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Generation of Kilowatt/Kilovolt Broadband Micowave Bursts with a Single Picosecond Photoconductive Switch

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ABSTRACT

A single picosecond GaAs photoconductive switch is used to pulse excite a microwave resonant cavity, generating various microwave waveforms. The generation of over 7 kW, with peak to peak voltage over 1.2 kV, of broadband microwave bursts is demonstrated.

INTRODUCTION

In the last few years, there has been a great interest in the generation of coherent microwave pulses using ultrashort optical pulses (1-4). These techniques use optical pulses to trigger photoconductive switches, thus allowing picosecond synchronization of the generated microwave pulses. However, drawbacks of the exported methods are 1) the low voltage and power outputs (1,2), and ii) the large number of photoconductive switches to be triggered (3,4). Earlier we demonstrated conversion of DC energy to single frequency RF energy, albeit at low voltage and power, using a single switch and a coaxial resonant cavity (5). In this paper we show the versatility of this technique. Among the different waveforms generated, we have produced over 7 kilowatts of broadband, single cycle, microwave pulses of peak to peak voltage of over 1.2 kV with over 50% energy conversion efficiency.

EXPERIMENTAL SYSTEM

Schematic of the experimental arragement is shown in Fig. 1. Coaxial slotted lines were used as quarter wave resonant cavities. Specifically, a 25 cm long HP slotted line cavity, resonating at 300 MHz, and 9 cm long homemade cavity, resonating at 1 GHz, were used. These resonanant frequencies are for high Q operation of the cavities. An active-passive mode-locked Nd:YAG laser is used to generate ~ 1 mJ of 1.06 μm radiation, of 100 picosecond pulsewidth, with repetition rate of 1 Hz, to trigger the GaAs switch. The performance of GaAs switches were tested, under DC bias of up to 4 kV, with 1.06 μm pulses for several thousand consecutive shots without any observable degradation in performance.

Activating the GaAs switch by the optical pulse generates a rectangular electric pulse of at most half the DC charged voltage. The electric pulse excites the resonant cavity through coupling element A_1. Coupling element A_2 allows the extraction of the generated microwaves from the excited cavity, to be observed by a 1 ns risetime storage scope. Two important and useful parameters that control the waveform, and hence the frequency distribution, of the generated microwaves are i) strength of the coupling provided by A_1 and A_2, and ii) length of the coaxial line C_2 connecting the GaAs switch to A_1.

In Fig. 2 we show a typical electric pulse (≈1.25 kV in magnitude and 2 ns in duration) used to excite the cavities. The width of the pulse is determined by the length of the charged coaxial line C_1. The rise time is determined by that of the optical trigger pulse.

RESULTS

In Fig. 3 we show the effects of coupling (A_1 and A_2) and the length of C_2. The generated waveform using the 300 MHz cavity, is due to "strong" couplings at A_1 and A_2. A strong coupling is obtained by directly connecting the center wire of an input/output coaxial line to the center wire of the coaxial resonant cavity. The generated waveform can be explained as follows; some of the incident voltage pulse on A_1 excites the cavity, while some is reflected with a change in sign (since the effective impedance of A_1 is less than the characteristic impedance of C_2). The reflected pulse suffers an open circuit reflection at the switch (thus keeping the same sign) and is incident on A_1 repeating the above process. The ratio of the magnitudes of successive pulses is constant, and depends on the coupling strength. The time between successive pulse excitations is given by twice the travel time in the length of C_2 (20 ns round trip time in this case). Note that the first cycle has a peak to beak voltage of ≈1.2 kV, and that the peak power is over 7 kWatts. The energy conversion efficiency, including all the reflected pulses, is over 50%.

In Fig. 4 we show the effect of changing the couplings and the length of C_2. Intermediate connection for A_2) is used to excite the 1 GHz cavity, together with a 5 ns (double travel time) long C_2. Note the relatively larger voltages of the reflected pulses due to the weak coupling at A_1.

In Fig. 5 we show the waveform generated by the 1 GHz cavity with stong couplings and with a ≈0.5 ns (double travel time) long C_2. Note that the width of the generated single cycle pulse is larger than the period of the resonance frequency. There are several reasons for this, the most important of which are; i) the nonzero (0.5 ns) time shift between the (successive) added microwave pulses, ii) the loading of the cavity, and iii) the finite risetime of the scope. The waveform generated by the 300 MHz cavity with strong couplings and with a 0.5 ns long C_2 is shown in Fig. 6.

Finally, a relatively high Q factor is obtained for the cavity when the coupling is weak (loop antennae for A_1 and A_2). In this case the triggered electrical pulse excites the cavity at its resonant frequency through A_1, while A_2 allowes the extraction of the generated narrow band microwaves. In Fig. 7 we show the observed waveform for the 1 GHz cavity when C_2 is ≈5 ns long. Note that over 100 mW of 1 GHz RF is generated, with an estimated bandwidth of less than 10 MHz. The modulated envelope is due to beating between the cavity resonant frequency and the length of C_2. The nonzero dip of the envelope is caused by the relatively long lifetime of the switch (few ns) when excited by a 1.06μm trigger pulse. This "smears" the effective length of C_2 and hence affects the beating with the cavity resonance frequency. Indeed we have observed a zero dip in the envelope when a short lifetime switch is used (e.g. Cr doped GaAs or 0.53μm trigger pulse.). Unfortunately the use of 0.53μm to trigger high voltage pulses is not practical (6).

The use of spectrum analysers, to examine the frequency distribution of the high voltage high power microwave bursts (Figs. 3-6), is not feasable due to the short duration of the bursts and their low repitition rate. However, more than qualitative information can be obtained by theoretical methods (7). The calculated frequency distribution of the power in single cycle (with positive and negative parts, as in Figs. 5,6) electrical pulses, with a period of τ, shows that the main lobe extends up to $2/\tau$. The significance of this is evident once one realizes that, similar calculations for one sided electrical pulses (as in Fig. 2) show that the main lobe extends up to $1/\tau$ only. The frequency distribution for the waveforms in Figs. 3,4 is given by that for a single pulse divided by $[1+a^2-2a\cos(2\pi f t_s)]$ where a is negative of the ratio of magnitudes of successive pulses (this depends on the coupling strength) and t_s is the separation between seccessive pulses (round trip length of C_2).

CONCLUSION

We have shown the versatility of microvwave generation, through the excitation of a resonant cavity with a single high voltage pulse, triggered by a photoconductive switch. The high power microwave bursts generated may find important applications in high resolution phased array radar operation.

ACKNOWLEDGMENTS

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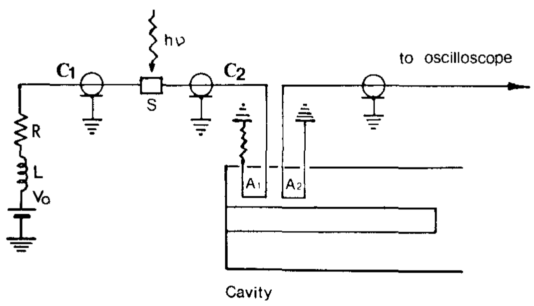

Fig. 1 Schematic of the experimental arrangement. S is GaAs photoconductive switch, A_1 and A_2 are input/output cavity coupling elements. C_1 and C_2 are coaxial cables. The resistance (R) and inductance (L) provide isolation between the DC power supply and the charged line C_1.

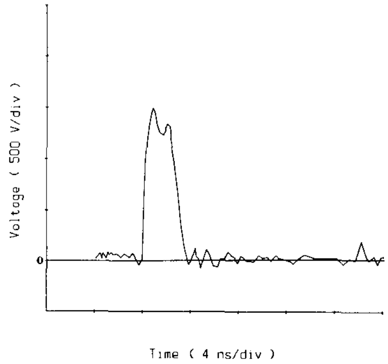

Fig. 2 Typical electric pulse, generated by optically triggering the photoconductive switch, used to excite the cavities.

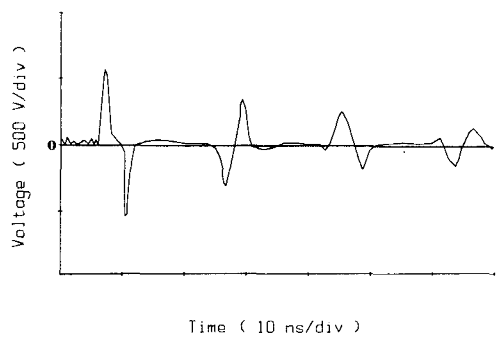

Fig. 3 Microwave pulse generated using the 300 MHz cavity with strongly coupled A_1 and A_2 (see text for definition of coupling strength) and 20 ns (round trip) long C_2.

Fig. 4 Microwave pulse generated using the 1 GHz cavity with intermediate coupling and 5 ns long C_2.

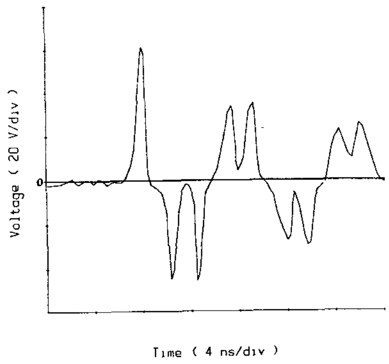

Fig.5 Microwave pulse generated using the 1 GHz cavity with strong coupling and ∿0.5 ns long C_2.

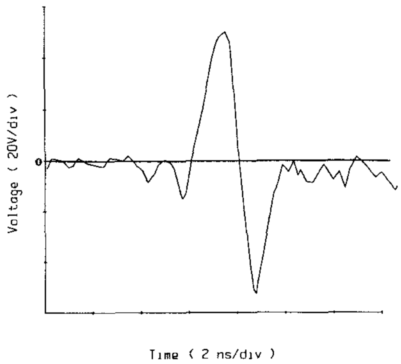

Fig. 6 Microwave pulse generated using the 300 MHz cavity with strong coupling and ∿0.5 ns long C_2.

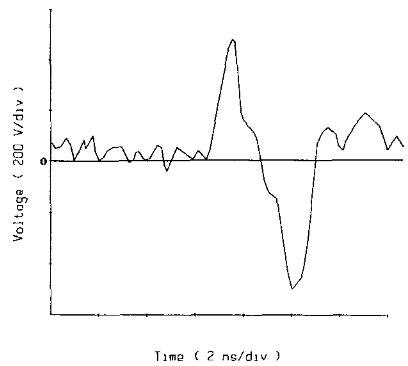

Fig. 7 Microwave generation using the 1 GHz cavity with weak coupling and ∿5 ns long C_2. (2V / vert. div. , 10 ns / hor. div.)