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Waveform-Selective Devices for Antenna Applications

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Abstract

In this contribution, we investigate several examples of antenna applications of waveform-selective devices, i.e., structures exhibiting different responses depending on the waveform of the incoming waves. In particular, as a first example, we describe an open-ended waveguide capped with an iris band-pass filter loaded with a lumped-element circuit. Thanks to the frequency- and time-domain selectivity properties of the loaded iris, the aperture antenna exhibits different radiating patterns depending on the waveform of the transmitted/received signal. Then, the same lumped-element circuit is used to design an antenna that is made invisible/visible to either a short pulse or a continuous signal. Exploiting a peculiar meandered cloaking metasurface loaded by the lumped-element circuit, the cloaking effects is automatically turned on/off depending on the time-domain characteristics of the incoming signal. This study aims paving the way for the design of antenna systems equipped with both frequency- and time-domain selectivity properties.

1 Introduction

In the last decades, metamaterials and metasurfaces have introduced unprecedented flexibility in antenna design, enhancing performance of conventional antennas [1, 2] or enabling innovative functionalities, such as blockage effect reduction between close antennas [3, 4, 5], improved absorption efficiency of receiving sensors [6], interference minimization in nanosatellite systems [7, 8], up to the concept of metasurface antennas [9]. At the same time, waveform-selective metasurfaces, i.e. devices able to distinguish between different waveforms have been introduced [10, 11, 12]. In this case, the system behavior not only depends on the frequency of operation, as conventional electromagnetic devices, but also on the waveform of the propagating signal. This concept has been exploited first for designing metasurface-based structures able to absorb high-power pulses while allowing propagation of low-power signals [10]; then, it has been used for designing devices able distinguishing between a short pulsed wave (PW) or a continuous wave (CW) signal. Such a waveform-selective mechanism is made possible by loading conventional metasurfaces with lumped-element circuits, exploiting the peculiar transient response of a capacitor or/and inductor.

Recently, the potentialities of this new degree of freedom for the design of novel antenna systems has been explored. In [12], the idea of a waveform-selective mantle cloak able to hide a wire antenna depending on the pulse width of the incoming signal has been conceived. In [13], it has been designed an antenna system where the communication between different monopoles connected by a waveform-selective metasurface is allowed just for specific time slots, through the control of the traveling surface waves.

In this contribution, we aim at further expanding the potentialities enabled by waveform-selective devices in antennas scenarios. In particular, with the aid of different examples, we will show that engineered waveform-selective devices can be successfully used to modify the radiative characteristics of antennas depending on both the frequency and time-domain characteristics of the transmitted/received signals.

2 Waveform-Selective Circuit

A waveform-selective metasurface can be designed using peculiar lumped-element circuits, exploiting a diode bridge and electronic passive elements like resistors (R), capacitors (C) and inductors (L) [10-15]. In Figure 1, the detailed circuit configuration is reported, where the RL or RC elements are loaded in parallel to the diode bridge. Here, the diode bridge rectifies the signal at the input port mostly at zero frequency, and the rectified signal is applied to the RLC elements.

In particular, in the case of RL series load (Figure 1 (a)), thanks to the transient time-domain response of the inductor, a strong electromotive force initially opposes to the flow of current in the circuit. Thus, during the transient response, the circuit behaves as a high-impedance bipolar element. However, this opposing force decreases over time, and almost unlimited current can flow in the circuit. In other terms, after an initial transient, the circuit behaves as a low-impedance element. Therefore, for a short-pulsed signal the circuit behaves as an open-circuit element, while it behaves as a short-circuit for a continuous wave signals persisting over time. Conversely, in the RC parallel case (Figure 1 (b)), at the first moment a strong current can flow along the circuit since the capacitor behaves as a low-impedance element. However, the capacitor quickly charges up, behaving finally as a high-impedance element. For a short-pulsed signal, thus, the circuit behaves as a short-circuit element, while it behaves as an open-circuit for a continuous wave signal.

Consequently, the circuit is able responding differently for long and short pulses, even at the same input frequency [11]. Changing its behavior from an equivalent short-circuit to an open-circuit configuration, acting essentially as a waveform-dependent switch.

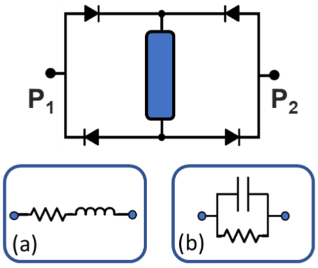

Figure 1. Wavefrom-selective circuit composed by a diode bridge rectifier and: (a) a series RL circuit, (b) a parallel RC circuit.

3 Aperture Antenna with Frequency and Time-Domain Selectivity

The proposed waveform-selective circuit can be exploited for conceiving a radiating structure able filtering out undesired spectral components and, at the same time, able radiating/receiving only electromagnetic signals with specific time-domain characteristics. In particular, capping an open-ended rectangular waveguide with a filtering iris, and then loading the filtering inclusion with the circuit previously reported, an aperture antenna exhibiting waveform-selective radiating properties can be realized (Figure 2).

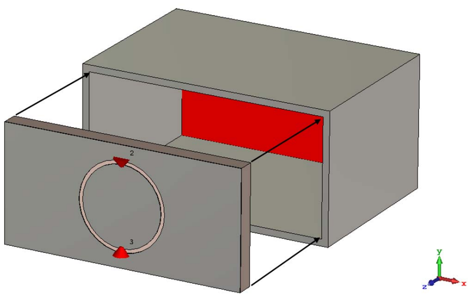

Figure 2. Perspective view of the waveguide filtering antenna consisting of a WR284 waveguide section capped by the circuit-loaded iris.

As discussed in [2], the circular iris allows the propagation of an electromagnetic field whose characteristics are determine by the boundary conditions imposed by the waveguide walls and the frequency response of the iris itself. Thus, the waveguide antenna operating bandwidth is controlled by the filter response. However, the iris by itself is not able distinguishing between signals at the same frequency, even though their time-domain behaviors are different. To add this functionality the previous reported circuit is loaded onto the central metallic disk of the iris, connecting the external part of the structure [14].

Through a proper set of circuital-electromagnetic co-simulations, we have analyzed the radiating properties when the iris is loaded with the RC-based diode bridge circuit of Figure 1 (b). As can be appreciated in Figure 3 from the radiation patterns of the antenna in the E- and H-plane, due to the time-domain behavior of the circuit, the antenna has poor radiation performances for a short pulse (pulse width T_{PW} = 10 ns), since the filtering iris is short-circuited. On the contrary, when the pulse width of the signal transmitted/received by the antenna is increased (pulse width T_{PW} = 1000 ns), the open-circuit condition of the iris is restored and the radiation performances resemble the ones of the unloaded filtering antenna.

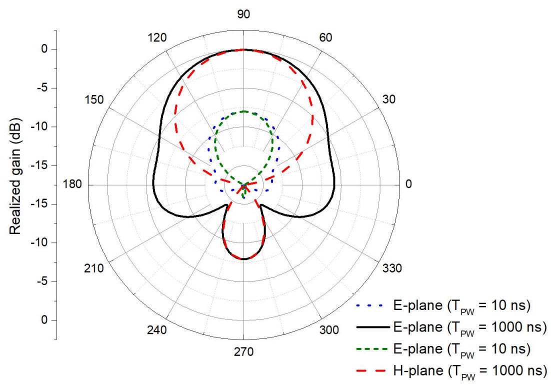

Figure 3. Realized gain radiation diagram on the E- and H-plane of the waveform selective filtering antenna for different pulse width values at 3 GHz.

4 Waveform-Dependent Invisibility for Wire Antenna

The same approach can be used to control the scattering properties of an antenna when it interacts with either a pulsed wave or a continuous wave signal and, in particular, for designing a wire antenna able to hide/show itself depending on the waveform of the received signal. Through the use of a waveform-dependent mantle cloak, whose cloaking metasurface is loaded with a waveform-selective circuit, it is possible to make an antenna invisible to the pulsed signal of a detecting radar, while allowing the antenna to communicate with a base-station through a continuous waveform characterized by a large pulse width.

Following the mantle cloaking approach for antennas [3-6], a cloaking device for a wire dipole antenna operating at 3 GHz has been designed. The mantle cloak exploits a peculiar meander-like metasurface whose meander is loaded by a RL series waveform-selective circuit, as reported in the inset of Figure 4 [15]. As can be appreciated in this figure, the scattering behavior of the dipole antenna once coated with the unloaded meander-like cloaking metasurface changes when forcing an open/short circuit condition of the meander, due to the induced variation of the cloak surface impedance. In particular, when the point P1 and P2 of the meander are open-circuited, the scattering signature of the antenna is reduced at operating frequency since the surface impedance assumes the designed cloaking value. Conversely, when the point P1 and P2 are short-circuited, the surface impedance of the cloak changes and the cloaking resonance shifts, restoring the original scattering behavior of the uncoated antenna.

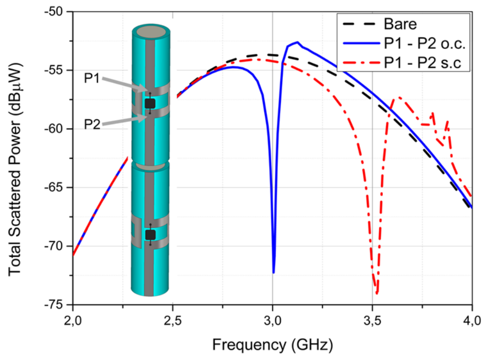

Figure 4. Total scattered power of the antenna in the case without the cloak (bare case), and when the antenna is cotaed by the menader-like metasurface with P1, P2 in open-circuit or short-circuit condition.

These switching behaviors are confirmed when the mantle cloak is loaded with the actual waveform-selective circuit and the antenna is excited by either a PW or a CW signal. Once loaded at the meander points the RL-based diode bridge circuit of Figure 1 (b), we have analyzed the radiating properties of the antenna with a set of circuital-electromagnetic co-simulations. As can be appreciated in Figure 5, where the radiation patterns of the coated dipole antenna in both the E- and H-planes are reported, the antenna has poor radiation performances for a short pulse (PW), due to the turn-on of the cloaking effect and the reduction of its scattering signature. On the contrary, when the pulse width of the signal transmitted/received by the antenna is larger (CW), the radiation performances match the ones of the uncoated antenna, since the cloaking effect turns off because of the short-circuiting of the meanders.

5 Conclusions

In this contribution, we have analyzed the potentialities of waveform-selective metasurfaces for designing innovative radiating devices. The designed antennas are able discriminating between different waveforms, even at the same frequency, depending on the pulse width of the transmitted/received signals.
In particular, we have reported the design of an aperture waveguide antenna capped with a filtering iris, loaded by a waveform-selective circuit, able to exhibit both frequency- and time-domain selectivity properties. Then, we have reported the design of an antenna able to automatically hide/show itself depending on the waveform of the received/transmitted signal. A circuit-loaded meandered metasurface exhibiting different values of the surface impedance in presence of either PW or CW exciting signal has been used to cloak a dipole antenna. Thanks to the peculiar waveform-dependent cloaking effect, the antenna switches from an invisibility state for radar pulsed signals, to its original scattering characteristic for a continuous waveform signal.

Further details and examples of antenna applications exploiting the new degree of freedom of waveform selectivity will be shown at the conference.

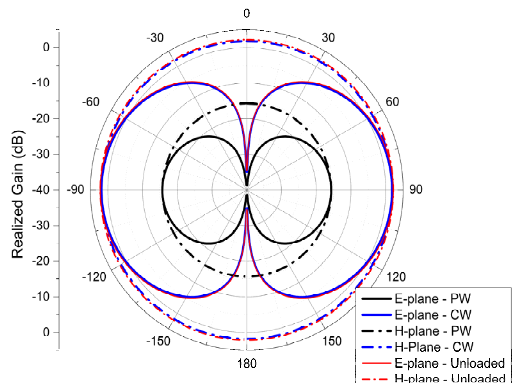

Figure 5. Realized gain radiation diagrams of the antenna evaluated on the E- and H- planes at 3GHz for a pulsed waveform signal (PW), a contiunous waveform (CW) signal, and in the unloaded scenraio.

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