A PERIODIC SECOND HARMONIC SPATIAL POWER COMBINING OSCILLATOR

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ABSTRACT

A periodic second harmonic spatial power combining oscillator is designed and fabricated. This circuit does not require an external resonator. It is planar, and therefore it makes the design of monolithic circuits easier. In this work, four X-band Gunn diodes are used. The effective radiated power is 370 mW at 18.6 GHz. The isotropic conversion efficiency is 10.2%.

INTRODUCTION

At millimeter and sub-millimeter wave frequencies solid state devices have limited capability to produce microwave energy. At these frequency ranges the efficiency of solid state devices drops dramatically. In order to obtain higher powers, it is very desirable to combine the power generated from many single solid state oscillators [1]. There is always a limit to the frequency at which a solid state oscillator can operate. In that limit, the negative resistance of the device becomes so small that it can not compensate the resonator's loss. In this case power combining alone cannot help. One way to generate millimeter and sub-millimeter wave frequencies is to use two terminal solid-state devices as harmonic generators. Even though solid state devices do not exhibit negative resistance above a certain range of frequencies, because of device nonlinearities, higher harmonics are being generated. Through proper circuit design harmonic generation can be enhanced and then filtered out for use. One problem with this method is the low conversion efficiency. Here again we can take advantage of different power combining techniques. In general at millimeter wave frequencies spatial power combining techniques are preferred since guiding structures are lossy [2].

In this paper we present for the first time a periodic second harmonic spatial power combining structure. A periodic combining structure design for fundamental power is described in [3]. The present circuit takes advantage of the periodicity of the structure to determine the frequency of oscillation and consequently the frequency of the second harmonic. In this method phase locking is accomplished without using an external resonator such as a Fabry-Perot resonator [4, 5]. Therefore this circuit is planar and suitable for use in monolithic integrated circuits. Since the fundamental frequencies are phase locked to each other, and assuming that all the devices are similar, then the second harmonics generated should have the same phase. An antenna array can be designed to radiate only the desirable harmonic frequency.

CIRCUIT CONFIGURATION

A periodic second harmonic spatial power combining

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oscillator is shown in Fig. 1. A microstrip transmission line is loaded periodically with four Gunn diodes with a distance equal to approximately a half guide wavelength at the fundamental frequency of oscillation (f_1). At the second harmonic ($f_2 = 2f_1$) the periodicity of the structure will be equal to approximately a full wave length. Because this satisfies the leaky wave stopband condition, the broadside radiation will result. Also the structure is connected to four microstrip patch antennas to compose an antenna array. The distance between each array element is equal to the periodicity of the main structure. The patch antennas are resonant at the second harmonic (f_2) and therefore only the second harmonic can be efficiently radiated. Since the diodes are about a half wave length apart at the fundamental frequency, the radiated power from discontinuities at f_1 should have its null in the broad side direction, so the interference between the fundamental and the second harmonic is minimal.

DESIGN

In this experiment we used low power packaged Gunn diodes designed to operate at X-band. The first step is to determine the impedance that the negative resistance device should see at the fundamental and the second harmonic in order to generate maximum power at the second harmonic. A single microstrip Gunn diode oscillator is designed. A half-wave microstrip resonator is used to determine the fundamental frequency of oscillation. The circuit is connected to a spectrum analyzer through a triple stub tuner. By adjusting the stub tuner and trimming the microstrip circuit, the power generated at the second harmonic can be maximized. We then remove the Gunn diode from the circuit without introducing any other change to the circuit. A piece of semi-rigid coax can be connected to the circuit in place of the Gunn diode. The impedance of the circuit at the fundamental (Z_1) and at the second harmonic (Z_2) is measured using a network analyzer after transfering the plane of reference to the end of the coaxial cable. The impedances that are measured are those that should be seen by the Gunn diode in order to generate the maximum second harmonic at a particular frequency. The large signal impedance of the Gunn diode at the fundamental is $-Z_1$. Also since Z_2 is the impedance to which the Gunn diode delivers maximum power, the impedance of the diode at the second harmonic is equal to the complex conjugate of Z_2 . In our experiment the fundamental frequency at which the Gunn diode generated maximum second harmonic is 9.3 GHz. The impedances seen by the diode are $Z_1 = 5 + j35\ \Omega$ and $Z_2 = 20 + j3\ \Omega$. Since the impedance Z_1 is mostly reactive, power at the fundamental is not absorbed, and the interaction between the fundamental and the device nonlinearities is maximized. The maximum power obtained from a single Gunn diode oscillator at 18.6 GHz (f_2) was about 5.7 dBm.

In order to provide diodes the proper impedances (Z_1 and Z_2), the length and the impedance of the feed line to the antennas, the impedance of the main line, and slightly the periodicity of the structure are adjusted so that the impedance looking at each diode port is Z_1 and Z_2 at f_1 and f_2 respectively. Since the structure is periodic, after providing one of the diodes the correct impedances the others will also see the same Z_1 and Z_2. The circuit design was mainly done using the Touchstone microwave circuit analysis program. The patch antennas were designed based on the transmission line model for microstrip patch antennas [6].

EXPERIMENT

A four diode spatial power combining structure was designed and fabricated Fig 2. The antenna radiation pattern is shown in Figs. 3 and 4. The effective radiated power (ERP) was determined to be 370 mW. The isotropic conversion efficiency was 10.2%. The cross polarization was 17 dB below the peak power in the broad side direction. The power radiated at fundamental frequency was 15 db below the power at the second harmonic measured in the broad side direction.

In order to determine the power combining efficiency of this structure the following measurement was performed. The maximum power generated by a single diode oscillator (5.7 dBm) was injected to a single patch antenna. The effective radiated power was measured to be 22 mW. This shows that the ERP from the four diode harmonic combiner (370 mW) is about sixteen times the ERP of a single diode. The extra factor of four is due to the array factor.

CONCLUSION

A periodic second harmonic spatial power combining oscillator is presented. The oscillators are phase locked at the fundamental frequency. The power is combined in free space. This power combining method makes use of external resonator circuits unnecessary. The effective radiated power from a four diode second harmonic combiner is sixteen times the ERP of a single harmonic generator.

ACKNOWLEDGMENT

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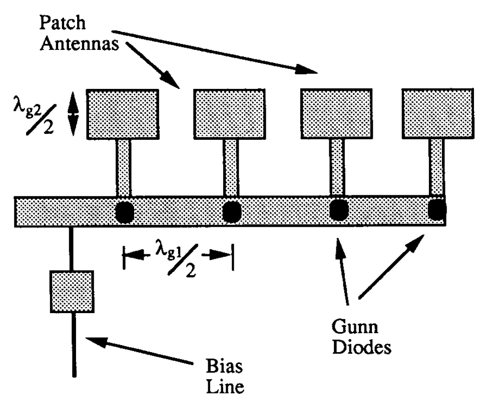

Fig. 1. Diagram of a four diode spatial second harmonic power combiner

λ_{g1} is the guided wavelength at foundametal frequency

λ_{g2} is the guided wavelength at foundametal frequency

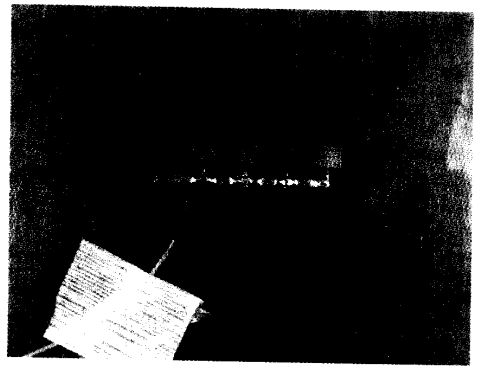

Fig. 2. Photograph of the four diode second harmonic power combining oscillator

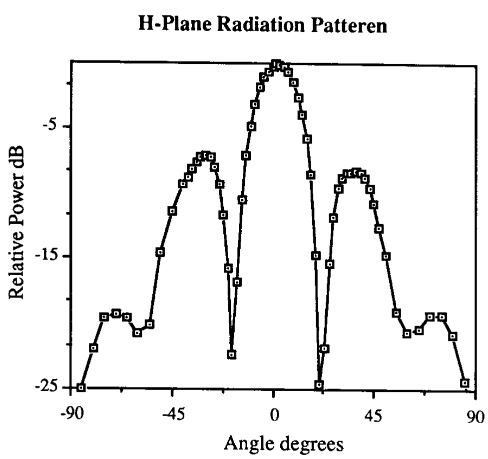

Fig. 3. The H-plane radiation pattern of the four diode harminic combiner

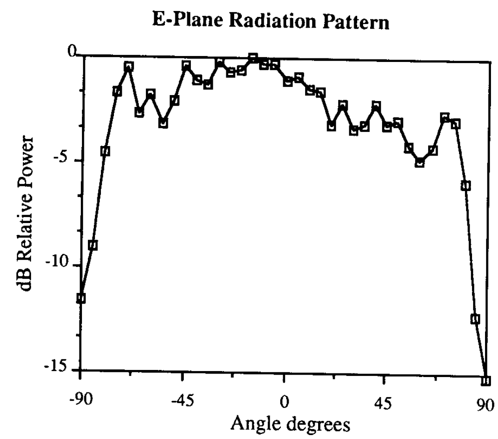

Fig. 4. The E-plane radiation pattern of the four diode harmonic combiner