Non-Foster Self-Oscillating Huygens Radiator

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***Abstract*— A recently proposed concept of a self-oscillating non-Foster antenna is extended to a Huygens radiator. The system is comprised of two orthogonal pairs of electric and magnetic near-field parasitic radiators, each of which is driven by a small electric dipole. The input ports of the driving dipoles are connected to a floating negative impedance converter, thus forming a broadly-tunable and nearly perfectly matched self-oscillating system. The developed concept is verified with a series of full-wave/circuit theory (CST/ADS) co-simulations. Obtained results reveal self-oscillations that can be tuned within a 1:1.5 frequency range, with familiar cardioid radiation patterns.**

Keywords—active antenna, active metasurface, Huygens radiator, non-Foster, oscillator

I. INTRODUCTION

The concept of a self-oscillating non-Foster radiating system has been proposed recently [1,2]. Briefly, it is comprised of two identical orthogonally polarized antennas that are mutually connected via a negative impedance converter NIC (Fig. 1).

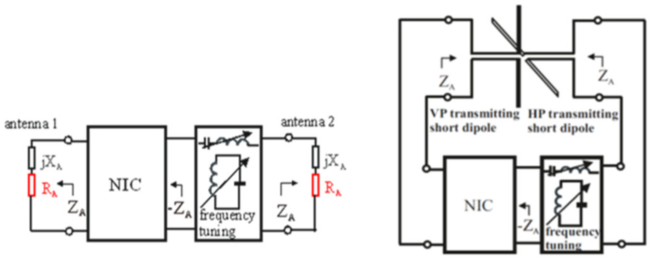

Fig. 1 **Left** – Basic idea of non-Foster self-oscillating radiating system with two antennas, **Right** – Realization with two short orthogonal dipoles [1,2]

In the case of the ideal NIC, the self-admittance of the first antenna (Y_A) is cancelled entirely by its 'negative image' ($-Y_A$) at every frequency. This cancellation causes self-oscillations at a frequency that can be adjusted by tuning the circuit across (theoretically) an infinite bandwidth with perfect matching. An extensive study [2] reported the use of the system shown in Fig.1 (with two short dipoles) as the unit cell of a self-oscillating metasurface. Experimental results with a scaled RF prototype [2] confirmed self-oscillations with nearly perfect matching and tuning ranges of 1:2 to 1:3.

A self-oscillating metasurface with an array of unit cells constructed according to the right part of Fig. 1 would radiate both in the forward and backward directions (due to the basic symmetrical dipole radiation patterns). In order to obtain a unidirectional radiation performance, e.g., only in the forward direction, one may think of a self-oscillating metasurface with Huygens elements as its unit cells. In this contribution we report a design and full-wave/circuit theory (CST/ADS) co-simulations of a non-Foster self-oscillating planar Huygens radiator.

II. NON-FOSTER SELF-OSCILLATING HUYGENS RADIATOR

A Huygens metasurface usually contains inclusions that are comprised of both electrically small electric and magnetic radiators [3]. Unfortunately, such an inclusion does not contain a single feeding port and, as a consequence, cannot be used to realize a non-Foster self-oscillating system (Fig.1). It was decided to modify a recently introduced miniaturized planar Huygens antenna [4], [5] to achieve this functionality. A sketch of the modified design is shown in Fig. 2.

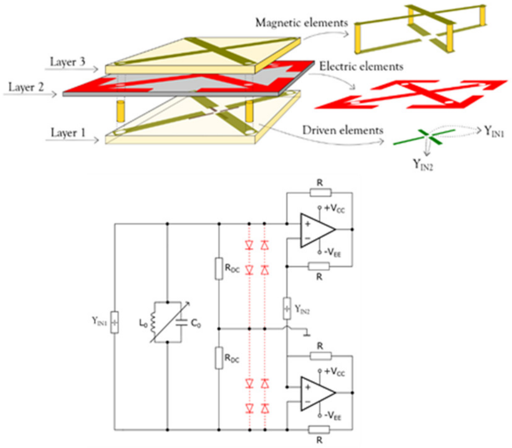

Fig. 2 **Upper -** Dual polarized planar Huygens antenna with two feeding ports, **Lower -** Differential NIC with frequency tuning network (the design details can be found in [2]).

On the bottom of the first layer, there are two orthogonal, driven dipoles, each equipped with an independent feeding port. These dipoles are electromagnetically coupled to two pairs of near-field resonant parasitic (NFRP) elements. The first pair of NFRP elements is comprised of orthogonal, capacitively loaded magnetic dipoles, i.e., the loops formed by the horizontal conductors lying on Layers 2 and 3 connected by the four vertical vias which act as their "end" conductors. The loops are strongly coupled to the two orthogonal electric dipoles with top-loaded capacitances located on Layer 2. From a miniaturization point of view for microwave applications, it would be desirable to use dielectric substrates for all of the layers [5]. However, it is extremely difficult to manufacture discrete NICs that operate in the microwave bands. Thus, we plan for the proof of concept to use scaled RF experiments with ‘low-frequency’ discrete NICs and the antenna elements ‘printed’ on foam [2].

Consequently, we choose to develop an initial design for the 30 MHz RF band using styrofoam layers (ε_r=1). The antenna’s footprint is 2.3 m x 2.3 m (0.23λ × 0.23λ). The floating NIC (lower part of Fig. 2) is based on two high-speed THS 4304 operational amplifiers and is equipped with diode limiters to prevent non-linear operation and to improve the conversion accuracy [2]. Note that there is a slight difference between the operation of the self-oscillating Huygens antenna (Fig. 2) and the self-oscillating unit-cell reported in [5]. The system in [5] uses two dipole-like ‘bare’ subwavelength radiators, the self-admittances of which are mutually cancelled by virtue of the NIC operation. The system in Fig. 2 also uses two subwavelength radiators. However, they are resonantly matched by tuning the electromagnetic near-field couplings. Subsequently, the self-admittances of these radiators are broadly cancelled by the NIC. In this sense, our approach is similar to the resonant non-Foster matching reported in [6].

The electromagnetic (EM) field part of the self-oscillating Huygens radiator (upper part of Fig. 2) was simulated in the CST^{TM} environment. The electric (dipoles) and magnetic (loops) radiators were initially simulated separately. They were driven by simple voltage generators and their dimensions were adjusted until the same resonant frequency (26.5 MHz) was achieved. These radiators were then integrated into the proposed configuration (upper part of Fig 2) and all of their dimensions, together with the distances between the radiators and the driven dipoles, were optimized. A sample of simulation results for the optimized design is given in Fig. 3. One sees that the system is reasonably matched at both ports (return loss of 9 dB) within a narrow frequency band (1.0 MHz bandwidth, 2.6% fractional bandwidth). The familiar cardioid radiation patterns were obtained with a peak broadside directivity of 2.3 dBi. These results also indicate that the cross coupling between the orthogonal radiators is lower than -40 dB. Such a low coupling will contribute to an accurate ‘negation’ of the antenna’s admittance by the NIC and will ensure stable self-oscillations over a broad tuning range [2].

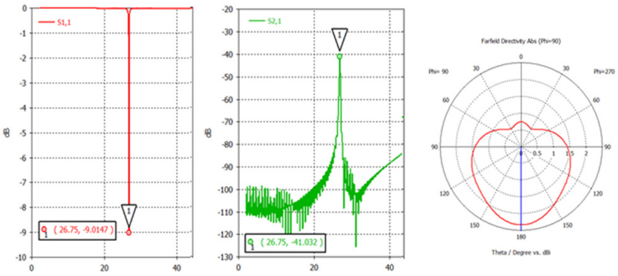

Fig. 3 The CST^{TM} simulation results for the bare Huygens antenna with the NFRP crossed dipoles and loops. **Left:** Return loss, **Middle**: cross coupling (Z_0=10Ω). **Right:** radiation patterns.

The self-oscillation properties were investigated with subsequent ADS simulations. The 2×2 scattering matrix of the system from the left part of Fig. 2 was imported into an ADS^{TM} SPICE-based model of the differential NIC [2]. A series of simulations were performed; the obtained results are shown in Fig. 4.

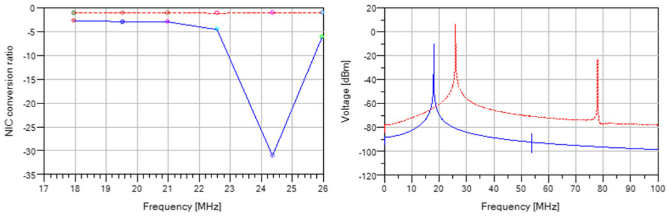

Fig. 4 The ADS^{TM} simulation results for Huygens antenna with crossed dipoles and crossed loops, connected the NIC. **Left**: Simulated NIC input admittance normalized to the input admittance of an ideal NIC, **Right**: simulated spectrum of self-oscillating signal for two tuned frequencies

The first set of simulations (left part of Fig. 4) compared the ‘negated’ antenna admittance with the admittance obtained using an ideal NIC. It was found that the NIC conversion errors are most pronounced at frequencies below the resonance. They are negligible close to the resonance. The analysis and experiments in [5] showed that these conversion errors are proportional to the load (antenna) Q factor. The (effective) antenna Q factor is lowered in the vicinity of the resonance, which decreases the NIC conversion error. The next set of simulations investigated the spectrum, power, and tuning range of a self-oscillating signal. The results are quite similar to those in [2] showing radiated power up to -6 dBm with more than 20 dB suppression of the harmonic components. The tuning range is about 1:1.5, i.e., a broadband admittance cancellation is demonstrated in spite of the fact that the bare radiators are inherently narrowband.

III. CONCLUSIONS

The concept of a non-Foster self-oscillating unit cell for active metasurface, previously demonstrated by the use of two orthogonal short dipoles, was extended to a Huygens radiating element. The EM/circuit theory simulations revealed stable self-oscillations that can be tuned across a 1:1.5 bandwidth while maintaining familiar cardioid-like radiation patterns. Realization of a 30 MHz scaled demonstrator is in progress and preliminary results will be presented at the conference.

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The work has been supported by the HRZZ Grant No. IP 2018-01-9753, “Electromagnetic Structures for Emerging Communication Systems”.