ACTIVE ANTENNA OSCILLATOR ARRAYS IN COMMUNICATION SYSTEMS

C. Kykkotis, P. S. Hall, and H. Ghafouri-Shiraz

School of Electronic and Electrical Engineering, The University of Birmingham, Edgbaston, Birmingham, UK

ABSTRACT

Active antenna oscillator arrays have been considered in millimetre-wave communication systems for increased power levels in low cost radio modules. In this paper, we have investigated the data-rate limitations, the modulation effects on the radiation pattern, and the bit error rate performance of antenna oscillator arrays in practical applications.

INTRODUCTION

Mutually coupled active antenna oscillators have recently been considered for millimetre-wave radio on fibre systems [1]. These systems require radio modules with sufficiently high power levels and minimum circuit complexity [2]. The concept of inter-injection locked oscillators is a promising technique for this purpose because it satisfies both requirements.

In active antenna oscillator array the synchronisation of all the elements can take place in free-space, without the requirement for interconnection between individual oscillators [3]-[4], where the circuit complexity would be increased. Furthermore, the intermediate element of the array can be injected with an external signal which will lock the array. The active device of the intermediate element can be a phototransistor which will be locked to an optical signal carrying millimetre-wave intensity modulated light [5].

However, modulation of active antenna oscillator arrays in a fixed communication system is not without limitations. Possible modulation schemes are restricted to those which are based on phase modulation. Amplitude modulation of an injection locked oscillator is not appropriate since the oscillator operates at a self limiting mode. Frequency modulation of oscillator arrays give rise to beam scanning. Phase shift keying (PSK) seems to be the most appropriate scheme, and the modulation effects of the active antenna oscillator arrays are investigated in the following sections.

ANTENNA OSCILLATOR ARRAY

A 5×1 linear array of active patch oscillators is shown in Fig. 1. The intermediate element is injected with an external signal and after a finite time, all the elements are locked to this signal.

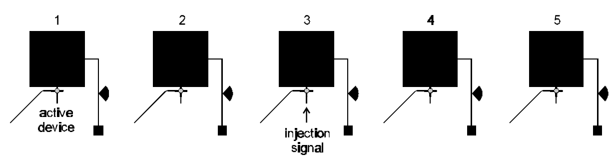

Figure 1: Mutually coupled active antenna oscillator array.

The circuit model for microwave oscillators which is shown in Fig. 2, is proposed by Kurokawa [6], and analysed for the purpose of inter-injection locked oscillators by Stephan [7].

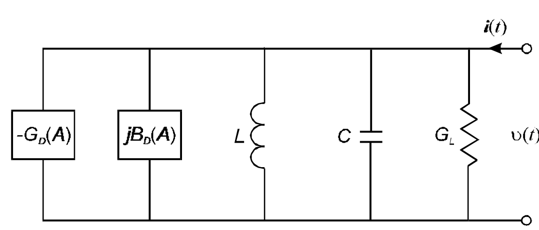

Figure 2: Equivalent circuit of injection locked oscillator.

0-7803-4603-6/97/$5.00 (c) IEEE

Oscillators of this type can be connected to a general N-port network where in the case of free-space coupling the network is passive and characterised by a Y-matrix. Current sources of magnitude I_i and phase $_i$ can be placed across the terminals of each oscillator to represent the injection signal to the individual element of the array which is denoted by a subscript i.

The amplitude and phase dynamics of the array are given by the following expressions,

$$\frac{dA_i}{dt} = \frac{A_i}{2C}(G_{D_i} - G_{L_i}) + \frac{1}{2C} I_i \cos(\;_i - \;_i) - \frac{1}{2C}\sum_{\substack{k=1\\k\neq i}}^{N} A_k \left[G_{ik}\cos(\;_k - \;_i) - B_{ik}\sin(\;_k - \;_i)\right] \quad (1)$$

$$\frac{d\;_i}{dt} = -\Delta\;_i - \frac{B_{D_i}}{2C} + \frac{1}{2CA_i} I_i \sin(\;_i - \;_i) - \frac{1}{2CA_i}\sum_{\substack{k=1\\k\neq i}}^{N} A_k \left[B_{ik}\cos(\;_k - \;_i) + G_{ik}\sin(\;_k - \;_i)\right] \quad (2)$$

The oscillator array of Fig. 1, and any similar array can be analysed using the above model. A numerical technique is used to solve a set of coupled differential equations in the time domain in order to simulate the behaviour of patch oscillator arrays under PSK or QPSK modulation.

MODULATION DATA RATE LIMITS

The elements of the array are separated by one (free-space wavelength), λ_o, and the parameters of the equivalent circuit are appropriate for 60GHz patch oscillators. Each patch oscillator is assumed to be coupled to its nearest neighbour only. The array is injected with a 60GHz signal which has a phase of 180°, that is a typical phase change in a PSK system. Figure 3, shows the phase response of the array.

It is clear that each element in the array requires a finite locking time which consequently puts some limits on the maximum modulation rate of the array. The intermediate oscillator is locked to the injection signal faster than all the remaining elements whereas the two end oscillators are the slowest.

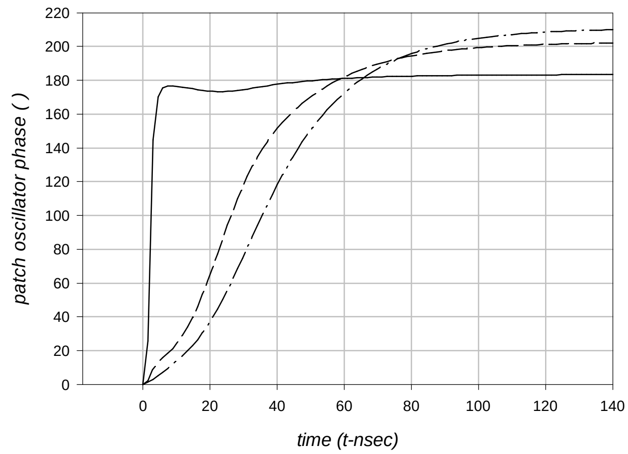

Figure 3: Phase response of patch oscillator array. [element spacing = $1\lambda_o$]

This phenomenon is due to the effective locking power, of the individual element, which reduces as we move away from the intermediate oscillator. However, it is evident that the maximum modulation rate is specified by the slowest elements in the array. The maximum data rate for this array can be estimated from Fig.3, which is about 18Mbps.

Maximum modulation rate of an active antenna oscillator array depends on various parameters such as the injection signal power, the network coupling strength, and the locking bandwidth of the oscillators. Higher values of these parameters give higher modulation rates.

EFFECTS ON RADIATION PATTERN

In the above array, the distance between adjacent elements is selected to be $1\cdot\lambda_o$, so that oscillators in the array have approximately the same phase. This is very important because the level of the broadside radiation pattern can be maximised if the array is in-phase. However, the radiation pattern is modulated during the lock-up time of the array due to the phase variations of the individual oscillator. The radiation pattern of the array is shown in Fig. 4, where the solid line represents the pattern when the array is at locked-

0-7803-4603-6/97/$5.00 (c) IEEE

state and the dashed line represents the pattern at an instant during the unlocked-state.

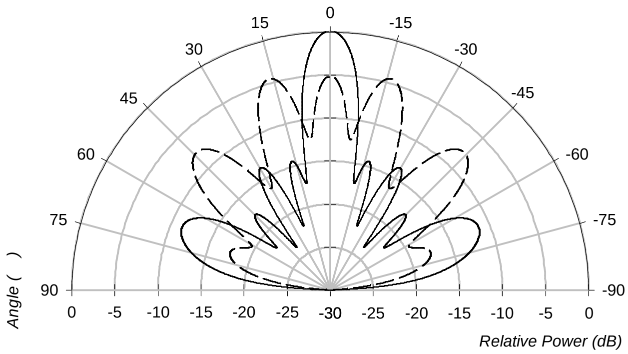

Figure 4: Radiation pattern of 5×1 patch oscillator array.
[solid line: locked-state at 55nsec
dashed line: unlocked-state at 13nsec]

The power level of the mainlobe is reduced by 5dB and the power level of the 45° sidelobe is increased by 10dB. This is an undesired effect in a cellular environment where the alterations of the sidelobe levels may cause interference with adjacent cells.

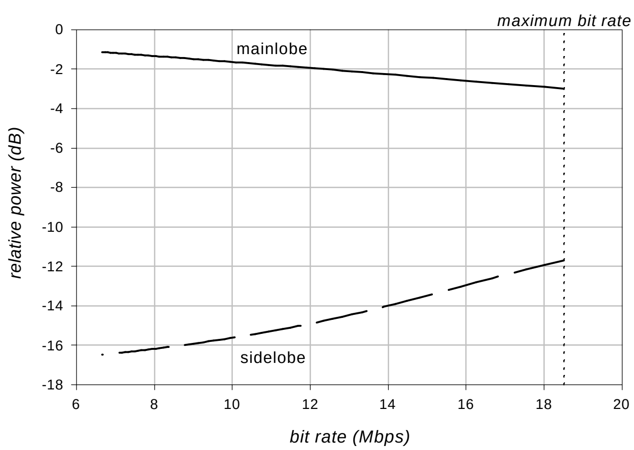

Figure 5: Time averaged power level of mainlobe and sidelobe.

The relation of the time averaged mainlobe and sidelobe power levels with the modulation rate is shown in Fig. 5, which can be used to estimate the margin between the mainlobe and sidelobe levels for a given bit rate.

For the purpose of simulation, it is assumed that all the oscillators are identical.

BIT ERROR RATE

In a practical communication system the bit error rate (BER) is an important issue which determines the performance of the system under a noisy environment. The fact that the signal phase and amplitude of the active antenna locked oscillator array are varying during the unlocked-state of the array, means that the BER depends on the characteristics of the array phase and amplitude dynamics.

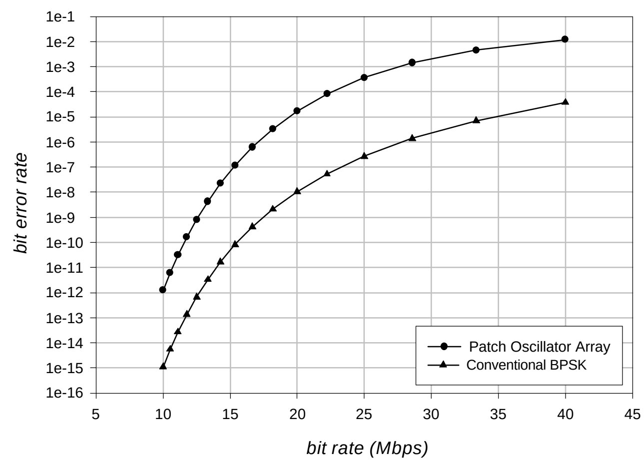

Figure 6: Bit error rate for 5×1 patch oscillator array.

The BER of the 5×1 patch oscillator array is shown in Fig. 6. Also the BER of a conventional binary phase shift keying (BPSK), system which does not involve injection locked oscillators, is shown in the same graph. It is assumed that both systems use matched filters and they have the same signal amplitude at the receiver.

From Fig. 6, it is clear that the BER of the patch oscillator array is significantly higher than the conventional system, which imposes another limitation to the concept of mutually coupled oscillator arrays.

OSCILLATOR PHASE CONTROL

The phase of the individual oscillator in the array is an important factor which if it is controlled properly, the performance of the active antenna oscillator arrays may be improved. When the distance between adjacent elements decreases, the effective locking power increases, which leads to higher modulation rates. In this case the phase of each oscillator must be controlled so that all the elements have the same phase. This will improve the radiation pattern and due to the higher power levels that can be achieved, system will also perform better as far as BER is concerned.

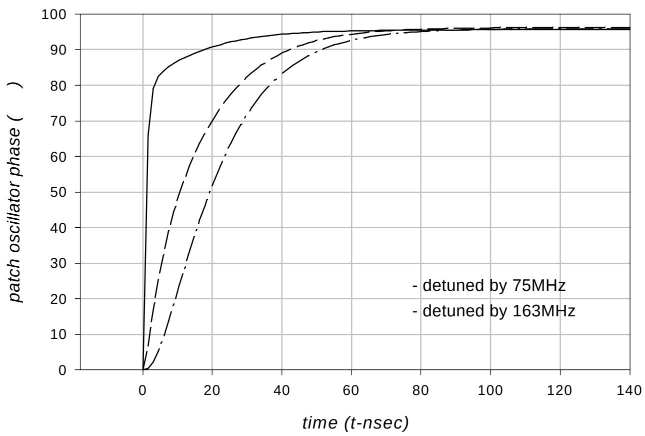

Figure 7: Phase response of patch oscillator array. [element spacing = 0.8λ_o]

A technique for phase control is to frequency detune some of the oscillators in the array. The change of their free-running frequency will force them to change their phase. Figure 7, shows that we may decrease the separation of the elements and by detuning some of the oscillators, an in-phase operation can be achieved.

CONCLUSIONS

Modulation effects of the active antenna oscillator arrays is an important practical issue when used in communication systems. The initial investigations of this paper have shown that high modulation rates are limited by the finite lock-up time of the array and that the radiation pattern is modulated during the unlocked-state of the array. The BER is worse compared with a system which does not involve injection locked oscillators. However, techniques such as detuning, may improve the performance of these arrays making them suitable for practical communication systems.

REFERENCES

1. C. E. Kykkotis, P. S. Hall, H. Ghafouri-Shiraz, and D. Wake, "New configurations for integration of microwave/millimetre wave and optoelectronic devices for compact radio on fibre modules", *Proc. 26th European Microwave Conf.*, vol. 2, pp. 1004-1009, Prague-Czech Republic, 1996.

2. D. Wake, C. R. Lima, P. A. Davies, "Optical generation of millimetre-wave signals for fibre-radio systems using a dual-mode DFB semiconductor laser", *IEEE Trans. Microwave Theory Tech*, vol. 43, pp. 2270-2276, 1995.

3. S. Nogi, J. Lin, and T. Itoh, "Mode analysis and stabilisation of a spatial power combining array with strongly coupled oscillators", *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 1827-1837, 1993.

4. J. Birkeland and T. Itoh, "Two-port FET oscillators with applications to active arrays", *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 112-113, 1991.

5. C. E. Kykkotis, H. Ghafouri-Shiraz, P. S. Hall, and D. Wake, "Optical fibre-fed radio system configurations", *Proc. 4th International Conf. on Millimetre-Wave and Far-Infrared Science and Technology*, pp. 125-128, Beijing-China, 1996.

6. K Kurokawa, "Some basic characteristics of broadband negative resistance oscillator circuits", *Bell Syst. Tech. J.* vol. 48, pp. 1937-1955, 1969.

7. K. D. Stephan and W. A. Morgan, "Analysis of interinjection-locked oscillators for integrated phased arrays", *IEEE Trans. Antennas Propag.*, vol. 35, pp. 771-781, 1987.

0-7803-4603-6/97/$5.00 (c) IEEE