Photoswitch Material Recombination Effects on the Injection Wave Generator

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Abstract

The photoswitched Injection Wave Generator[1,2,3] (IWG) is an alternate method of generating multiple cycles of microwave energy using parallel switches in a transmission line geometry that overcomes the limitations of the traditional and present day microwave sources. The photoswitches isolate initially charged transmission line segments from the output transmission line; with the simultaneous closure of the switches, the energy from the charged transmission line segments is released onto the output line in the form of pulses at spatial half-wavelength locations.

The generator is limited by the switches used to generate the injected pulses. As neighboring pulses begin to overlap, the efficiency of the generator decreases and energy is shifted to the lower harmonics. This work studies the effect of switch material recombination time on the performance of the IWG. Four levels of Chromium-doped GaAs have been used for the switches, providing four unique recombination times. The generator has been tested at three operational frequencies for each material switch set.

Introduction

The Injection Wave Generator (IWG) is a method of generating multiple cycles of microwave energy using parallel switches in a transmission line geometry as shown in Figure 1. These switches isolate initially charged transmission line segments from the output transmission line; with the simultaneous closure of the switches, the energy from the charged transmission line segments is released onto the output line in the form of pulses at spatial half-wavelength locations.

At each injection point, two pulses are generated immediately following switch closure: a forward wave moving toward the load, and a rearward wave moving toward the short-circuit stub at the opposite end of the line. As illustrated in Figure 2, the rearward-moving wave is negatively reflected by the short-circuit stub and follows the forward-moving wave to the matched load after a time delay defined by the two-way transit time from the switch to the short. In essence, each charge section delivers a full cycle of energy. In general, however, the two halves of the cycle are separated by the two-way transit time between the charge section and

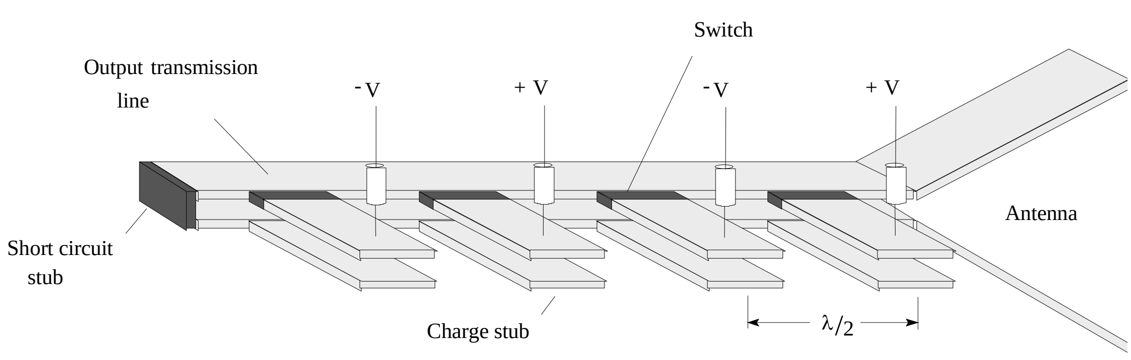

Figure 1. The Injection Wave Generator.

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the short-circuit stub. Only the injection point closest to the short-circuit stub produces a cohesive cycle of energy.

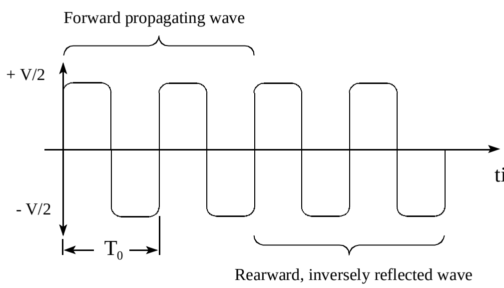

Figure 2. Operation at the fundamental frequency, f_o ($1/T_0$).

Subsequent charge sections simply add pulses to the front of the forward-moving wave and to the end of the rearward-moving wave.

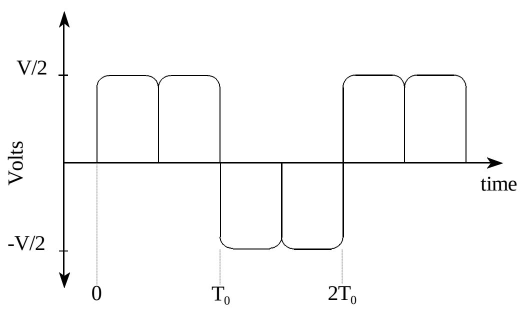

Figure 3. Alternate pair charging output waveform.

Frequency agility is an inherent capability of the IWG, since the charge sections operate independently and may be charged in a number of ways. To generate the highest frequency possible, successive sections are charged with alternating polarities. However, if pairs of neighboring sections are alternately charged, the output waveform shown in Figure 3 results, producing a signal in which the period of the output frequency is doubled. Thus, multiples of the fundamental frequency may be delivered by simply varying the polarity of the charge sections. For example, a 16-stage IWG is capable of delivering 5 frequencies: assuming a fundamental frequency of 10 GHz, the subsequent frequencies become 5, 2.5, 1.25, and 0.625 GHz. This method of frequency agility is referred to as shot-to-shot frequency agility, since the frequency remains constant within a single firing set.

Switch Performance

Ideally, the switch would close nearly instantaneously, conduct for the full half cycle, as defined by the spatial separation of the charge sections, and open immediately after the energy is released. Unfortunately, the ideal switch behavior needed for the IWG is not currently available. Possible switch candidates include: photo-conductive switches, high frequency FETs, high electron mobility transistors, snap-off diodes, and Cu:GaAs on-off switches. This work uses the photoconductive switch, or simply the photoswitch, to study the IWG. The conduction profiles exhibited by the photoswitch make it an ideal candidate for studying the IWG.

Typical intrinsic photoswitches do not deliver the desired square pulse profile. In fact, the voltage waveform generated by the switch appears as a non-symmetric gaussian pulse, in which the fast-rising leading edge is followed by a slow decay, as shown in Figure 4. The leading edge, or the closure of the switch, closely follows the pulsed optical illumination, affected by the conduction inductance and the carrier recombination time. However, upon the removal of the optical source, the switch resistance returns to its steady state value at a rate defined by the recombination rate of the carriers in the material. For bulk, intrinsic photoconductive materials, such as GaAs, this recombination time can be slow, resulting in the long trailing edge of the Gaussian profile.

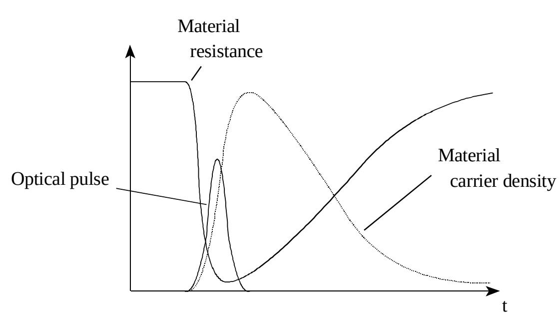

Figure 4. A typical photoswitch conduction waveform.

Extended conduction time plays a negative role in the behavior of the IWG. Since the injection points must be spatially separated by the length of the energy packet, or one half-wavelength ($\lambda/2$), defining this length becomes a problem. For example, consider a typical Gaussian waveform in which the full width half maximum (FWHM) is 50% of the pulse length. If the $\lambda/2$ separation is defined as the full pulse width, then the radiated distortion will be seen simply as the frequency components of the photoswitch-generated gaussian waveform. Conversely, if the $\lambda/2$ separation is defined as the FWHM of the pulse, then the neighboring injection points will overlap with respect to the full pulse width. In essence, the n^{th} wave will "see" an impedance mismatch at the n+1 junction since the switch at this junction has not fully recombined. This impedance mismatch causes reflections and ultimately leads to signal distortion and loss of efficiency.

Experimental Arrangement

The IWG fabricated for this work is based on an operating frequency of 1 GHz and a terminating resistance of 50 Ω. Therefore, the output transmission line is designed to match the 50 Ω load, and the charge sections are designed for an impedance of 25 Ω so as to match the parallel configuration of the output line. The charge sections have been fabricated for a $\lambda/2$ length instead of the original specification of $\lambda/4$ length so as to better realize the effect of extended recombination times. Figure 5 illustrates the experimental IWG design.

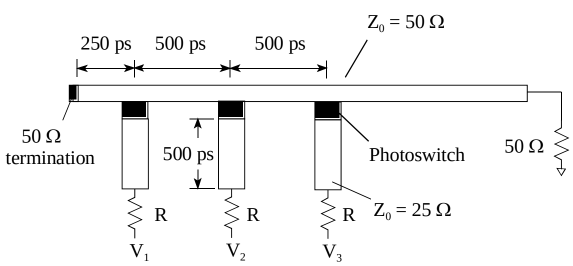

Figure 5. The basic IWG design.

Four material samples of Cr:GaAs have been used in this study; each is marked by a unique recombination time. The recombination time for each material was measured and is listed in Table 1.

Table 1. Measured recombination time for each switch type.

Material	Recombination time
1	500 ps
2	1 ns
3	3 ns
4	> 8 ns

Each material was identically processed by Sandia National Laboratories. The individual switches were designed for 5 kV operation and are characterized by a 1 mm gap spacing and a switch width of 5 mm.

A Nd:YAG laser (35 ps, 40 mJ) is used to drive the IWG. The optical energy is delivered to each switch by a fiber bundle system, which consists of 4 sets of 125 multi-mode fibers (100 μm core diameter). Approximately six percent of the source optical energy is made available to the photoswitches.

Experimental Results

The response of each switch has been measured with neighboring switches conducting; however, since the neighboring charge sections were not charged, only the charge section of interest delivered energy onto the output transmission line. Figure 6 illustrates the individual response for each material superimposed with the other materials. The first pulse, located nearest to the load, propagates unaffected to the load. However, the subsequent pulses show the effect of the neighboring injection points, primarily visible in the attenuation of the pulse.

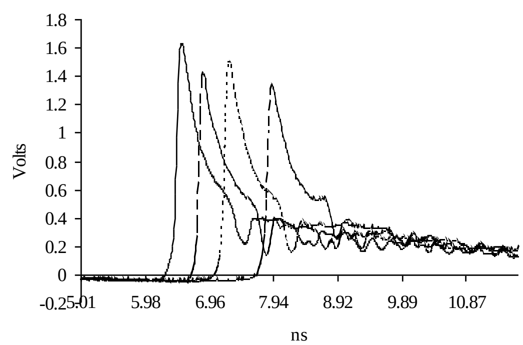

Figure 6. The response of the each switch with the effect of neighboring switches conducting.

The IWG was tested with each switch material, generating the three allowable frequencies. Figure 7 provides the results of each material producing the fundamental frequency (1 GHz). In the time domain, the material with the fastest recombination time appears to give the most desirable response. However, as shown in Figure 8, the frequency response of each material producing the fundamental frequency shows that the longer recombination times force more energy into the frequency of interest. In essence, the pulses are filled to appear more square in nature, resulting in higher energy content.

Figures 9 – 12 display the time and frequency responses for each switch type operating at the first and second order frequencies, 500 MHz and 250 MHz, respectively.

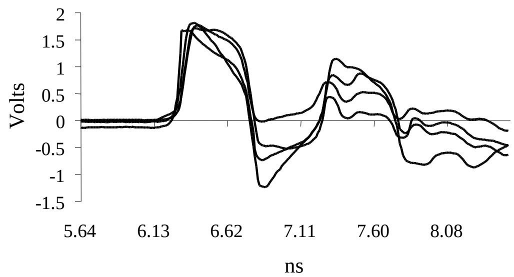

Figure 7. Each switch type operating at f_0.

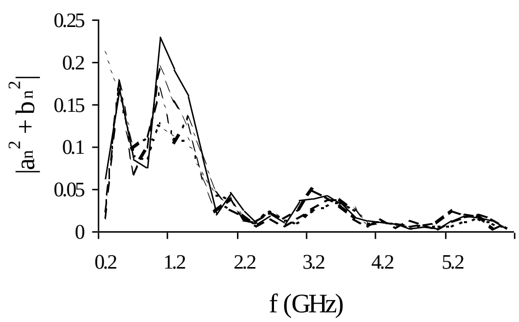

Figure 8. The frequency response of each switch type operating at f_0.

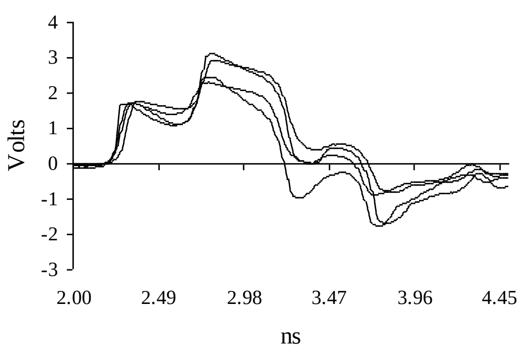

Figure 9. Each switch type operating at f_1.

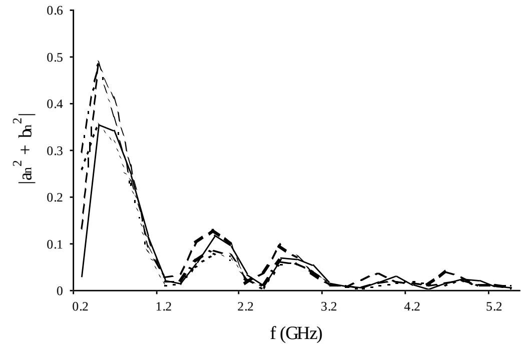

Figure 10. The frequency response of each switch type operating at f_1.

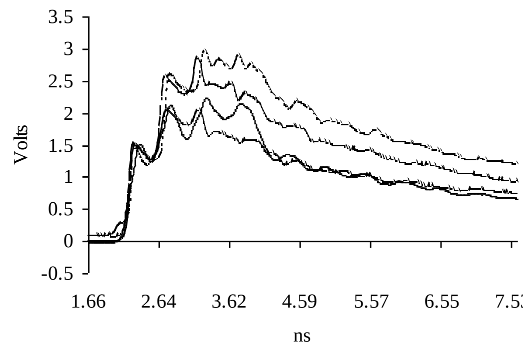

Figure 11. Each switch type operating at f_2.

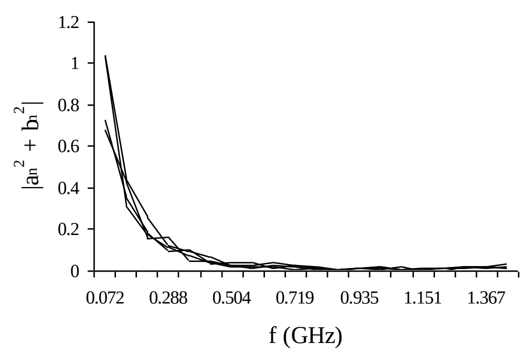

Figure 12. The frequency response of each switch type operating at f_2.

Conclusion

The effect of extended photoswitch recombination time on the efficiency of the Injection Wave Generator was studied. Four switch materials were compared.

In the time domain, it appears that the fastest material produces the best results—implying that the entire pulse should be contained within the spatial separation and that the pulses should not overlap. However, analysis in the frequency domain suggests that the longer recombination times do not add energy to the sidelobe frequencies; instead, more energy is put into the frequency of interest as the pulse defined by the charge section separation is filled out. However, as recombination time increases, lower frequency components become more prominent, as the waveform appears to have an offset.

These results point to the need for switches that can produce square-like pulses. Two possible options lie in the use of on-off switches, such as the Cu:GaAs switches developed by Schoenbach or the typical photoswitch with a limited energy store. The results presented in this paper show that the pulses do suffer from the impedance mismatches seen at the injection points where the photoswitch has not completely recombined; however, the distortion of these pulses is not dramatic. It is proposed that shorter charge sections may be used, thereby limiting the amount of energy delivered by each charge section. Thus, distortion would be limited to impedance mismatches, negating the effect of pulse overlap.

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