# PLANAR FET CIRCUITS FOR ACTIVE ANTENNA ELEMENTS

J. Birkeland and T. Itoh
Department of Electrical and Computer Engineering
The University of Texas at Austin
Austin, Texas 78712

## ABSTRACT

We present the design and test of active transceiver antenna elements suitable for use in phased arrays and spatial power combining. The circuits are constructed using microstrip technology, with GaAs MESFETs as the active elements. The circuits consist of an FET, configured so as to provide a negative resistance port at the drain, connected to one of several types of resonant antenna structures, which serves as the frequency selective element. By injecting a received signal into the FET, the device functions as a self-oscillating mixer for conversion to the IF frequency. Operating in this way, the circuit elements can be used as Doppler radar modules.

## INTRODUCTION

Active antennas offer distinct advantages over other types of approaches at microwave frequencies. Recently there has been a considerable amount of interest in these structures [1-3]. Most of the work done to date has focused on Gunn or IMPATT diodes as the active element. However, in MMIC designs, where the active antenna concept may have its greatest impact, the active device of choice is the MESFET (or one of its variants, such as the HEMT). In addition, FET based circuits generally show better dc-rf conversion efficiency than their corresponding Gunn or IMPATT based counterparts.

In this paper, we describe three types of active antenna array elements using FETs as the active device. In each case, the FET and its corresponding gate and source circuits may be viewed as a one-port negative resistance element by looking into the drain. The remainder of the circuit is formed using one of three different kinds of microstrip resonant antenna: the microstrip patch linear array, the coupled rampart line, or the annular ring. The resonant antenna serves as the frequency selective element in the circuit. In the coupled rampart line and annular ring circuits, two FETs oscillating in the push-pull mode are used. In these two cases, the resonant antenna not only determines the frequency of oscillation, but the mode (even or odd) as well.

The circuits described above are operated as a transceivers by using the oscillating FETs as self-oscillating mixers for down conversion of the received signal. The incoming signal may be received using the same antenna as the transmitted signal, hence injected into the drain of the FET, or a separate receive antenna may be provided for injection of the received signal into the gate terminal. If a separate receive antenna is used, its polarization may be different from that of the transmit antenna.

## ELEMENT DESIGN

The three types of circuits described here are shown in Figure 1. In the microstrip patch linear array and the coupled rampart line circuits, the operation principle is explained in terms of the leaky-wave stop band of a periodic, open guiding structure. This approach is similar to that of Song et. al. [4] where dielectric waveguide was used.

For periodic guiding structures, pass bands and stop bands appear in the dispersion characteristics [5]. The first stop band occurs when the periodicity of the structure equals one half of the guide wavelength. This stopband occurs in the bound wave portion of the dispersion diagram, and therefore corresponds to a standing wave in the guide, with no associated radiation. The next stopband occurs at approximately twice the frequency of the first, when the periodicity of the guide equals the guide wavelength. In this case, propagating spatial harmonics are excited, and radiation occurs from the guide, normal to the direction of propagation. This is the so called leaky wave stopband, and it is in this region that we are interested. In conventional antenna applications this situation is avoided, due to the high VSWR associated with this phenomenon. In our case, however, we use this effect to advantage by using the antenna as a frequency selective band reject filter providing feedback to the negative resistance element (the FET) and sustaining the oscillation. For the linear microstrip patch array, the periodic perturbations are the microstrip patch elements. The widths of the patch elements are varied along the length of the structure, to narrow the stopbands thereby minimizing the chance of oscillation at a frequency other than the design value.

The rampart line antenna has been described by Hall [6]. In the case of the coupled rampart lines, the coupled sections provide the perturbation. If we select the even mode impedance of the coupled sections to be equal to the characteristic impedance of the uncoupled sections, and the odd mode impedance to be lower than this value, then the stop bands will occur in the odd mode only. In this case, the radiation will be polarized perpendicular to the axis of the antenna.

For the annular ring antenna, a section is removed as shown in Figure 1. This antenna will radiate when excited in either the even or the odd mode, with opposite polarizations.

By varying the length of the intervening section between the resonant antenna and the FET, we can adjust the impedance seen by the FET, thereby satisfying the oscillation condition at the desired frequency.

In all of the circuits described in this paper, the FETs are used in the self-biased mode, with the source dc short-circuited to ground, and the gate terminal either open or short circuited. While this is not essential to the circuit performance, it greatly simplifies the circuit layout. In addition, by biasing the devices in this fashion, we cause them to oscillate in a more non-linear manner, which appears to improve their performance as self-oscillating mixers.

In the linear patch array and annular ring circuits, the same antenna is used for transmit and receive, thus the received signal is injected into the drain of the FET. In the coupled rampart line circuit, we have chosen to use a separate receive antenna, and inject the received signal into the gates of the FETs. In both cases the low frequency IF signal is taken off the drain bias line using an IF transformer. In the annular ring circuit, we can use two transformers to determine the polarization of the received signal; the IF signals will be in-phase when the received signal is polarized parallel to the transmitted signal, and out-of-phase when the transmitted and received signals are perpendicular.

## EXPERIMENTAL RESULTS

Prototype circuits were constructed to operate at 10 GHz for the leaky-wave antenna circuits and at 6 GHz for the annular ring circuit. The circuits were constructed using soft substrate and packaged NE710 FETs.

We define the isotropic receiver gain as the ratio of received power in the IF to that due to an isotropic receiver with 100% dc-rf conversion efficiency, following the example in [7]. The isotropic transmitter gain is defined as the ratio of the radiated power to that of an isotropic source with 100% dc-rf conversion efficiency [8]. These values are plotted in Table 1 for the three types of circuits.

When the circuits were set up as Doppler motion detection modules, with the audio frequency IF signal displayed on an oscilloscope, both showed similar performance. For example, the signal caused by waving a metal box at a distance of 20 feet was easily detected. The signal due to a person walking about in the room at a distance of 10 to 20 feet was also easily detected, indicating that these circuits have applications as low-cost, planar motion detection modules.

## CONCLUSION

By combining all features of a transceiver module in a single, uniplanar circuit using FETs we can acheive good transmit and receive conversion efficiency. The circuits may be used for Doppler motion detection applications at X-band, where they are smaller and lighter than conventional circuits. In addition, the approach may be easily scaled to higher frequencies.

For Doppler radar and motion detection applications, the preferred may be to use the same antenna for transmit and receive functions. One advantage of the balanced circuit over the single ended approach, however, is that an RF premplifier may be inserted between the receive antenna and the mixer to significantly improve the receiver gain and noise figure.

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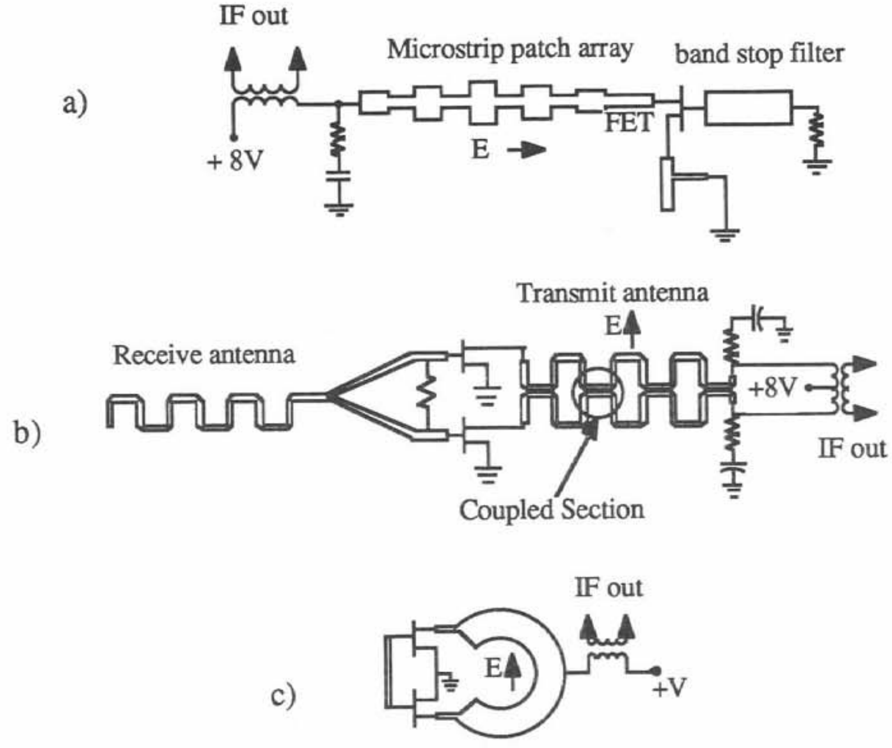


Figure 1. Three types of transceiver modules: a) linear patch array
b) coupled rampart line
c) annular ring

| | Isotropic Transmitter Gain | Isotropic Receiver Gain | DC Input Power (dBm) |
|---|---|---|---|
| microstrip patch | 2.0 dB | 3.1 dB | 18.5 dBm |
| rampart line | 3.9 dB | -0.3 dB | 14.7 dBm |
| annular ring | -14.4 dB | -5.4 dB | 26.0 dBm |

Table 1. Performance of transceiver modules in Figure 1.