Antenna Miniaturization Beyond the Fundamental Limits

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Since the publication of Wheeler's 1947 paper on fundamental limits, most theoretical efforts have focused on defining these limits more accurately. The practical efforts have focused on designing antennas to reach those limits. Traditional antenna design limits the size of antennas with acceptable performance to about one-tenth of a wavelength. Smaller antennas exhibit larger losses, and thus lower efficiency. A true breakthrough is needed to satisfy requirements for small antennas. Such a breakthrough cannot be accomplished with traditional design approaches. The design philosophy presented, termed impedance modulation, promises to push past Wheeler's fundamental limits rather than simply approach them.

The fundamental limit for small antennas can be simplified to $Q=1/(ka)^3$, where k is the wave number, a is the minimum radius of a sphere which encloses a lossless antenna, and Q is the quality factor of the antenna. This simplifications arises from three conditions: the near field of the antenna has a single mode, TM_{01}, on the surface of the enclosing sphere; the antenna behaves in a linear manner; and calculations are in the frequency domain at a single frequency. The fundamental limit is valid if the antenna follows these conditions. To break the fundamental limits, one first needs to circumvent these conditions.

The input impedance of a narrowband antenna can be modeled as an *RLC* resonator around its resonant frequency. This input impedance is treated as a signal in the frequency domain. One can use the inverse Fourier transformation to transform this signal to the time domain. Because the real part of input impedance has even symmetries and the imaginary part has odd symmetries, the time domain input impedance is a real signal. Let's assume that the center frequency of an *RLC* resonator, ω_0, can be modulated with a known signal. A varactor-based tunable antenna is a good candidate for impedance modulation. Impedance modulation makes the structure time-variant which breaks an important condition of fundamental limits. As an example, a square wave is used as the modulation function, $f(t)$, for an impedance-modulated narrowband antenna for two simultaneous frequency bands. The square-wave frequency, f_T, has to be twice as fast as the widest frequency band of the operating channels (Nyquist sampling theorem). If more than two frequency bands are needed, one needs to use a multilevel signal instead of the square wave as $f(t)$. This method has been applied to a tunable narrowband antenna to achieve a multiband antenna. The measured return loss of the antenna confirms the dual frequency operation.