Compact, Scalable THz Source*

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***Abstract*—A vacuum electronic device is under investigation as a compact, high-power terahertz source. Particle-in-cell simulations have been performed to predict general RF performance for a range of device parameters. Results to date indicate the potential for operation beyond 1 THz at power levels in excess of 50 W in a highly compact configuration.**

I. Introduction And Background

It is generally acknowledged that widespread use of THz radiation in real-time and high-throughput applications requires higher power sources than presently available. This is especially true for "standoff" applications that require a significant distance between the THz system and the object being analyzed. To address this shortfall, Advanced Energy Systems has begun the development of a vacuum electronics device (VED) capable of producing high power THz radiation. Simulation results indicate the device to be scalable to frequencies up to at least a few THz. One particularly significant result is a simulation showing greater than 25 W of power being produced at 221 GHz using an 8.5 kV electron beam with an electronic efficiency of 1.5%.

The initial configuration is that of an oscillator. Amplifier operation is possible and will be investigated at a later date.

II. Results

Using a combination of a 2.5 dimensional particle-in-cell (PIC) simulation (MAGIC[1]) and eigenmode analysis (FMEigen[2]), the operational parameters of the VED have been studied. The PIC code simulations initially focused on a nominal design using a 50 kV, 1 A electron beam in order to establish base line performance with regard to power levels, tuning bandwidth and frequency scaling. High RF powers have been obtained with beam voltages ranging from 20 kV to 150 kV and currents as low as 200mA. These results are only indicative of device performance, as simulation run-times have precluded exhaustive exploration of the device parameter space. Limits remain to be explored.

Two representative cases are shown in Table 1. Note from the table that the electronic efficiency at the lower frequency is approaching 1% with a power level in excess of 200 W at 0.31 THz. Although decreasing with frequency, the simulated power levels still exceed 50 W at 1.3 THz.

In addition to the baseline simulations, modifications to the design were explored with the goal of reducing the current and voltage requirements, and extending the frequency range using harmonics of the fundamental interactions. To date, interaction at the fundamental frequency has been simulated from 0.1 THz to 1.3 THz. Further extension of the upper end of the frequency range remains to be explored.

	Case 1	Case 2
Beam voltage	30kV	50kV
Beam current	0.8A	0.5A
Extracted Power	210W	55W
Frequency	310GHz	1.3THz

Table 1. Results from two PIC code simulation runs.

The growth of the electromagnetic wave occurs very rapidly as can be seen in Figure 1 where saturation is reached in less than 1.5 ns. Figure 2 shows an FFT of the simulation electric field illustrating the narrow bandwidth of the output signal. The resolution of this transform is likely limited by the time window, but still shows a bandwidth of less than 200 MHz. This feature is useful for spectroscopic applications.

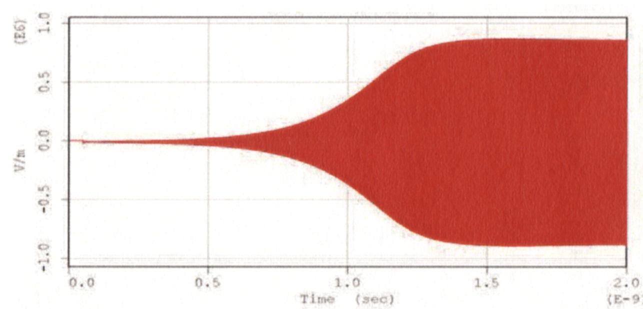

Figure 1. Growth of electric field at center of interaction structure as a function of time.

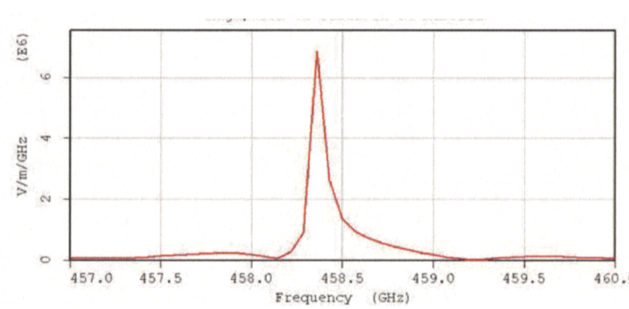

Figure 2. FFT of electric field showing narrow bandwidth.

Spectroscopic and other applications also require a certain amount of tuning range. With some modifications to the basic circuit, simulations indicate a frequency tuning range of +/- 18.5% is possible by changing the electron beam voltage through a range of 8.5 – 45 kV.

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The ability to operate with sub-10kV electron beam energy opens the door to a very compact package. With the active device occupying an estimated volume of less than 1000 cm^3, the power supply is the primary driver of size and weight. Thus, with operation at 8.5 kV successfully simulated, some effort was also spent on means for reducing the required oscillator start current culminating in a configuration with projected parameters of 8.5 kV, 200 mA, and 25 W of power at 0.221 THz.

In order to extend the operating frequency of the basic configuration, harmonic output was also studied. Modified structures were investigated that seemed to provide enhanced power in the harmonics of the fundamental interaction frequency. One example of this is demonstrated by the FFT shown in Figure 3 where the level of the harmonics is a factor of five greater than for a basic structure. In a second example of operation at harmonics of the fundamental frequency, the powers from the fundamental, second and third harmonics were extracted. At the fundamental frequency the structure produced 300 W of extracted power shown in Figure 4, while the second harmonic was greater than 15 W and the third harmonic was in excess of 7 W as seen in Figure 5. Simulation time constraints precluded a full simulation through saturation for the harmonic frequencies, thus the ultimate achievable power may be higher.

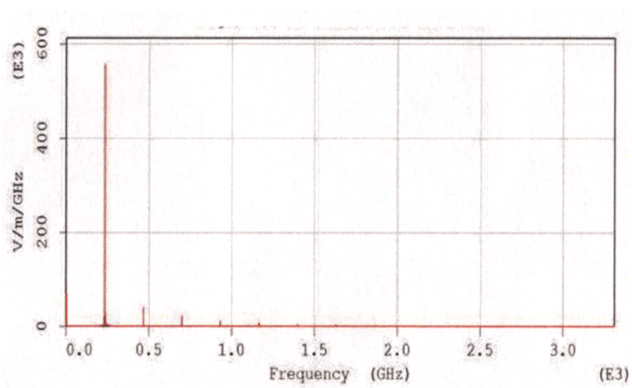

Figure 3. FFT of electric field showing enhanced harmonic content.

This harmonic performance extends the possible frequency range to almost 4 THz with a minimum power of 1 W at the higher end of the range. Combining the frequency tunability with harmonic operation provides the possibility of assembling four or five devices in a compact package covering a frequency range from 0.1 THz to 3.8 THz and perhaps beyond.

As a final note, the VED is compatible with depressed collection of the electron beam energy yielding high system efficiency.

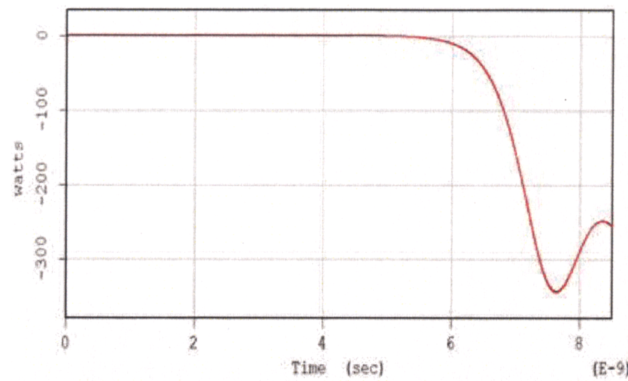

Figure 4. Fundamental frequency power extracted from the structure when configured for harmonic operation.

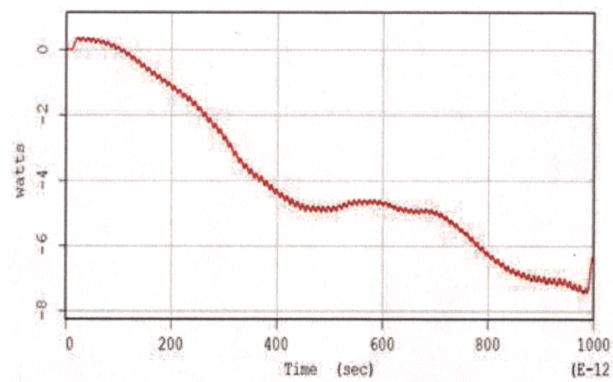

Figure 5. Third harmonic power extracted is in excess of 7 W.

III. SUMMARY

Simulations of a VED using realistic parameters indicate unprecedented THz power levels can be achieved in a compact device with size and weight determined by the power supply. Frequencies between 0.1 – 4 THz appear to be possible with powers in excess of 1 W and single-device tuning ranges of > ±15%. Operation as a continuous wave device is projected to yield high levels of narrowband THz power.

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1) B. Goplen,, L. Ludeking, D. Smithe, and G. Warren,"User-Configurable MAGIC for electromagnetic PIC calculations," Computer Physics Communications **87** (1995) 54-86
2) R. H. Jackson, *et al.*, Final Report Air Force Office of Scientific Research STTR No. FA9550-05-C-0080 (2007)

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