UNIVERSITY OF MARYLAND

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Electromagnetic Effects on Integrated Circuits and Systems at Microwave Frequencies: Experimental Design and Methodology*

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Outline

- Overview of DoD E^3 test standards and methods
  - Conducted and radiated susceptibility (CS and RS)
  - Limitations at short wavelengths
- Studies of microwave effects in discrete, integrated and distributed circuits and components
- Nonlinear effects: IM products, frequency and mode conversion, saturation and breakdown
- Interaction of microwave radiation with electronic systems and structures

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MIL-STD-464

TABLE IA. External EME for systems capable of shipboard operations (including topside equipment and aircraft operating from ships) and ordnance

Frequency (Hz)	Environment [RMS V/m]	
	Peak	Average
10k-150M	200	200
150M-225M	3,120	270
225M-400M	2,830	240
400M-700M	4,000	750
700M-790M	3,500	240
790M-1000M	3,500	610
1G-2G	5,670	1,000
2G-2.7G	21,270	850
2.7G-3.6G	27,460	1,230
3.6G-4G	21,270	850
4G-5.4G	15,000	610
5.4G-5.9G	15,000	1,230
5.9G-6G	15,000	610
6G-7.9G	12,650	670
7.9G-8G	12,650	810
8G-14G	21,270	1,270
14G-18G	21,270	614
18G-40G	5,000	750

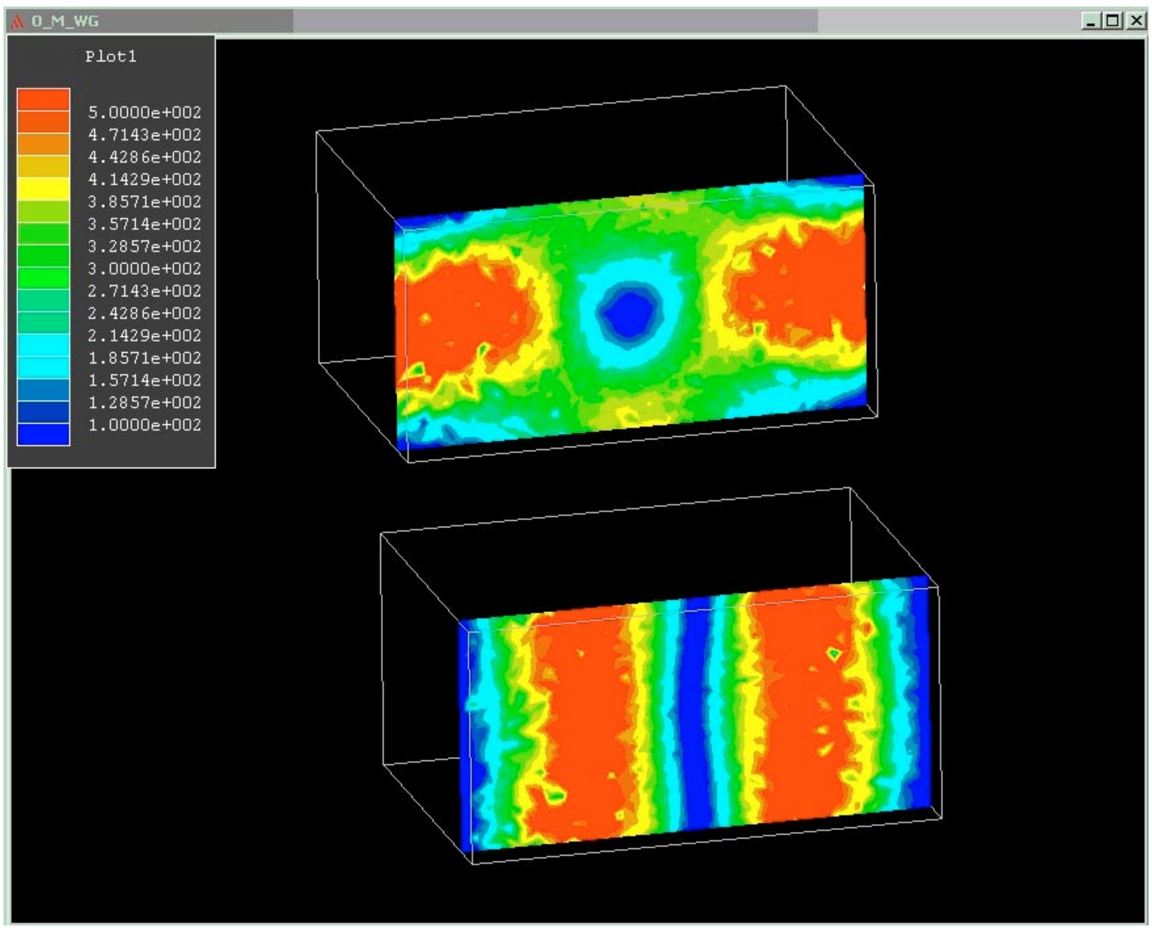
E^3 Limitations

- Based on empirical formulations, prior test results and failure analysis.
- Little relation to device physics or specific component susceptibility (MIL STD 883).
- Covers mainly VLF~18 GHz with limited standards to 40 GHz (MIL STD 461E and 464).
- What is not addressed:
  - EM wavelengths much smaller than structure dimensions,
  - Time dependent effects (fast rise microwave pulses, sneak through),
  - Nonlinear effects (frequency conversion, saturation, IM products and breakdown),
  - Resonant interactions at mm scales,
  - Multi-mode and distributed interactions,
  - Pulsed microwaves with complex and/or wideband modulation.

Studies of Component Susceptibility

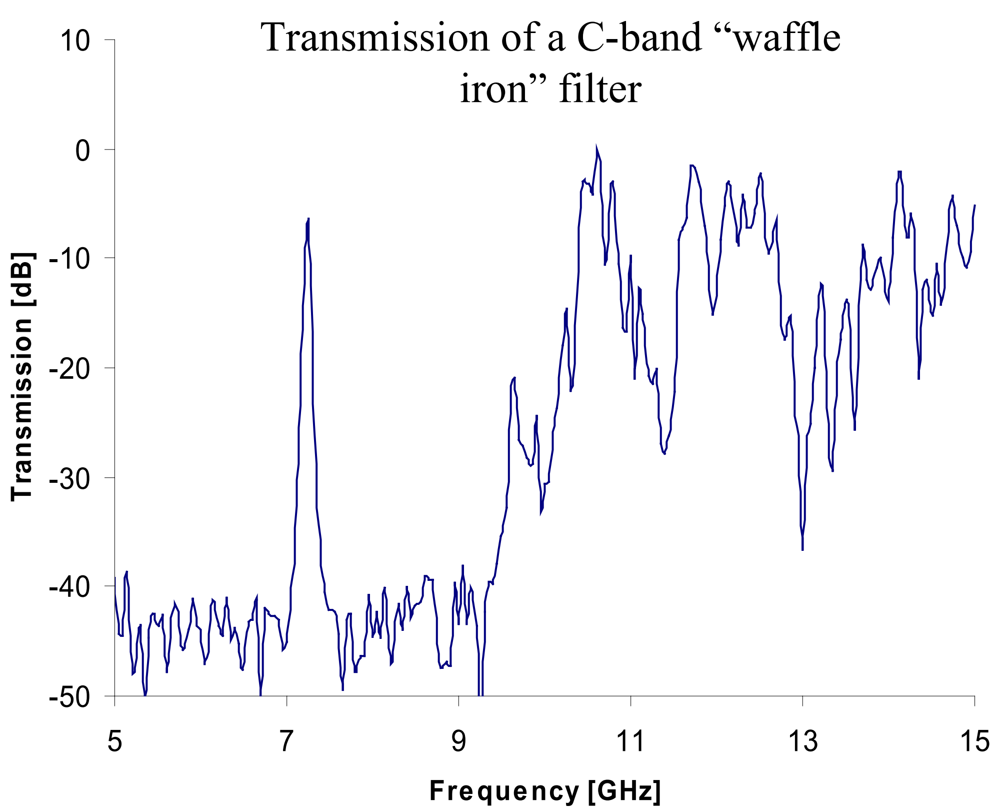
- **Basic issues:**
  - How does susceptibility depend on device type and architecture?
  - What are the interrupt processes, and what electronic mechanisms are involved?
  - What is the frequency and time domain response of devices way outside their normal operating range?
  - How random are the processes?
  - What circuit models will adequately predict interrupt processes?
  - Are nonlinear effects important?
- **Experimental program:**
  - Determine intrinsic susceptibilities using direct injection studies,
  - Identify particularly sensitive device types,
  - Study fast-pulse, wideband and complex modulation effects

Field pattern in a rectangular waveguide operated at frequencies above cutoff for high order modes



High order modes can produce spurious response in circuits designed for fundamental mode operation.

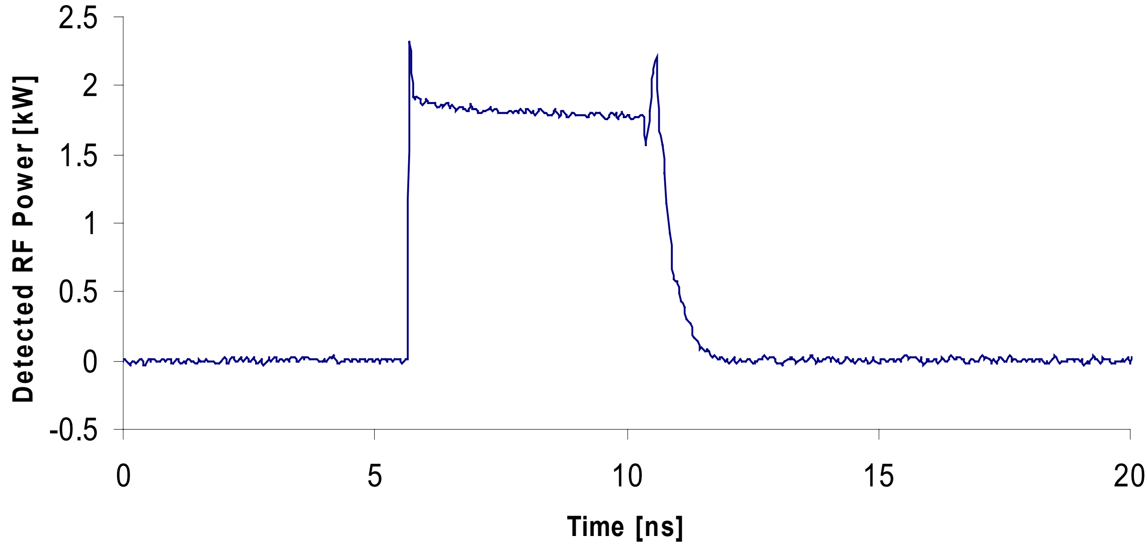
Frequency response of devices beyond their normal operating range



Many devices intended to protect systems from out-of-band signals do not work at very high frequencies where high order modes are possible.

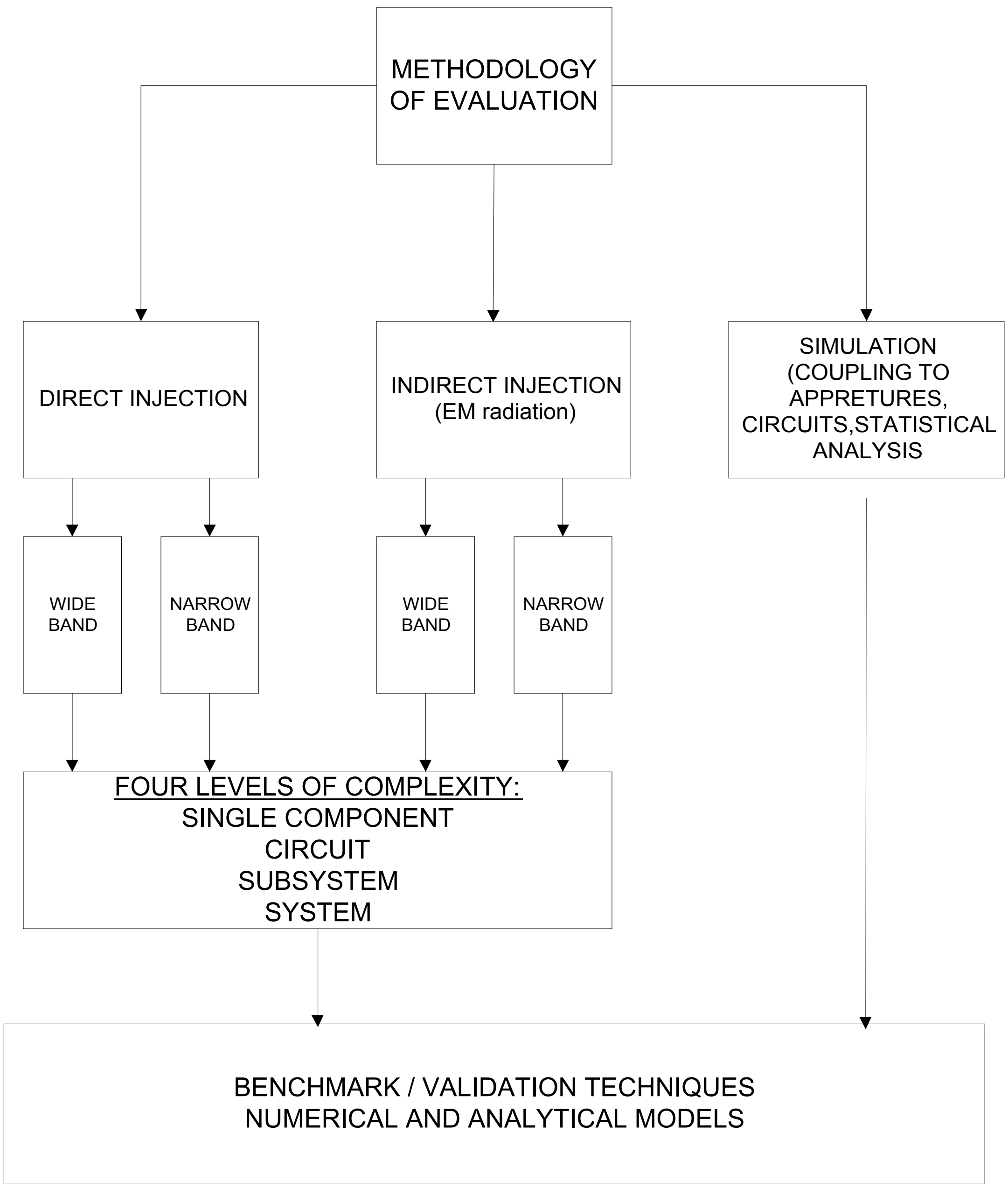
Pulsed RF "Sneak Through"

Response time of a Ku-band, power limiting gas cell designed to break down at ~10 W. Actual RF pulse length is 10 microseconds.

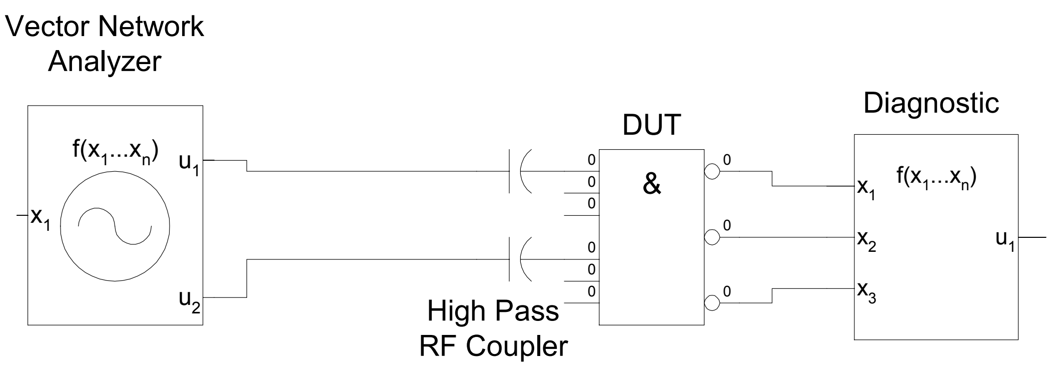


Most protection circuits operate by an avalanche process. The front of a high power RF pulse can "sneak" by if its rise time is short compared to the ionization rate of the device.

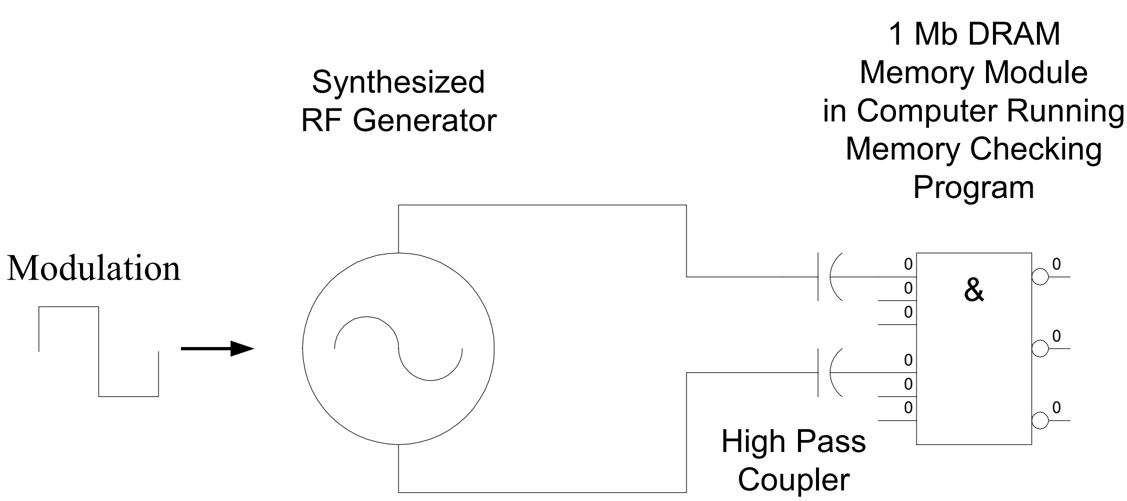
Flow Chart Showing Test Methodology



Schematic of Direct Injection Experiments

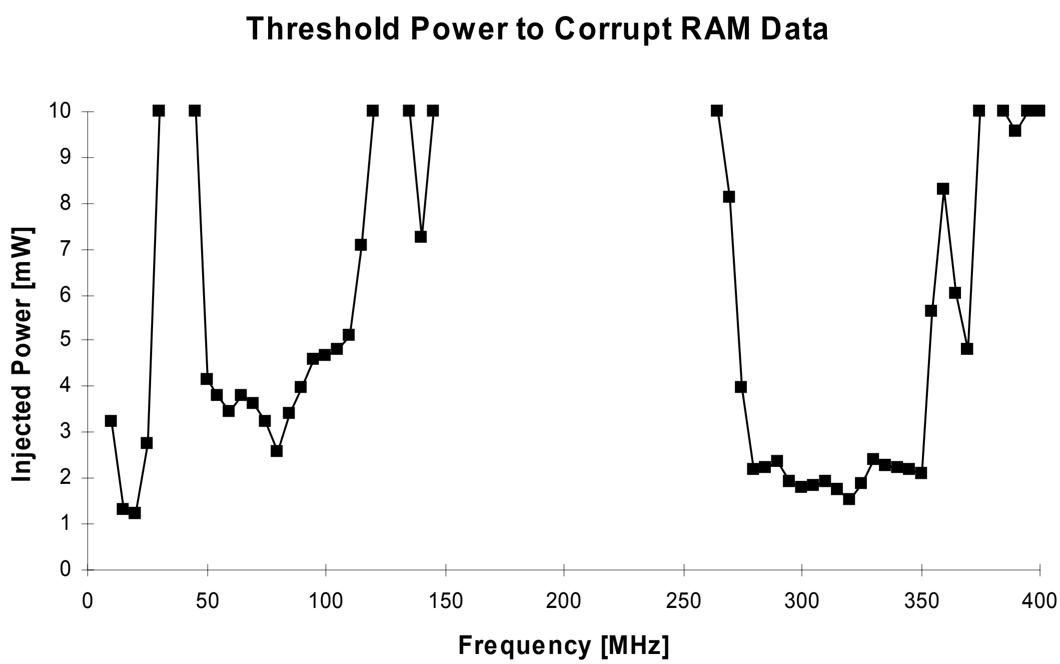


S-parameter Component Testing



Injection of CW and Modulated RF

Preliminary Results of Direct RF Injection into 33 MHz DRAM on a PC Running EC Code



Conclusions

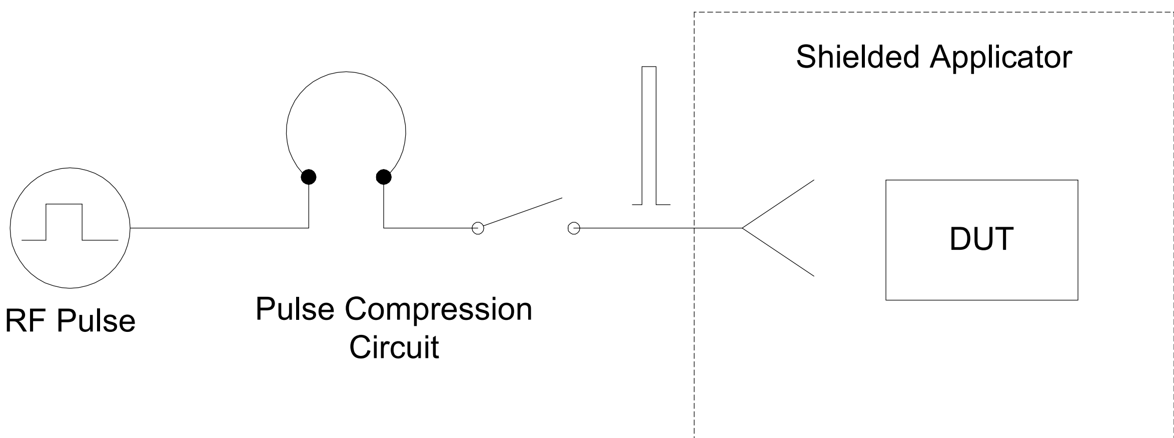
- Upset may be very frequency and modulation-dependent and device-specific.
- We need to understand the frequency and time domain response of various devices and their resonant characteristics at high frequencies.
- Nonlinear effects (frequency conversion, saturation, etc.) may be important.

Characterization of Component Susceptibility

- Response of critical front-end protection to fast rise microwave pulses and high order modes:
  - TR switches
  - Limiters
  - Filters
  - Duplexers
  - Active protection (AGC, clippers, clampers, etc.)
- Identification of sensitive electronics and structures
  - CPU's and controller chipsets
  - High speed memory
  - Ultra-low power devices
  - Mixed signal circuits (D/A, A/D, transducers)
  - High speed analog circuits
- Verification of EM and lumped circuit models for analytical and numerical studies.

Fast Rise Pulse Studies

- Many hazardous EM effects (sneak through, breakdown, saturation, etc.), involve nanosecond time scales.
- We plan to employ pulse compression techniques to increase the pulse power and rise time of the RF applied to devices.



Schematic of Fast Pulse Experiment

Summary

- Experiments will concentrate on:
  - Device characteristics at frequencies outside their normal range of operation,
  - Nonlinear response,
  - Fast time-domain effects,
  - Experimental data will help develop new HF circuit models for analytical and numerical studies.
- Existing IREAP instrumentation and capability:
  - Continuous frequency coverage up to 100 GHz,
  - Network analyzer to 40 GHz,
  - Complex modulation capability,
  - Pulse power capability > 100 MW and <5ns up to ~40 GHz,
- Needs:
  - High pass direct injection probe,
  - Extend pulse compressor frequency coverage,
  - Configure an existing HPM sources as a wideband plasma oscillator for high power radiation studies,
  - Construct chamber for radiation studies.