Power Combining of Ku-band Active Dipoles in a Cylindrical Resonant Cavity

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ABSTRACT

This paper presents a Ku-band source with a new simple technique to combine the output powers of individual HEMT oscillators using half-wave dipole antennas and a cylindrical resonant cavity. The structure of the source should have potential also for millimeter-wave power combining.

INTRODUCTION

Recent technological advances have made it possible to generate millimeter-wave power using three terminal devices such as the high electron mobility transistor (HEMT). Solid-state devices outperform earlier tubes by orders of magnitude in reliability, weight, and size. Many power combining techniques [1] have been developed to evade the inherent problem of low output power of a single solid-state device. Lately, particularly quasi-optical power combining [2] has received much attention.

In 1973, Harp and Stover [3] and, in 1980, Dydyk [4] reported cylindrical TM-mode resonant cavity power combiners that used IMPATT diodes. This paper presents a new simple technique where the power of a number of three-terminal devices can be combined in phase using half-wave dipole antennas [5] and a low loss TE-mode cylindrical resonant cavity.

ACTIVE DIPOLE

The active dipole consists of an AlGaAs HEMT and a half-wave dipole antenna (Fig. 1). A packaged, commercially available HEMT (NE20283A) is mounted upside down on a large metal plate. The gate and drain leads of the package which project into air, parallel to the metal plate, have been cut to be quarter-wave long. Thus, the half-wave dipole is actually made up of the package itself. Both source leads have been bent down and are grounded to the underlying metal plate.

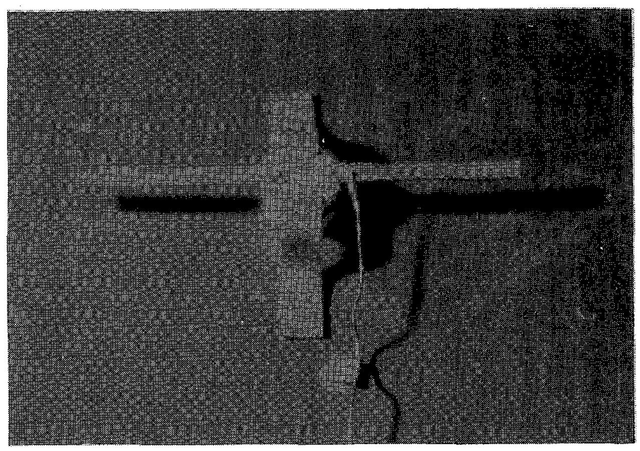

Fig. 1. A packaged HEMT as an active dipole.

The antenna structure is equivalent to a microstrip dipole where the dielectric constant is unity.

It is hardly possible to place the active and radiating elements closer together, than in this case, unless monolithic technology is used. Thus, losses are minimized and the structure is very simple and compact.

Only the drain of the HEMT is biased from outside circuitry. The gate becomes self-biased to a floating negative voltage. This is due to the rectifying effect of the gate Schottky diode as the oscillation builds up.

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The fact that the gate is practically open circuited at all frequencies (well) below the operating frequency, is essential for stability against unwanted low frequency oscillations. Consequently, the circuit needs no resistors, by-pass capacitors, or other components in the biasing circuit for stabilization against low frequency spurious oscillations. Besides the HEMT, the only additional component needed to make the packaged HEMT a self-radiating oscillator is a single layer capacitor (about 0.3 nF) which is used for RF-grounding the bias wire.

The oscillation frequency can be estimated by a well-known linear analysis where the active device (HEMT) impedance and the resonator (microstrip dipole) impedance are compared at a common reference plane [6]. The relevant impedances for the analysis are the drain-to-gate impedance of the HEMT and the balanced input impedance of the microstrip dipole antenna.

The drain-to-gate impedance of the HEMT was calculated using the small signal common source S-parameter file that is available in the data sheets of the device. A circuit simulation software that includes a center-tapped transformer element conveniently performs the task. A circuit model of the active antenna is shown in Fig. 2.

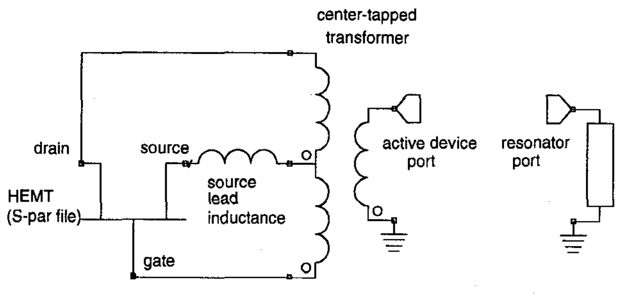

Fig. 2. Oscillator model for Libra (bias circuit omitted).

The center-tapped transformer with 1:1 turns ratio balances the input voltage so that equal portions of it are applied on gate and drain sides with respect to the source lead potential. A source lead inductance was also included in the model.

On the other hand, the input impedance of the microstrip dipole antenna (Fig. 3), when radiating into an open half-space, was calculated using a PC program using the Mixed Potential Integral Equation method [7].

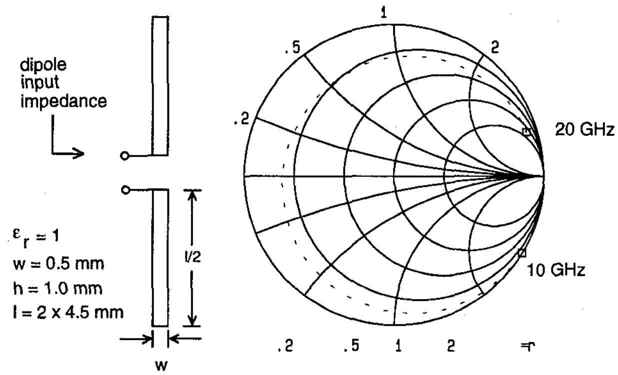

Fig. 3. Input impedance of the microstrip dipole antenna on Smith chart calculated using the method described in Reference [7].

The predicted oscillation frequency was 15 GHz.

A single active dipole was constructed and tested [5]. The oscillation frequency could be tuned from 14.4 to 14.6 GHz while the drain bias was adjusted from 1 to 4 V. Maximum DC-to-RF efficiency was 24% while the drain current was 6.7 mA.

POWER COMBINING

In order to achieve more power, a single frequency operation, and to have a connectorized oscillator structure a power combining scheme for the active dipoles was developed.

Four active dipoles were constructed on a circular plate. The plate was mounted in a cylindrical resonant cavity forming the other end of the cylinder (Fig. 4). Another metal plate formed the other end. Both end plates of the cylinder had threads and thus the length of the cavity was adjustable by rotating the plates.

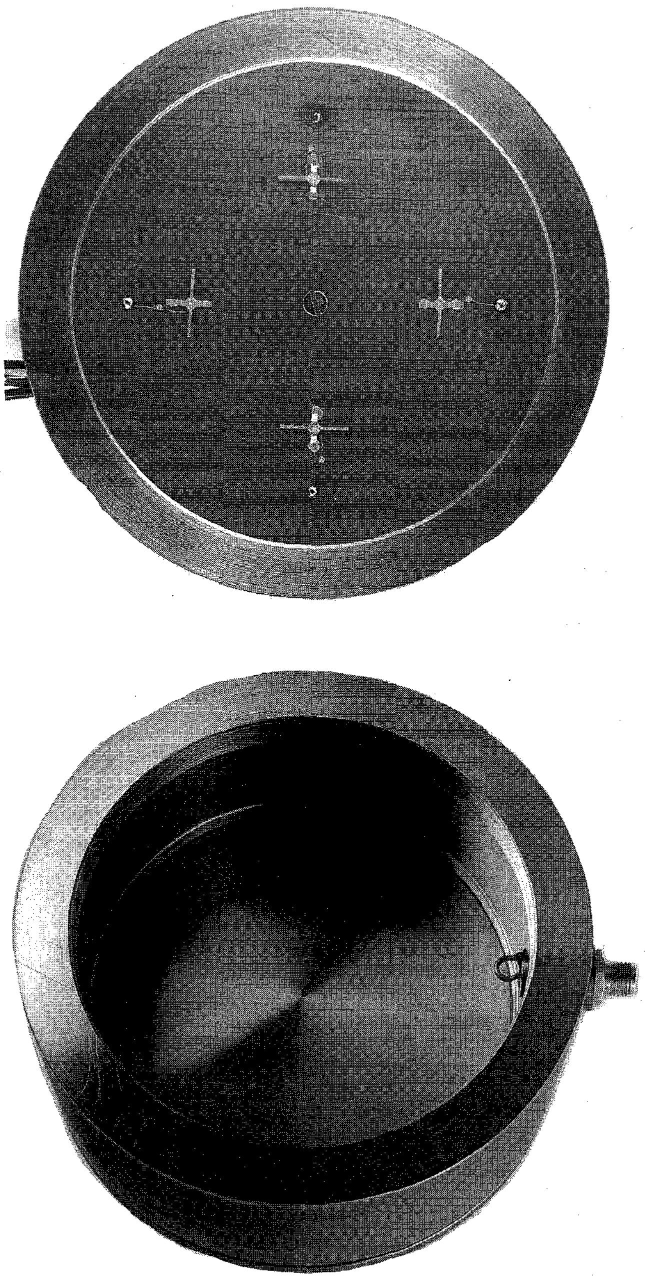

Fig. 4. Active dipoles mounted on the end wall (top) of a cylindrical resonant cavity (bottom).

The power was coupled out via a horizontal magnetic loop at the cylinder wall. The dimensions of the loop, that was soldered to a Suhner SMA-connector, were by no means optimized. The diameter of the loop was 5 mm. The inside diameter of the cylinder was 79 mm and the inside height could be adjusted between 23 mm and 35 mm.

At certain lengths of the cavity the four active dipole oscillators could be mutually injection locked and single frequency operation was achieved. The intended resonant mode was TE_{013}, which has low loss when the cavity is large. The resonant frequency of the TE_{013} mode can be calculated from [8]

$$f_{TE013} = \frac{1}{D}\sqrt{\frac{(cu)^2}{\pi^2} + \frac{9(cD)^2}{4L^2}}$$

where D is the cavity diameter, c is speed of light, u is the first root of Bessel function $J'_0(u) = 0$, and L is the length of the cavity.

The output power spectrum is shown in Fig. 5. The spectrum showing just one frequency is stable and free of spurious oscillations. The output power was +4.7 dBm at 13.9 GHz with DC-to-RF efficiency of 10%.

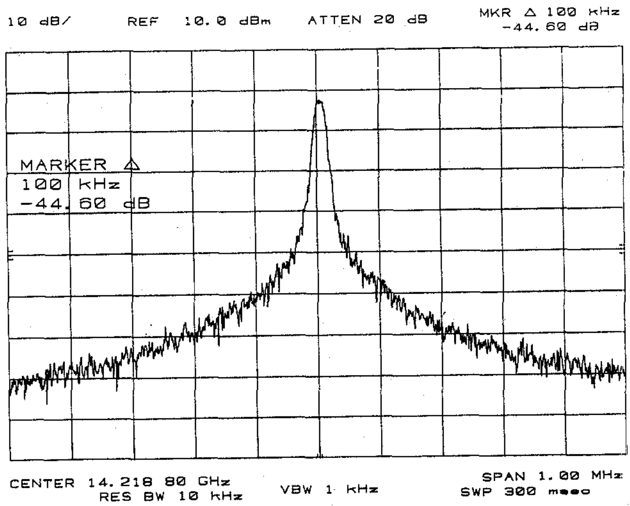

Fig. 5. Output power spectrum of the Ku-band source.

The calculated resonator length L for the TE_{013} mode at this frequency is 34.3 mm and the actual length was 32.4 mm. The maximum output power of +10.8 dBm was measured at 14.3 GHz with 8.2% efficiency. The oscillation frequency could be tuned either by rotating the end-plates or by adjusting bias.

It can be expected that the phase noise of the source could be reduced by optimizing the coupling loop or by optimizing the coupling from the dipoles to the cavity.

Active microstrip dipole antennas were constructed and tested also using CuClad substrate material and Fujitsu FHX-06-LG HEMT's. The circuit layout is shown in Fig. 6. The substrate height was 1.6 mm and the dielectric constant was 2.5. Low dielectric constant was selected for radiation efficiency and low surface wave excitation. The bias circuit was further simplified to consists of only two microstrip elements: a high-impedance quarter-wave transmission line and a low-impedance open stub. No auxiliary discrete components were needed. This structure showed slightly lower efficiency but behaved otherwise as the air-dielectric version described above.

Finally, we integrated eight active microstrip dipole antennas on a single substrate and mounted the structure into the cavity described above. Again single frequency operation was achieved at certain lengths of the cavity.

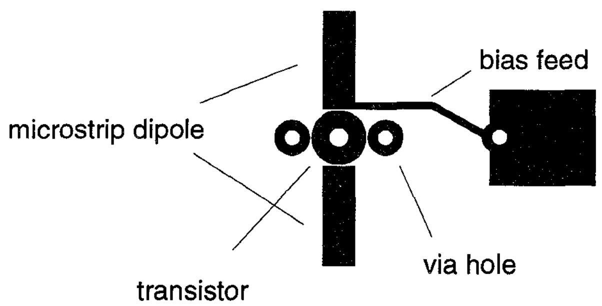

Fig. 6. Layout of the active microstrip dipole.

CONCLUSIONS

This paper presented design and linear analysis of a Ku-band source with a new simple technique to combine the output powers of four (or more) individual HEMT oscillators using half-wave dipole antennas and a cylindrical resonant cavity. The measured output power was +4.7 dBm with DC-to-RF efficiency of 10%. The structure of the source should have potential also for millimeter-wave power combining.

ACKNOWLEDGMENT

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