Step-Recovery Diode Pulse Generators for Time-Domain Microwave Breast Screening

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***Abstract*—The main motivational factor of the here-reported work is the circuitry required for microwave-range operation of a time-domain breast screening prototype. A sub-nanosecond impulse generator was fabricated and evaluated for generation of 2-4GHz impulses for the initial device prototype. The circuit consists of shunt and series cascaded step-recovery diodes. The measured pulses have a full-width half-maximum (FWHM) of 95ps and peak amplitude of 280mV.**

I. Introduction and Background

Breast cancer detection based on ultra-wideband (UWB) radar has been actively investigated as an alternative screening option for high-risk populations. The differences in dielectric permittivity, ϵ_r, between cancerous and non-cancerous tissues in the gigahertz frequency range are the basis of the hypothesis, investigated by groups worldwide, that the malign tissues can be detected non-invasively with microwave emissions. UWB breast-cancer detection systems typically require specialized and expensive high-frequency equipment, such as a vector network analyzers (VNAs). Time-domain systems can also be realized, with potential reductions in cost and scan time [1]. Time-domain systems consist of a wideband pulse source, amplification stages, an antenna network, and finally a time-domain receiver. The time-domain systems reported to date were used to demonstrate feasibility of detection, but all still predominately depend on expensive high-frequency equipment.

This work addresses the need for low-cost wideband pulse generators in time-domain UWB breast cancer detection systems. Recently, CMOS circuits have been demonstrated as viable UWB signal generators [2], but are restricted to labs with CMOS design and fabrication capability. Techniques for narrow pulse generation include step-recovery diodes (SRDs), tunnel diodes, non-linear transmission lines (NLTL), or other high-frequency MICs [3]. SRD impulse generators are attractive due to their low cost and simplicity of design and fabrication.

Besides low-cost, the pulse circuit must produce sufficient pulse power and low jitter. The amount of power available from the pulse in the desired band is determined by the product of the amplitude and pulse width. To generate pulses in the desired band of 2-4 GHz, unfiltered pulses of width less than 200ps must be produced. A pulse amplitude of approximately 3V was deemed sufficient as input to the filter and amplifier. Jitter is also a key performance parameter, which can degrade localization of targets. Jitter can be introduced by the SRDs, but was shown to be dominated by waveform which drives the circuit [4]. Measurements in this work use a low-jitter precision function-generator. Future work will entail the analysis of low-jitter SRD driving circuits, particularly when evaluating the overall system.

SRD-based pulse generators were first established in the 1960s, and design procedures and applications are clearly described in [5]. A thorough review of published SRD circuit configurations is presented in [6]. In [7], an impulse with 6-V amplitude and 150-ps FWHM was reported using one SRD in shunt-mode configuration. In [8] using three SRDs, an impulse with 6.2-V amplitude and 170-ps FWHM was presented. In this work, a pulse generator using SRDs in a combined shunt-series configuration is evaluated.

II. Methods

A diagram of the current experimental system is shown in Fig. 1. The pulse-forming network consists of a Picosecond Pulse Labs impulse generator and a 2-4 GHz passive microstrip filter. The pulses are amplified using a wideband power amplifier with maximum CW output of 3W. The received signals are recorded in the time domain using an equivalent-time sampling oscilloscope. The impulse generator produces pulses with amplitude of 7.5V and widths of 70ps. Pulses in the existing system need attenuation, which indicates an opportunity for lower power pulse generators.

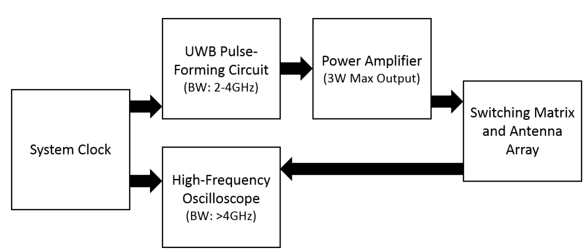

Fig. 1. System diagram: components of the time-domain microwave breast screening system.

III. Description of Step-Recovery Diode Circuit

The circuit evaluated was a simple two-pair SRD circuit with input and output matching using discrete elements. The

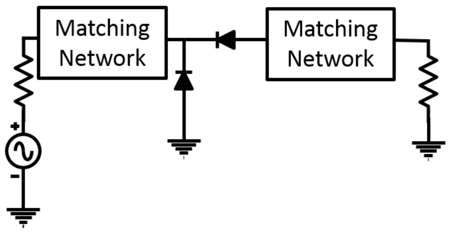

Fig. 2. Schematic of the SRD circuit under evaluation.

device was manufactured on a PCB with SMA connectors for integration into the 50-ohm system.

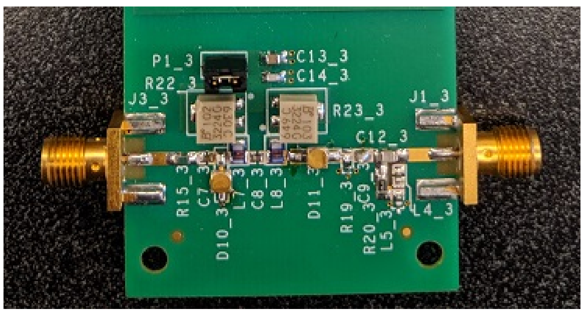

Fig. 3. Photograph of the SRD circuit under evaluation.

IV. Measurement and Results

The circuit was measured by driving with a HP 8116A function generator. The function generator is triggered by a low-phase noise clock source (AD9576) - also used as the system clock for the sampling oscilloscope (Picoscope 9200A) with 50 ohm input. The resulting waveform for an input 7-V amplitude CW is shown in Fig. 4. The pulse has an amplitude of 290mV and a FWHM of 95ps. The peak power is centered at 3.4GHz and the 3dB cutoff occurs at 12GHz. As the input signal amplitude is increased, the output pulse increases linearly.

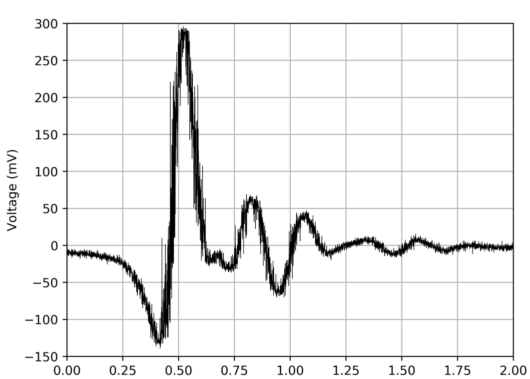

Fig. 4. Measured output pulse at 2 TS/s using a Picoscope 9201a

The amplitude of this pulse generator is below the reported performance of similar circuits in the literature, while the pulse width is exceptionally low, as desired. For higher power generation within the desired frequency band, an SRD circuit producing higher amplitude pulses will be investigated. The jitter is below 100ps, which will not affect localization of 2-4 GHz impulses. However, future SRD circuits will need to be driven with a custom-built synthesizer with emphasis on low-phase noise.

V. Conclusion

We presented a SRD circuit for pulse generation aimed at sourcing a time-domain microwave breast screening prototype. The present options for pulse sources are expensive; the SRD circuit offers a promising low-cost alternative. The circuit has a very low-pulse width, but limited pulse power. The literature on SRD-based pulse generators indicates that higher-amplitued pulses can be generated by a circuit of similar structure and comparable level of complexity. Ongoing work is aimed towards investigation of low-cost SRD circuits and driving circuits against the system requirements for bandwidth, higher power output in the range 2-4 GHz and jitter.

VI. Acknowledgement

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