QUASI-OPTICAL CIRCUIT APPLICATIONS OF GaAs DEVICES

Invited Paper

Tatsuo Itoh*

ABSTRACT

This paper will summarize some of the recent developments in the applications of GaAs based devices in planar quasi-optical integrated circuits. After a short review of quasi-optical mixers, more recent efforts on increasing the catalog of components made of quasi-optical planar technology are presented.

INTRODUCTION

In recent years, advances of GaAs based devices have accelerated significantly. A number of advanced devices have been proposed, tested and eventually used in integrated circuits. As the operating frequency and system complexities increase, these components must be placed in a simpler but more efficient circuit environment. The quasi-optical planar integrated circuits provide an answer to these problems. Essentially, in these configurations, the planar antenna on the substrate becomes an integral part of the entire integrated circuit component or subsytem. The antenna now performs several functions. This property generates several benefits. First, the interconnection between the antenna and the device is eliminated, resulting in reduction of the insertion loss. Second, the overall circuit structure becomes simpler.

The first application of the quasi-optical planar structure was the mixers, particularly those at frequencies exceeding 100 GHz. However, the concept is not limited to the mixers. In fact, most of the recent effort is directed toward developing other "active" planar quasi-optical components, such as oscillator and power combiners as presented below. In additon, the applications of the planar quasi-optical components are not limited to extremely high frequencies. Simplicity of the circuit configuration often provides an opportunity for low cost applications at relative low frequencies.

QUASI-OPTICAL MIXERS

Some of the earlier works on planar quasi-optical mixers are represented by the one by Kerr, et al. [1] and Clifton, et al.[2]. Both of them makes use of the slot antenna while the latter is a GaAs monolithic construction. Since the quasi-optical scheme can take advantage of the polarization of the incoming beam, the polarization duplexing mechanism was implemented for balanced mixer operation [3].

As the frequency of operation is increased, direct supply of fundamental LO becomes increasingly more difficult and more expensive. A subharmonically pumped mixer provides a possible solution. By taking advantage of the broadband nature of the bowtie antenna, a subharmonically pumped quasi-optical mixer was constructed and its broadband characterisitcs were proven [4].

Because quasi-optical mixers can be made compact and are potentially low cost, they may be an excellent candidate for imaging array. This array may be illuminated by a single LO source. An example is a bowtie array feeding Schottky-barrier diodes integrated on a GaAs substrate. [5]

FREQUENCY MULTIPLIER

An effort to provide a coherent quasi-optical source is to make use of the concept of the frequency multiplier made of a planar array of nonlinear devices. The array will emit a second harmonic of the incoming fundamental. One way to supply the fundamental is to use a plane wave illumination of the array. One example of this method is a wire grid design on a GaAs substrate. [6] Another way to

---

*Department of Electrical and Computer Engineering, The University of Texas, Austin, Texas 78712, USA.

supply the fundamental is the use of a guided wave to feed the diodes. An example is the array of slots loaded with diodes and fed by a microstrip line. [7]

OSCILLATOR AND POWER COMBINER

Development of quasi-optical oscillators is closely related to the spatial power combining technique. A milestone work on this topic is the use of a Fabry-Perot cavity to provide a high Q environment for 21 IMPATT diodes to oscillate in a power-combined fashion. [8] A similar idea was tested by the use of 25 transistors for an X band application. [9] The effect of the Fabry-Perot cavity for Gunn diode oscillator/combiner was investigated by Stephan. [10]

GaAs IMPATT diodes were monolithically integrated with a microstrip resonator and a loop antenna. [11] The chip was mounted on a waveguide wall to form a power combining array.

The problem of frequency stabilization can be resolved by the use of a leaky wave antenna. When a periodic structure is operated with the frequency at which one guide wavelength is equal to one period of the structure, the leaky wave stopband is encountered. This stopband provides a high input VSWR and hence the structure provides a frequency selective feedback to an active device. This concept was realized with an MESFET [12] as an oscillator. With the coupled periodic structure, a balanced oscillator and a frequency doubling oscillator made of two MESFETs were realized. [13]

PLANAR INTEGRATED QUASI-OPTICAL RECEIVER AND TRANSCEIVER

The quasi-optical leaky-wave oscillator [13] can be used as a self-oscillating mixer. Therefore, this structure can be used as a transceiver or a Doppler motion detector. On the other hand, the even and odd modes in a coupled slot was used for development of a simple quasi-optical receiver. [14] The coupled slot mode is used for receiving the incoming RF signal from free space while the coplanar waveguide mode is used as a part of the local oscillator circuit which consists of either a Gunn diode or a GaAs MESFET integrated on the same substrate of the coupled slot. Two Shottky diodes are implemented in the coupled slot so that the resultant mixing operation is a balanced one. The IF output was taken out by a microstrip line on the other side of the substrate.

The diplexing function of the coupled slot was used for development of a quasi-optical self-oscillating mixer.[15] Instead of two mixer diodes, two MESFETs or HEMTs are placed in the coupled slot. The resultant local oscillator is in a balanced mode of operation so that the two devices are gate-coupled to produce the LO power in the odd mode. The incoming RF signal is captured by the coupled slot and coupled to the coupled slot mode. The circuit is extremely simple and yet provides an (isotropic) conversion gain and reasonable noise performance.

CONCLUSIONS

Recent advances in the planar quasi-optical applications of GaAs structures were briefly reviewed. Readers interested in more details may refer to the recent review article on the same subject by the author. [16] Although many works are still in the laboratory stage, there are a number of areas which would enjoy the benefit of planar quasi-optical configurations. Most of the applications will be in the high frequency range such as the millimeter-wave region. However, the inherent simplicity of the configuration may find usefulness for applications even at lower microwave frequencies if low cost manufacturing is desired.

ACKNOWLEDGMENTS

This work was supported by the U. S. Army Research Office under Contract DAAL03-88-K-0005, the Joint Services Electronics Program through the Air Force Office of Scientific Research Contract F49620-89-C-0044 and the Texas Advaced Technology Program.

REFERENCES

[1] A. R. Kerr, P. H. Siegel and R. J. Mattauch, "A simple quasi-optical mixer for 100-120 GHz," 1977 IEEE MTT-S International Microwave Symposium, June 1977, San Diego, CA, pp.96-98.

[2] B. J. Clifton, G. D. Alley, R. A. Murphy and I. H. Mrockowski, "High-performance quasi-optical GaAs monolithic mixer at 110 GHz," IEEE Trans. Electron Devices, Vol. ED-28, No.2, pp.151-157, February 1981.

[3] K. D. Stephan, N. Camilleri and T. Itoh, "A quasi-optical polarization-duplexed balanced mixer for millimter-wave applications," IEEE Trans. Microwave Theory and Tech., Vol.MTT-31, No.2, pp.164-170, February 1983.

[4] K. D. Stephan and T. Itoh, "A planar quasi-optical subharmonically pumped mixer characterized by isotropic conversion loss," IEEE Trans. Microwave Theory and Tech., Vol. MTT-32, No.1, pp.97-102, January 1984.

[5] D. B. Rutledge, Private Communication.

[6] C. F. Jou, W. W. Lam, D. B. Rutledge and N. C. Luhman, Jr., "Watt-level monolithic quasi-optical diode frequency multiplier grid," Tenth International Conference on Infrared and Millimeter Waves, December 1985, Lake Buena Vista, FL, pp.56-57.

[7] S. Nam, T. Uwano and T. Itoh, "Microstrip-fed planar frequency-multiplying space combiner," IEEE Trans. Microwave Theory and Tech., Vol. MTT-35, No.12, pp.1271-1276, December 1987.

[8] J. W. Mink, " Power combining of solid state millimeter wave sources," Tenth International Conference on Infrared and Millimeter Waves, December 1985, Lake Buena Vista, FL., pp.52-53.

[9] D. B. Rutledge, Z. B. Popovic and M. Kim: "Millimeter wave grid oscillators," Thirteenth International Conference on Infrared and Millimeter Waves, December 1988, Honolulu, Hawaii, pp.1-2.

[10] K. D. Stephan and S.-L. Young, "Mode stability of radiation-coupled interinjection-locked oscillators for integrated phased array," IEEE Trans. Microwave Theory and Tech., Vol.36, No.5, pp.921-924, May 1988.

[11] N. Camilleri and B. Bayraktaroglu: "Monolithic millimeter-wave IMPATT osicllator and active antenna," IEEE Trans. Microwave Theory and Tech., Vol.36, No.12, pp.1670-1676, December 1988.

[12] J. Birkeland and T. Itoh, "Planar FET oscillators using periodic microstrip patch," IEEE Trans. Microwave Theory and Tech., Vo.37, No.8, pp. 1232-1236, August 1989.

[13] J. Birkeland and T. Itoh, "FET-based planar circuits for quasi-optical sources and transceivers, "IEEE Trans. Microwave Theory and Tech., Vol.37, No.9, pp. 1452- 1459, September 1989.

[14] V. D. Hwang, T. Uwano and T. Itoh, "Quasi-optical integrated antenna and receiver front end," IEEE Trans. Microwave Theory and Tech., Vol. 36, No.1, pp.80-85, January 1988.

[15] V. D. Hwang and T. Itoh, "Quasi-optical HEMT and MESFET self-oscillating mixers," IEEE Trans. Microwave Theory and Techniques, Vol. 36, No.12, pp.1701-1705, December 1988.

[16] T. Itoh, "Recent progress of quasi-optical integrated microwave and millimeter wave circuits and components," Alta Frequenza, July 1989.