Spatial Power Combining using Push-Pull FET Oscillators with Microstrip Patch Resonators

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Abstract

We describe the design and performance of spatial power combining arrays of FET oscillators. The individual oscillators consist of single microstrip patches driven by two FETs oscillating in the push-pull mode. Arrays formed from these elements show nearly perfect power combination in prototype modules operating at 6 GHz. Maximum ERP for a 4 patch array combining the power of 8 FETs is 32.8 dBm. Results for an oscillator using four FETs combining in a single patch are also discussed.

Introduction

Arrays of synchronized radiating oscillators have received attention for their applications to spatial power combining [1-3] and active antennas [4,5]. Spatial power combining finds applications at frequencies where high output powers are not acheivable using single devices.

In this report, we describe a new approach to the spatial combining of powers from many active devices. In our approach, the first level of power combination occurs at the elemental level of the array, where we synchronize the oscillations of two devices using a single patch resonator/antenna. The same approach is also demonstrated for the case where four devices are synchronized using a single patch.

These patch oscillators are then combined to form an injection locked array. The injection locking between the elements is accomplished using radiation coupling between the microstrip patches, and does not rely on the use of additional reflectors or Fabry-Perot elements.

The use of GaAs MESFETs as active elements is attractive for several reasons. FETs generally have higher conversion efficiencies than competing devices such as Gunn or IMPATT diodes, and FET MMIC technology is relatively mature. In addition, the gate terminal on the FET alows the control of unwanted modes of oscillation in the multi-device structures.

Prototype versions of the circuits described here which operate at 6 GHz were constructed using packaged FETs. (The choice of the prototype operating frequency was determined by the size of the circuits, the larger circuits being much easier to fabricate using packaged devices.) The arrays showed nearly ideal power combination.

Design

A schematic view of one of the patch oscillator elements is shown in Figure 1. The circuit consists of a multi-port microstrip patch antenna connected to the active devices, with additional mode damping resistors added to control unwanted oscillations. The patch acts as the resonant element for the oscillator circuit as well as the radiating element.

Since the FETs are relatively broad band negative resistance devices in this configuration, it is necessary to accurately model the input impedance of the patch elements over a very broad range of frequencies. The improved cavity model of Richards, et. al., [6] was found to be adequate for this purpose. For the two device circuit, the even and odd input impedances were calculated by including only the even or odd modes in the field expansions for the patch. For the patch shown in Figure 1, the radiating (1,0) mode corresponds to an odd excitation, requiring that the FETs oscillate in push-pull.

The conditions for oscillation of a negative resistance device connected to a resonator have been discussed by Kurokawa [7]. For the multiple device case, we may generalize these results by examining the eigennetworks associated with the orthogonal excitations of the resonator. For example, for the two device oscillator shown in Figure 1, we must examine the even and odd mode circuits created by alternatively placing open and short circuits along the axis of symmetry. We then adjust the circuit so that the oscillation condition is satisfied only in the desired mode and frequency. This same approach may be applied to a single patch, four device oscillator; results for such a circuit are reported at the end of this paper.

The individual patch oscillators are combined to form an array as shown in Figure 2. The patches are coupled by the radiated fields. The distance beteween the individual patches controls the magnitude and phase of the injection locking signals between the oscillators as well as the radiation pattern of the array. If the oscillators are too closely spaced, overcoupling occurs, and the locking is unstable; if spaced too far apart the coupling is weak and locking does not occur. It was found that a spacing of approximately $3\lambda_0/4$ was adequate to insure injection locking and an acceptable radiation pattern.

Prototype Circuits and Results

The circuits were fabricated on 32 mil thick substrate with er = 2.55, using Harris HMF314 and NEC 71083 packaged FETs.

The patch antennas were designed for a resonance frequency of 6.1 GHz; the oscillators were designed to operate below resonance at 6.0 GHz to match the FETs.

Radiation patterns for the single patch with two FETs are shown in Figure 3. The cross-polarized maximum in the E and H planes was 18 dB below the main lobe, indicating the well balanced oscillation of the FETs.

Radiation patterns for 2, 3 and 4 patch arrays constructed using dual FET oscillators are shown in Figures 4-6. Due to the variation between the individual FETs used in the circuits, the circuits were tuned using V_{DS} to acheive injection locking.

For synchronous power combining of radiating elements, we expect the effective radiated power (ERP) to increase with the square of the number of elements. Table 1 shows that the combining efficiencies are near 100% for each of the arrays tested. (Values in excess of 100% are likely due to interactions between the elements.) Isotropic conversion gain, G_{iso}^{T} may be defined as the ratio of effective radiated power to dc input power [8]. For the four element array we acheive G_{iso}^{T} of 6.3 dB, at an ERP of 31.7 dBm, while at an ERP of 32.8 dBm we have G_{iso}^{T} = 2.7 dB. A photograph of this array is shown in Figure 7.

A schematic view of the single patch, four FET oscillator is shown in Figure 8. This circuit was constructed and tested, and stable oscillation was noted. This circuit demonstrated an ERP of 22 dBm, with a G_{iso}^{T} of -8 dB.

Conclusions

The arrays described here provide a stable method for combining the powers of several FETs in free space. By combining active devices at the patch level before integration into the array, we are able to double or quadruple the output of a given number of patches. The combining scheme shows excellent power combining, does not require the use of an external cavity, and is applicable to large numbers of devices.

Acknowledgements

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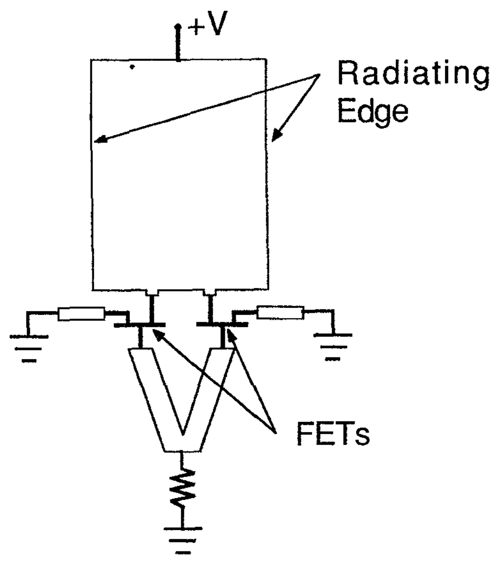

Figure 1. The push-pull oscillator

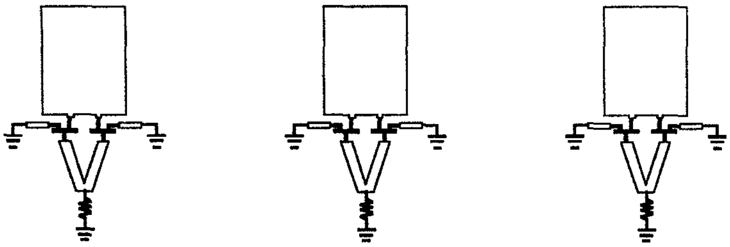

Figure 2. Power combining array.

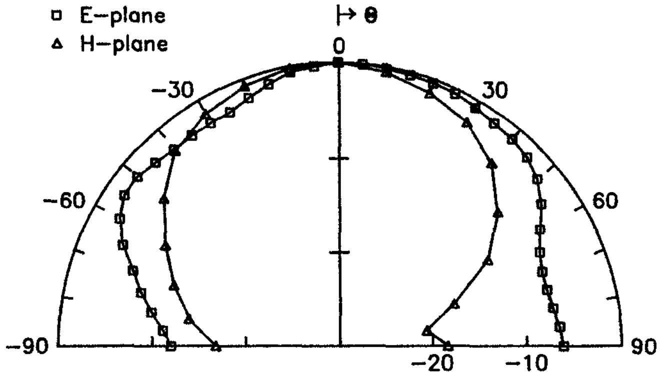

Figure 3. Radiation patterns for single push–pull oscillator.

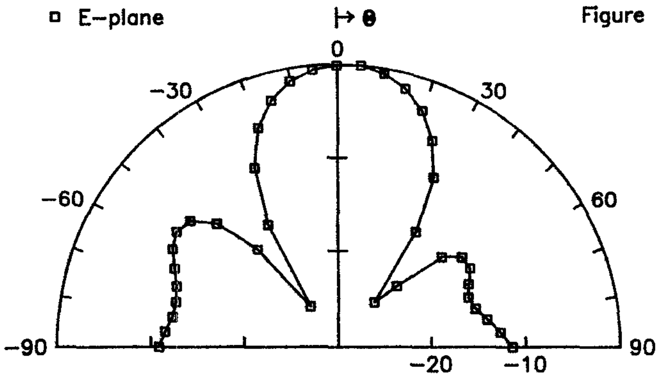

Figure 4. Radiation pattern for two element array.

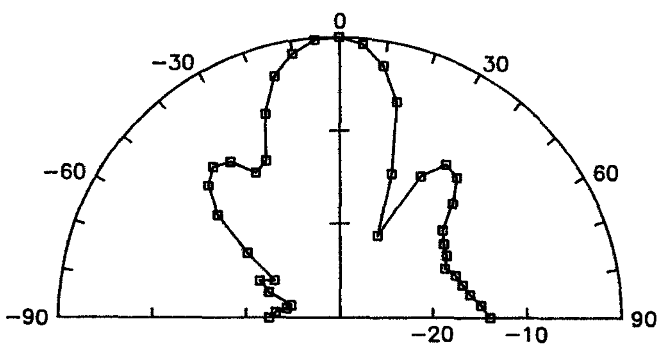

Figure 5. Radiation pattern for 3 element array.

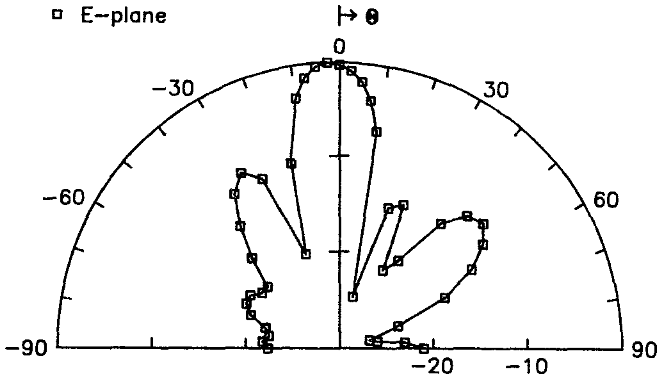

Figure 6. Radiation pattern for four element array.

Array	Individual Oscillator ERPs	Total ERP	Combining Efficiency
2 Patch - 4 FET	18.1 dBm 15.9 dBm	22.9 dBm	105%
3 Patch - 6 FET	17.4 dBm 18.7 dBm 21.7 dBm	28.9 dBm	98%
4 Patch - 8 FET	19.4 dBm 18.0 dBm 21.4 dBm 19.3 dBm	31.7 dBm	101%

Table I. Combining efficiencies for the arrays.

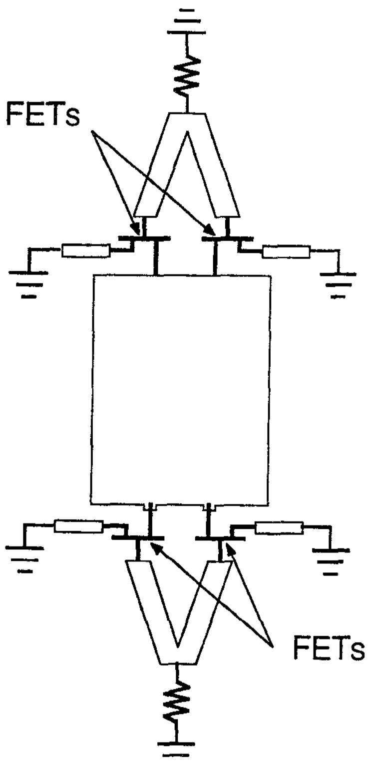

Figure 7. The four FET oscillator.

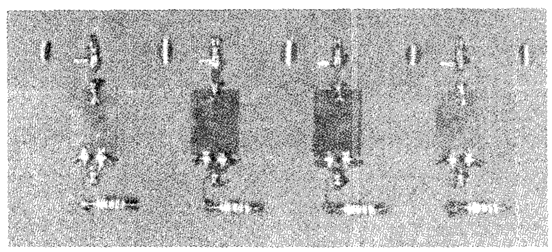

Figure 8. A photograph of the 4 patch, 8 FET power combining array.