Quasi-Optical Array VCO's

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Abstract – **Quasi-optical array voltage controlled oscillators (VCO) are presented. A quasi-optical VCO consists of an array of oscillators, a variable capacitance array and a mirror. In the oscillator array, a large number of MESFETs feed a two-dimensional periodic metal structure on a dielectric substrate. The mirror provides feedback for locked power-combining of the oscillators. The electrical frequency tuning is achieved with another array loaded with varactor diodes. When the varactor bias voltage is changed, the capacitance of the diodes changes, which in turn modulates the frequency of the output power-combined wave. Two types of arrays are presented, one consisting of short dipoles, and the other of bow-tie elements. As expected, the bow-tie VCO has better performance than the dipole VCO, due to its broadband impedance. The best obtained result from a bow-tie VCO is a 10% tuning bandwidth with less than 2 dB power change. Modulating the gate bias is shown to be inferior to varactor array tuning. The VCO is the first demonstration of a quasi-optical system consisting of several periodic arrays loaded with solid-state devices.**

Quasi-optical solid-state power combining has recently received a lot of attention. So far, the largest number of devices that have been combined was in a 5 GHz 100-MESFET planar grid oscillator [1]. A similar oscillator was also built at Ku band [2], and mixer and amplifier grids [3,4] demonstrate the versatility of this approach. In the grid oscillators, transistors load a grid with a period that is small compared to a wavelength. The grid is on a dielectric substrate and backed by a metal mirror that ensures positive feedback and locked oscillation. The frequency of oscillation can be tuned by mechanically translating the mirror. For most applications, however, it is more advantageous to have an electrically tunable oscillator. Electrical tuning presented in this work is achieved with a second grid loaded with varactor diodes. When the varactor array bias voltage is changed, the capacitance of the diodes changes, and therefore the reflection coefficient of the array changes. When such a variable impedance plane is placed in parallel with the oscillator array, the two active sheets form a quasi-optical VCO, Figure 1. The two arrays are placed back-to-back and there is a dielectric spacer between them. When the varactor array is placed in the near field of the oscillator array, it has more effect than when it is in the far field, the probable reason being diffraction loss in the latter case. The configuration shown in Figure 1 is also advantageous from the mechanical stability and packaging point of view.

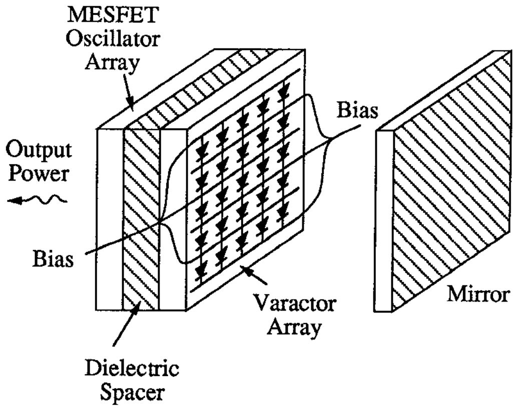

Figure 1. A quasi-optical VCO consists of a grid oscillator and a grid tuner backed by a mirror. The radiated frequency can be tuned by changing the bias of the varactor array.

The radiation impedance of the radiating grid structure is part of the transistor oscillator imbedding circuit. This radiation impedance needs to be broadband for maximum frequency tuning. Two types of arrays were fabricated – a short dipole array and a bow-tie array. In both cases the period was 15 mm and is much smaller than the free-space wavelength of the radiated wave. Figure 2(a) and (b) shows the dipole transistor and varactor array, and Figure 3(a) and (b) the respective bow-tie arrays. The bow-tie array is self-complementary and has a broadband impedance [5], provided the source bias lines are thin. The dipole transistor oscillator array is designed following the method described in [1] for operation at 2.5 GHz on a 0.5 mm thick Rogers' Duroid substrate with $\epsilon_r = 2.2$. The bow-tie array with the same period oscillated at a higher frequency around 3.5 GHz. All four arrays are 7 by 7, and the devices are biased in parallel.

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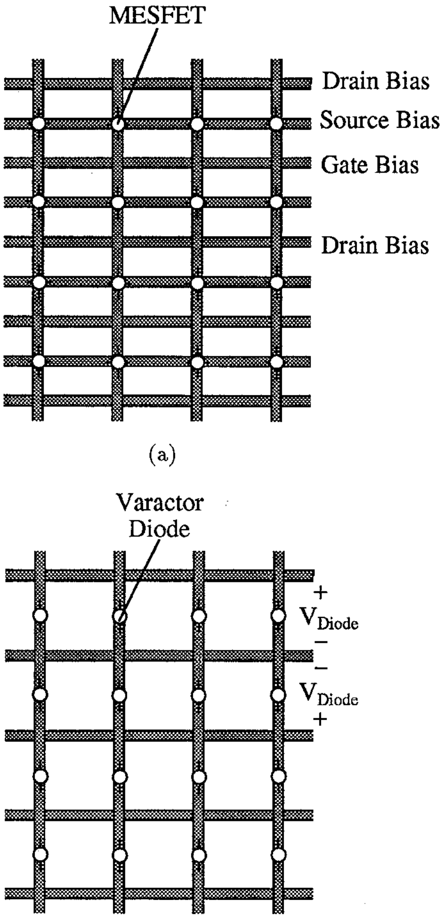
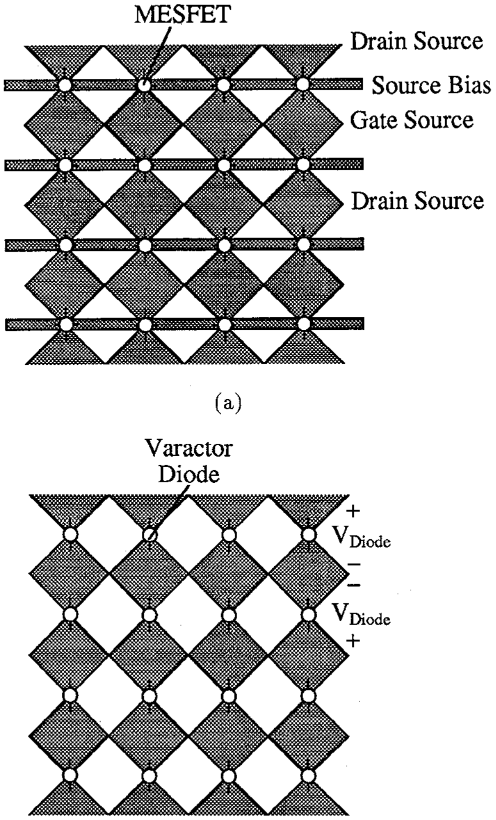


(a)

(b)

Figure 2. The geometries of the dipole MESFET oscillator (a) and varactor tuner (b) arrays. The arrays consist of 49 elements each.

The varactor diodes are Metelics MSV34-64, with a ratio of $C_{max}(0\,\mathrm{V})/C_{min}(30\,\mathrm{V}) = 2.5$. The varactors are aligned with the transistors, so that each transistor is tuned by one diode in a unit cell of the array. If the varactor capacitance were the only capacitive element that determined the oscillation frequency, the shape of the voltage frequency tuning curve would be the same as that of the $1/\sqrt{C}$ curve of the diode. The two curves differ, as shown in Figure 4 for the bow-tie array. The difference is even larger in the case of the dipole array. This agrees with the fact that the dipole array has a smaller frequency tuning range, and is therefore less affected by the varactor capacitance. Figure 4 indicates that the varactor capacitance is not the only reactance affecting the oscillation frequency in this case. The design of a suitable grid structure for best tuning is in progress.



(a)

(b)

Figure 3. The geometries of the bow-tie MESFET oscillator (a) and varactor tuner (b) arrays with 49 elements each.

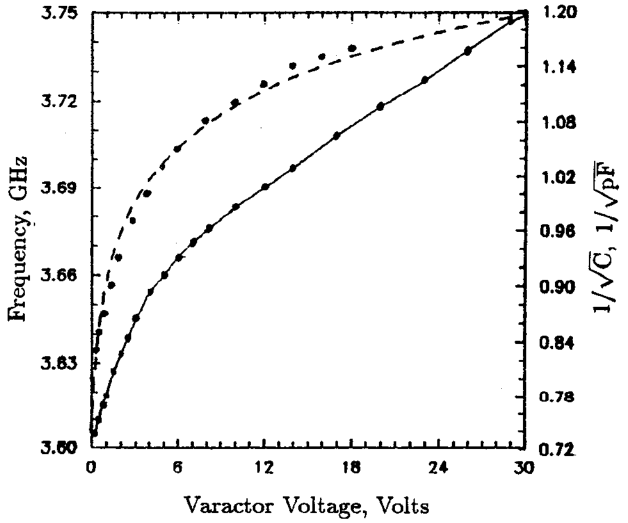
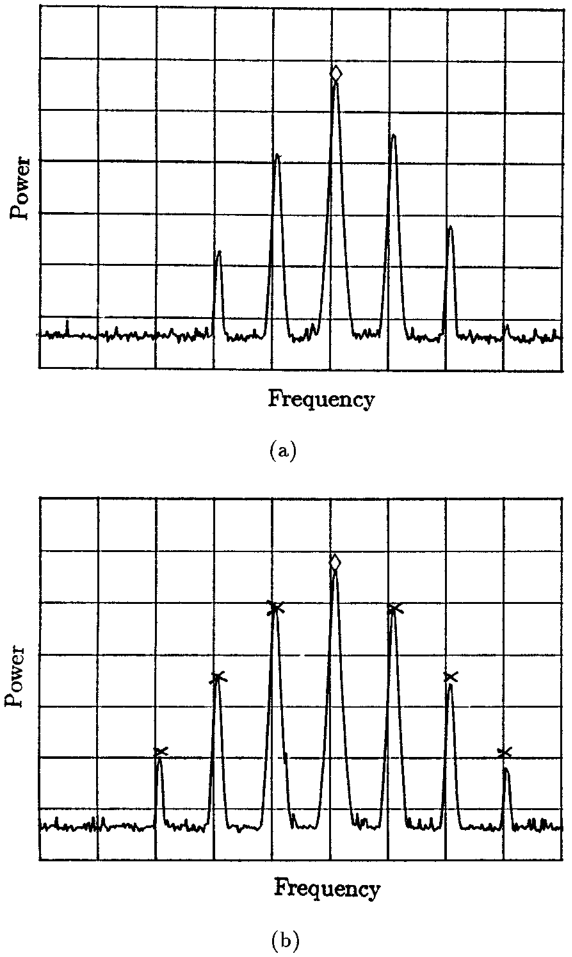


Figure 4. $1/\sqrt{C}$ of the measured-low frequency varactor diode capacitance C versus varactor bias has the same qualitative behaviour as the measured frequency tuning of the grid oscillator as a function of the varactor array bias.



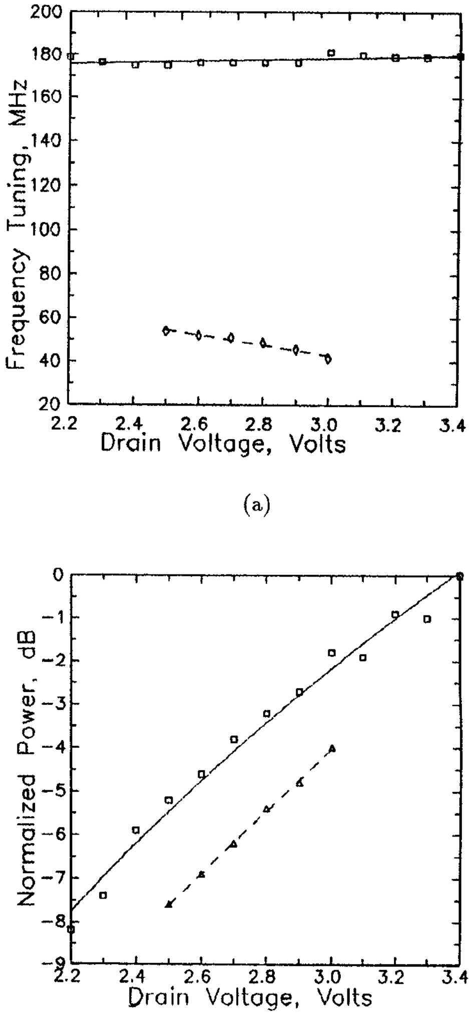
(a)

(b)

Figure 5. FM spectra for the bow-tie VCO with gate bias tuning (a) and varactor tuning (b). The vertical scale is 10 dB/div, the horizontal scale is 5 Mhz/div, and the center frequency is 3.5 GHz. In (b), the crosses show calculated Bessel function coefficients $J(\beta)$, for f_m = 5 MHz and v = 1.3 V.

The oscillation frequency of the MESFET array also varies with the gate bias. Frequency tuning of 80 MHz and 20 MHz was obtained for the dipole and bow-tie oscillators, respectively. The drain bias was kept at 2 V, and the gate bias varied over 1.5 V. The output power varied over 5 dB within the tuning range. Similar power and frequency tuning is observed when the drain bias is varied. As a conclusion, for tuning and modulation functions, the varactor grid approach has better performance. This was verified by superimposing a 5 MHz sinusoidal signal on the gate bias lines in one case, and on the varactor bias lines in the other case. The reason for using such a low modulation frequency were bias line chokes that had highest attenuation between 50 to 150 MHz, so not much modulation signal reached the transistors in this range. The resulting FM spectra are shown in Figure 5 for the bow-tie arrays. Parasitic AM is present in the case of bias tuning, Figure 5(a), even with the low 5 MHz modulation frequency. The calculated Bessel function coefficients corresponding to frequency modulation are shown in Figure 5(b), together with the measured varactor modulation spectrum. When the dipole array was bias tuned, the parasitic AM was 2 dB larger than in the case of the bow-tie array, whereas the varactor modulation was purely FM.

A comparison of varactor frequency tuning and output power versus drain bias of the transistors for the bow-



(a)

(b)

Figure 6. The maximum tuning frequency range (a) and normalized output power (b) versus the drain voltage for V_G = −1 V. The curves for the bow-tie VCO are shown with solid lines, and that of the dipole VCO with dashed lines.

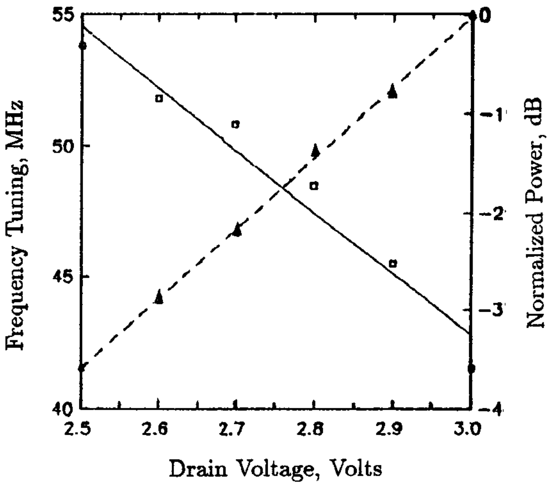
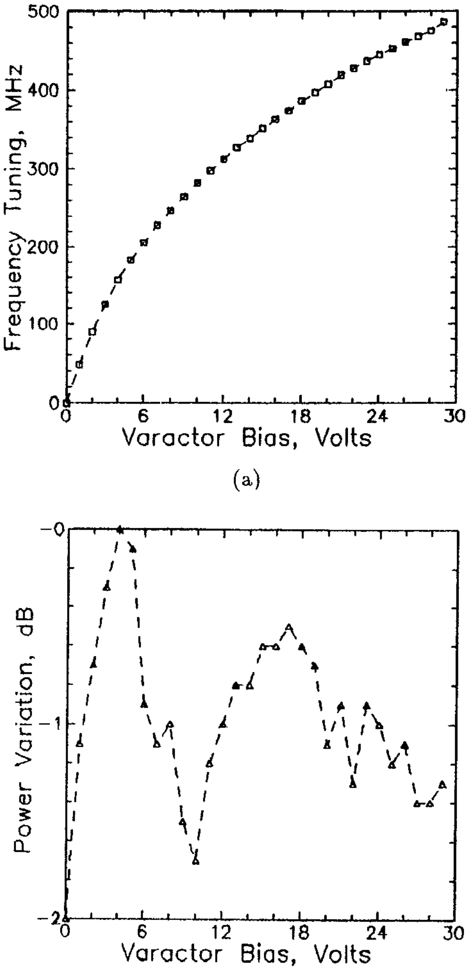


Figure 7. Measured bandwidth and normalized output power versus drain bias for the dipole grid. The frequency tuning curve is shown with a dashed line. The optimized operating point with respect to both power and bandwidth is for $V_{DS} = 2.77\,\text{V}$ for a gate bias of $V_{GS} = -1\,\text{V}$.

tie and dipole VCO's is shown in Figure 6. The bow-tie VCO has better overall performance than the dipole VCO, in terms of both bandwidth and output power. For larger drain bias voltage, the overall Q increases, so the output power increases, whereas the tuneability decreases. There is a compromise between bandwidth and power for the VCO's, shown in Figure 7 for the dipole grid. The largest obtained bandwidth of 10% with less than 2 dB change in power was obtained for a very low bias point of a 5 GHz bow-tie VCO, and the measured results are shown in Figure 8.

In summary, a quasi-optical system consisting of two arrays loaded with solid-state devices has been demonstrated for the first time. Two different VCO configurations have been demonstrated – one with short dipole arrays, and the other with bow-tie arrays. Measurements show that the bow-tie VCO has better performance, as was expected for this broadband antenna element. We believe that such quasi-optical systems that consist of a number of simple single-function solid-state arrays in which all of the devices share the same bias, matching and tuning elements, are promising candidates for both microwave and millimeter-wave frequency applications.



(a)

(b)

Figure 8. Maximum obtained varactor frequency tuning (a) of 10% with less than 2 dB change in power of the entire tuning range was achieved with a bow-tie VCO at a low bias point, V_D =V, V_G = V, I_D =mA.

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