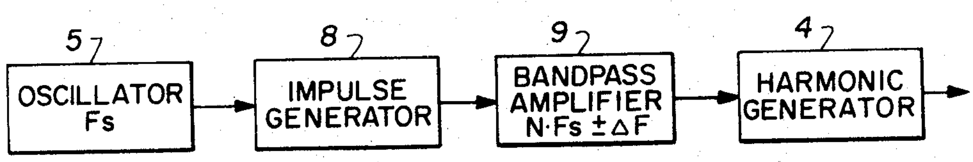
[57] ABSTRACT

A harmonic generator such as a step recovery diode device is driven by two or more input signals of different frequencies to produce a comb spectrum consisting of lines at multiples of the input signal frequencies interspersed with lines at the frequencies of the intermodulation products.

6 Claims, 4 Drawing Figures



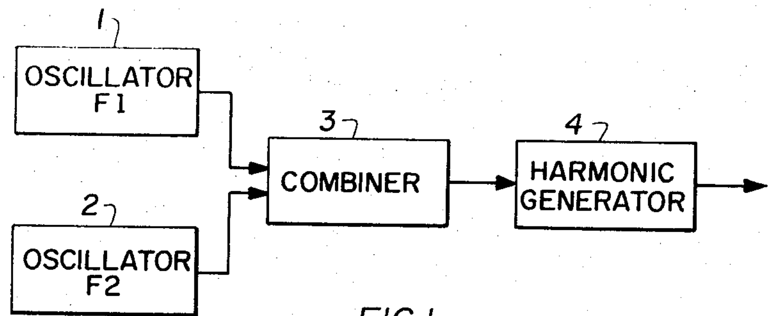


FIG. 1

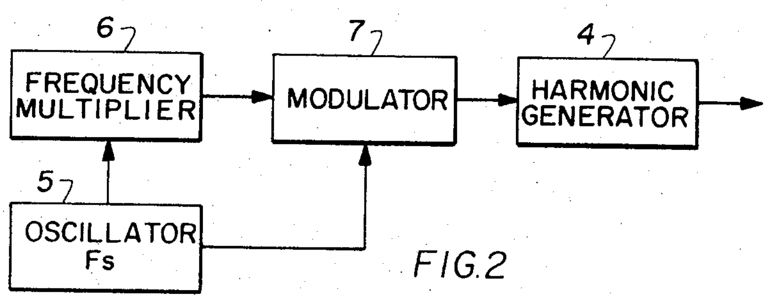


FIG. 2

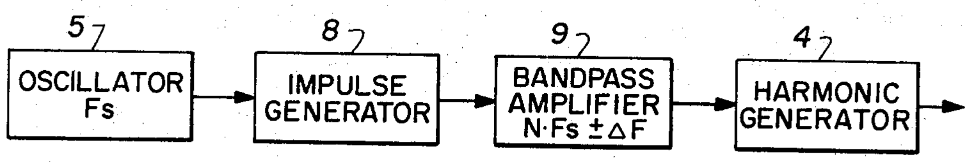


FIG. 3

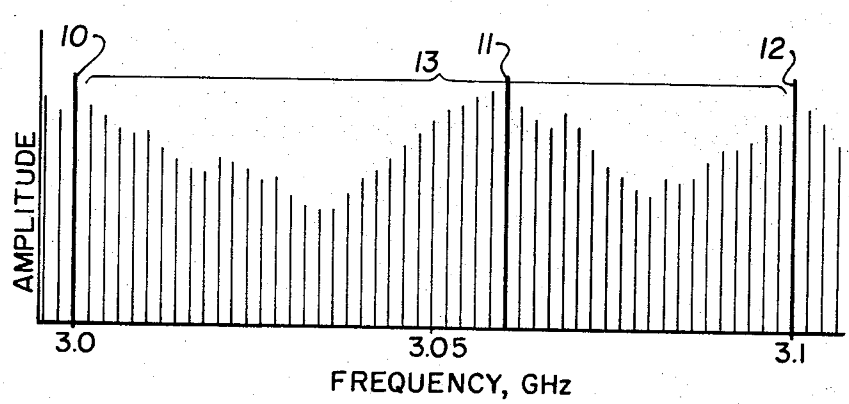


FIG. 4

GENERATION OF MICROWAVE FREQUENCY COMBS WITH NARROW LINE SPACING

BACKGROUND

1. Field

The invention pertains to improvements in microwave harmonic generators of the type wherein a train of narrow high amplitude pulses is produced to provide a broad spectrum of discrete frequencies. Such spectra are often called "combs," and devices for producing them are called comb generators.

2. Prior Art

A well-known type of microwave comb generator comprises a step recovery diode (SRD) and associated circuit elements arranged to be driven by a repetitive input signal such as a sine wave and produce a train of very short pulses repetitive at the input signal frequency. The resulting comb contains signal components, called lines, at frequencies which are consecutive integral multiples of the input signal frequency.

SRD multipliers operate well when driven at frequencies above about 10 MHz. At lower frequencies the efficiency becomes too low for useful comb generation, owing to recombination of minority carriers near the diode junction. Accordingly the minimum comb line spacing that can be obtained with reasonable efficiency using prior art SRD generators is about 10 MHz.

Another limitation on the closeness of line spacing in prior art comb generators results from the fact that the amplitude generally decreases with increasing harmonic order, becoming too low to be useful in lines above the 150th to 200th, for example. Therefore the minimum obtainable comb line spacing in any event is about one half to one percent of the frequency of the uppermost useful comb line.

SUMMARY

According to this invention, the foregoing obstacles to efficient generation of close-spaced microwave combs are avoided by operating the harmonic generator also as an intermodulation generator. A conventional comb generator, preferably of the SRD type, is driven simultaneously by two or more signals of different frequencies to produce two or more different combs with line spacings corresponding to the respective drive signal frequencies. The comb generator is inherently a non-linear device and therefore produces the intermodulation products of the different combs, resulting in a composite comb consisting of lines that are spaced by the difference between the frequencies of the driving signals. Since the line spacing of the composite comb depends on the difference between the drive signal frequencies, these frequencies may be chosen within a range of efficient comb generator operation.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a block diagram of a simple embodiment, illustrating the basic principle, of the invention.

FIG. 2 is a block diagram of a modification of the embodiment of FIG. 1.

FIG. 3 is a block diagram of another modification of the embodiment of FIG. 1.

FIG. 4 is a graph depicting a typical group of comb lines.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, two oscillators 1 and 2, operating at respective different radio frequencies F1 and F2, are connected to a combiner 3. The resultant output of the combiner is applied to a harmonic generator 4. The harmonic generator 4 may be a prior art comb generator, for example one of the SRD type described at pages 89–92 in the Hewlett-Packard catalog of Solid State Devices, published in 1969 by Hewlett-Packard, Inc., Palo Alto, Calif.

The combiner 3 in this instance may be a known linear passive device, such as a bridge network or a hybrid, for merely coupling both oscillators 1 and 2 to the single input port of the harmonic generator 4. The oscillators 1 and 2 are designed to operate at frequencies of, say, 100 MHz and 102 MHz respectively, and the harmonic generator 4 is designed to operate with an input frequency of about 100 MHz, like the Hewlett-Packard module 32002A described in the above mentioned catalog.

In the operation of the embodiment of FIG. 1, the harmonic generator 4 operates in normal manner in response to oscillator 1 to produce a comb consisting of lines at 100 MHz intervals, and in response to oscillator 2 to produce another comb of lines at 102 MHz intervals. A small portion of the composite comb, in the region from 3.0 to 3.1 GHz, is shown in FIG. 4. The heavy lines 10 and 12 represent the 30th and 31st harmonics respectively of 100 MHz, and the heavy line 11 represents the 30th harmonic of 102 MHz, at 3.06 GHz. Such lines are referred to hereinafter as primary comb lines.

The three lines 10, 11 and 12 would be the only ones present in the illustrated position of the composite comb if the component 100 MHz and 102 MHz combs were generated separately and passively combined. Because both combs are generated in the same non-linear device, intermodulation occurs between pairs of elementary components of different frequencies that are present or generated in the device, producing additional components whose frequencies are the sums and differences of the frequencies of the respective pairs. The additional components appear at successive frequencies that differ by the smallest difference between those of original generating components, in this case 2 MHz. The finer lines in FIG. 4, collectively designated by the reference numeral 13, represent the 48 additional secondary comb lines between lines 10 and 12 that are produced by intermodulation.

The signal in each comb line 13 is the summation of a large number of different intermodulation products, all of the same frequency. For example, the line at 3.062 GHz includes the sum frequency product at that frequency formed by line 11 at 3.06 GHz and a signal component at 2 MHz which in turn is the difference frequency product of 100 MHz and 102 MHz. The 3.062 GHz line also includes the difference frequency product of line 12 at 3.1 GHz and a component at 38 MHz, which in turn is the 19th harmonic of the aforementioned 2 MHz component. Another intermodulation product at 3.062 GHz results from the difference between 31st harmonic of 102 MHz, at 3162 MHz, and the 100 MHz fundamental. These and many other such intermodulation products, all at 3.062 GHz, combine to produce the resultant comb line signal at that frequency. Secondary comb line signals are formed in similar manner at 2 MHz intervals throughout the entire comb line spectrum.

The amplitude of any particular intermodulation product depends upon, and is lower than the amplitudes of the signal components from which it is produced. Successively higher order harmonic intermodulation products are of successively lower amplitude. Each composite comb line signal has a respective amplitude that depends upon the amplitudes of its constituents, and upon how they are combined to produce it. In general, the nearer a secondary comb line is to one of the primary lines, the greater its amplitude. Typically, the weakest secondary comb line signal may be of the order of 15 db below the nearest primary comb line signal.

Unless the oscillators **1** and **2** are phase locked, or controlled by a common frequency determining means, the phase relationship between the intermodulation products of a given frequency will vary more or less at random, producing corresponding time variations in amplitude of the individual secondary comb lines. Such variations may be desirable in some applications, but generally it is preferable to maintain constant amplitudes. To this end, the oscillators may be phase locked in any of several well known manners, or the desired drive signals may be obtained from a single original source.

Referring to FIG. **2**, an oscillator **5** is designed to operate at a frequency Fs equivalent to the desired line spacing, say 2 MHz. The output of oscillator **5** is supplied to a frequency multiplier **6** and also to an amplitude modulator **7**. The frequency multiplier **6** is designed in known manner to provide an output of frequency NFs, where N is, for example, **50.**

The 100 MHz output of multiplier **6** is amplitude modulated in the modulator **7** by the 2 MHz input from oscillator **5**, to produce an output consisting of a 100 MHz carrier and the lower and upper sidebands at 98 MHz and 102 MHz. This output is applied to the harmonic generator **4**, which operates essentially as in the system of FIG. **1** to produce a composite comb with 2 MHz line spacing. The phase relationships between the intermodulation components remain substantially constant because the drive signals are obtained from the same ultimate source, the oscillator **5**.

Referring to FIG. **3**, the above described frequency multiplier and amplitude modulator are replaced by an impulse generator **8** which is driven by the oscillator **5** to produce a train of brief pulses recurrent at the frequency Fs, resulting in a frequency comb containing lines of appreciable amplitude in the region of NFs, say from 96 to 104 MHz.

The impulse generator **8** may be similar to the harmonic generator **4**, but designed to operate at lower input and output frequencies. Its efficiency may be quite low compared to that of the generator **4**, but may be improved to some extent by means of a resonator incorporated in the device and operating in known manner to concentrate the output energy in the desired spectral region around 100 MHz. The relatively low level output in this region is amplified by a band pass amplifier **9** to provide the plural frequency drive signal for the harmonic generator **4**, which operates as previously described to produce the final high frequency close spaced comb.

I claims:

1. The method of generating a microwave frequency comb with narrow line spacing, comprising the steps of:

a. producing signals that differ in frequency by the desired line spacing,

b. generating harmonics of said signals, and

c. generating intermodulation products of said harmonics.

2. The method of generating a microwave frequency comb with narrow line spacing, comprising the steps of:

a. producing a signal of a frequency equal to the desired line spacing,

b. utilizing said signal to produce at least two further signals that differ in frequency by the desired line spacing,

c. generating harmonics of said further signals, and

d. generating intermodulation products of said harmonics.

3. The method of operating a step recovery diode comb generator which comprises driving said generator at two frequencies that differ from each other by the desired comb line spacing.

4. The method set forth in claim **3**, wherein said two frequencies are integral multiples of said comb line spacing.

5. Apparatus for generating a microwave frequency comb with narrow line spacing Fs, comprising:

a. a harmonic generator adapted to be driven by signals of frequencies in the vicinity of NFs, where N is a number substantially greater than unity,

b. means for producing at least two drive signals of frequencies in the vicinity of NFs that differ in frequency by the desired line spacing Fs, and

c. means for applying said drive signals simultaneously to said harmonic generator.

6. The invention set forth in claim **5**, wherein said harmonic generator is a step recovery diode device, and said means for producing said drive signals comprises an oscillator of frequency Fs; an impulse generator driven by said oscillator, and band pass filter means designed to pass frequencies in the vicinity of NFs.

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