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Analysis and Measurement of a Millimeter-Wave Holographic Power Combiner for 5 IMPATT Oscillators

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Abstract

IMPATT diodes are the most powerful solid-state devices for millimeter-wave frequencies, but their power still has to be increased to compete with vacuum tubes. This can be accomplished by combining the power of an oscillator ensemble. In the millimeter-wave region, the most efficient method to perform power combing is holography. A 65 GHz holographic power combiner for five IMPATT oscillators has been designed and experimentally investigated utilizing quasi-optical multiple-device circuit technology.

1 Classical Methods of Power Combining

Power combining, i.e. summarizing the output power from many individual sources, is a necessary means if one likes to replace vacuum tubes by all-solid-state sources in the frequency ranges of submillimeter and millimeter waves. Eliminating tube sources from many systems is, on the other hand, often inevitable if space-borne and even air-borne applications shall be met because of their inherent disadvantages of great consequence : complicated bias supply, large size and weight, and in particular limited lifetime. Although power combining seems to be a mature concept for microwaves [1], it is accompanied by a great deal of conceptual and technical problems for millimeter waves [2]. This may be explained by considering the basic requirements for any power combining circuits. An ideal method of power combining should show the following features :

- sufficient spacing for appropriate heat sinking,
- combining efficiency independent of number of sources,
- combining efficiency approaching unity,
- negligible ohmic losses,
- arbitrarily large number of sources,
- individual sources with equal (i.e. maximally available) output power,
- uniform distribution of coupling for stable mutual synchronisation,
- unlimited scalability with frequency,
- broad bandwidth performance,
- graceful degradation with respect to failure of single devices,
- low sensitivity to geometrical parameters,
- flexibility and robustness.

All hitherto known principles of power combining do not meet even one of these requirements if the frequency exceeds about 60 GHz whereas holographic power combining which is developed at our institute will fulfill all of them.

The classical methods of power combining encompass the Kurokawa circuit, ladder networks, spatial power combining [3], grid amplification, and resonant quasi-optical power combining [4]. They all suffer from undesired miniaturization with increasing frequency which limits their performance drastically. Hence one will not find any successful experimental solutions to the problem at frequencies above say 60 GHz.

In summary, there did not exist till now any principle for millimeter (or even submillimeter) wave power combining showing more than one or two of the desired twelve features which have been listed before. Moreover, the features these principles could meet have only been reached as a first approximation. Hence one can state that the problem of millimeter wave power combining is yet unsolved. Naturally, the same statement also holds for the inverse problem of power splitting which is inherent in the realization of multiple device frequency multipliers and of down-converters for both focal plane arrays and subharmonic pumping.

2 Holographic Power Combining

Fig. 1 shows a typical source of Gaussian beams. It involves a horn antenna as beam launcher and a (solid–state) source of millimeter waves. As has been emphasized, a millimeter–wave source has normally a large electrical dimension. This also holds for an effective beam launcher, i.e. the diameter of the horn is a relatively large multiple of a wavelength.

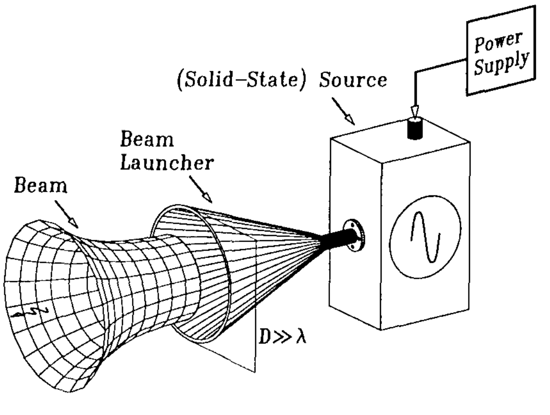

Figure 1: A millimeter–wave source along with a beam launcher

Trying to spatially combine the power output by a group of these Gaussian beam generators, we arrange a linear array of them. In regard to their dimensions and according to the theory of antenna arrays, the radiation pattern of such array contains a few grating lobes, as can be recognized from the contour plot of Fig. 2.

The reason why only a few number of grating lobes has a significant power level is the highly directive radiation of each array element, i.e. of the beam launchers. Hence the aim should be to suppress the grating lobes and deflect their power in the boresight direction.

One could explain the formation of the grating lobes by a phase deviation in the radiated wavefront as compared with a plane or a well–collimated wave. Keeping this fact in mind, one should propose

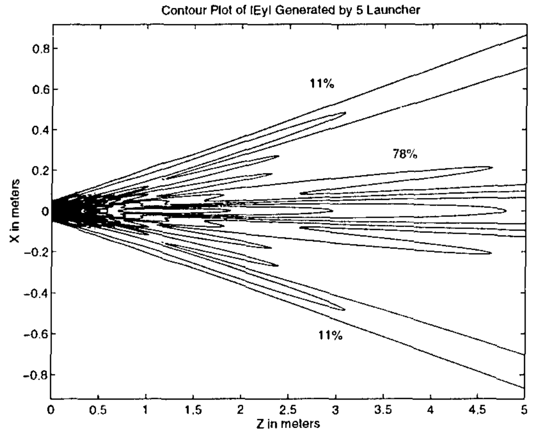

Figure 2: Radiated field by a 5–element antenna array with an inter–element spacing of 30 mm. The antennas radiate at 65 GHz.

a scheme for phase front transformation in order to eliminate the undesired grating lobes. Holography offers an appropriate solution.

It is well known that in holography for a complete reconstruction of a wave scattered by an object, i.e. the object wave, its interference with a reference wave, usually a plane wave, is recorded in a hologram. Recording can be performed by changing the local electrical characteristics of the hologram in accordance with the interference pattern. Illumination of the hologram with the same reference wave makes the reconstruction of the object wave possible.

This principle is remarkable for any type of wavefront transformation like that we are looking for. In other words, to eliminate the grating lobes, we should record the interference of the wavefront generated by the array with a plane wave. Hence illumination of the hologram with the array produces the reference plane wave which must carry the combined power. For instance, using an optimization approach, we designed a hologram for suppression of grating lobes appearing in the radiation pattern of a five–element antenna array. Fig. 3 depicts the impact of this computer–generated hologram on the radiation intensity of the array. The hologram used in this simulation is made of dielectric and has a very simple groove shape.

It can be seen that the hologram reduces the grating lobes and directs their power in the desired direction. The obtained efficiency in this process, i.e. the ratio of the total power carried by the main lobe to the total radiated power by the array, is 97%.

Fig. 4 illustrates a holographic power combiner. It is evident that this power combining approach is appli-

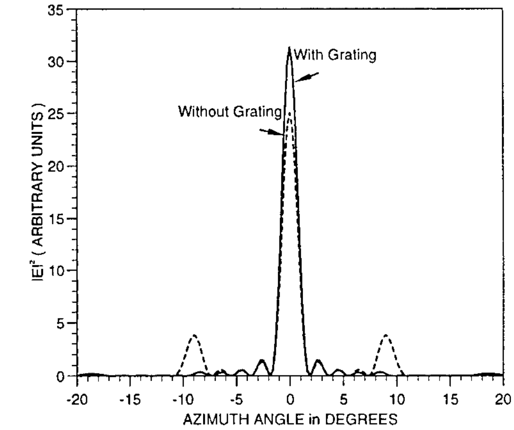

Figure 3: Reduction of the grating lobes with a hologram. The array has the same characteristics as that in Fig. 2.

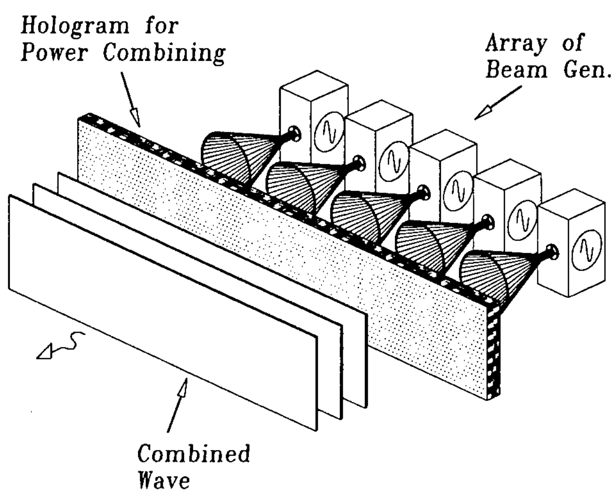

Figure 4: A holographic power combiner

cable to an arbitrary number of identical sources, and may be scaled up to extremely high frequencies. Furthermore, an optimized design of the hologram simplifies the process of mutual synchronization between the sources by a low–power reflection from the hologram, which is particularly relevant for any nonresonant power combining method. More details on this subject can be found in [5].

In order to design the holographic power combiner, one needs a powerful (i.e. a numerically efficient but still rigorous) tool. This has recently been developed in form of a model of (coupled) transmission lines [6]. Its numerical evaluation has proved that all features of ideal power combining stated above are really obtained by a holographic combiner. Hence the experimental demonstration is the only task which must still be done. It is the topic of our present work.

3 Results for a 65 GHz 1-D Holographic Combiner

We have chosen a 1-D array of 5 IMPATT oscillators operating at 65 GHz as a first example. Each diode delivered more than 100 mW of output power. In the oral presentation, we will report about the design of both the oscillator array and the combining hologram, describe its optimization, and discuss the practical problems which had to be solved. The most important and difficult of them is to perform mutual phase synchronization so that all single sources are oscillating in the in-phase mode. To this end, a partially reflecting dielectric plate of approximately half of a wavelength thickness has been located at the output side of the hologram. First experimental results show an overall combining efficiency of 84% while the theoretical limit is 97%.

References

[1] K. J. Russell, "Microwave Power Combining Techniques," *IEEE Trans. Microw. Theo. Tech.*, vol. MTT–27, pp. 472–478, May 1979.

[2] K. Chang, C. Sun, "Millimeter–Wave Power–Combining Techniques," *IEEE Trans. Microw. Theo. Tech.*, vol. MTT–31, pp. 91–107, Feb. 1983.

[3] R. A. York, R. C. Compton, "Quasi–Optical Power Combining using Mutually Synchronized Oscillator Arrays," *IEEE Trans. Microw. Theo. Tech.*, vol. MTT–39, pp. 1000–1009, June 1991.

[4] J. W. Mink, "Quasi–Optical Power Combining of Solid–State Millimeter–Wave Sources," *IEEE Trans. Microw. Theo. Tech.*, vol. MTT–34, pp. 273–279, Feb. 1986.

[5] M. Shahabadi, K. Schünemann, "Holographic power combining: A new principle for millimeter and submillimeter-wave power combining", in *Proc. 26th European Microwave Conf.*, Prague, Czech Republic, Sept. 1996, pp. 115-119.

[6] M. Shahabadi, K. Schünemann, "Millimeter-wave holographic power splitting/combining," *IEEE Trans. Microw. Theo. Tech.*, vol. MTT–45, pp. 2316–2323, 1997.