Non-Linear Transmission Lines for Pulse Generation, Compression, Shaping, and Transmission for Ultrafast Electronics

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***Abstract*— This report aims to summarize the latest progress of the 2022 MTT fellowship awardee's Ph.D. project partly supported by the 2022 MTT-S Graduate Fellowship Program. This work proposes a complete ultrafast wireless system in support of transmission and reception of picosecond ultrashort pulses by estimating and incorporating various antenna effects. Pulse generators based on simultaneous rise and fall time compression are developed and the techniques for the combination of ultrashort electrical transients are studied and discussed. Theoretical demonstration is conducted by transforming the concept of soliton and shock waves from the hydrodynamics domain to the corresponding electrical domain.**

***Keywords*—Picosecond pulse transmission, Picosecond pulse reception, Pulse generator (PG), Picosecond pulse shaping, Ultra-fast electronics, and nonlinear transmission line.**

I. INTRODUCTION

With the advent of microfabrication techniques and microsystem developments, the timescale of electronic devices and measurement systems are continuously shrinking for fast response and ultra broadband, which need an ultrashort pulse generator such that they meet a required range or other parametric measurement resolution in different applications such as target detection, vital signs monitoring, and radar communication applications. Interestingly, the chronological progress of pulsed-based time resolution or time response for electronics and instrumentations, for example, can be well reflected through the following observation. The early development of the 1950s were focused on 100ns intervals of time for electronic instrumentation, which was significantly improved to 10ns then in the 1960s. By the 1970s-1990s, it had progressed to temporal scales of 1ns as shown in Fig. 1. In the early 2000s, special efforts from different researchers and groups worldwide were directed towards the picosecond arena. This continued progress has been enabled by much improved high-speed electronics through the development of advanced diodes and transistors like Schottky diodes, step-recovery diodes, avalanche transistors, and resonant tunnelling diodes in the picosecond domain. Of course, this advancement has been pushed forward by the development of high-speed interconnects and short electronic pulse systems. In any case, the fast electronics is currently being lagged far away behind the fast photonics in terms of time scale, which is now running in the attoseconds. This difference was even highlighted by the recent Nobel Prize Winning topic where a short pulse is first positively chirped (dispersed) in time, while passing through the diffraction gratings. It is amplified by as much as 11 orders of magnitude and then recompressed by passing through the other set of diffraction gratings, but negatively dispersive pair of gratings this time. The recompressed output pulse has now an energy of million times higher than the original counterpart with a pulse duration of 2ps [1].

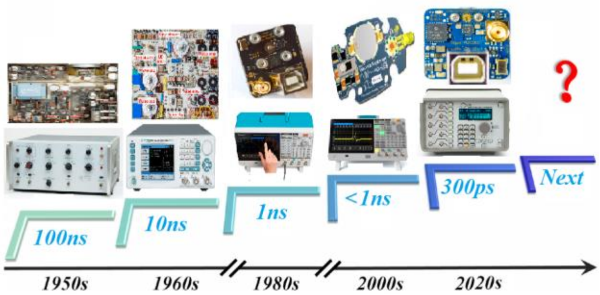

Fig. 1. Generational evolution of commercially developed pulse generators by different industrial organizations including Hewlett Packard, Colby, Tektronix, Tau Tron, BNC, Ana-Pico, etc.

This doctoral thesis research aims to investigate and propose novel pulse generation, compression, and shaping schemes and then transmit and receive it properly with signal integrity. In the framework of this thesis, several innovative and crucial ideas are explored related to simultaneous tuning and rise/fall time compression based on NLTLs [2-6]. In addition, a new class of NLTLs are also developed that are termed as NLMTLs and having capability of two-dimensional simultaneous tuning [7,8].

II. SYSTEM MODEL DEVELOPMENT

A complete system model for radiated pulse characteristics having all modules is shown in the form of a block diagram in Fig. 2. This system consists of an arbitrary waveform generator (AWG) for an input signal to the targeted pulse generator (PG). This PG is integrated with a pulse shaping network for the transformation of a Gaussian pulse into a monocycle pulse (the first derivative). It is due to the reason why the Gaussian pulse spectrum generally contains very high dc and low-frequency components. Antennas are well known for neither transmitting nor receiving signals with rich dc spectral contents. After the pulse shaping network, a clean monocycle pulse is generated that is transmitted using various designed wideband antennas. At the receiver side, similar wideband antennas are set up for receiving the output pulse that is ultimately examined using an oscilloscope. The complete setup including all modules integrated are shown in Fig. 2.

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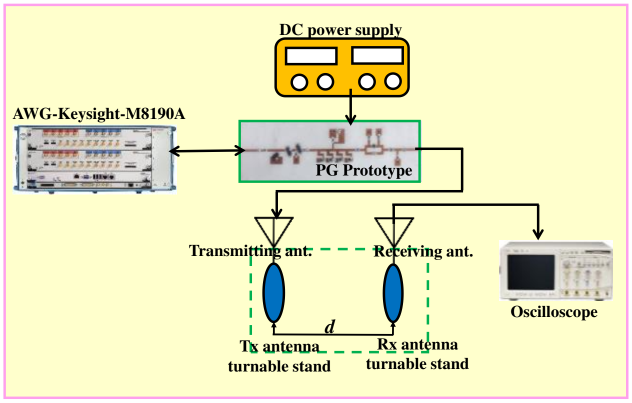

Fig. 2. Complete measurement setup block diagram.

III. MONOCYCLE PULSE GENERATOR AND MEASUREMENTS

This section briefly provides the circuit schematics of the developed monocycle PG and antipodal Vivaldi antenna with corresponding output responses. First, a monocycle PG is developed by integrating a pulse-shaping network with the Gaussian PG developed in our previous work. The schematic and prototype of this PG are shown in Fig. 3(a) while the corresponding output response is shown in Fig. 3(b) and (c). As can be seen that when the PIN diode is ON, this PG provides a Gaussian pulse and when the PIN diode is OFF, a monocycle pulse is formed at the output. After that various wideband antennas are developed, and the signal response is observed at the output. As can be seen from Fig. 4(a)-(c), that pulse is retrieved at the receiver side while maintaining signal integrity.

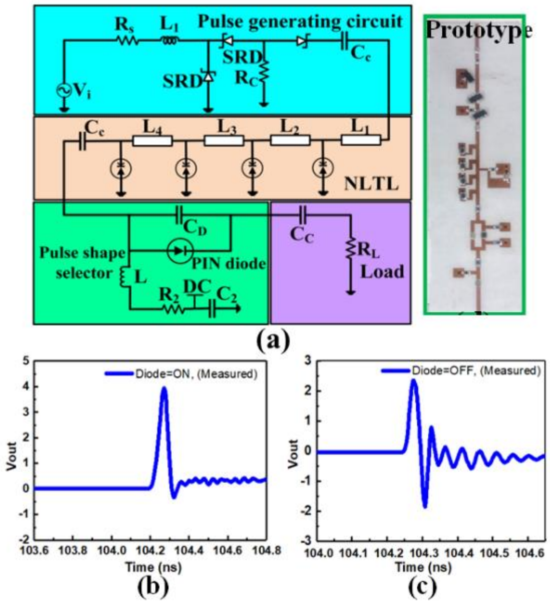

Fig. 3. Ultrashort picosecond PG. (a) Schematic and prototype of the PG; (b) Gaussian PG; (c) Monocycle PG.

IV. CAREER PLAN AND FELLOWSHIP IMPACT

Receiving the MTT-S Graduate Fellowship Award was a true honor. Being chosen as one of the recipients increased my motivation and confidence in continuing my research. It's been a fantastic experience and opened up new opportunities for me.

I would like to thank the committee members for their efforts and the difference they're making in student's careers. I am now on track to finishing my Ph.D. by the end of Winter term 2023. I would also like to continue my research work on pulse engineering and high-speed interconnects and keep working closely with the MTT-S community.

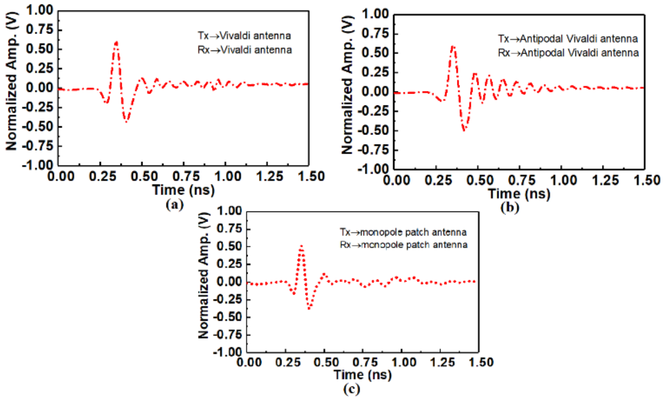

Fig. 4. Received pulse at the output with Tx and Rx antennas having. (a) Vivaldi antenna; (b) Antipodal Vivaldi antenna; (c) Monopole Wideband antenna.

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