FREQUENCY MULTIPLYING ACTIVE SLOT ARRAY

Natalino Camilleri and Tatsuo Itoh
Electrical Engineering Research Laboratory
The University of Texas at Austin
Austin, TX 78712

Abstract

A quasi-optical frequency multiplying slot array for high power microwave applications has been demonstrated. Single slot conversion loss of 2 dB at 8 GHz output has been measured. A 14-element multiplying array exhibited -14 dB sidelobe level at 8 GHz. The simple planar structure makes MMIC fabrication feasible.

1. Introduction

The frequency multiplying slot array presented here is a slot antenna, a frequency multiplier and a space combiner integrated into one component. This structure provides an alternative to a conventional solid state source or an in-waveguide frequency multiplier, particularly for quasi-optical applications. As the frequency is increased, a high power solid state source becomes difficult to obtain. A conventional multiplier has a limitation that the nonlinear element cannot handle more than a few hundred milliwatts. It is conceivable to power combine solid state sources or multipliers. However, it is exceedingly difficult to combine more than several units due both to mechanical and electrical restrictions.

The proposed structure (Fig. 1) alleviates the difficulties described above. It has the following features: (1) only one source is required, (2) no splitting feed network is used, (3) small size, (4) no post-fabrication tuning is necessary, (5) built-in space power combining and (6) possibility of planar integration.

Each slot in which a nonlinear element is installed is one-half free-space wavelength long and hence is resonant at the second harmonic frequency. These slots form a slot array for the second harmonic, thereby the harmonic power is combined in free space. The slots are distributed along a single feeding transmission line in which the fundamental is guided. Since the slots are electrically small (one-quarter free-space wavelength long) at the fundamental frequency, a relatively small fraction of power couples to each slot. This is an important feature, unlike conventional multipliers in which the maximum fundamental power is coupled to the diodes. This is because in the present structure we would like to feed as many diodes as possible so that the total (combined) power is increased. From the antenna point of view, this makes the output beam narrower, that is, the array has a higher gain.

2. Design

The fundamental can effectively be fed to the slots in a variety of ways.

Several types of transmission lines can be used for this purpose. A waveguide has been initially chosen as shown in Fig. 1 since it is by far the best transmission line available at millimeter waves. Microstrip transmission lines have also been worked out for planar integration.

An important consideration in the design of frequency multipliers is that the output needs to be isolated from the input. The second harmonic generated at the diode is resonant in the slot and radiates but should not couple back to the transmission line feeding in the fundamental. In the usual multiplier design a low pass filter [1] is used to prevent the second harmonic from going back to the transmission line feeding the fundamental. In the present structure the fundamental couples to the slot via the TE_{10} mode. The waveguide used has one half of the height of a conventional one such that at the second harmonic only the TE_{10} and the TE_{20} mode propagate. The positions of the slots is then chosen such that the slots do not couple to the TE_{20} mode. Coupling of the second harmonic to TE_{10} mode is inevitable. This coupling has been measured to be 15 dB down for the second harmonic while the coupling for the fundamental to the slot is about 10 dB down. These values have been measured by replacing the diode with a coaxial feed. As described in the Introduction the power coupling from the waveguide to the slot is relatively small so that many slots need to be excited for a good system efficiency. Matching of the nonlinear diode to the slot can be obtained by choosing an appropriate location on the slot.

Before multiplying slot arrays are built, the conversion loss of a slot with a diode is measured. In order to measure the conversion loss, a coaxial feed with a 5 GHz low pass filter has been used to reject the 8 GHz signal produced at the diode. This feed has been used to get an accurate measurement of the power coupled to the diode in the slot. For a doubler with 8 GHz output, 2 dB conversion loss has been obtained using NEC V138 varactor diodes operating at zero bias.

3. Multiplying Slot Array

Since the multiplying slot array is a phased array at the harmonic, the phase relationship of each antenna element at such a frequency needs to be taken into account in the design stage of the array.

In our design, the slots are placed $\lambda_g/4$ apart where λ_g is the guide wavelength at the fundamental. Since the multiplying diode elements act as square law devices, the slots are alternately out of phase by 180° at the second harmonic even though they are placed at 90° ($\lambda_g/4$) phase difference at the fundamental. If a single main beam is desired this 180° phase shift can be compensated for by placing the diodes alternately in opposite directions. In this way all the slots will be in phase at the second harmonic output.

This phase behavior can be best explained by Fig. 2, where two slots are placed $\lambda_g/4$ apart at the 4 GHz fundamental frequency. The pattern of Fig. 2a shows that the slots placed $\lambda_g/4$ apart are out of phase by 180° at the harmonic output while the pattern of Fig. 2b shows that they are in phase due to the phase change caused by reversing the polarity of one of the diodes. This additional phasing effect due to the square law behavior of the diodes makes it feasible to place the slots close to one-half of a wavelength apart at the radiating second harmonic frequency, thereby obtaining a single beam. From the power combiner point of view, this phasing effect increases the density of the multiplying elements, resulting in a more compact design for a given number of elements. The two nulls occurring in Fig. 2b at 50° are due to the fact that the slots are .65 of a wavelength apart at the radiating 8 GHz output.

Fig. 3 shows the results of a two-by-seven element array multiplying from 4 to 8 GHz. The slots are placed $\lambda_g/4$ apart at the fundamental (corresponding to .65 of the free-space wavelength at the radiating second harmonic) in the E-plane and one free-space wavelength apart in the H-plane direction. This array produced sidelobes in the E-plane that are 14 dB below the main lobe. The H-plane has a maple leaf shaped pattern due to the spacing of the slots. This slot spacing in the H-plane has been chosen so that the slots do not couple to the TE_{20} mode of the waveguide as described earlier. This particular slot array produced sidelobes less than -12 dB over 20 percent of the operating bandwidth.

4. Conclusions

A novel multiplying slot array with space combining capability has been demonstrated. The feasibility of adequate single element conversion efficiency and the use of high density slot elements has been successfully demonstrated. The simplicity of construction of such a device makes it useful at millimeter wave frequencies. The possibility of monolithic design is very feasible due to simplicity of the structure. Several beam shapes can be synthesized by using different diode polarities.

Acknowledgment

This work was supported by U. S. Army Research Office Contract DAAG29-84-K-0076.

References

1. P. Penfield and R. D. Rafuse, "Varactor Applications," MIT Press, Cambridge, MA (1962).

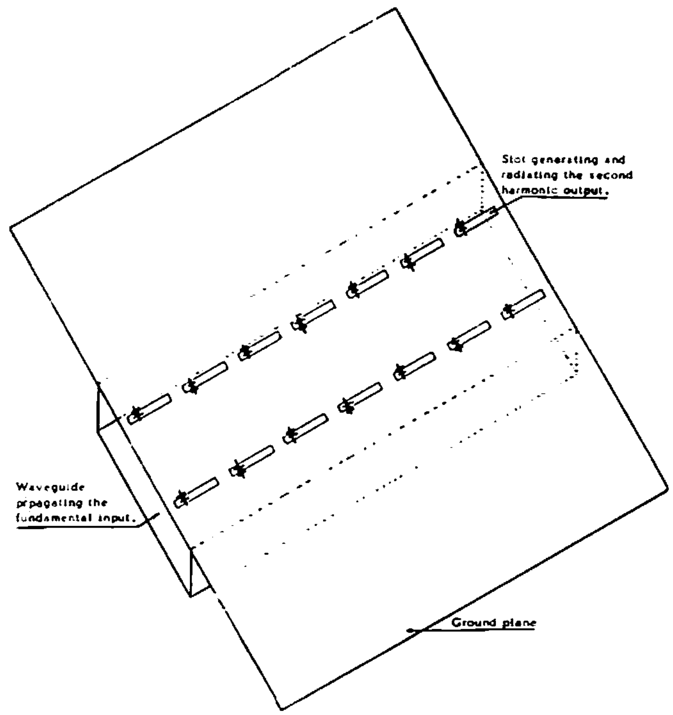

Fig.1. A two-by-seven frequency multiplying slot array fed by a waveguide.

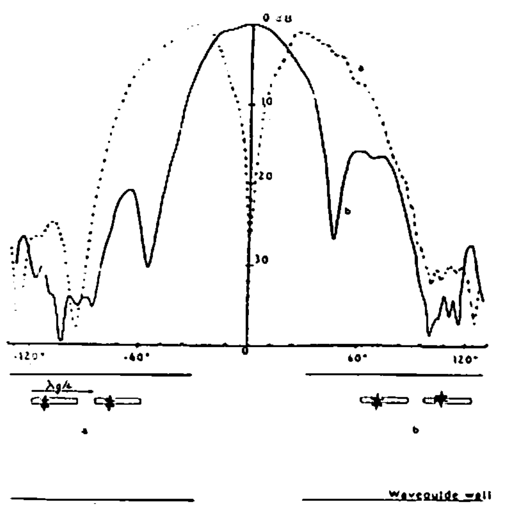

Fig.2. E-plane radiation patterns measured at 8 GHz for two slots placed $\lambda_g/4$ apart at the fundamental (4GHz). These plots are identical for slots that are fed 180° out of phase. The square law effect of the diode changes the 90° phase shift to 180°.

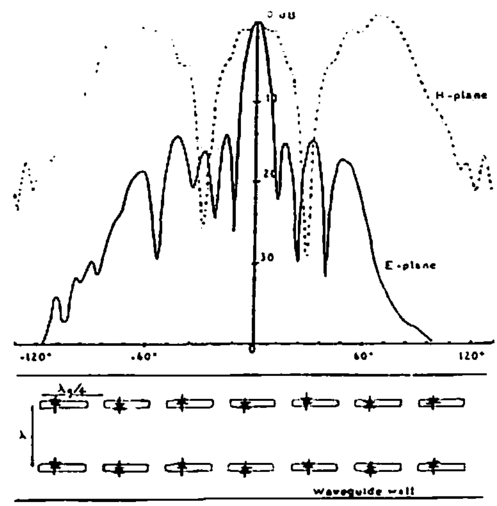

Fig.3. Radiation pattern measured at 8 GHz for a two-by-seven multiplying slot array. This active array converts the 4 GHz waveguide fed input to 8 GHz radiated output.