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AUTHOR(S): H.A. Davis
R.R. Bartsch
E.G. Sherwood
R.M. Stringfield
L.E. Thode

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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Observation of High-Power Millimeter Wave Emission from a Virtual Cathode

H.A. Davis, R.R. Bartsch, E.G. Sherwood, R.M. Stringfield, L.E. Thode
Los Alamos National Laboratory, Los Alamos, New Mexico 87545
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Intense bursts of mm wave power have been observed in microwave generation experiments with a relativistic electron beam (REB) virtual cathode oscillator.[1] In this device an electron beam is injected into a drift space at a current above the space-charge-limit, and a potential develops downstream which is large enough to reflect electrons back to the source region. Two mechanisms can give rise to microwave oscillations in a virtual cathode device: electrons reflexing between the real and virtual cathodes, and oscillations in the amplitude and position of the virtual cathode. Typically both mechanisms are present, but in the present experiments reflexing has been shown to be dominant.

Peak power levels of ~100 MW in the band from 30 to 40 GH have been measured using one experimental configuration. Other configurations with differences in cathode geometry and diameter of the downstream region have yielded similar results. The mm wavelength output accompanies the dominant output of ~0.5 GW at 17 GHz.

The experimental arrangement is shown in Fig. 1. The electron beam is emitted from a 2-cm-diam cathode with an annular or flat front surface centered inside a 3.6-cm-diam housing. A 6 micron aluminized plastic foil serving as the anode is typically 5 mm from the cathode face. The maximum diode voltage varies from 1.2 to 3 MV, depending on the anode-to-cathode spacing, with a peak current of 75 to 90 KA. The beam pulse duration is 60 nsec (FWHM) with a risetime of about 40 nsec. Microwave radiation is produced in a circular waveguide (typically 6-cm-diam X 1.25 m long), located just downstream of the anode foil. This waveguide is followed by a 1.25 m long conical taper to a 0.6-m-diam vacuum window large enough to avoid microwave breakdown at the vacuum-air interface. The diode region and output waveguide are maintained at a base pressure of approximately 3×10^{-5} Torr.

Microwave measurements are made by sampling the radiation field in a plane 2 m from the output window with open sections of standard rectangular waveguide. These signals are heavily attenuated and transmitted through short runs of waveguide to standard detectors. Frequency identification is made by comparing with dispersively delayed signals transmitted through long runs of waveguide. Power levels are inferred by integrating radial profiles measured by scanning the radiation field from shot to shot. Mode indentification at the dominant output wavelength is made by observing the light output from an array of fluorescent tubes illuminated with the microwaves and from the measured radiation profiles.

Typical microwave signals are shown in Fig. 2. The microwave burst occurs halfway up the rise of the beam pulse with a FWHM of ~12 nsec and a risetime of ~1 nsec which is the limit of the detection system. 100-200 MHz modulations of the microwave pulse and the premature termination of the microwavc signal before the maximum of beam current and voltage are under investigation. Scans of the radial power density profile with probe-horn polarization oriented in the r and θ directions and qualitative observations of the output power density pattern utilizing array of fluorescent bulbs indicate that the output is predominantly axisymmetric with a radial electric field. This implies that the pattern is TM_{0n} (transverse magnetic) as expected from the geometry of the source region. For the 6-cm-diam waveguide in the virtual cathode region, a mode pattern with $n=3$ can be identified. At 17 GHz the TM_{03} mode is the highest order propagating TM_{0n} mode with a cut-off frequency of 13.77 GHz. Radial profiles of the power density in the band from 30-40 GHz are shown in Fig. 3 for two diameters of cylindrical waveguide in the virtual cathode region. The total power for the 12-cm-diameter case is estimated to be 100 $\pm$30 MW.

A fully relativistic and fully electromagnetic particle-in-cell code (CCube) has been used to simulate virtual-cathode configurations.(2,3) Excellent agreement with experimental results has been achieved except for the abrupt termination of the microwave emission early in the beam pulse. Simulations indicate that there are two possible mechanisms which could give rise to the observed mm radiation. One is the second harmonic relationship with the dominant output at 17 GHz, which is due primarily to reflexing electrons between real and virtual cathodes. The other is that oscillations in the virtual cathode lead to bunches of electrons moving downstream from the virtual cathode with an associated frequency approximate twice that of the output due to reflexing.[1]

Present virtual cathode microwave generation experiments are directed toward understanding the quenching phenomena and exploiting the "pure" virtual cathode oscillations in the absence of reflexing.

1. H.A. Davis, et al., submitted for publication.

2. T.J.T. Kwan and L.E. Thode, Phys.Fluids 27, 1570 (1984)

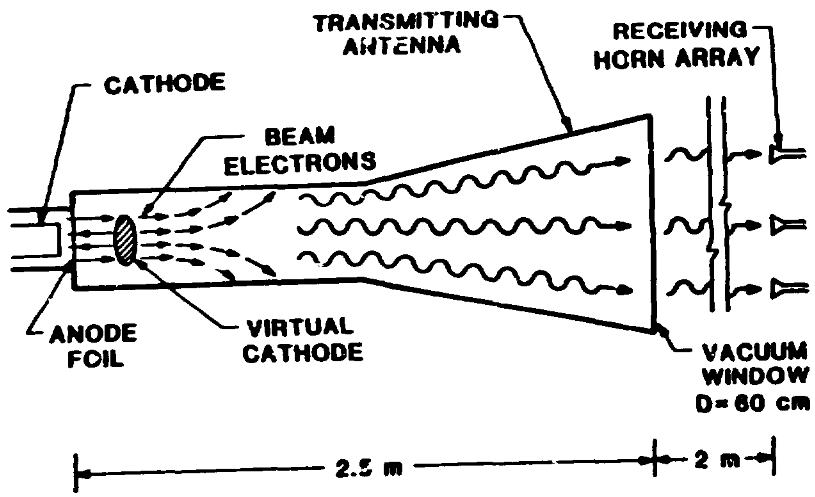
3. L.E. Thode and C.M. Snell, Conference Record IEEE International Conference on Plasma Science, 1985, p.88.

Figure 1. Crossection of the virtual cathode microwave experiment.

Figure 2. Time signature of microwave output; (a) K-band, (b) Ka-band.

Figure 3a. Ka-band, detection-plane power density vs. radius for 6-cm-diam virtual cathode region.

Figure 3b. Ka-band, detection-plane power density vs. radius for 12-cm-diam virtual cathode region.



TRANSMITTING ANTENNA
RECEIVING HORN ARRAY
CATHODE
BEAM ELECTRONS
ANODE FOIL
VIRTUAL CATHODE
VACUUM WINDOW D=60 cm
2.5 m
2 m

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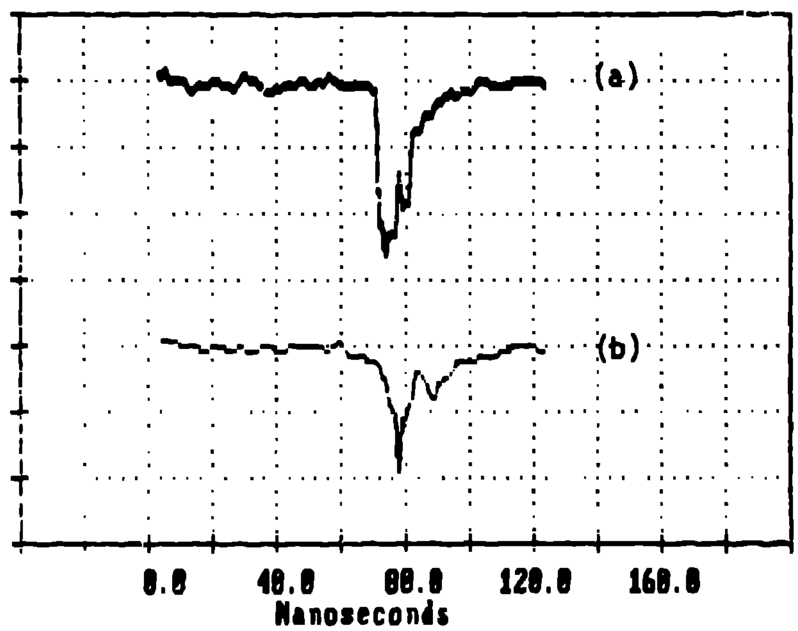
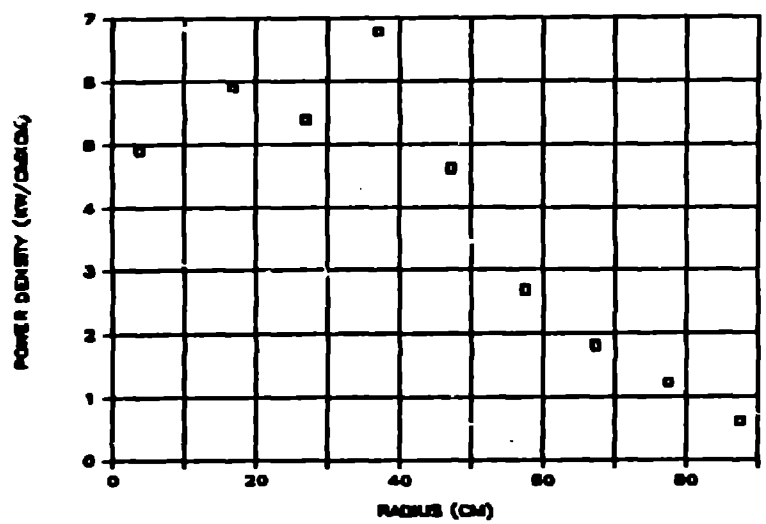


Ka BAND POWER DENSITY VS RADIUS



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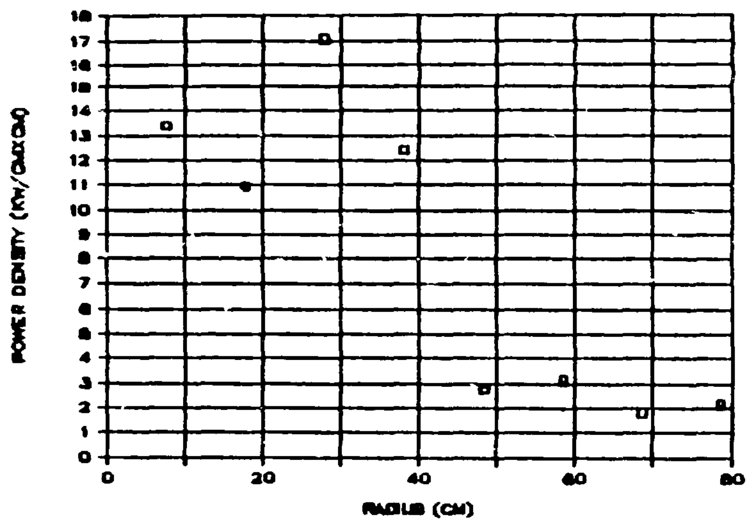

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