A Dynamic Pattern Dipole Antenna for Secure Wireless Communications

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***Abstract*—We present the design and measurement of a switched dipole antenna for directional modulation in a single antenna via radiation pattern dynamics. The antenna is fed by a single port, the output of which is fed to two locations on the dipole. By switching between the two states, the complex radiation pattern is quasi-static within a secure region in the mainlobe, and dynamic outside of the secure region. We show that the complex pattern dynamics outside the secure region impart additional modulation onto the radiation pattern that will distort transmitted or received data. We present the design of the dynamic pattern antenna and measured radiation patterns of the two antenna states. We numerically characterize the secure wireless capability through calculation of the bit-error-ratio on various digital modulations in communications, demonstrating the ability to maintain a small secure region.**

I. Introduction

Secure wireless operations for both communications and sensing can be implemented at the physical layer by dynamically changing the radiation pattern of the antenna. Such directional modulation techniques impart an angle-dependent time-varying modulation onto the transmitted or received signals, resulting in a distorted signal at angles outside of a region where the directional modulation is negligible, called the secure region [1]. Directional modulation techniques are generally implemented using electrically large arrays [2], where pattern reconfigurability is easier to implement. Reducing the size of systems that are capable of directional modulation has been explored through multi-port antennas [2], [3]. However, these systems are complicated due to the need for multiple simultaneous signal inputs and their designs are non-trivial.

We present the design of a pattern dynamic dipole antenna with a single signal input that can support secure wireless operations through directional modulation. In our prior work we explored the theoretical foundations of dynamic patterns in a single antenna [4]; here we demonstrate the concept through experiment. By switching the input between two feed points on a $3\lambda/2$ dipole antenna, we show that the radiation pattern results in sufficient diversity between the two states to significantly impact information transfer outside the mainlobe, while information transmitted through the mainlobe remains unaffected. We present the design of a 2.135-GHz switched dipole antenna that includes parasitic elements for increased gain. Measured radiation patterns of the two switched states demonstrate appreciable differences outside of the mainlobe. We characterize the secure wireless capability by evaluating the bit-error ratio (BER) as a function of angle for various modulation formats, demonstrating that the antenna maintains a secure region with negligible BER in the mainlobe while imparting high BER outside the center lobe.

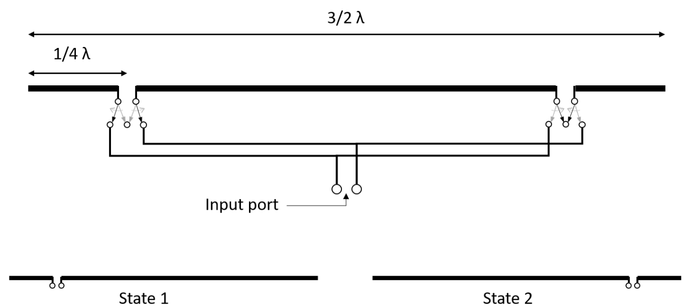

Fig. 1. Dynamic pattern dipole antenna concept showing the two states resultant from switching between two feed points. The mainlobe is consistent in both states, while the pattern outside the mainlobe is dynamic. By rapidly switching between the two states, the additional amplitude and phase modulation imparted on transmitted data by the sidelobe pattern differences can distort the information, providing a secure transmission in the mainlobe.

II. Switched Dipole Antenna Design

The dynamic pattern dipole antenna concept [4] is shown in Fig. 1. The antenna is a $3\lambda/2$ dipole, providing a small overall size compared to other directional modulation designs, but sufficient current variability as a function of feedpoint to impart pattern changes. A single signal is input to the antenna, which is then switched between two locations $\pm\lambda/2$ from the center of the dipole. The feed locations are designed such that the mainlobe is constant while the pattern outside the mainlobe changes appreciably between the two states. Switches are connected to the feed structure to ensure continuity of the current at the port that is not being fed, yielding an asymmetric dipole with an asymmetric radiation pattern. Switching between the two states at a rate equal to that of the information rate results in a modulation of the amplitude and phase of the transmitted signal. If the dynamic pattern modulation is appreciable compared to the signal modulation the information will be distorted. For a communications signal, the result is that demodulated symbols manifest at incorrect locations on the constellation diagram, rendering the information unrecoverable.

We designed and fabricated a printed dipole with two parasitic elements to enhance the directivity, shown in Fig. 2.

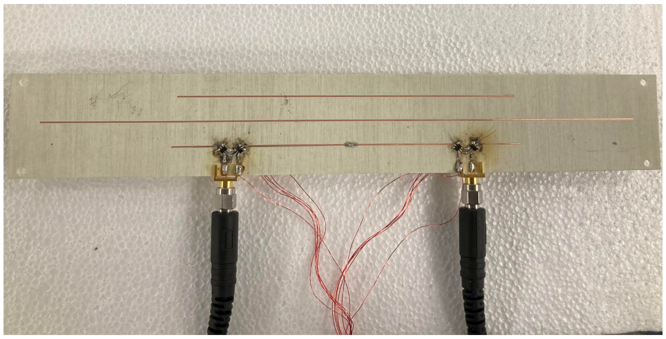

Fig. 2. The fabricated dynamic pattern dipole antenna. Two parasitic elements provide increased gain in the main lobe.

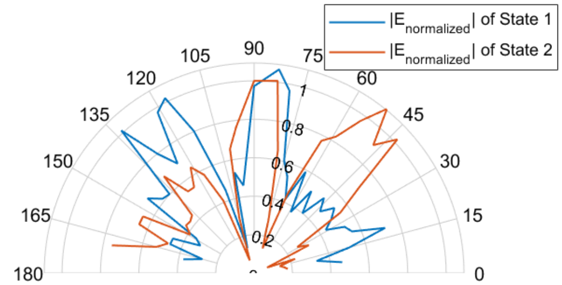

Fig. 3. Measured electric fields patterns (normalized) of the prototype switched dipole antenna.

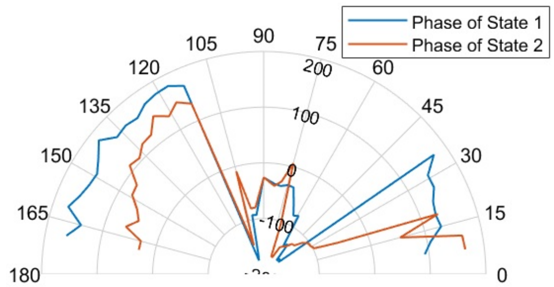

Fig. 4. Measured phase patterns of the prototype switched dipole antenna after making the phase static at 90°.

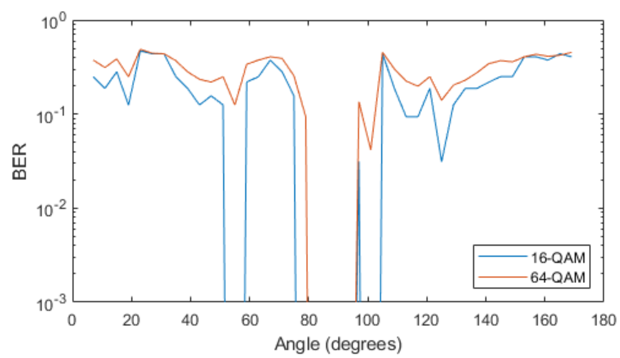

Fig. 5. Bit error rate resulting from the measured amplitude and phase patterns for 16-QAM and 64-QAM communication signals. The larger amplitude and phase differences of the symbols in the higher order modulation schemes make the information more susceptible to distortion from the pattern modulation.

The simulated design resulted in a large gain in the main-lobe and sufficient differences in the sidelobe structure to support sufficient amplitude dynamics to achieve directional modulation. Four switches were connected along the dipole to achieve the two states. The antenna radiation was measured in a semi-enclosed anechoic range in the far-field. The measured normalized electric fields and phase patterns are shown in Fig. 3 and Fig. 4, respectively. A constant phase shift was added to the resulting phase pattern of one state to match the phases at 90° representing a one-time static phase calibration. The fields are static around 90°, thus when switching between the two states, transmitted information will remain largely unaffected, yielding a secure region. In the other directions there is appreciable amplitude and phase dynamics which will add modulation to any transmitted or received data when the pattern is dynamically switched.

To evaluate the directional modulation capabilities, we characterized the ability of an eavesdropper to recover information of a transmitted communication signal by evaluating the BER as a function of angle of a pseudo-random bit sequence (PRBS) for 16-QAM and 64-QAM). The PRBS was modulated by the dynamic pattern amplitude and phase characteristics. The worst-case scenario was considered where the channel was noise free and the bit rate and modulation order were known to the eavesdropper. The resulting BER versus angle is shown in Fig. 5. The results show that for both 16-QAM and 64-QAM, the BER is very low only in the secure region, and out side the secure region the BER is above 10^{-3}, which is beyond what current forward error correction can recover. Generally, higher order modulations yield narrower secure regions, since at higher order schemes then the symbols in the constellation diagram are closer together and less tolerant to additional modulation. These results demonstrate that a simple switched antenna can generate sufficient antenna pattern diversity to impart modulation onto transmitted or received data, providing a method for secure wireless operation.

Acknowledgment

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References

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