

Over-the-Air Transmission of Wideband, High-Order Digitally Modulated Waveforms at the HF Band Using a Non-LTI Electrically Small Antenna with Enhanced Bandwidth-Efficiency Product

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We present the design and measurement results of a non-linear-time-invariant (non-LTI) electrically small antenna (ESA) operating at the high-frequency (HF) band. This non-LTI ESA addresses the bandwidth-efficiency product limitations of passive, linear-time-invariant (LTI) ESAs. Due to the long wavelengths of electromagnetic waves in the HF band, practical HF antennas are typically electrically small, resulting in large quality factors and limited bandwidths of passive ESAs. These constraints are governed by well-established physical limits and have been thoroughly investigated and confirmed by many ESA designs. Different techniques, such as non-foster impedance matching, active matching, and direct-antenna modulation among others, have been investigated to overcome these limitations. These techniques do not violate the laws of physics. Rather, they violate the linear-time-invariance or passive operation assumptions used in the derivation of the fundamental physical limits.

In a recent work (*European Conf. Antennas Propag.*, Glasgow, UK, 2024, doi: 10.23919/EuCAP60739.2024.10501289), our team introduced a non-LTI ESA combining an electrically small radiator and a class-E switch-mode power amplifier. Simulations demonstrated this ESA could radiate wideband, digitally modulated waveforms with bandwidth-efficiency products exceeding the fundamental limits, with experiments confirming this expected performance using a dummy load emulating the antenna. In this work, we present experimental measurement results of the radiation of wideband, digitally modulated waveforms using a fabricated prototype of this non-LTI ESA. The fabricated non-LTI ESA prototype consists of a 1-m long monopole loaded with a series inductor at its base and a class-E switch-mode power amplifier employing a GaN transistor switch. The class-E amplifier drives the nearly resonant, low-impedance load. This system performs the tasks of RF carrier generation, power amplification, and digital modulation at the non-LTI ESA stage. Modulation of the radiated waveform is performed by applying pre-defined, pulse-width-modulated gate-driving signals (GDS) to the switch-mode circuit. Amplitude, phase, and frequency of the radiated waveforms are controlled by adjusting the duty cycle, timing, and frequency of the GDSs. Experiments were performed using this system in an outdoor antenna measurement facility at a frequency of 10.66 MHz. The antenna was characterized as part of a complete RF transceiver system in which the radiated waveforms were demodulated at the receiver and the bit-error-rate (BER) of the communications link was measured for different modulation schemes and symbol rates. Specifically, digitally modulated waveforms with ASK, BPSK, QPSK, and 8PSK at symbol rates ranging from 100 kHz to 1 MHz were successfully transmitted using this electrically small non-LTI antenna with a $ka = 0.26$ at 10.66 MHz. To compare the performance of this antenna with its LTI counterparts, similar OTA experiments are also conducted using a conventional LTI ESA transmitter with the same radiating element, an impedance-matching network, and a commercially available power amplifier. Measurement results quantifying the bandwidth-efficiency products of the LTI and NLTI ESAs will be presented and discussed at the symposium.

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