Spatiotemporally modulated antennas

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Antennas are the basic tool we use to bridge structural modes into free-space radiation. The properties of an antenna depend on its geometry, materials, and electric size, as well as on its environment. These are the degrees of freedom that one typically has in an antenna design, which determine its characteristics such as directivity, gain, input impedance, radiation efficiency etc. However, one may ask what about the time variable? Can it be used as an additional degree of freedom, namely, would it be possible to increase the variety of properties of a given antenna by modulating its materials, or by loading its terminals by a time dependent resonant tanks?

For example, conventionally the antenna input impedance as function of frequency is fixed for a given structure. However, it can be shown that the input impedance of a spatiotemporally modulated antenna depends among others also on the modulation frequency and modulation depth, increasing the degrees of freedom the designer has.

Another example is reciprocity, a common property of antennas, implying that the radiation patterns in transmit and receive are identical. Usually this is an essential property in communication links. However, in a sense, it limits our ability to design a more involved communication network with limited number of antennas. In addition it is partially responsible to the increased noise level in high-power systems. Non-reciprocity can be violated by using magnet-based non-reciprocal phase shifters to non-reciprocally feed the elements of an antenna array. An advantage of these elements is their tunability by modifying the magnetic biasing which leads to the ability to have electronic beam forming. However, we show that one may dismiss the use of magnet-based phase shifters which are relatively bulky elements and instead use time modulated loads of the array elements. Thus, achieving non-reciprocal and electronically tunable radiation and matching properties with relatively simplified structure.

We study a general model consisting of transmission lines that are periodically loaded with lumped RLC networks. The resistor part models the radiation resistance. The resonance frequency of the LC tank is modulated in time and space by a low frequency signal that can propagate on the same structure as the RF signal and may have the same velocity. We show that the structure exhibits electrically tunable and, under certain conditions, also non-reciprocal radiation. The band diagram of the unmodulated structure splits and shifts into sub-bands each corresponding to different dominant space-time harmonic, and therefore possesses different wave characteristics. The additional degree of freedom obtained in this family of designs may have vast implications in the design of antennas and matching networks.