An FET Oscillator Element for Spatially Injection Locked Arrays

Joel Birkeland† and Tatsuo Itoh‡

†Motorola Semiconductor Product Sector
Tempe, AZ 85284

‡UCLA Department of Electrical Engineering
Los Angeles, CA 90024-1594

Abstract - A new type of oscillator element for spatially injection locked arrays is presented. The element consists of an FET oscillator equipped with two patch antennas: one for reception of the injection signal and the other for radiating the oscillator output power. This element exhibits much broader locking bandwidths for a given injection signal than previous approaches. Prototype circuits operating at 6 GHz exhibit a 270 MHz locking range with 46.5 dB isotropic gain.

I. INTRODUCTION

Synchronising the oscillator elements in large quasi-optical power combining arrays is usually accomplished by relying on the weak interactions between the elements to cause phase locking [1,2]. This may involve adjusting external reflecting elements, and/or device bias. A related problem is locking the array to an external source. Injection locking using a spatial feed has been reported [1,2], however the locking ranges have been small with relatively large injected signal levels.

In this paper, we report a new method for spatially injection locking an oscillator array, where the array elements are provided with separate receive antennas for reception of the injection signal. In our method, the elements operate independently, so that the array would be synchronised only when the injection signal is present. Using this approach, broad locking bandwidths are achieved with relatively low injected signal levels. In addition using the elements described here, arrays may be constructed which focus the radiated field.

II. SPATIALLY INJECTION-LOCKED RADIATING ARRAYS

Figure 1 shows a schematic description of a spatially injection-locked quasi-optical power combining array. A signal radiated from the source antenna is incident on the array, thereby injection locking the oscillators. The combined signals radiated from the array are received by the load antenna. The following analysis is for a single element.

The power of the injected signal, P_{inj} is given by the Friis equation:

$$P_{inj} = P_{source}\frac{g_S\, g_R\, \lambda^2}{(4\pi\, r_1)^2}, \tag{1}$$

where P_{in} is the power delivered to the source antenna, and g_S and g_R are the gains of the source antenna and the element receive antenna, respectively. Similarly, the power received at the load antenna due to the single element, P_{rec}, is:

$$P_{load} = P_{rad}\frac{g_L\, g_T\, \lambda^2}{(4\pi\, r_2)^2}, \tag{2}$$

where P_{rad} is the power delivered to the element transmit antenna and g_L and g_T are the antenna gains of the load antenna and the element transmit antenna, respectively. Combining these expressions gives the overall gain of the system,

$$\frac{P_{load}}{P_{source}} = \left(\frac{\lambda}{4\pi}\right)^4 \frac{g_S\, g_L}{(r_1\, r_2)^2}\; g_{iso}, \tag{3}$$

where we have used the isotropic gain of the oscillator element:

$$g_{iso} \equiv g_R\, g_T\, \frac{P_{rad}}{P_{inj}}. \tag{4}$$

In the isotropic gain we lump together the gain of the element receive and transmit antennas and the injection gain of the oscillator. For an oscillator element, P_{rad} is approximately constant under locked conditions, so g_{iso} will increase with decreasing injection signal. On the other hand, the injection locking bandwidth will decrease with decreasing injection signal level.

III. DESIGN

Oscillators built from FET amplifiers with feedback provided by directional couplers have been analyzed in [3]. It was shown that they provide broader injection-locking bandwidth than other topologies using the same active devices. This type of oscillator is used here as a spatially injection-locked radiating element by configuring it with two patch antennas as shown schematically in Figure 2.

The receive antenna is connected to the input port of the coupler, so that most of the received signal is injected into the gate of the FET. The signal from the drain of the device passes through the coupler and is radiated from the transmit antenna, except for a small portion which is fed back into the gate to sustain the oscillation. For the circuits described here, a coupling coefficient of 11 dB was necessary to sustain the oscillations.

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Prototype circuits were constructed for operation at 6 GHz using the three layer structure shown in Figure 3. The oscillator is constructed in microstrip above the ground plane in the center, using PTFE substrate material with a thickness of 0.79 mm. The patch radiators were made from rectangular pieces of copper tape, with dimensions of approximately 1.5x1.3 cm, applied to squares of dielectric measuring 2.5x2.5 cm and 3.2 mm thick. This dielectric was then attached to the oscillator circuit board using double sided foam tape. The patch antennas are oriented 90 degrees to each other, to allow discrimination between the injected and the radiated signal. The transistors used were plastic packaged small signal devices, which were biased at I_{DSS} to minimize the bias circuitry required.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

For testing the oscillator elements, the arrangement shown in Figure 1 was used. WR137 open ended waveguide flanges were used for the source and load antennas, with measured antenna gains of 4.2 dB. The antenna separations were r_1 = 27.9 cm and r_2 = 26.7 cm.

With the antennas and the oscillator element aligned on center, and the element biased at VDS = 5 V and ID = 30 mA, a power level of 7.4 dBm at the input to the source antenna resulted in an isotropic gain of 46.5 dB and an injection locking bandwidth of 267 MHz at a center frequency of 6.1 GHz. Variation of locking bandwidth with injected signal level is shown in Figure 4, where injected signal level is referred to the input of the source antenna. The actual injected signal level which appears at the oscillator input is lower by the factor given in equation 1, which in this case is approximately 20 dB.

To determine how many elements could be locked to a single feed, the position of the element in the transverse plane was varied, and the injection locking bandwidth was measured at each point, with results shown in Table 1. These results indicate that an array of these prototype elements with an area of 2300 cm^2 could be injection locked from a single WR137 feed and exhibit a locking bandwidth of 1% for a 7.4 dBm injection locking signal into the feed horn. The area of a single prototype element is approximately 13 cm^2, indicating that 175 such elements could be synchronised.

The above discussion does not take into account the interactions between the oscillator elements in the array. Experience indicates that the principal interaction mechanism is the coupling between the receive antennas. Coupling between adjacent patch antennas has been measured at -15 dB. During oscillation, a small amount of rf energy is radiated out of the input port of the oscillator. This signal level is typically 13 - 15 dB below that which appears at the output port. Interactions between the elements must be considered when the injection signal is the same order of magnitude as any unwanted injection from the adjacent element.

The topology of the oscillator elements described here is amenable to the addition of a predetermined phase shift between the injected and re-radiated signal for each element in the array. This would allow for focussing the beam radiated by the array.

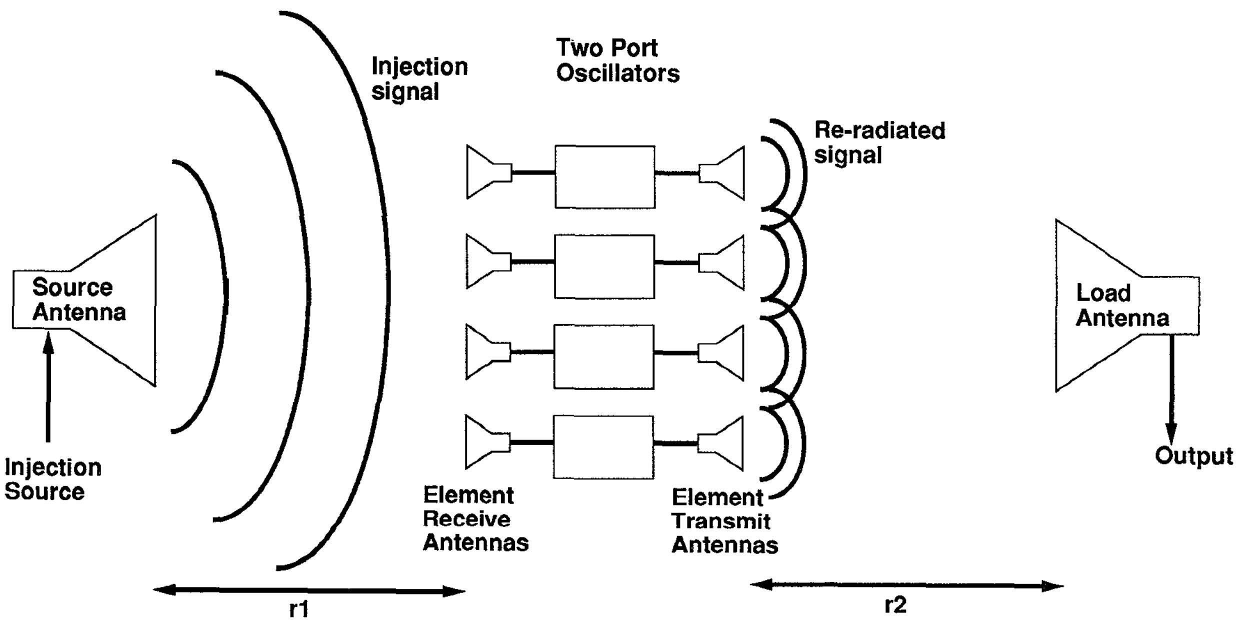

FIGURE 1. SCHEMATIC REPRESENTATION OF SPATIALLY INJECTION LOCKED ARRAY

V. CONCLUSIONS

We have demonstrated that spatially injection locked quasi-optical oscillator arrays are possible using a new type of element with separate antennas for receiving the injection signal and re-radiating the oscillator output power. The results given here show that using this new element, broad bandwidths are achievable for low injected signal levels. In addition, the new elements allow the possibility of focussing the radiated beam from the array.

VI. REFERENCES

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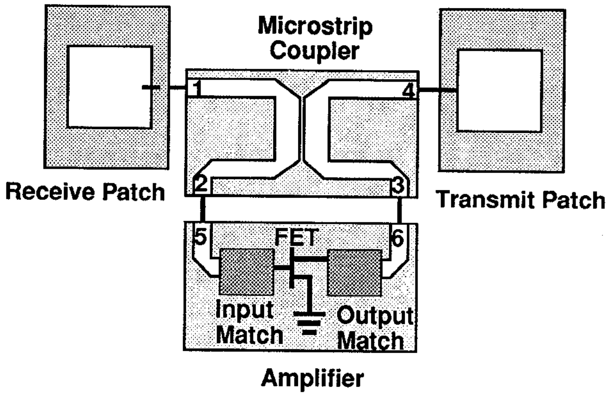


FIGURE 2. SCHEMATIC OF OSCILLATOR ELEMENT

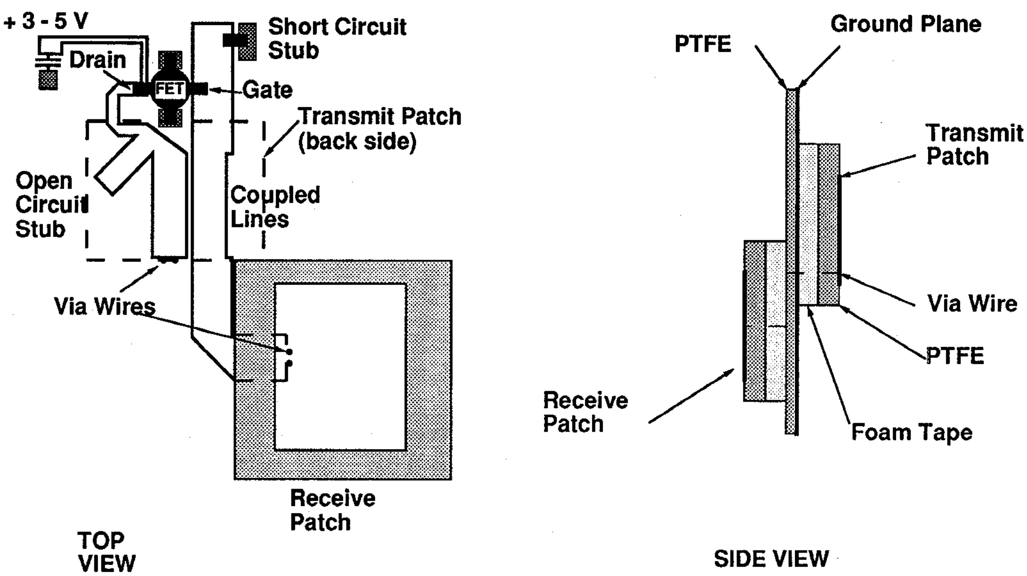
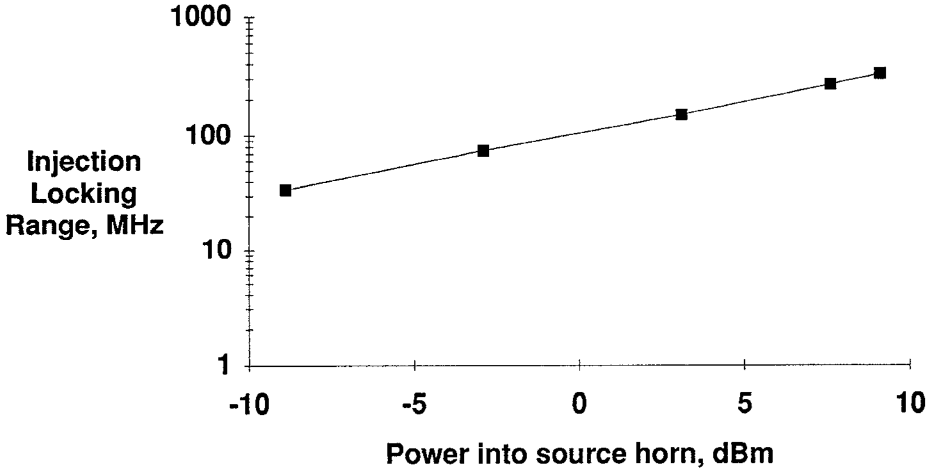


FIGURE 3. LAYOUT OF OSCILLATOR ELEMENT

FIGURE 4. INJECTION LOCKING RANGE VERSUS FEED POWER



Displacement in transverse plane	Locking Range, MHz
x=0, y=0	267
x=0, y=-25 cm	189
x=22.5cm, y=-25 cm	61
x=-22.5 cm, y=0	116

Table 1. Injection locking range as a function of element displacement in transverse plane. X=0, Y=0 is centerline, power at source horn is 7.4 dBm.