Two-Port FET Oscillators with Applications to Active Arrays

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Abstract—**Investigations of two-port FET oscillators and their use in active arrays for spatial power combining are reported. The oscillator consists of a single FET amplifier with a microstrip coupler providing feedback, thereby creating distinct input and output ports. This type of oscillator exhibits increased locking bandwidth over alternative approaches. Results are given for a five element linear array operating at 6 GHz.**

I. Introduction

THE USE of FET based radiating elements for active antennas and spatial power combining has received attention recently [1]–[4]. By synchronising the oscillations of large numbers of such oscillators, a high-power source may be achieved. The typical approach is to rely on weak interactions between the individual elements to cause locking.

An alternative approach is presented here, where the individual oscillating elements are each equipped with an injection port. The array is then synchronised by applying an external injection signal. As is shown in Section II, the locking bandwidth of the type of oscillator we describe is greater than can be achieved using the radiating patch as a resonant element.

II. Oscillation Condition

The two port oscillator considered here is shown in schematic form in Fig. 1. The oscillator consists of a single FET amplifier, with feedback provided by a directional coupler. A similar approach, described by Tajima [5], used a capacitor and a bond wire from the drain to the source of a FET to provide feedback for oscillation. The coupler provides for greater control of the feedback in the circuit, thereby improving circuit performance.

The oscillation condition for the circuit of Fig. 1 is determined by first expressing the wave amplitudes as [6]

$$\Gamma \boldsymbol{a} = S^{\text{tot}} \boldsymbol{a}, \tag{1}$$

where S^{tot} is a block diagonal matrix whose elements are the S parameter matrices of the individual circuit elements, and Γ is the interconnection matrix, whose i,jth element is 1 if ports i and j are connected, and 0 otherwise. Oscillation occurs when

$$\det(\Gamma - S^{\text{tot}}) = 0. \tag{2}$$

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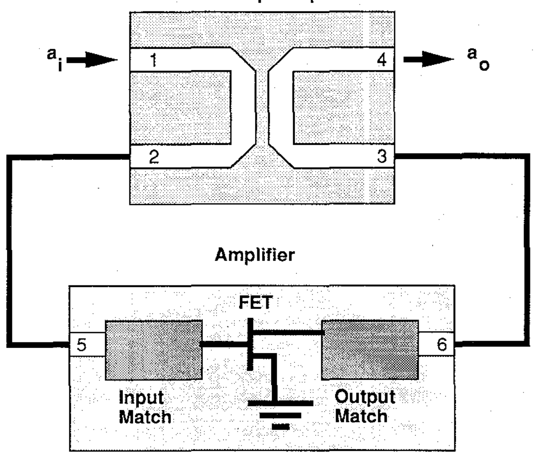

Fig. 1. Schematic diagram of two port oscillator.

Since S^{tot} depends on the amplitude of the scattered waves as well as their frequency, this expression determines the frequency and output power of the oscillator. For a matched, unilateral amplifier, and a matched coupler with infinite directivity, (2) reduces to the familiar expression

$$1 - S_{21}^A \ S_{23}^C = 0,$$

where the superscripts A and C refer to the amplifier and the coupler, respectively.

III. Injection Locking

The injection locking range may be determined by replacing $\boldsymbol{a}$ by $\boldsymbol{a} + \boldsymbol{a}_{\text{inj}}$ in (1). For the matched, unilateral amplifier, and matched coupler, with an injection signal a_i present at port 1 of the coupler, this gives

$$S_{21}^C a_1 + S_{21}^A \ S_{23}^C a_5 = a_5. \tag{3}$$

For $a_i \ll a_5$, we may assume that the first term affects only the phase of the left side; in addition, we have $|S_{21}^A \ S_{23}^C| \approx 1$.

The extrema of the injection locking range occur when the left hand terms of (3) differ in phase by $\pm 90°$. The phase ϕ of $S_{21}^A \cdot S_{23}^C$ at these points is denoted by $\phi^{\pm}$, and may be determined from

$$\phi^{\pm} = \angle S_{21}^A \ S_{23}^C \approx \pm \frac{|S_{21}^C a_i|}{|S_{21}^A \ S_{23}^C a_5|} = \pm \frac{|S_{21}^C|^2 \, |a_i|}{|S_{23}^C| \, |a_o|}, \tag{4}$$

where a_o denotes the output signal, and we have used $a_o = S_{21}^A \ S_{21}^C a_5$. Near the center frequency of the coupler, we have $|S_{23}^C| = C$ and $|S_{21}^C| = \sqrt{1 - C^2}$, where C is the voltage coupling coefficient. For small injection levels, we expect ϕ to vary linearly with frequency, which gives

$$\Delta\omega = \frac{1 - C^2 |a_i|}{AC|a_o|}, \quad (5)$$

where $A = \frac{d\phi}{d\omega}$.

Comparing (5) with Adler's equation [7, (19a)] gives an effective Q for our oscillator of

$$Q_{\text{eff}} = \frac{A\,C\,\omega_o}{2(1 - C^2)}, \quad (6)$$

which is typically less than 1 for our circuits. For a reflection type oscillator, the appropriate Q value would be the external Q of the microstrip patch, which is typically in the range of 10–20. Because of this, the small signal locking range of the two port oscillator as described here will be an order of magnitude greater than that of the reflection type.

IV. Prototype Circuits

Oscillator circuits were fabricated for operation at 6 GHz using microstrip techniques and packaged devices. The amplifier and coupler were fabricated on woven glass reinforced PTFE circuit board .031 inches thick with an ε_r of 2.55. The FET's used were packaged small signal devices from Avantek with a typical maximum stable gain of 15 dB at 6 GHz. Output power for the oscillators was in the range of 13–15 dBm when operated into a 50 ohm load.

The antennas used were rectangular microstrip patches fabricated on .125 inch thick polyethylene substrate that was chosen to maximize bandwidth. The resulting antennas exhibited a Q of approximately 8. The antennas were attached to the oscillators perpendicularly as shown in Fig. 2.

With the oscillator output port connected to the antenna, a locking bandwidth of 870 MHz at a center frequency of 6.2 GHz was obtained for an injection power of −5 dBm. This indicates an effective Q of about 0.5.

A linear array of five oscillator elements was made by connecting the output of one oscillator to the input of the next using directional couplers as shown in Fig. 3, with a spacing of 1.4 inches between antennas. In this case, the entire array is synchronised by a single injection signal supplied to the first oscillator. The array exhibited a locking bandwidth of greater than 500 MHz with a 0-dBm injection signal, however, the radiation pattern had sidelobe levels below −10 dB for only 300 MHz of this range. Variation of the main lobe with frequency is shown in Fig. 4. The main lobe direction variation is about 7% per 100 MHz of frequency change.

V. Conclusion

Two port oscillators provide a considerable increase in locking bandwidth over reflection type oscillators. In addition to the large locking bandwidths, the separate injection port on the oscillators described here allows for convenient introduction of the locking signal. This is useful in applications where it is necessary to synchronise large numbers of oscillators to an external source.

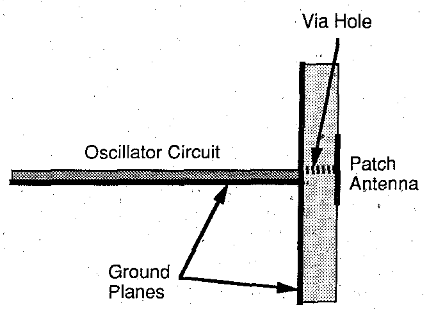

Fig. 2. Illustration of antenna connection to oscillator circuit.

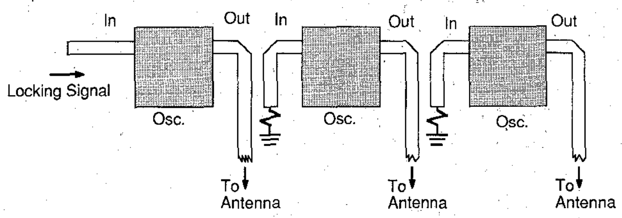

Fig. 3. Series array of injection locked elements.

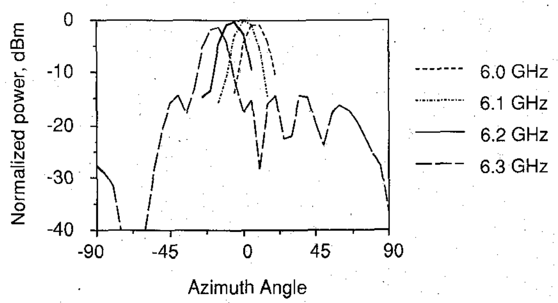

Fig. 4. Antenna pattern for five element oscillator array.

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