Passive Microwave Planar Circuits for Arbitrary UWB Pulse Shaping

I. Arnedo, *Student Member, IEEE*, J. D. Schwartz, *Student Member, IEEE*, M. A. G. Laso, *Member, IEEE*, T. Lopetegi, *Member, IEEE*, D. V. Plant, *Fellow, IEEE*, and J. Azaña, *Member, IEEE*

***Abstract*—We propose and demonstrate a new technique for generating customized pulse-shapes intended for use in ultra-wideband (UWB) applications. The technique employs tailored microstrip lines that have been designed using an exact analytical series solution of the synthesis problem derived from the coupled mode theory. This solution permits the synthesis of waveguides and transmission lines with arbitrary impulse responses limited only by the principles of causality, passivity and stability. Time-domain measurements are performed demonstrating the generation of two pulse-shapes using microstrip circuits and satisfying pre-established UWB mask requirements.**

***Index Terms*—Filter synthesis, impulse-radio, microstrip technology, pulse shaping, ultra-wideband (UWB).**

I. Introduction

RESEARCH on ultra-wideband (UWB) systems has been spurred by the Federal Communications Commission (FCC) granting unlicensed use of the 3.1 to 10.6 GHz frequency band for signals with spectral power density below −41.2 dBm/MHz [1]. Numerous applications have been targeted for UWB technology, including high data-rate wireless communication [2], [3], homeland security [4], and specialized radar imaging [5], [6]. Many of these applications require pulses with tailored shapes [7], [8]. Several techniques for generating customized UWB pulse waveforms have been proposed in both CMOS technology [9] and using photonics components [10]. CMOS solutions are limited in regards to the temporal shapes that can be practically synthesized [9] and optical hardware tends to be costly and difficult to integrate with microwave technologies [10].

We have recently reported a general synthesis method [11], which allows designing waveguides and transmission lines with nearly any target impulse response. Based on this method, we propose here a novel microwave solution for arbitrarily reshaping a given temporal impulse (generated, for instance, by a conventional impulse generator) into any desired UWB pulse waveform. The proposed approach is demonstrated by experimentally generating, with simple microstrip circuits, two different pulse waveforms complying with the FCC-defined mask.

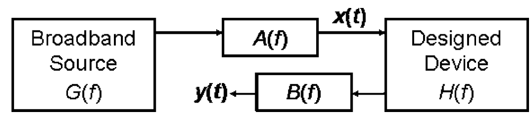

Fig. 1. General schematic of the UWB pulse shaper demonstration.

II. Design of UWB Pulse Shapers

We begin the discussion of UWB pulse synthesis by assuming some practical impulse generator creating impulses with spectrum $G(f)$. Our aim is the design of a pulse-shaping device of frequency response $H(f)$, see Fig. 1, for *ad hoc* UWB signal generation. Some application-dependent auxiliary devices (e.g., antennas, directional couplers, power dividers) with responses $A(f)$ and $B(f)$ known *a priori* may be also taken into account during the design. Let $x(t)\,[X(f)]$ and $y(t)\,[Y(f)]$ be the input excitation and desired UWB output response in time [frequency], respectively.

We obtain the frequency response of the waveguide or transmission line to be synthesized, $H(f)$, from the desired UWB output response $Y(f)$ by means of:

$$H(f) = \frac{Y(f)}{X(f)\cdot B(f)} \cdot e^{-j\cdot 2\cdot\pi\cdot f\cdot\tau_d} \tag{1}$$

where a linear phase term has been added to ensure causality (i.e., τ_d is some arbitrary delay).

In order to synthesize a waveguide or transmission line with a given frequency response, $H(f)$, only limited by causality, stability and passivity, we use [11, eq. (32)] to obtain its coupling coefficient, $K(z)$, where $H(f)$ is implemented by means of the reflection parameter, $S_{11}(f)$, of the synthesized device. Once the coupling coefficient is known, the physical parameters can be obtained using [11, eq. (9)].

III. Examples of Synthesis of *ad hoc* UWB Pulses

To verify the suitability of the proposed method to generate ad-hoc pulses, we used the experimental setup shown in Fig. 2, where a commercial impulse generator (Picosecond Pulse Labs 3600) and a commercial directional coupler (Pulsar CS08-15-

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I. Arnedo is with the Electrical Engineering Department, Public University of Navarre, Pamplona 31006, Spain and also with the Institut National de la Recherche Scientifique Energie, Matériaux et Télécommunications (INRS-EMT), Montréal, QC H5A 1K6 Canada.

J. D. Schwartz and D. V. Plant are with the Photonics Systems Group, Department of Electrical and Computer Engineering, McGill University, Montreal, QC H3A 2A7, Canada.

M. A. G. Laso and T. Lopetegi are with the Electrical and Electronic Engineering Department, Public University of Navarre, Pamplona 31006, Spain.

J. Azaña is with the Institut National de la Recherche Scientifique Energie, Matériaux et Télécommunications (INRS-EMT), Montréal, QC H5A 1K6, Canada.

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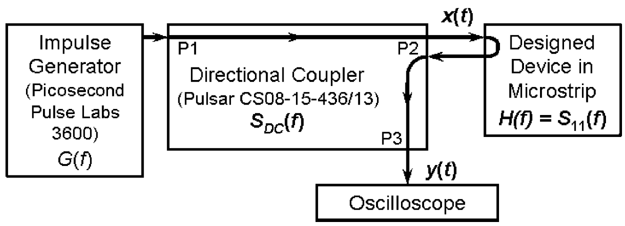

Fig. 2. Experimental setup.

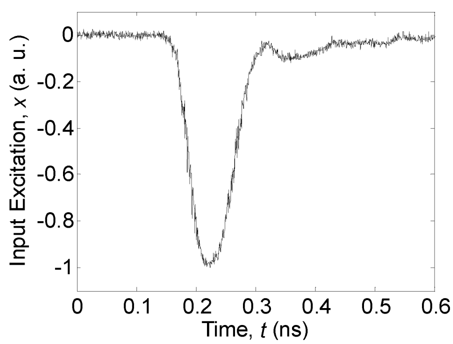

Fig. 3. Input excitation, $x(t)$.

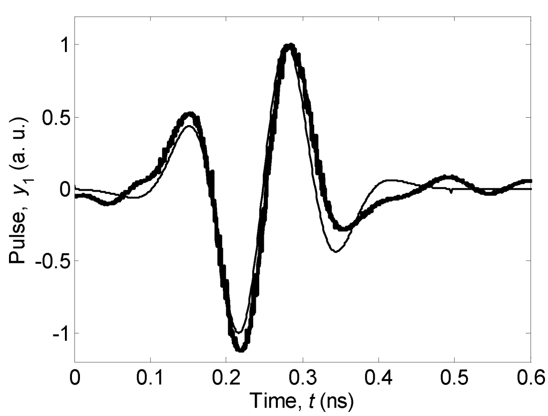

Fig. 4. Fourth-derivative of a Gaussian monocycle (Pulse #1): target signal (thin line), and measurement (thick line).

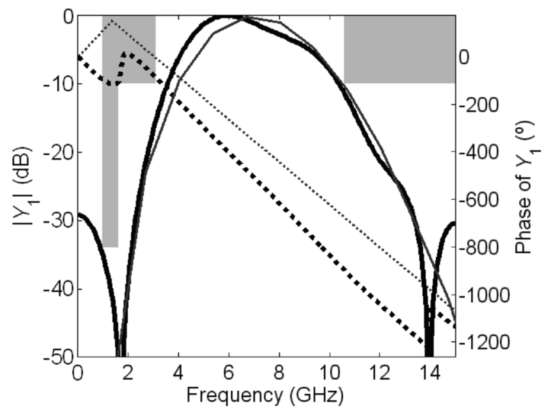

Fig. 5. Spectrum (magnitude in solid line and phase in dotted line) of the target signal (thin line) and Fourier-transformed measurement (thick line) for Pulse #1. FCC mask for UWB is also shown in grey.

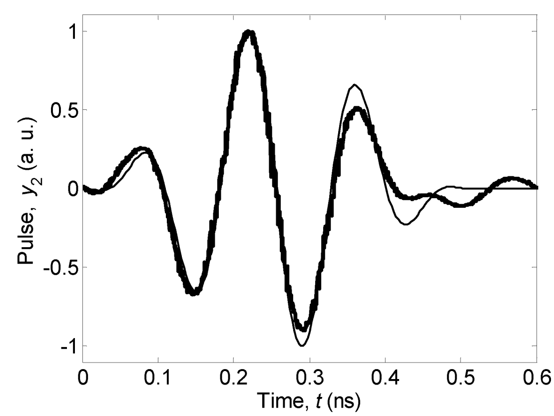

Fig. 6. Sinusoidal waveform windowed by a squared-cosine (Pulse #2): target signal (thin line), and measurement (thick line).

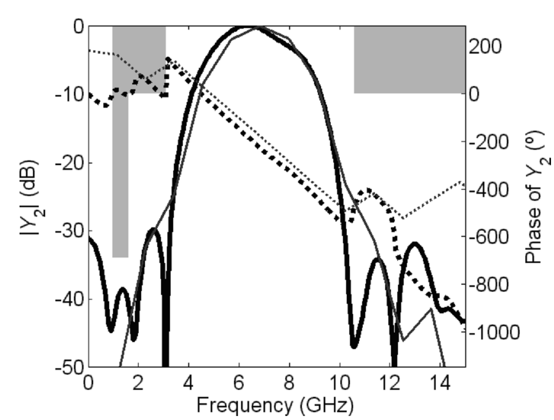

Fig. 7. Spectrum (magnitude in solid line and phase in doted line) of the target signal (thin line) and Fourier-transformed measurement (thick line) for Pulse #2. FCC mask for UWB is also shown in grey.

436/13) have been selected to generate the input excitation, $x(t)$, whose measurement is shown in Fig. 3. The excitation signal introduced in the designed device, synthesized in microstrip technology, produces as response a reflected signal that is routed to the oscilloscope through the other branch of the commercial directional coupler. According to (1), the target pulse is obtained if the designed device satisfies (2)

$$S_{11}(f) = \frac{Y(f)}{X(f) \cdot S_{DC32}(f)} \cdot e^{-j \cdot 2 \cdot \pi \cdot f \cdot \tau_d}. \quad (2)$$

As a demonstration, two signals complying with the FCC mask have been chosen. We first sought to generate the fourth derivative of a Gaussian monocycle [7] (Pulse #1), with $T_c = 0.25$ ns and $T_{au} = 0.102$ ns

$$y_1(t) = \frac{d^4}{dt^4}\left(A \cdot \frac{t - T_c}{T_{au}} \cdot e^{-2 \cdot ((t - T_c)/T_{au})^2}\right) \quad (3)$$

shown with a thin line in time domain in Fig. 4, and in the frequency domain in Fig. 5. The FCC mask is included for verification purposes. We then aim to synthesize a sinusoidal waveform windowed by a squared-cosine (Pulse #2), with $T_c = 1.75/f_o$ and $f_o = 6.58$ GHz (Figs. 6 and 7, thin lines)

$$y_2(t) = -A \cdot \sin(2\pi \cdot f_0 \cdot (t - T_c)) \cdot \left[\cos\left(\frac{\pi \cdot (t - T_c) \cdot f_0}{3.5}\right)\right]^2. \quad (4)$$

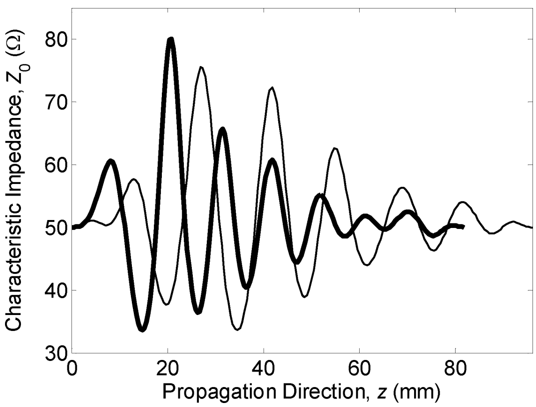

Fig. 8. Characteristic impedance profile of the designed microstrip circuit for Pulse #1 (thick line) and Pulse #2 (thin line); total circuit lengths are 82 and 96 mm, respectively.

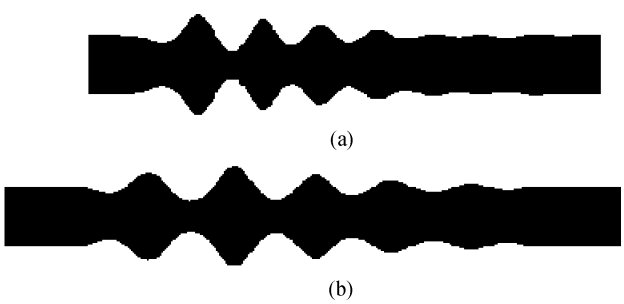

Fig. 9. Sketch of the conductor strip-width for the microstrip designs: a) Pulse shaper #1 and b) Pulse shaper #2. (Not to scale).

As discussed in Section II, the necessary coupling coefficients of both pulse-shapers have been calculated using [11]. Their corresponding characteristic impedance profiles have been obtained from [11, eq. (45)] and are shown in Fig. 8. It is important to highlight that although the impedance variation range that can be achieved in a practical device is limited, the impedance excursion only fixes the maximum variation range of the coupling coefficient, but not its shape. Consequently, the shape of the achievable impulse response is not limited in practice. The technological constraints can be overcome by scaling down in magnitude the target $S_{11}(f)$ (multiplying it by a constant minor than one), thus achieving the required reduction in the coupling coefficient excursion.

We fabricated the microstrip circuits (Fig. 9) to match these characteristic impedance profiles by continuously varying the conductor strip-width according to classical microstrip design formulas [12]. The substrate employed was an RT/DUROID 5880 (thickness $h = 0.508$ mm, $\varepsilon_r = 2.2$) having 50 Ω ports. Time-domain measurements of the output signals (performed using a Tektronix CSA 8000 oscilloscope) are presented in Figs. 4 and 6 (thick lines), where they are compared to the target signals. Finally, the numerical Fourier transforms of the measured time-domain signals (using time-gating to remove spurious reflections) are compared to the target spectrum in Figs. 5 and 7.

Good agreement is observed between the target pulse shapes and spectra, and the corresponding measured results, which clearly satisfy the UWB FCC mask. Slight differences can be attributed to connectorization, device losses and fabrication tolerances which were not taken into account in the design procedure.

IV. Conclusion

A passive and easily integrable microwave solution for arbitrarily reshaping a given temporal impulse into any desired UWB pulse shape has been proposed and demonstrated. As a proof-of-concept, two different UWB pulses fitting the FCC spectral mask have been generated using simple microstrip circuits. The proposed technique is based on a general synthesis method, previously developed by the same authors, that makes possible any target impulse response with the tailored microwave guide, the method being constrained only by causality, passivity and stability. The technique is also amenable to any additional auxiliary elements required by the system, provided their frequency responses are known *a priori*. This may include a model of the channel, which could help minimize distortion of the received pulse.

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