Study of Atmospheric Breakdown by High Power Microwave Pulses

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Motivation

- It has been suggested that high power microwaves can be utilized as a detector of concealed radioactive sources
- Study statistics of high power microwave breakdown of atmosphere
- Based on the statistics can we determine a reliable scheme for the detection of concealed radioactive elements?

Atmospheric Breakdown

- Plasma frequency at critical electron density

$$\omega_p = \sqrt{n_c e^2/m\epsilon_o} \approx \omega$$

- Dispersion Relation

$$\omega^2 = k^2 c^2 + \frac{\omega_p^2}{\omega + i v_c}$$

- For $v_c < \omega$: low pressure condition
- For $v_c \geq \omega$: high pressure condition

- Conductivity of homogenous unmagnetized plasma

$$\sigma = \frac{i n_e e^2}{m_e(\omega + i v_c)}$$

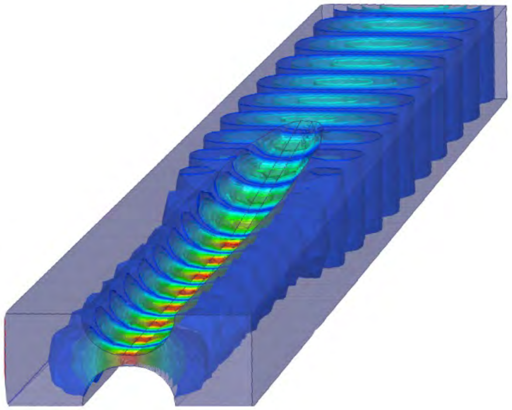
- For $v_c < \omega$, σ is imaginary and therefore there are no ohmic losses and the plasma behaves like a dielectric
- For $v_c \geq \omega$, σ is real and the plasma behaves like a conductor where the rate of ohmic energy transfer to plasma

$$\frac{dU_e}{dt} = \langle P \rangle = \frac{1}{2} R_e\{\sigma\} E^2$$

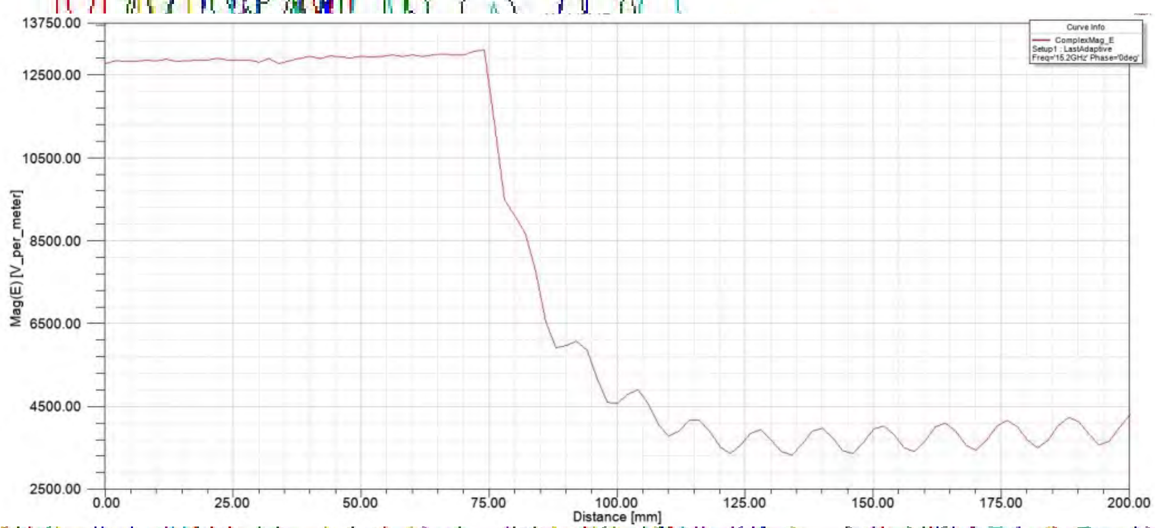
- Electric Field required for breakdown

$$E_c = 3.2 \times 10^6 p \sqrt{1 + \frac{\omega^2}{v_c^2}}$$

Experimental Design

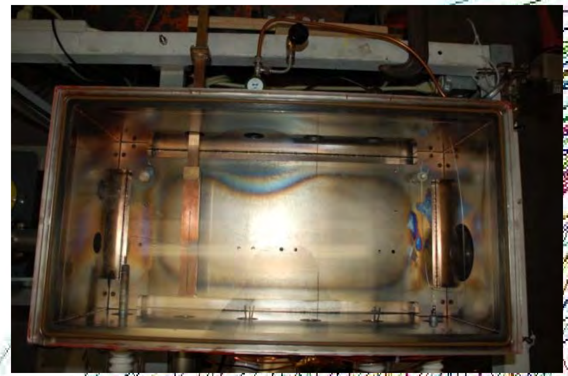


Design for Tapered Waveguide using 3D electromagnetics code HFSS:
Waveguide is tapered to concentrate electric field to 3 to 4 times higher than the critical field required for breakdown

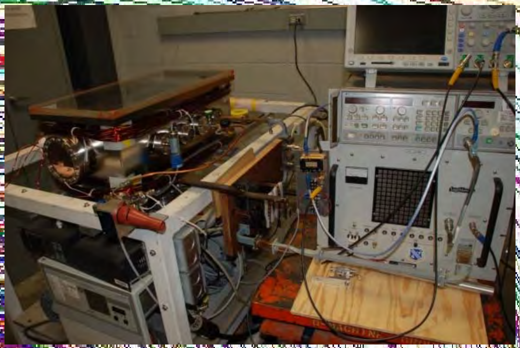


HFSS prediction for the magnitude of the electric field within the waveguide

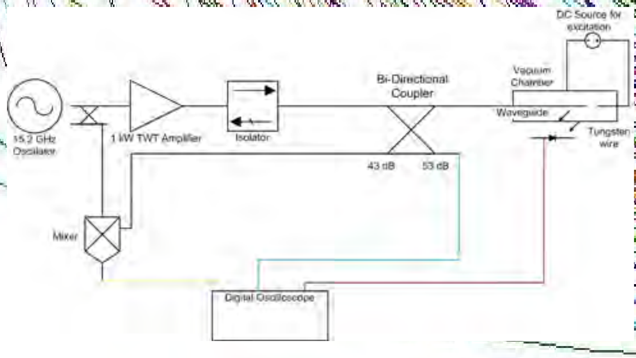
Experimental Setup



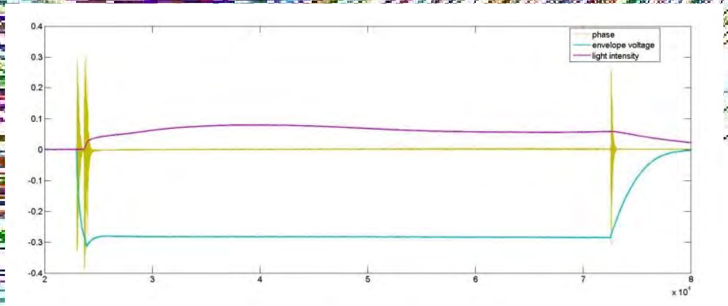
Tapered waveguide inside vacuum chamber



Setup: vacuum chamber, TWT , oscillator, and oscilloscope

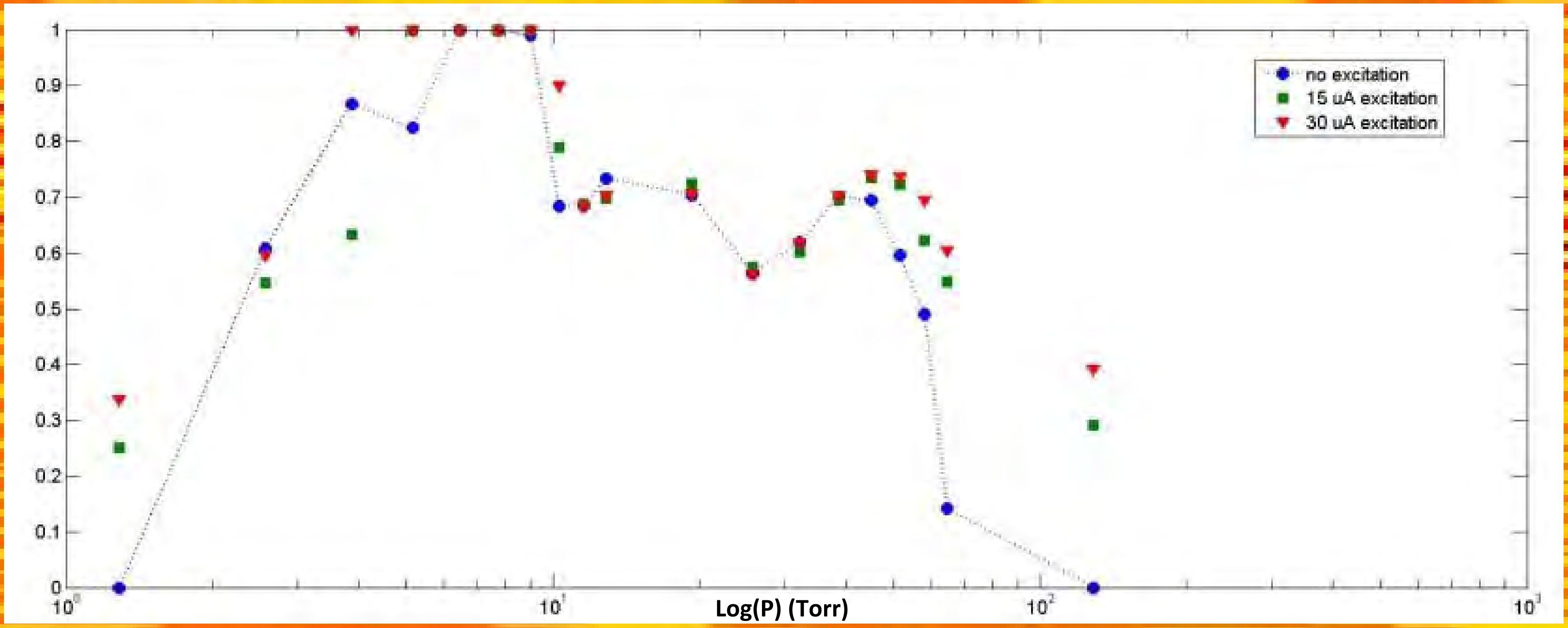


Guided wave diagram

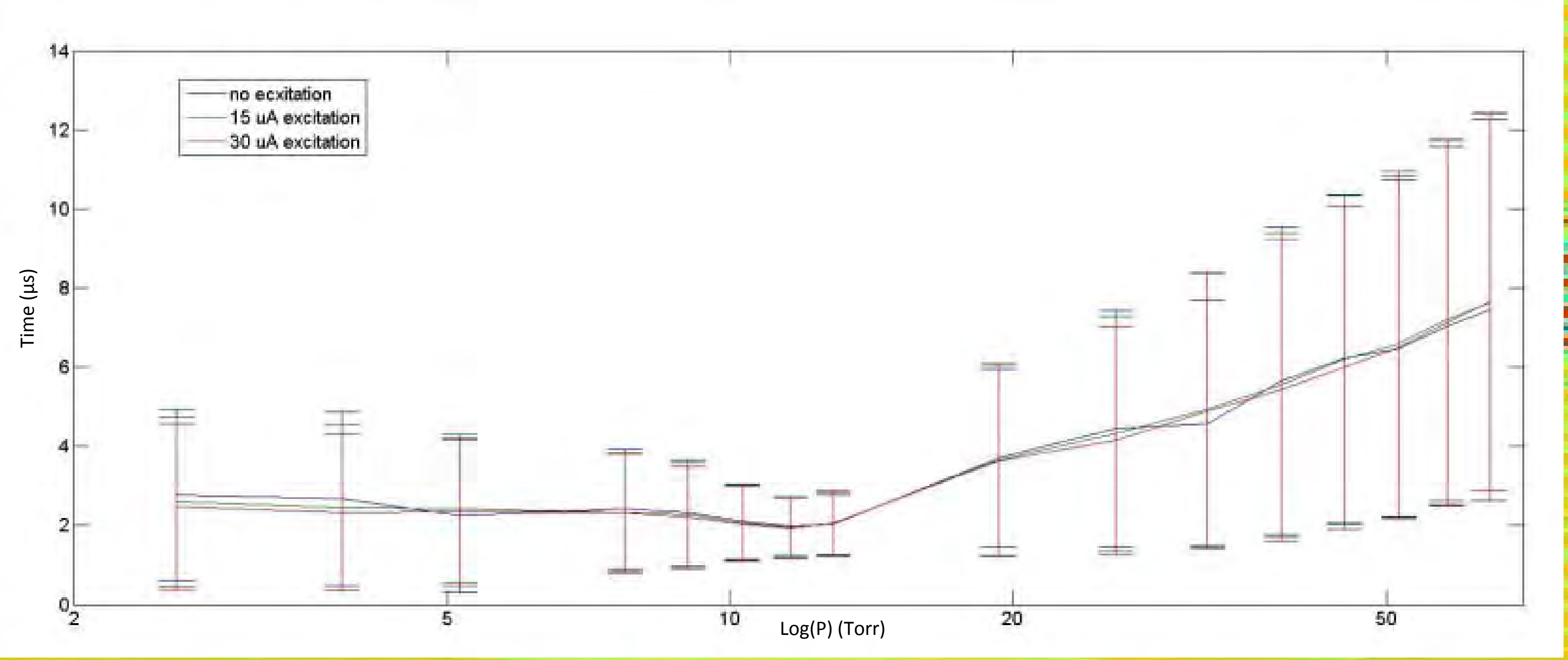


Oscilloscope measurements

Breakdown Statistics: Probability of breakdown as a function of pressure



Statistical Analysis



Breakdown statistics showing mean and standard deviation of time delay (in µs)

Conclusions

- The breakdown statistics vs. field, ionization level, and pressure have been investigated and characterized
- The time delay to breakdown is statistically shorter with elevated ionization
- The electric field required for reliable detection needs to be 3 to 4 times higher than the critical field