UWB Type High Power Electromagnetic Radiating System for Use as an Intentional EMI Source

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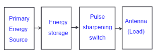
Indian Institute of Science, Bangalore 560012

Abstract:

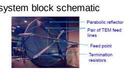
Use of sophisticated electronics for compactness and faster operation is ever increasing. Such electronics being very sensitive can get easily disturbed functionally or damaged physically by the unwanted or Intentional Electromagnetic Interference (IEMI). Short duration Ultra Wide Band (UWB) type pulse is one of such intentionally generated EMI source. To test the electronic systems' susceptibility a UWB source of appropriate rating is required. The high power UWB pulse generation requires a high voltage pulsed power source called pulser along with a high bandwidth antenna. The pulser has an energy storage device followed by a fast discharge switch. The role of this switch is very important in the UWB system operation as the switch performance parameters like rise time and dielectric recovery decide the intensity of the radiated electric field and the system energy output. Most of the UWB systems developed worldwide so far have used pressurised dielectric gas as the switching medium in the pulser. In this work gases at sub atmospheric pressure have been tried as the switching medium. To enhance the overall system energy output, energy from every switching shot is enhanced by optimising the switch breakdown voltage instead of improving the Pulse Repetition Rate (PRR) as attempted by previous researchers.

Overall, the work consists of design, analytical and numerical simulation studies along with experimental evaluation of various performance parameters of the pulser, the switch, the impulse radiating antenna(IRA) and the UWB system as a whole. The system developed under this work is on par with similar systems developed worldwide and sometimes even exceed in some of the performance parameters like Figure of Merit (FOM) and the PRR.

Introduction and Problem/Hypothesis:



UWB system block schematic



IRA antenna based UWB system

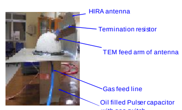
Problem/Hypothesis:

- No UWB based IUEMI nsystem in the country
- No sysytem built worldwide has gases used at sub atm pressure Gases at sub atmospheric pressure
- To enhance the overall system energy output, the only method tried by previous researchers is improing the Pulse Repetition Rate (PRR) for the pulser switch: Need to have an effective alternate method

Methods used/work done:

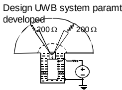
- Design, analysis, computational and experimental studies on a 50 kV HIRA antenna based UWB system for IEMI application
- Use of gases at sub atm pressure to achieve sub ns rise time
- Analysis of pulser equivalent circuit to have alternate method of achieving higher enrgy output per switching shot by optimizing the switch breakdown voltage

Parameter	Design value
Maximum output voltage (peak)	50 kV
Rise time t_r	≤ 700 ps
Fall time (e-folding)	2 ns (± 20 %)
Pulse Repetition Rate (PRR)	≥ 200 Hz
Load (antenna) impedance	100 Ω



Design and computational studies:

Design UWB system paramters Photograph of the HIRA based system developed



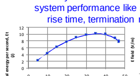
Electrical eqvt. circuit for analysis

Switch geometry and position

Basic circuit analysis carried out to decide the electrical paramters of the system
C=25 pF, L= 10 nH and R=100 Ω for 50 kV operation of pulser and HIRA antenna
Geomtery of pulser capacitor and switch: Coaxial peaking capacitor with coaxially housed pressurized/depressurized gas type spark gap switch

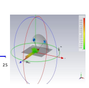
Rise time estimation empirically and PRR estimation from circuit analysis
Computational studies:

I. Optimization of excitation pulse voltage for higher energy output per switching shot
II. Antenna analysis
Radiated fields temporal and spectral characteristics using analytical models and numerical simulations
III. Analysis of the effect of pulser and antenna parameters on UWB system performance like switch rise time, termination resistance, etc



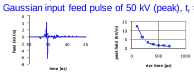
Optimization of excitation pulse voltage for higher energy output

Radiated field at 5 m in the bore sight direction



Antenna pattern of radiated field

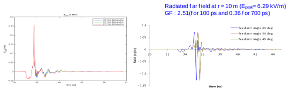
Analysis of the effect of pulser and antenna parameters on UWB system performance
Effect of pulser: Feed pulse rise time (t_r)
Radiated E_{peak}, FoM and G.F. : a direct function of t_r
Gaussian input feed pulse of 50 kV (peak), t_r =100 - 700 ps (variable)



$$\mathrm{FoM} = r.E_{far} = 62.9\ kV$$

$$\text{Gain Factor} = \frac{r.E_{far}}{V_{feed}}$$

Radiated far field at r = 10 m (E_{peak}= 6.29 kV/m)
GF : 2.51(for 100 ps and 0.36 for 700 ps)

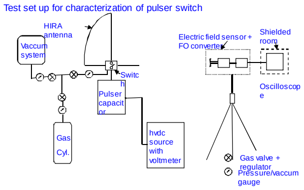


Effect of antenna termination resistance and feed angle of TEM feed arms of antenna

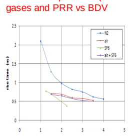
Experimental Studies and results:

I. Pulser : Switch -- performance parameters: for various gases/mixtures
II. UWB system : radiated field performance in the temporal, spectral and spatial domain and evaluation of effect of pulser rise time on the radited field

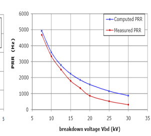
Test set up for characterization of pulser switch



Rise time vs pressure (above atm pressure) for the switch for various gases and PRR vs BDV



Rise time vs gas pressure

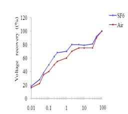


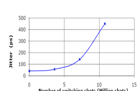
PRR vs BDV

- As gas pressure ↑ E ↑ t_r ↓ ,i.e. inverse relationship between t_r and pressure
- SF_6: the biggest contender for better t_r
- Inverse relationship with breakdown voltage V_{bd}
- As V_{bd} ↑ arc plasma density ↑ $t_{recover}$ ↑ PRR ↓, ∴ as V_{bd} ↑ PRR ↓
- After V_{bd} of 12.5 kV, ≥ 20 % error from computed values by circuit model

Voltage recovery characteristics (SF_6 and air) and switching jitter

- Switch operation at: fixed gas pressure

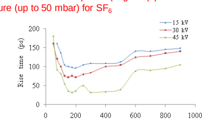




- Similar distinct profile for both the gases (intermediate plateau region)
- For a given $t_{recover}$ SF_6 recovers to a larger extent than air

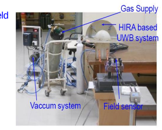
- Jitter measured for N_2 gas at 1 kHz after 3.6 M, 7.2 M and 10.8 M (3 hrs) shots
- Jitter increase by an order of magnitude after 10.8 M shots
- Recommendation for electrode maintenance

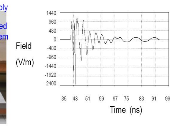
Test results for sub atmospheric (negative) pressure: Rise time vs. gas pressure (up to 50 mbar) for SF_6



- Characteristics similar to Paschen's law
- As Voltage ↑ rise time ↓ (at 200 mbar t_r is minimum at each voltage)
- Can be used for fast sub atmospheric high voltage pulsed power systems

Radiated field performance in the temporal, spectral as well as spatial domain (near and far field regions)
Test Set up



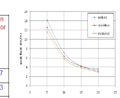


Radiated field at 12 m distance (far field region) at 25 kV

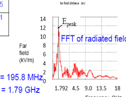
- ✓ Main pulse : duration 193 ps
- ✓ E_{peak} : 2.4 kV/m, FoM = 28.9 kV and GF = 1.15

Measured vs. calculated E_{peak} at 10 m distance for various gas types and pressures

Gas Type	Pressure range abs (bar)	Highest V_{peak} Voltage, (kV)	Measured t_r (ps)	Cal. E_{peak} at 10 m (Baum's Model) (kV/m)	Measured E_{peak} at 10 m (kV/m)	Gain Factor
N_2	1-4	20	336	1.68	1.55	0.77
dry Air	1-4	32	319	2.83	2.67	0.83
SF_6	1-2.25	46	193	6.74	5.31	1.15
air + 30 % SF_6	1-4	42	231	5.14	4.67	1.11



- SF_6 : fastest rise time and hence better GF
- Close agreement between simulated and measured peak fields



f_l = 195.8 MHz
f_h = 1.79 GHz
b_r = 9.15 pbw = 160.6 %

Comparison of the UWB system developed with some of the best UWB systems developed worldwide

Name of the UWB system	Pulser	Far field	Figure of merit
Swiss IRA, NEMP Laboratory, Spiez, Switzerland	2.8 kV, 100 ps / 4 ns, **800 Hz**	220 V/m at r = 41 m	**10 kV**
TNO IRA, The Hague, Netherlands	9 kV, 100 ps / 4 ns, **800 Hz**	3.4 kV/m at r = 10m	**34 kV**
Univ of Magdeburg, Magdeburg, Germany	9 kV, 100 ps / 4 ns, **800 Hz**	3.4 kV/m at r = 10m	**34 kV**
UWB system developed in this thesis work	46 kV, 193 ps/2.1 ns, **1 kHz (at 27kV)**	**5.3 kV/m at r = 10m**	**53 kV**

Comparing with of the best develkoped UWB systems worldwide the UWB system developed under this work is better in terms of FoM and PRR

Conclusions:

- A 50 kV HIRA based high power UWB radiating EM weapon system has been successfully developed for the first time in the country. (good agreement between analyzed, simulated and experimental results)
- Influence of gas pressure on the pulser switch rise time is analyzed for different gaseous switching media.
- A relationship is derived between switch breakdown voltage (V_{bd}) and the energy delivered by the pulser in every switching shot. Optimal voltage to achieve maximum energy per switching shot is at V_{bd} = 0.75 V_{dc}.
- The switch gas breakdown characteristics at fixed voltage has been evaluated for sub atmospheric pressure levels up to 50 mbar. The pressure vs. rise time characteristics are found to be similar to the Paschen's curves. With an increase in the switch voltage the rise times is found to reduce.

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by

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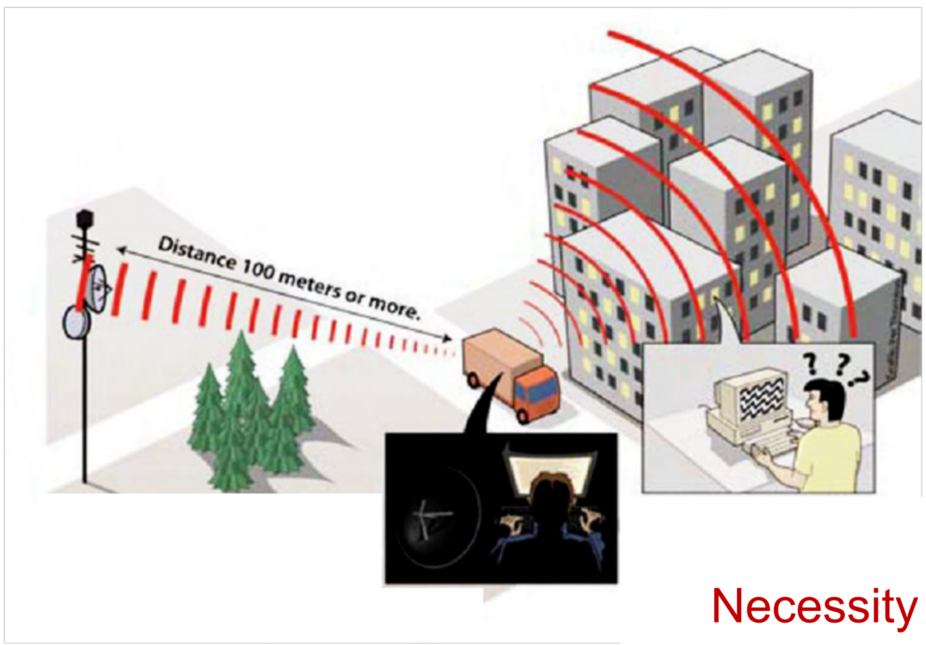
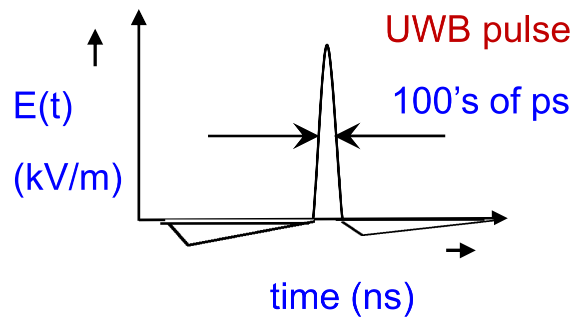
Contents

- Introduction: HPEM/IEMI sources and their effects on electronic systems, UWB system as IEMI source (EM weapon)
- Objectives of the present study
- Design and development of a 50 kV HIRA antenna based UWB system
- Computational studies on the performance of UWB system
- Experimental studies of the UWB system developed
- Conclusions

Introduction

- ❑ Electromagnetic interference (EMI) and its importance
- ❑ HPEM sources and their effects on electronic systems, UWB system as EM weapon
  - ➢ Un intentional sources : Lightning (LEMP), ESD
  - ➢ Intentional (IEMI) sources: HPM, NEMP or UWB weapon



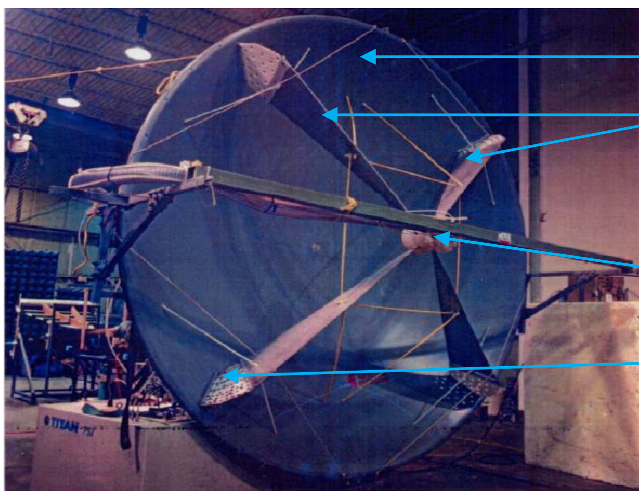


Necessity to have IEMI sources

A typical UWB radiating system and some contributions

Primary Energy Source → Pulsed power system → Pulse sharpening switch → Antenna (Load)

➢Very limited work done so far on the sub ns switching for UWB systems with gaseous switching media below atmospheric pressure level.



IRA antenna based UWB system

➢Higher energy output :

- Either increase energy per pulse/increase the PRR: most of the researchers have worked on increasing the PRR

First time development of UWB type IEMI source (EM Weapon) in the country

Objectives of the study

Objectives

Design and development of a 50 kV high power HIRA based UWB radiating system

Parametric analysis, simulation and experimental evaluation

Studies of the effect on performance parameters of the pulser switch

- Rise time, pulse repetition rate, jitter, etc. for use of various types of switching gaseous dielectrics at pressures above the atmospheric level and below the atmospheric level

and hence the effect of switch on the UWB radiating system as a whole

Optimization of pulser energy output

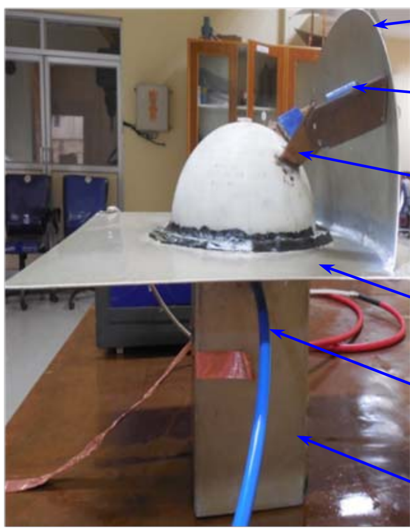
as a function of peak amplitude of the pulser output voltage pulse

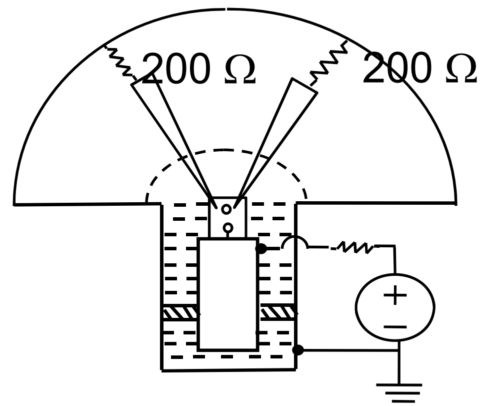
(i.e. breakdown voltage of the switch)

UWB system (Pulser) design parameters

Parameter	Design value
Maximum output voltage (peak)	50 kV
Rise time t_r	≤ 700 ps
Fall time (e-folding)	2 ns (± 20 %)
Pulse Repetition Rate (PRR)	≥ 200 Hz
Load (antenna) impedance	100 Ω

Design : Circuit analysis to decide the pulser parameters and its geometry (coaxial cap with switch)





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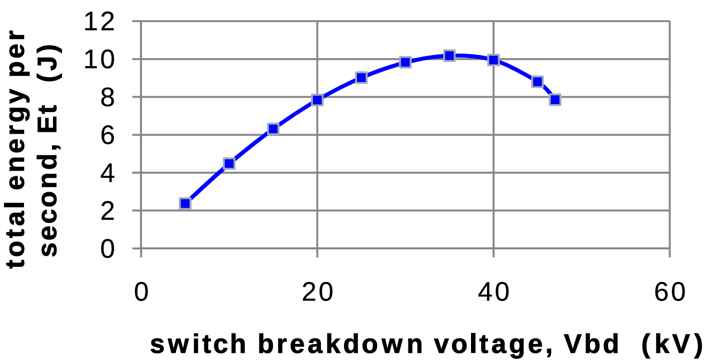
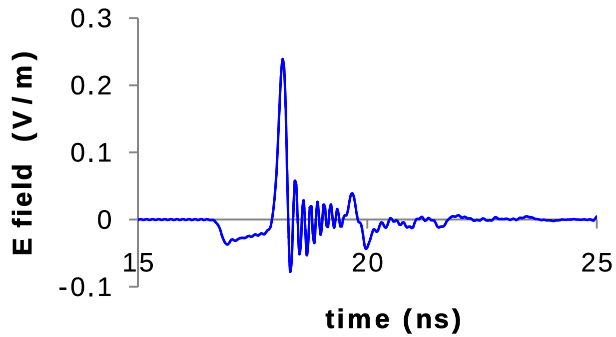


$E_m = 10.2 \text{ J}$

Optimization of excitation pulse voltage for higher energy output



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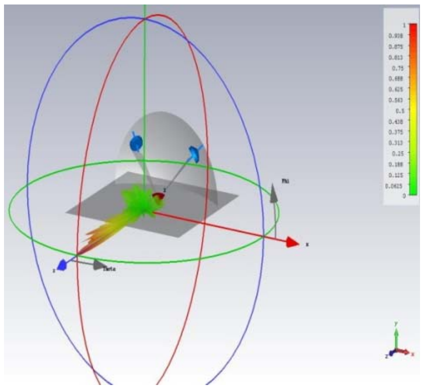

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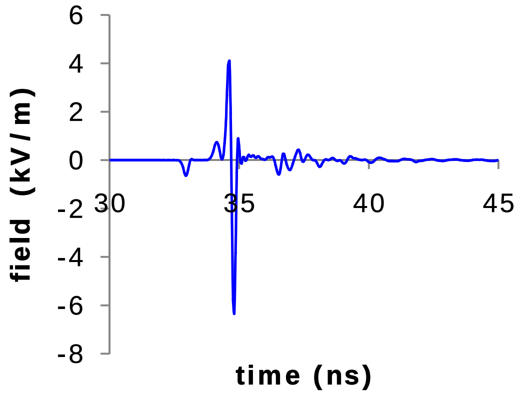
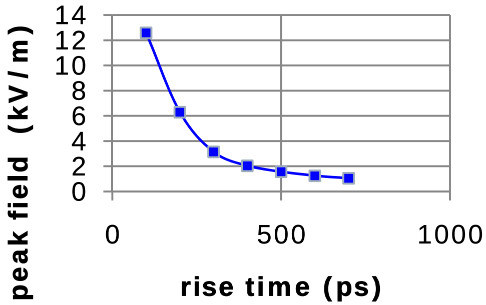
Gaussian input feed pulse of 50 kV (peak), t_r =100 - 700 ps (variable)





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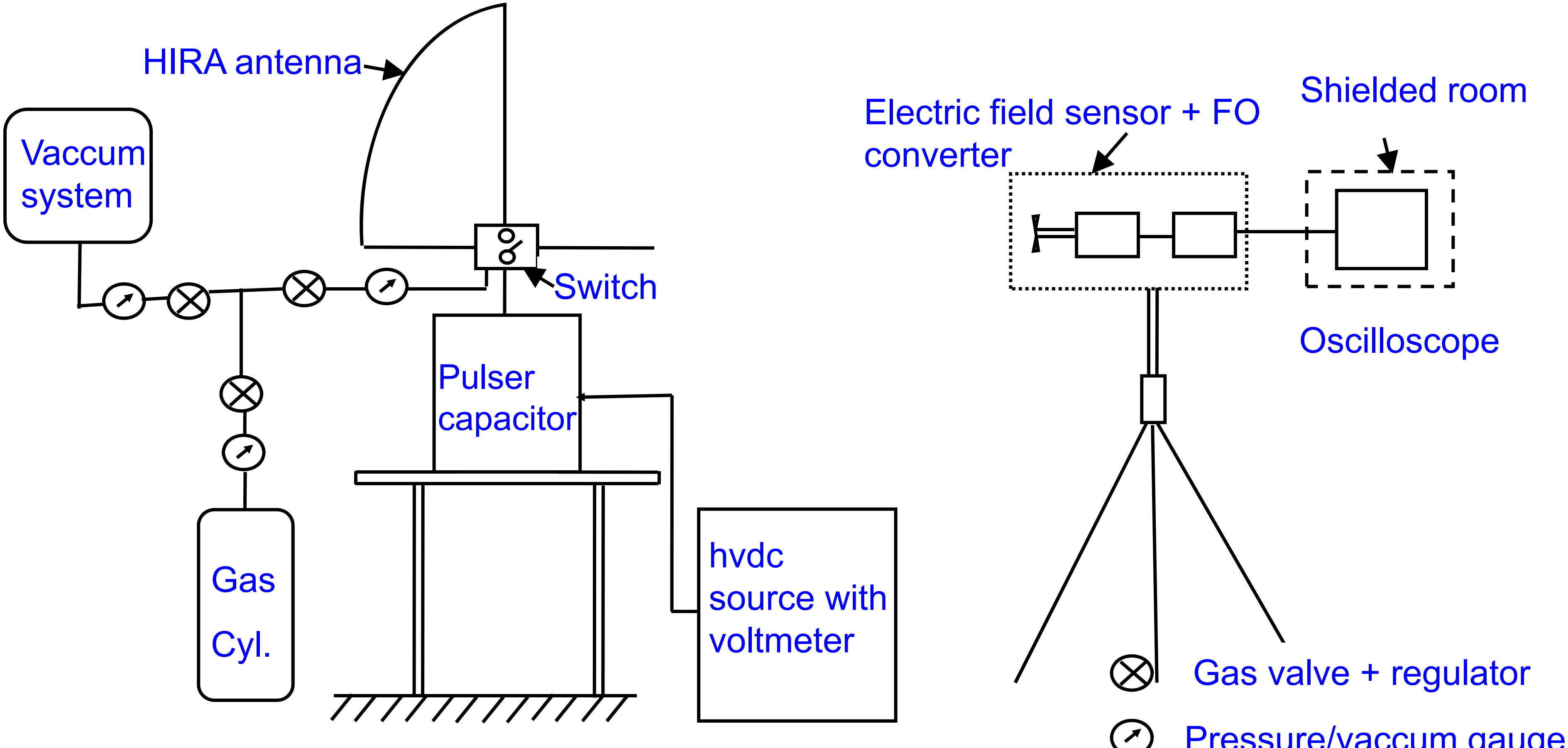

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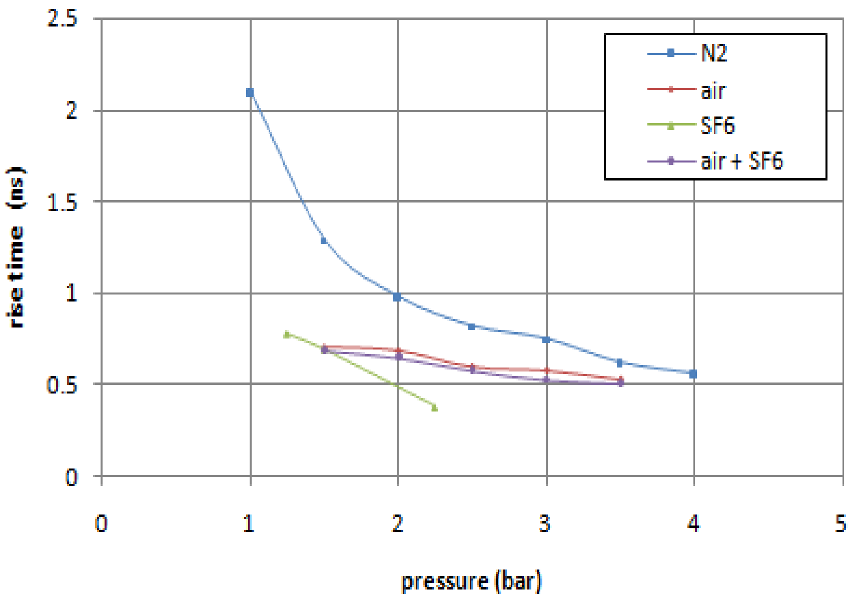
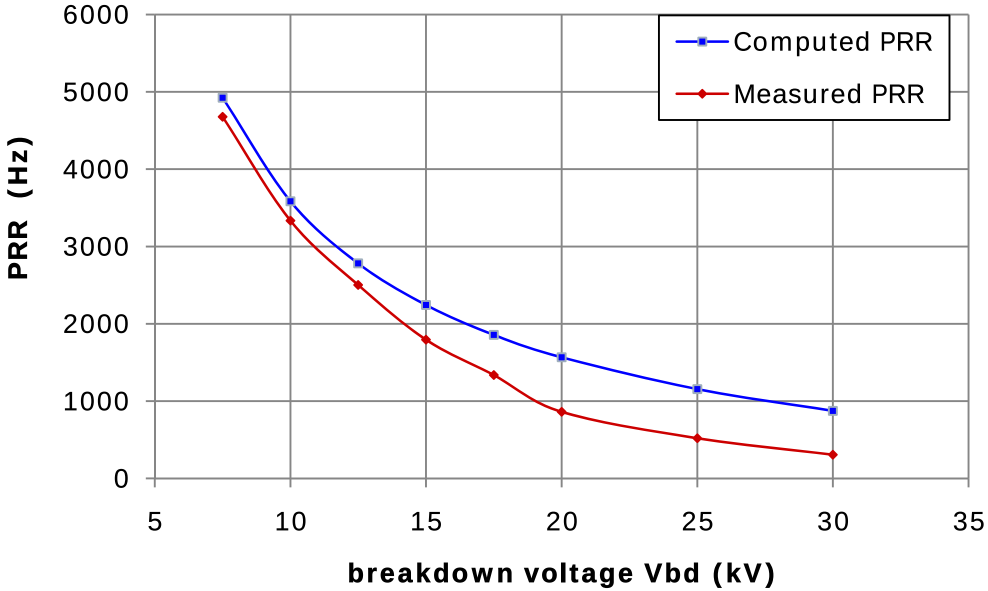


Rise time vs gas pressure



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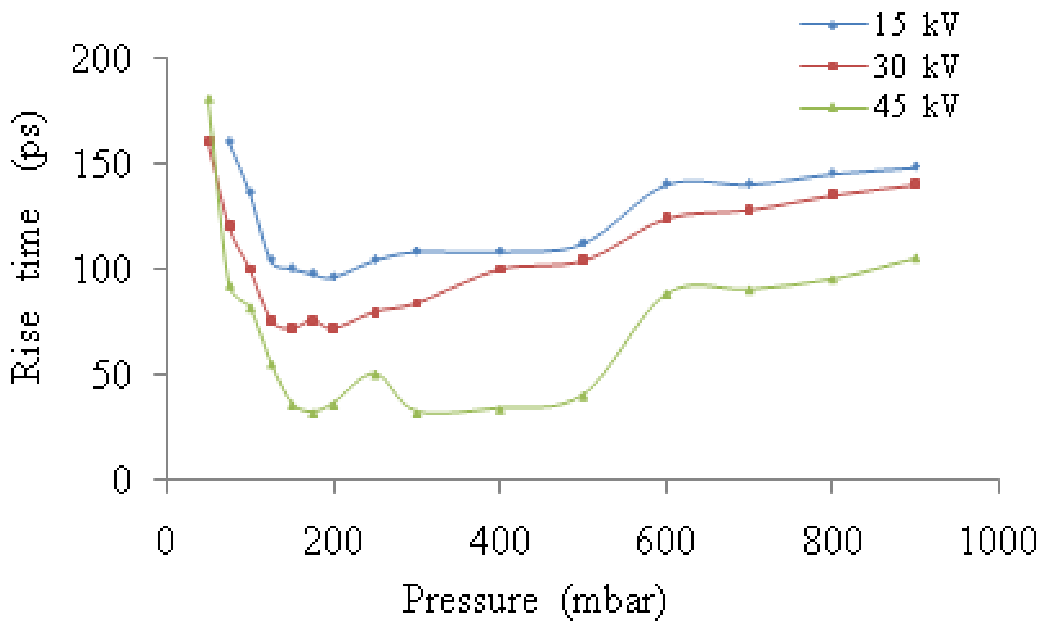
Test results for sub atmospheric (negative) pressure: Rise time vs. gas pressure (up to 50 mbar) for SF_6

Sub atmospheric pressurized gas switches for achieving sub ns rise time pulses has not been exploited to the full extent till date



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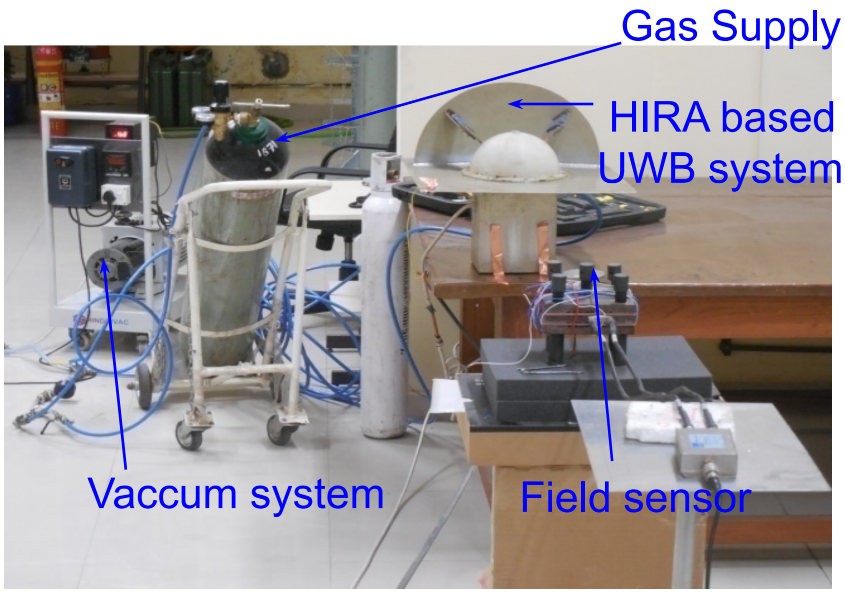

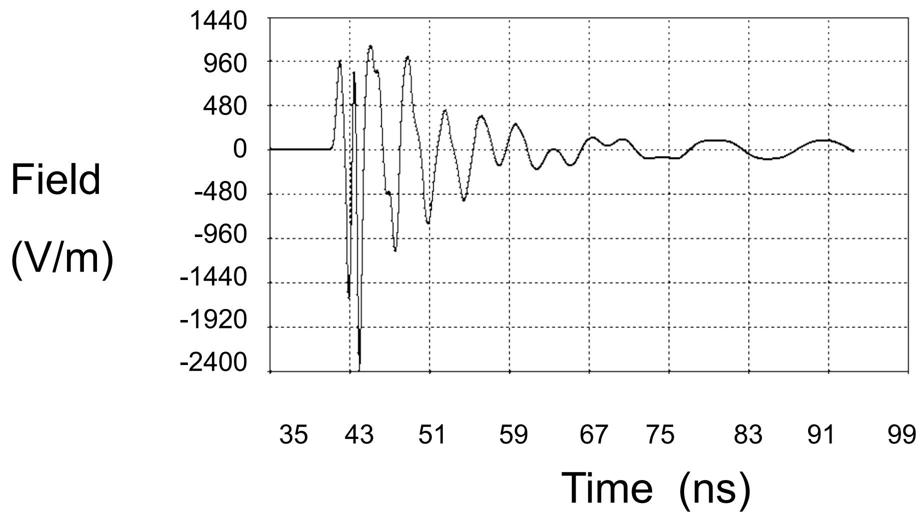

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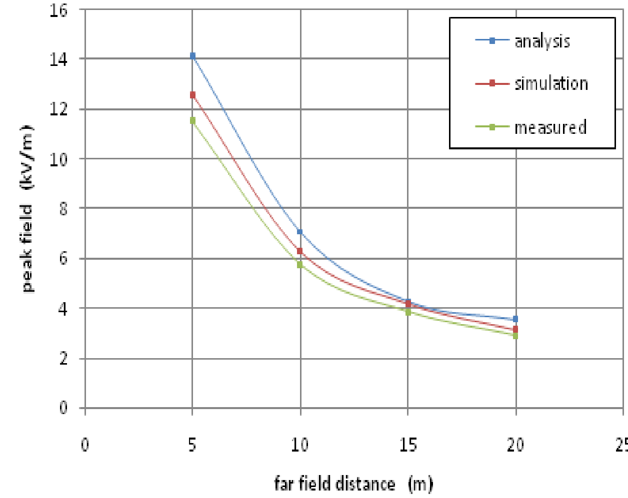

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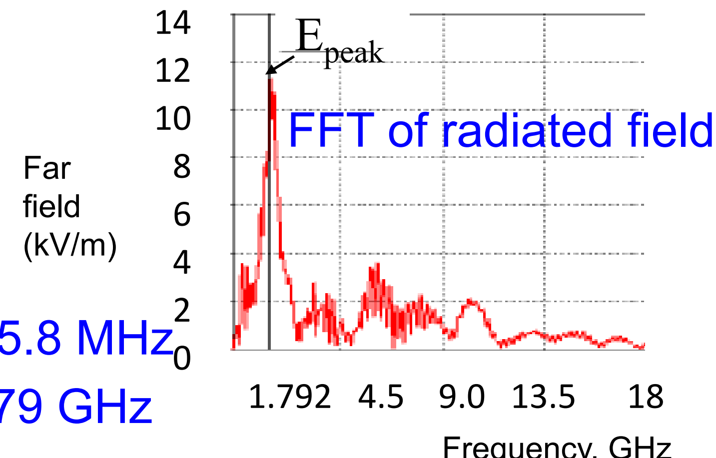

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