A Low Power Density Concept for Beaming Microwave Power

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Abstract

A system for wireless power transfer is described which minimizes the required power density to obviate the need for high power microwave components. In addition, the potential for interference with other local electronic devices is minimized. The radio frequency power is generated by a distribution of low power solid state devices and the power transfer is achieved via spatial power combining in the aperture of the transmitting antenna. Beam control is implemented by mutual injection locking of the rf sources. A modular approach to the construction of large apertures is suggested involving triangular sub-arrays controlled by arrays of coupled oscillators.

1. Introduction

The concept of transferring significant amounts of power from one point to another without wires has been attractive for many decades. Perhaps the earliest serious analysis effort was published by Goubau and Schwering in the late 1950's and early 1960's [1]. They showed that efficient power transfer could be accomplished with focusing reflectors ellipsoidal in shape and this geometrical scheme has become known as a "beam waveguide." Beam waveguides are currently used to wirelessly interconnect the large reflectors of the NASA Deep Space Network with their feed systems in such a manner as to permit adjustment of the pointing direction without disrupting the connection. Beam waveguide like systems have been proposed for the transfer of much larger quantities of power in such applications as bringing the power generated by a large solar array in earth orbit to the ground for injection into the power grid. Another proposed application is supplying power to an airborne vehicle by wireless transfer from the ground [2]. However, in such applications the power levels proposed are so great as to pose a design challenge as well as a potential health hazard to those exposed to the beam. Thus, there is considerable incentive to design a system that transfers large amounts of power without hazardous power densities. Such a system is proposed here.

2. Spatial Power Combining and Beam Control

If the microwave power is generated by a large number of low power solid state sources distributed over a large area, the power density can be quite low while the total power achieved via spatial power combining can be very high. To reap the benefits of spatial power combining, however, one must devise a means of controlling the phases of these low power sources so as to achieve coherence over the aperture. Moreover, it is desirable that the aperture phase be adjustable for both beam steering for tracking and beam spoiling in emergencies. It is proposed here that a scheme developed by R. A. York and his students at the University of California, Santa Barbara and depicted in Figure 1 may provide such phase control [3]. York, et. at showed that an array of oscillators coupled to nearest neighbors as shown in Figure 1 could be made to mutually injection lock and oscillate coherently as an ensemble. They further showed that the locked ensemble could be made to produce linear phase progressions across the array if the perimeter oscillators were detuned antisymmetrically. It was later discovered that the fundamental solutions for the phase distribution were paraboloidal, planar being a special case. Thus, beam spoiling and focusing can also be accomplished in this manner [4]. Very high power is achieved by using a solid state amplifier at the output of each oscillator in the array and using the amplifier outputs to excite the elements of a phase array antenna. Very large apertures can be made from smaller modules in a multilevel structure with oscillator arrays controlling the phase distribution at each level. Of course, the practicality of this approach will be critically dependent upon the economics of deploying very large numbers of solid state devices over a very large area relative to deploying a very large reflector feed and dealing effectively with the dangerously high power densities at the feed.

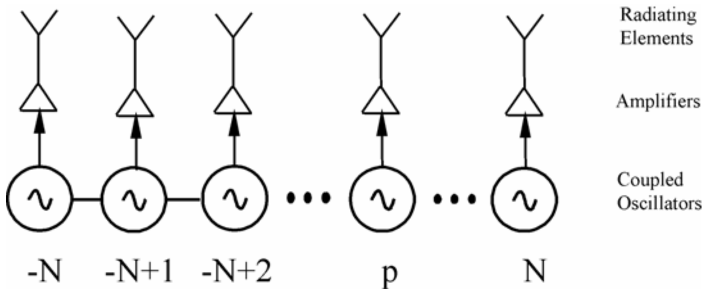

Figure 1. Oscillator array feeding the elements of a phased array antenna.

3. Large Apertures and Sub-arrays

When large apertures are formed from sub-arrays as described above, the beam control system becomes hierarchical. That is, the sub-arrays become the elements of a larger array and their phases are also controlled by coupled oscillators and so on as depicted in Figure 2. This means that at the largest sub-array level, the coupling lines between oscillators must be very long and therefore introduce significant coupling delay. The effects of such coupling delays have been studied recently [5, 6].

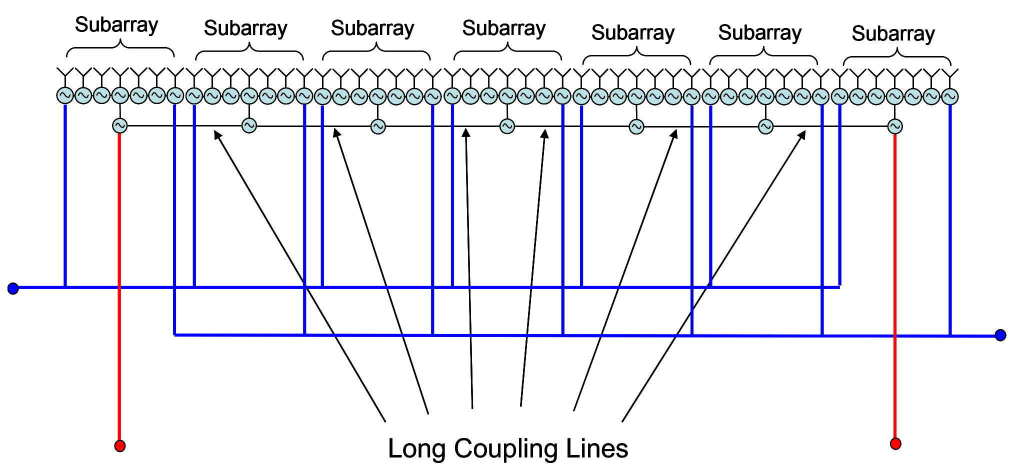

Figure 2. Large linear array of subarrays.

While during a beam steering transient period there arises some phase aberration over the array aperture, the primary effect is an overall slowing of the array response by a factor of 2d+1 where d is the coupling delay measured in inverse locking ranges. The remarkably simple result, while difficult to obtain intuitively, is predicted quite naturally by the theory. It means that the dynamic response of the hierarchical array will be different at each level in the hierarchy according to the coupling delay at that level. Thus, the transient response as viewed in terms of the beam behavior in the far field will be more complex than in the zero delay case but is easily predicted using the simple theoretical result mentioned above.

A triangular architecture is suggested for the hierarchical array based on the analysis of Pogorzelski as shown in Figure 3.[7] Here, although three tuning biases are required as opposed to the two used in the linear array, there exists a relationship among them resulting in only two degrees of freedom as might be expected. The figure shows a 435 element array which can become a building block sub-array for use in constructing a very large aperture.

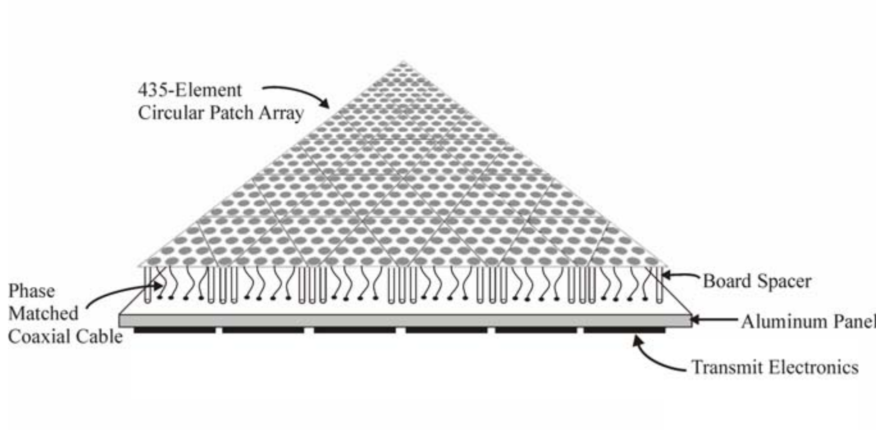

Figure 3. Concept of 435-element triangular coupled oscillator array.

4. Concluding Remarks

By taking advantage of spatial power combining in a phased array controlled by coupled oscillators, one may achieve transfer of large amounts of power wirelessly while avoiding high power densities. Thus, one need not use high power microwave components and sources with their attendant potential for hazardous breakdown and interference. Very large array can be both constructed and controlled hierarchically via sub-arraying. The ultimate practicality of such as system will depend heavily upon the scale-up of the assembly of the modest power solid state devices to very large numbers.

5. Acknowledgments

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6. References

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