TUNABLE HIGH FREQUENCY RADIATION SOURCE UTILIZING A RELATIVISTICALLY PROPAGATING IONIZATION FRONT

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SUMMARY*

We have experimentally demonstrated a new type of tunable, high power radiation source capable of producing very short pulses. This technique utilizes a laser-produced ionization front which passes through a pulse of microwave radiation and in doing so causes the frequency of the radiation to upshift dramatically. By controlling the density of the plasma in the ionization front, we can continuously vary the degree of upshift. Source radiation at 35 GHz has been upshifted to more than 116 GHz.

The source radiation is provided by a pulsed magnetron that gives 300 nsec long, 10 kW peak power pulses at 35 GHz. This radiation is fed via rectangular waveguide through the side wall of a cylindrical copper cylinder that is closed by quartz windows at each end. The TE_{01} mode is excited and resonates in the cavity which is evacuated and filled with azulene vapor, which is chosen because it is easily ionized by ultraviolet radiation. A short (50 psec), intense (40 mJ) ultraviolet (266 nm) laser pulse is introduced through one of the quartz windows and propagates down the axis of the cavity. As the laser ionizes the azulene vapor, a sharp boundary is formed between the neutral gas and the newly created plasma. It is this boundary, which propagates at the group velocity of the laser radiation in the plasma-filled guide, that we refer to as an ionization front.

As the front propagates down the cavity, it encounter both the co-propagating and the counter-propagating radiation that make up the standing wave of source radiation in the cavity. Theory predicts that the frequencies of these two waves will

be upshifted by different amounts, but that in both cases the degree of upshift will be proportional to the plasma density in the front. This density is varied by adjusting the neutral azulene pressure in the cavity.

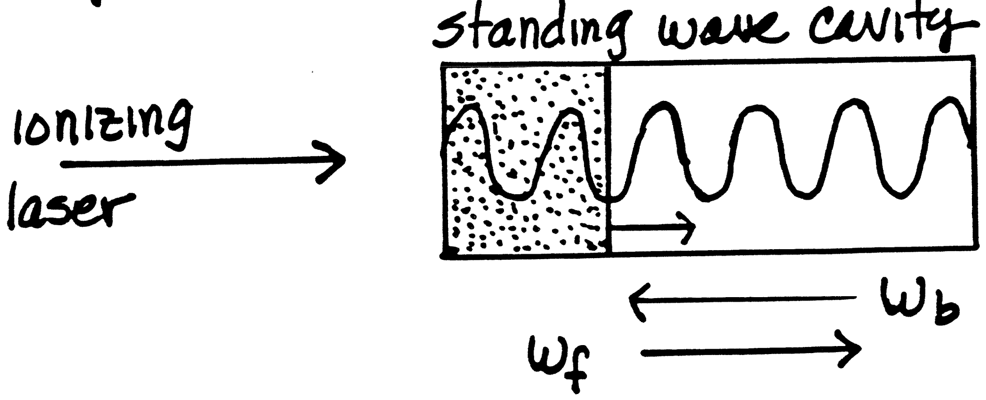
The upshifted radiation is detected by a series of diode detectors preceeded by sections of rectangular waveguides in various sizes that form a set of high-pass filters. A 1 Ghz bandwidth oscilloscope is used to display the upshifted radiation which appears in a single sub-nsec pulse. The detectors are rotated in the plane of the laser table about the output of the cavity in order to measure the antenna pattern of the radiation. This information is then used to estimate the amount of power in the upshifted pulses.

This proof-of-principle experiment has shown that the frequency of source radiation can be upshifted in a continuously tunable fashion to greater than a factor of three times the source frequency. The peak power in the upshifted pulses is more than half that of the source for 20 percent frequency upshift. The significant reduction in upshifted power detected at higher frequencies may be largely due to pump laser energy depletion along the cavity and the reduced response of the detection circuit as the duration of the pulses becomes shorter at higher frequencies. With slight modifications, this technique should be capable of producing short, high power pulses of radiation well into the terahertz frequency regime.

* A more detailed account of this work is published in Proceedings of the IEEE MTT-S International Microwave Symposium, June 11-14, 1991, Boston, Massachusetts, by the same authors under the title "Generaton of Highly Tunable Microwave Radiation Via a Relativistic Ionization Front."

Frequency Upshift in a resonant microwave cavity operating near cutoff.

$V_g < C$



Theory:

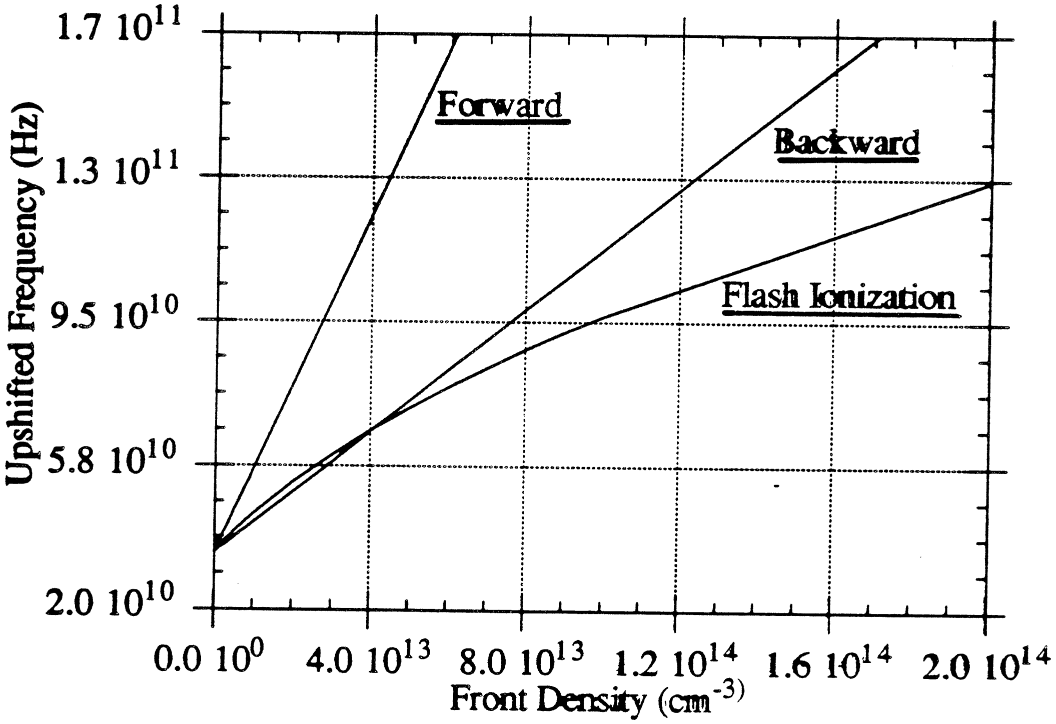
$$\omega_{up\,\substack{b\\f}} = \omega_0 \gamma^2 (1 \pm \beta v_g/c)\left[1 - \beta\left(1 - \frac{\omega_t^2}{\omega_0^2}\frac{1}{\gamma^2(1 \pm \beta v_g/c)^2}\right)^{1/2}\right]$$

$$\omega_t^2 = \omega_p^2 + \omega_c^2$$

Specific predictions:

1) large frequency upshifts $\frac{\omega_{up}}{\omega_0} \propto n$ $\omega_{up_f} > \omega_{up_b}$

2) backward wave is reflected in the lab frame when $\omega_t > (1 + \beta v_g/c)\omega_0$ and leaves cavity in the forward direction

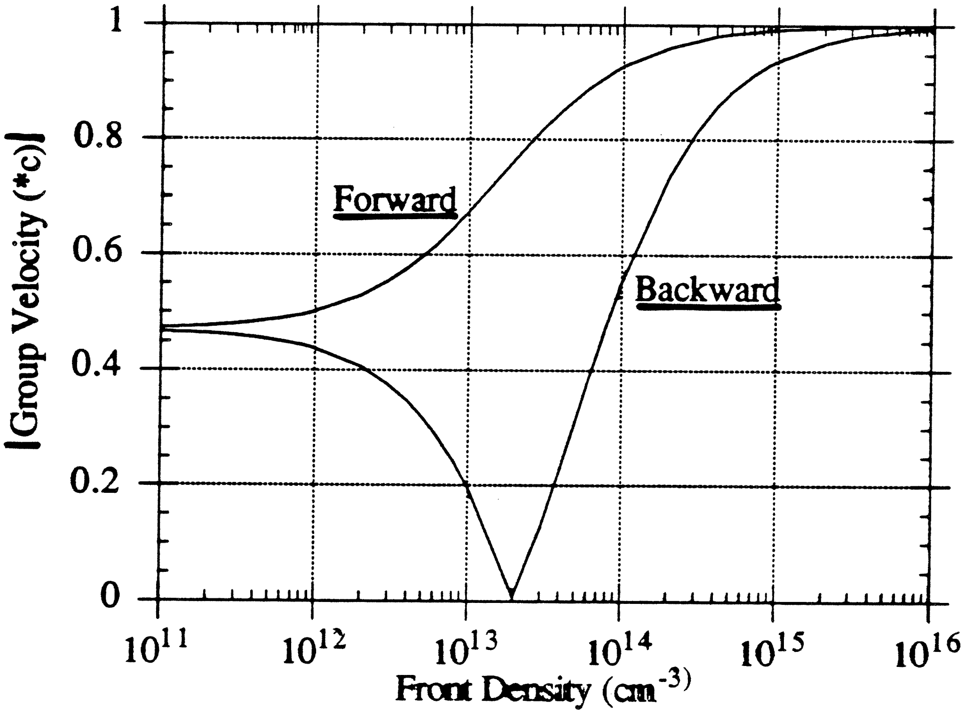


Flash ionization*: 1) $\omega_{up} = (\omega_0^2 + \omega_p^2)^{1/2} \quad \propto \sqrt{n}$

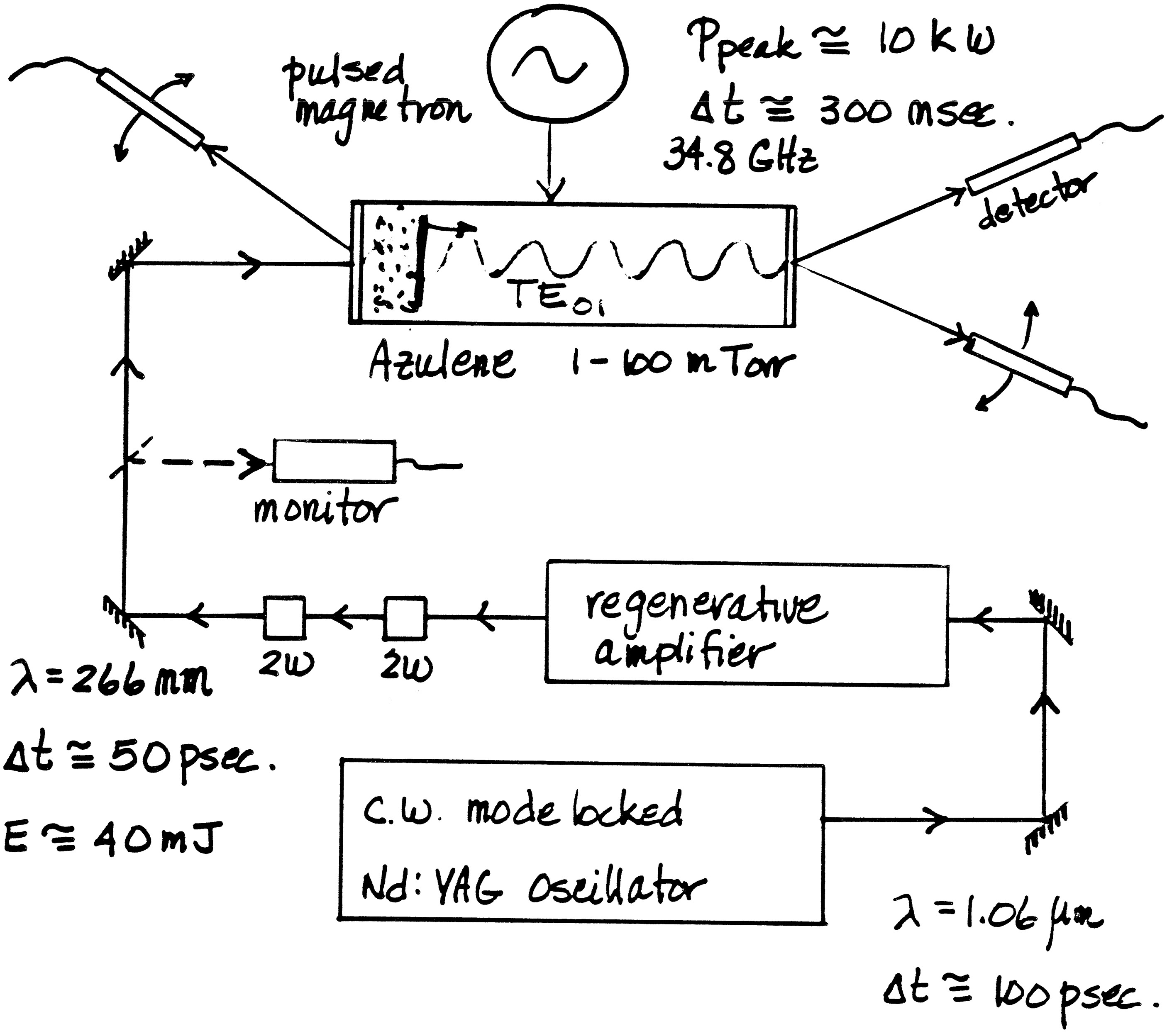
2) $\omega_{up_f} = \omega_{up_b}$

* Wilks, Dawson, Mori PRL 61 1988

Joshi, etal IEEE Trans. Plasma Sci. 18 1990


|Group Velocity (*c)|
1
0.8
0.6
0.4
0.2
0
Forward
Backward
10^{11}
10^{12}
10^{13}
10^{14}
10^{15}
10^{16}
Front Density (cm^{-3})

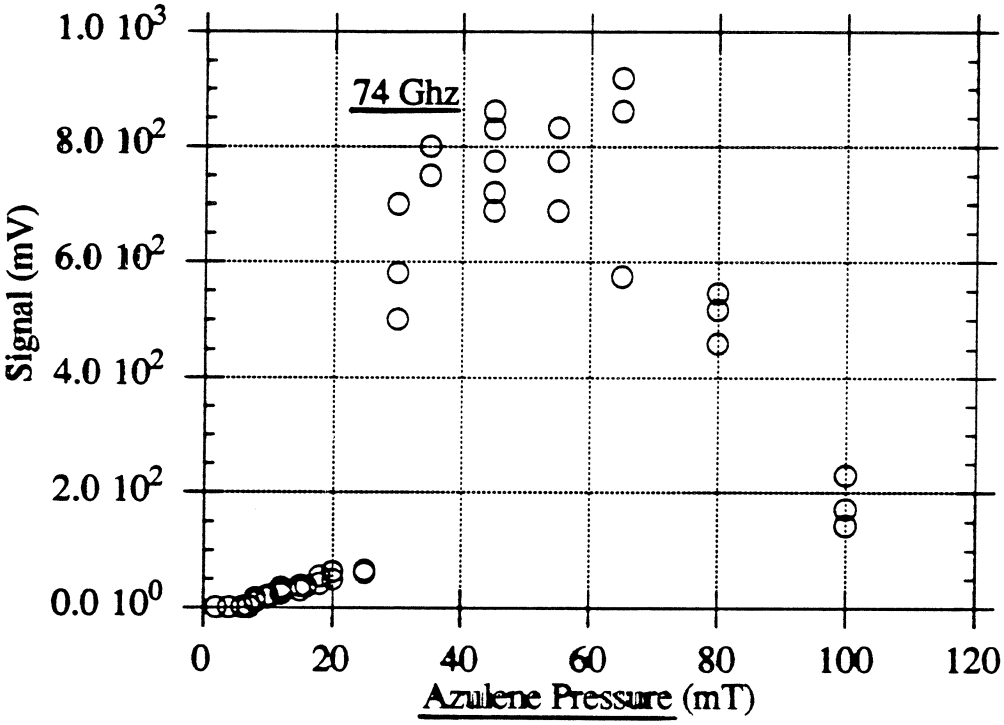
Experimental Setup



cavity length - 35 cm., diameter 1.2 cm

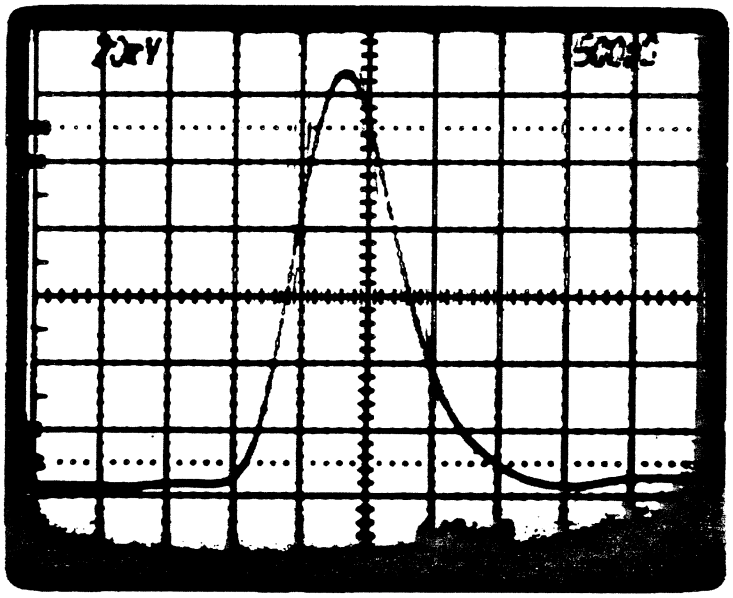
V_g - .47C

wavelengths inside guide - 19

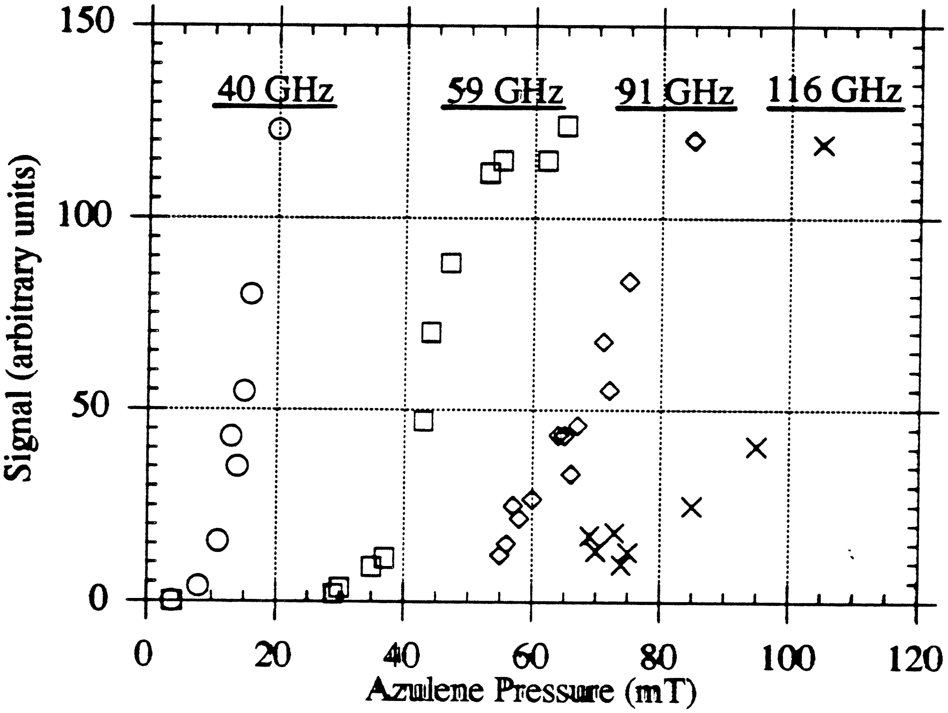

74 Ghz
Signal (mV)
1.0 10³
8.0 10²
6.0 10²
4.0 10²
2.0 10²
0.0 10⁰
0
20
40
60
80
100
120
Azulene Pressure (mT)

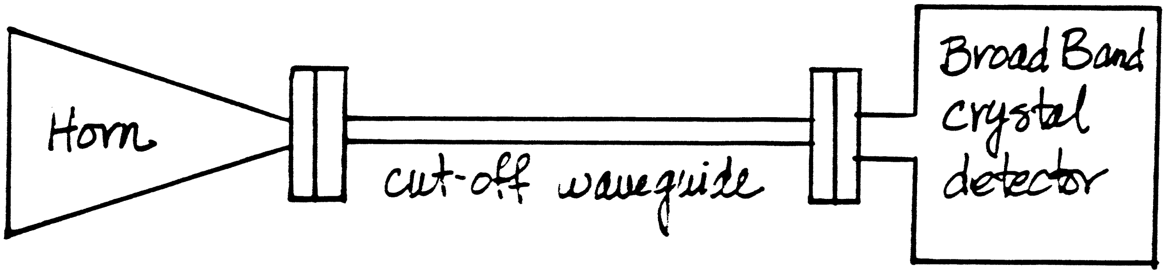
59 GHz channel - forward direction

Typical upshifted pulse

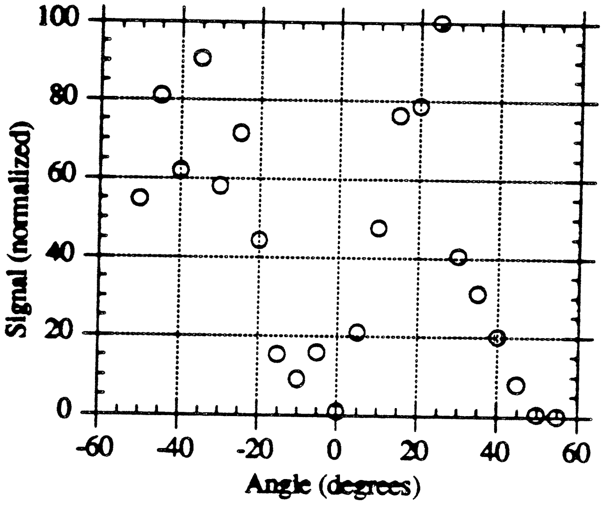


→| |← 500 psec.


40 GHz
59 GHz
91 GHz
116 GHz
Signal (arbitrary units)
150
100
50
0
0
20
40
60
80
100
120
Azulene Pressure (mT)

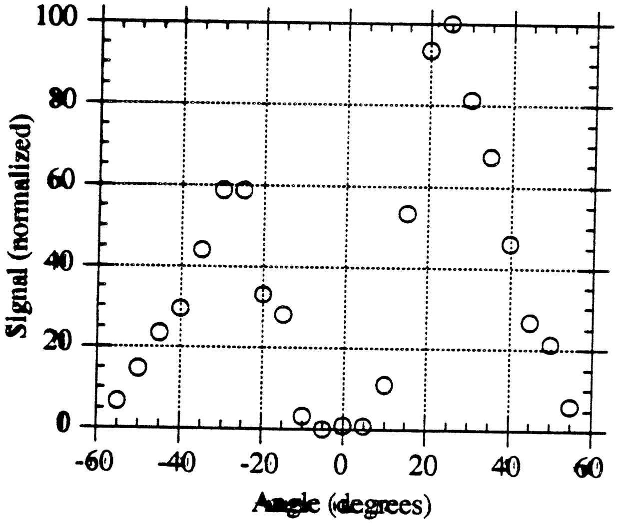

Horn
cut-off waveguide
Broad Band crystal detector

Source frequency detector 34.8 GHz



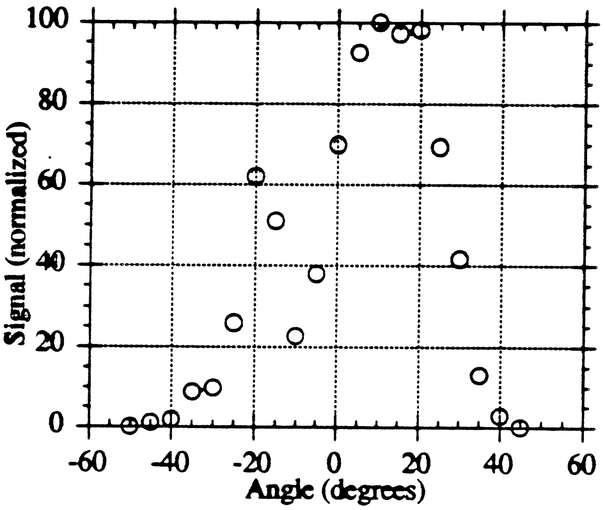
$P_{tot.} \approx 5.8$ kW

40 GHz detector channel

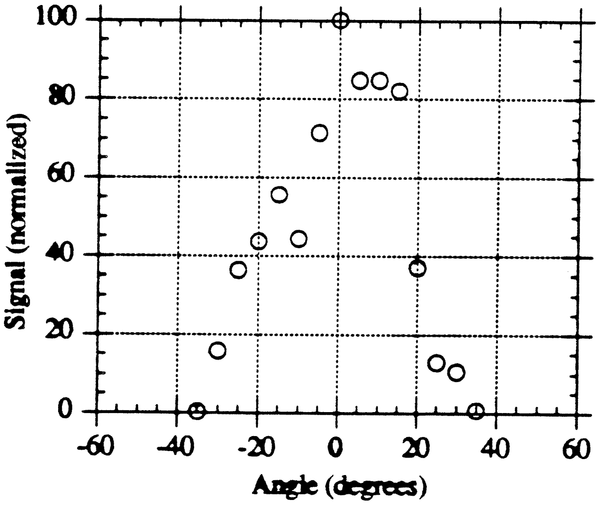


$P_{tot.} \approx 3.2$ kW

59 GHz
detector
channel



91 GHz
detector
Channel



$P_{tot.} \approx 22\,W$

Summary

1) observed large frequency upshifts $\frac{\omega_{up}}{\omega_0} > 3$

2) upshifted radiation in both forward and backward directions
$\omega_{up_f} > \omega_{up_b}$ for a given front density

3) upshifted pulse widths less than 1 nsec

4) upshift scales roughly linearly with front density as predicted by relativistic ionization front theory

5) for $n = 5\times10^{14}\,cm^{-3}$, $\frac{\omega_f}{2\pi} = 1.1$ THz