Miniaturized THz Source with Free-Electron Beams

Hans W.P. Koops
HaWilKo GmbH Ober-Ramstadt
64372 Ober-Ramstadt, Germany
Hans.koops@t-online.de

Ahmed Al-Mudhafar, Hans L. Hartnagel
MWE of TUD Technische Universität Darmstadt
Darmstadt, Germany

Abstract— **The paper presents a novel miniaturized tunable, portable THz source for this frequency range using the Dynatron oscillator to control two miniaturized field emitter electron beam sources of high brightness, which emit charge pulses in each half wave's time to fly across a resonator, however through opposite apertures with opposite directions. The emitted infra-red dipole radiation is guided by a resonator and focused by lenses to the object. The output power at 0.2 THz to 10 THz is estimated to reach 0.5 W.**

Keywords: High Brightness miniaturized Dynatron oscillator, THz-IR- radiation source, Security scanner, Field emission triode.

I. MOTIVATION

To enable wide-spread investigations with terahertz radiation sources in many groundbreaking applications, it is necessary to develop small-size terahertz sources and spectrometers. Characterization of explosives requires monochromatic and tunable sources in the frequency range of 1 to 10 THz [1]. Electron beam based sources promise there the great efficiency [2] required. Presently 200 GHz radiation sources are employed in airport body scanners which are several dm³ in size. Industry requires a miniaturized source to enhance speed and resolution of the scanning process. The wavelengths of 200 GHz to 10 THz (as needed for analytic applications), require the application of miniaturization by optical, electron beam and EBID lithography.

II. Proposal of a Novel Miniaturized Tunable, Portable THz source

A. The Dynatron oscillator

The paper presents a novel miniaturized tunable, portable THz source for this frequency range using the Dynatron oscillator concept. This is composed of a triode tube with a grid voltage higher than the anode voltage. This configuration accelerates secondary electrons from the anode to the grid, which makes the Dynatron to act as a negative resistance, see figure 2. A serial or parallel oscillator circuit is connected between the anode and a working point potential source with a value lower than the extraction grid. The primary electron beam charges the oscillator capacitance to self excited oscillations, see figure 1. Tubes built with WW2 technology reached 3.4 GHz, and were employed in radar systems. The proposed miniaturization allows one to extend the frequency range up to 10 THz [3].

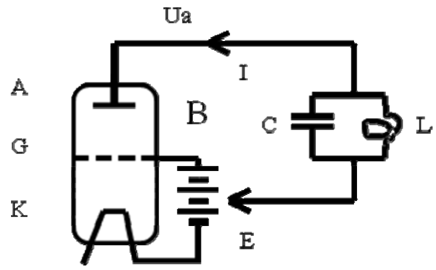

Fig.1: Dynatron oscillator circuit with parallel resonator

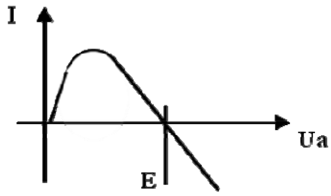

Fig.2: Dynatron acts as a negative resistance

B. The Field emission triode and free electron beam sources

In the presented system a miniaturized triode with field electron emitter is employed, having a cathode to grid capacitance of 24 10^{-18} F and a total beam length of 1 µm. EBID (Electron Beam Induced Deposition) field emitters can emit up to 1 mA [4] at an extractor voltage of 20 V, and can provide at an anode voltage of 100 V a beam power of 0.1 W using the miniaturized focusing optics. Such sources render a very high brightness of 1.5 10^{6} A/cm² sr V [5]. As a series oscillator is chosen, this charges the capacitor at the resonance frequency up to Q times the applied fixed anode voltage (Q quality factor of the resonance circuit). The oscillator signals control two miniaturized field emitter electron beam sources, which emit charge pulses in each half wave's time to fly across a resonator, however through opposite apertures with opposite directions[6], see figure 3. The amplified signal which controls the left electron beam is reversed by a capacitor (C12) to send the pulse of the second half wavelength from the right side. The signals must be adjusted to be in phase by circuit CAD design. Generating IR- dipole radiation with free flying charges avoids energy loss by resistive energy loss and Joule heating in the emitter wire of an emitter antenna system. Such pulsed free flying beams can

couple directly a high percentage of the beam energy into the THz radiation. They suffer no resistive loss like wire transmitters do. If a higher extractor voltage is needed for a more powerful field emission, the oscillator voltage can be amplified with miniaturized triodes with field emission cathodes.

III. Electrical limitations of a miniaturized source

The usable voltage is limited in miniaturized beam sources, due to stability requirements of electrostatic elements. Experimentally 100 V can be used in a safe way in vacuum, especially at metal line distances as small as 1 µm. Electrons reach by acceleration at 100 V a speed of 6 µm / psec. The oscillator voltage cuts the DC beam in charge pulses of half a wavelength in length, which corresponds to half the time span of a period. For example: at 500 GHz the pulse length is 1 psec. To clearly separate the two electric fields each beam must pass an aperture of 6 µm diameter located in the center of the resonator through which the electric and the magnetic field of the Hertz Dipole radiation is delivered into the resonator having a dimension of half a wavelength, which is 300 µm at 500 GHz. The required dimensions for sources in the 0.2 to 10 THz range are listed in table 1.

Table 1: Dimensions for IR-sources in the 0.2 to 10 THz range.

Frequency THz	Wave-length µm	Resonator E0 µm	1 Electron pulse at 100 V travels µm = IR window µm	S/N at 1 mA DC
0.2	1500	750	15	173
0.5	600	300	6	77,5
1	300	150	3	54
5	60	30	0,6	24,6
10	30	15	0,3	17

The output of the source in the electron beams can reach up to 100 mW to generate the Hertz dipole radiation (1 mA current and 100 V total accelerating voltage by battery B2). From Klystrons it is known, that free flying bunched electrons can emit 47% of the beam power as THz-IR radiation [7]. This would in total be a DC 47 mW IR radiation power / mA field emitter source current. At 10 THz the signal to noise (S/N = sqrt N) is 17 for a 1 mA beam, delivering 300 electrons per pulse of 0.05 ps duration in each direction. The emitted power is 1 mA x 100 V x 0.47 = 47 mW. Since emitter-extractor systems produced using FEBIP (Focused Electron Beam Induced Processing) can be placed on 1 µm pitch, several parallel beams can cross the IR window in parallel. This could lead to a total current of 12 mA, which corresponds to 0.56 W emitted source power. A schematic diagram of a source for a body scanner in security applications with 1.12 W emitted power is given in figure 4. The total dimension could be 4 x 4 x 4 mm³. The radiation emitted from the resonator to both sides is aligned by reflectors and focused by lenses. The source is pumped by a Getter pumping unit below the resonator; it can be manufactured in large numbers with micro systems fabrication technology. The transfer of the WW2 Dynatron to the miniaturized design requires considering the effects of stray capacitances and inductances and may change the specifics of the proposed design. However, our simulation using CST Software (Particle and Microwave Studios) shows that this can even be beneficial for the technical realization of the miniaturized THz source.

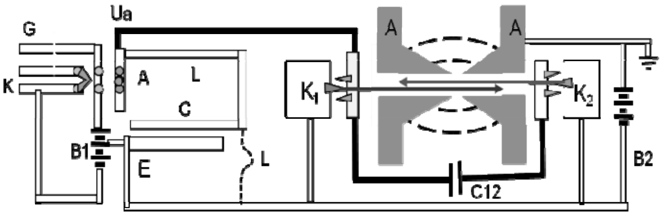

Fig. 3: Layout of the THz-source. Ua oscillator control voltage for free beams control, C12 capacitor for signal reversal

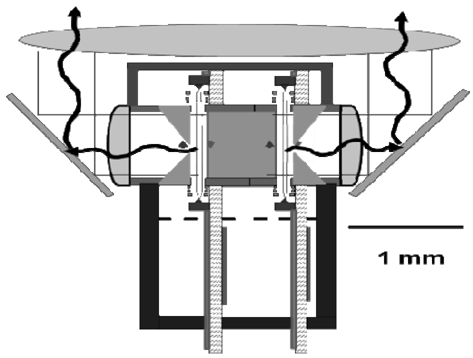

Fig. 4: Schematic of a 200 GHz source for safety survey applications

IV. References

[1] M.R. Leahy-Hoppa et al. / Chemical Physics Letters 434 (2007) 227–230 (John Hopkins Univ. Laurel MD, Baltimore MD, USA) H.W.P. Koops "Electronic tube system and method of manufacturing same" WO 97/33295 (12.09.1997)

[2] H.W.P. Koops et al. "Miniaturized terahertz radiation source" US 6 909 104 B1

[3] Karl Willy Wagner „Erzeugung von Kippschwingungen durch das Dynatron" Dietrich'sche Verlagsbuchhandlung, Klemm, Wiesbaden, 1947, 530ff., and H. Barkhausen „Einrichtung zur Erzeugung kurzer elektrischer Wellen in Dynatron-Schaltung" in Elektronenröhren Band 1 (1945) S.75 und Bd.3 (1935), S.73ff, Hirzel Verlag Leipzig

[4] J. Kretz et.al. Microelectronic Engineering 23(1994) 477-481.

[5] H.W.P. Koops, „Verfahren und Vorrichtung zur Herstellung von Korpuskularstrahlsystemen" 29.07.2004 DE 10 302 794 A1,

[6] H.W.P. Koops "THz radiation with free electron beams" EP application HaWilKo GmbH 2010

[7] H. Matsumoto "Development of the C-band (5712 MHz) 50 MW Class PM Klystron (II)" Proc. 26th Linear Accelerator Meeting Japan, 2001