Direct Antenna Modulation:
Analysis, Design, and Experiment

Staff Research Seminar
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Dev Palmer, US Army Research Office
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Direct Antenna Modulation

Location: Duke University

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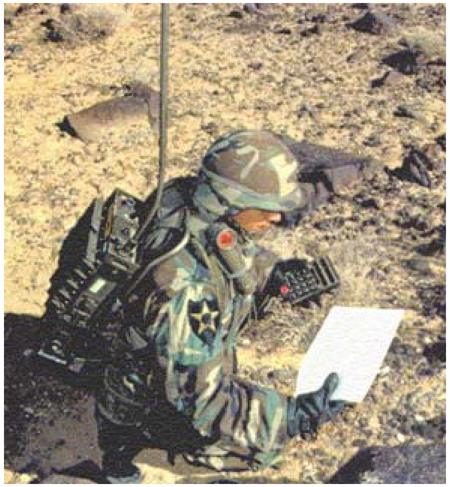
- Electrical and Computer Engineering Department
- Sensing and Waves Research Group

Research Assistant: Mr. Steven Keller

- Second-year graduate student
- BSEE from Cornell University
- Hands-on experience with systems development
- US Citizen

Motivation

- 80% of Army ground mobile communications occurs in the HF - UHF bands
  - Low frequency: 3 MHz – 1 GHz
  - Long wavelength: 30 cm – 100 m



Manpack Radio Set AN/PSC-3
www.tobyhanna.army.mil

M577A3 Tracked Command Post Carrier sill-www.army.mil

Long wavelengths =

Long antennas =

"Shoot me first!"

Research Goal

Investigate direct antenna modulation (DAM) as a technique to increase the operating bandwidth and radiation efficiency while simultaneously reducing the size and signature of tactical antennas for Army mobile wireless communications.

Background

- Antennas typically are designed to operate at resonance
  - Resonant matching network to the transmit/receive circuitry for maximum power transfer
  - Inherently narrowband system
- Operation in linear but non-resonant modes gives increased bandwidth at the cost of greatly reduced efficiency
- DAM uses techniques developed for high-efficiency switching amplifiers to decouple the antenna resonance
  - Drives antenna in saturation rather than in a linear mode
  - Should enable efficient operation over extremely wide bandwidths with electrically small antennas

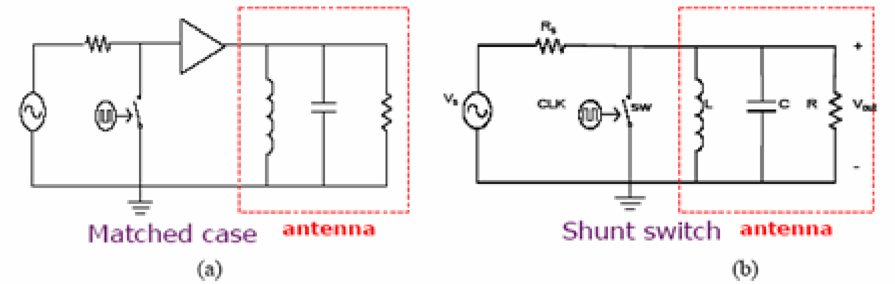


Fig.6 (a) Circuit model of the conventional transmitter (b) Circuit model of the DAM transmitter

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Prior Art

- Keyword search on IEEE Xplore, ISI Web of Knowledge, the Defense Technical Information Center (DTIC), and the US Patent and Trademark Office website

[1] J.T. Merenda (to Hazeltine Corporation), "Synthesizer Radiating Systems and Methods" US Patent 5,402,133, March 28, 1995.

[2] C.M. Montiel, L. Fan, and K. Chang, "A novel active antenna with self-mixing and wideband varactor-tuning capabilities for communication and vehicle identification applications," IEEE Trans. Microwave Theory and Techniques, vol.44, no.12, pp. 2421–2430, December 1996.

[3] V.F. Fusco and Q. Chen, "Direct-signal modulation using a silicon microstrip patch antenna," IEEE Trans. Antennas and Propagation, vol.47, no.6, pp. 1025–1028, June 1999.

[4] W. Yao and Y.E. Wang, "An integrated antenna for pulse modulation and radiation," Conf. Rec. 2004 IEEE Radio and Wireless Conference, pp. 427–429.

- Montiel et al. funded under 34068-EL
- Wang (UCLA) currently funded under 48762-EL-H

Prior Art

- Merenda
  - Delta-sigma modulated version of signal
  - Requires extremely high data pulse rate (>10x signal bandwidth)
- Montiel
  - Circular patch antenna with an integrated Gunn diode oscillator
  - Self-mixing oscillator on transmit mode
  - Local oscillator on receive mode
- Fusco and Chen
  - X-band patch antenna with integrated Schottky diode on silicon substrate
- Wang
  - S-band patch antenna with discrete Schottky diodes on low-loss PC board substrate

Application

- Merenda technique tested by the Natick Soldier Center as a SINCGARS radio antenna integrated into a MOLLE vest to replace a 30 inch whip antenna
- Results not yet available

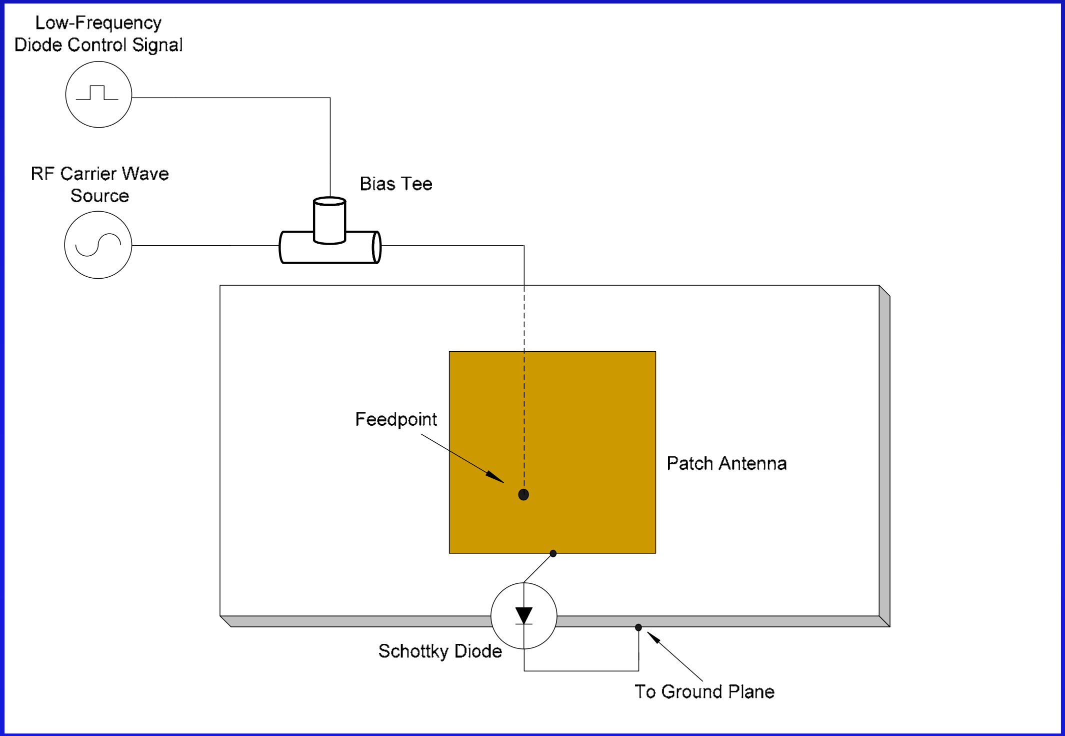
New Ground

- Modeling and simulation techniques do not exist
  - Not a steady-state problem
- Demonstrated for transmit mode only
  - Extension to receive mode
- Limited to on-off keying or amplitude modulation
  - JTRS requires n-QAM and QPSK capability
- High spectral content of the drive signal may produce spurious radiation patterns at harmonics of the signal frequency
  - Affects BER in single antenna elements
  - Affects LPI/LPD capability in antenna arrays

Objectives

- Verify the concept of direct antenna modulation by reproducing and extending published experimental results at microwave frequencies
- Investigate and develop modeling and simulation techniques applicable to operation of antennas driven by amplifiers in saturation
- Extend the operation of direct antenna modulation to HF/VHF/UHF frequency ranges where the best potential payoff lies in reducing the physical size of tactical antennas for Army mobile wireless communications systems
- Demonstrate the performance of DAM antennas with realistic communications waveforms
- Transfer research results to Army activities at ARL, CERDEC, and AMRDEC

General Concept

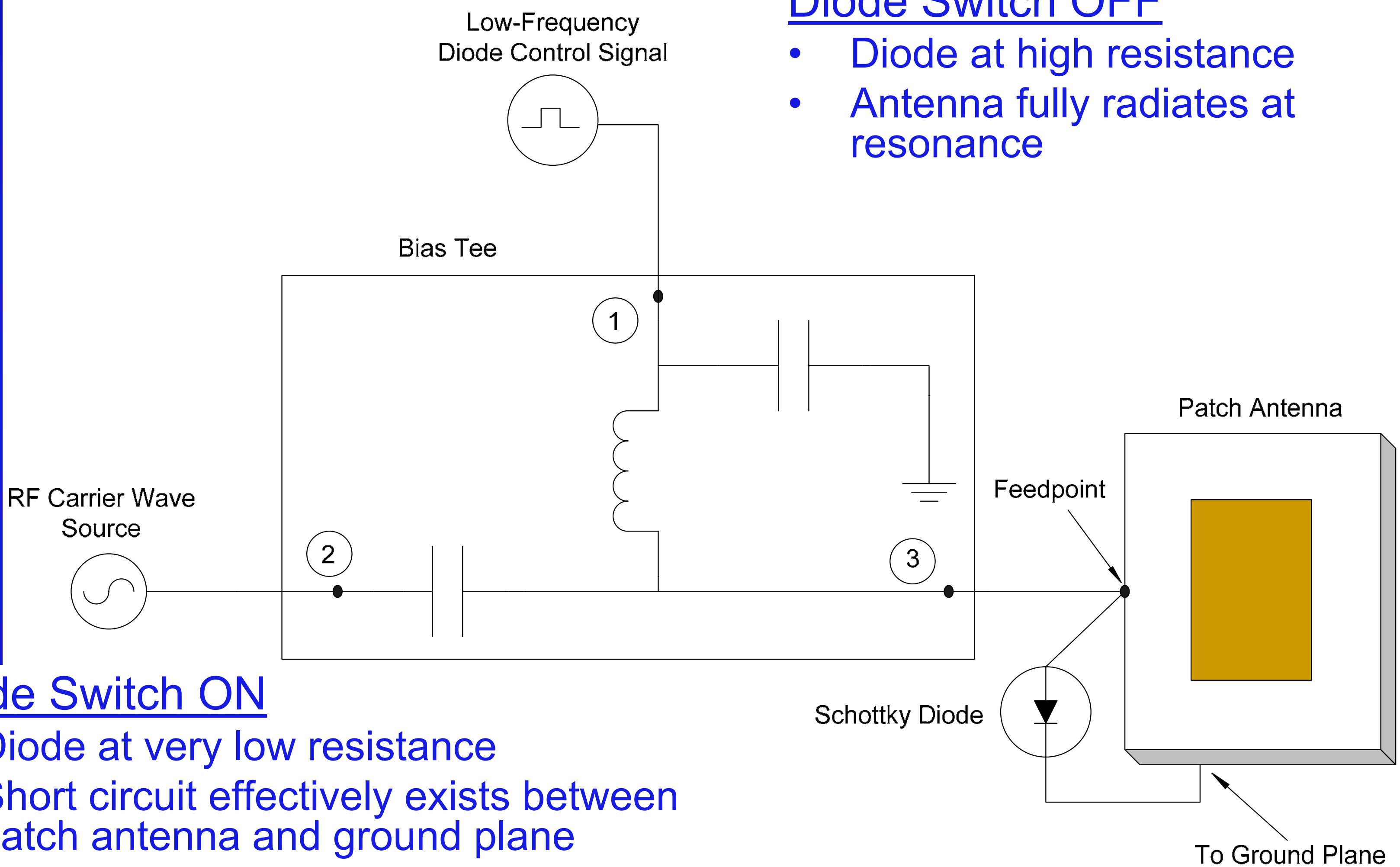


- External carrier wave source passes through bias tee and drives patch antenna at resonance
- Fast-switching diode (e.g. Schottky) connected between patch antenna and ground plane
- Baseband signal-of-interest (SOI) passes through bias tee and controls diode switching
- Diode switching directly controls antenna radiation, resulting in a modulated carrier wave signal

General Concept

Diode Switch OFF

- Diode at high resistance
- Antenna fully radiates at resonance



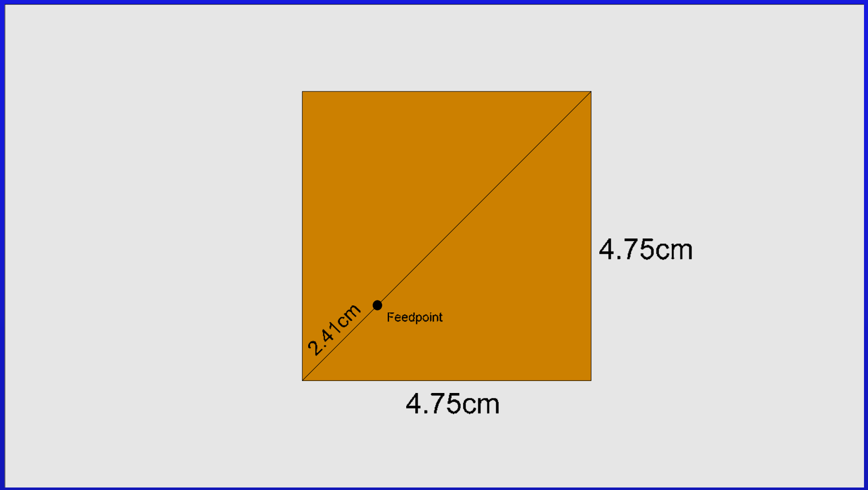
Diode Switch ON

- Diode at very low resistance
- Short circuit effectively exists between patch antenna and ground plane
- Oscillating charges on antenna radiation slots flow through diode to ground plane
- Antenna radiation effectively ceases

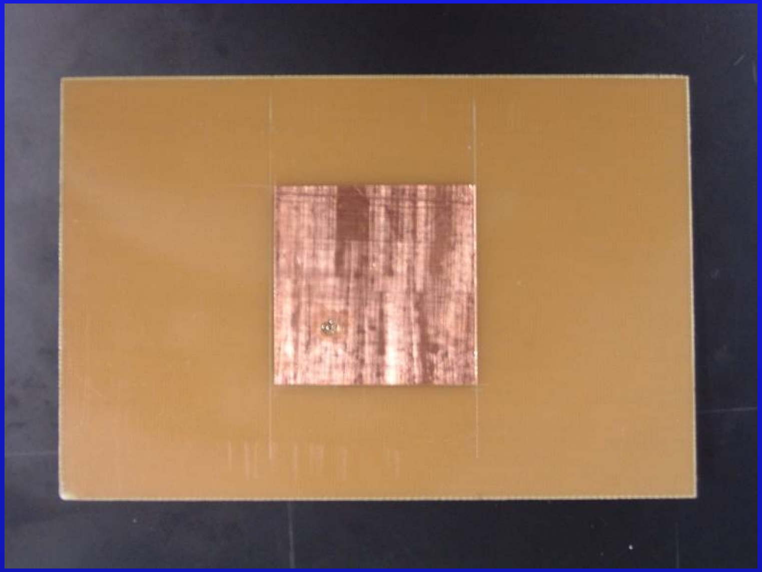
Direct Modulation of Patch Antenna

Antenna Design

- Symmetric 1.5 GHz patch antenna
- G10 epoxy glass substrate, $\varepsilon_r \sim 4.24$
- ~15 to 20 MHz Bandwidth (narrowband)



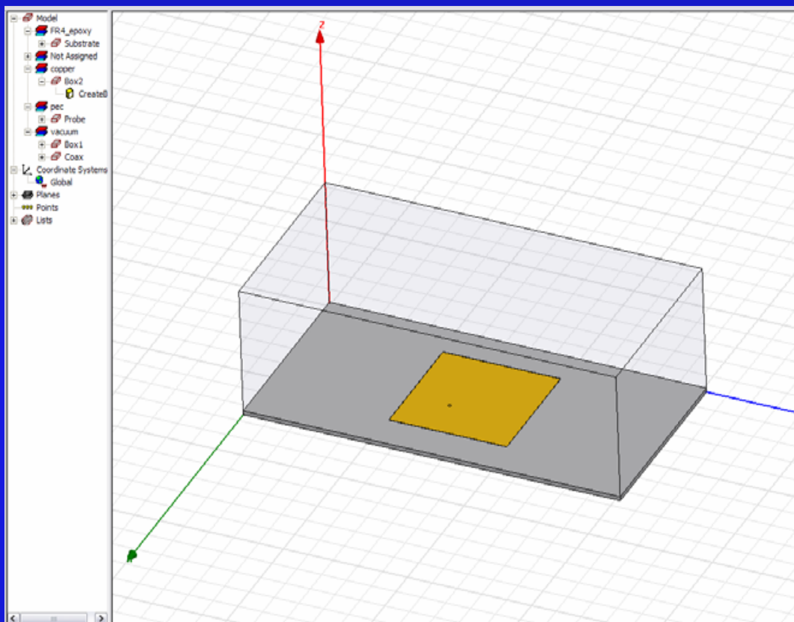
Initial design



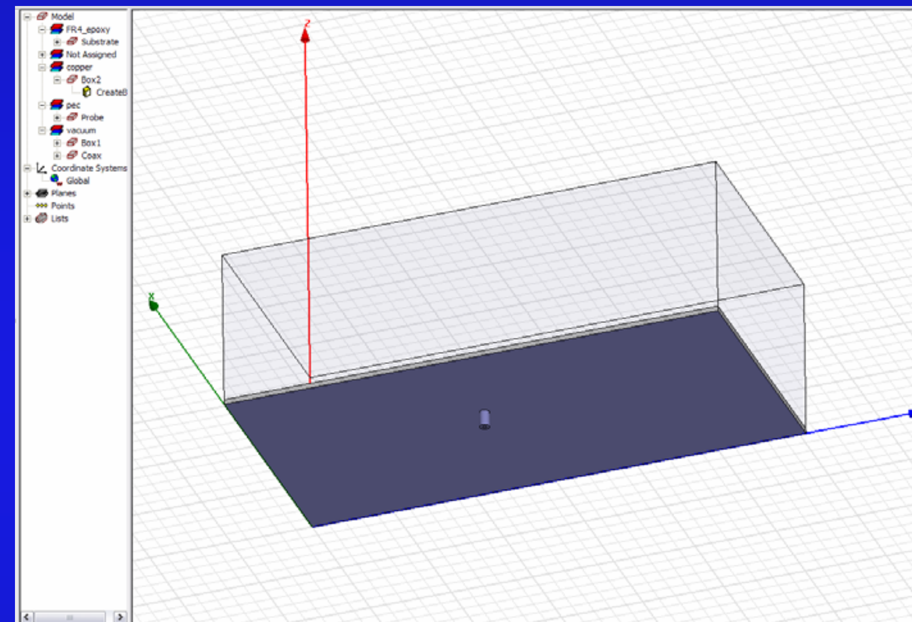
Prototype antenna

Direct Modulation of Patch Antenna

Top of Patch



Bottom of Patch

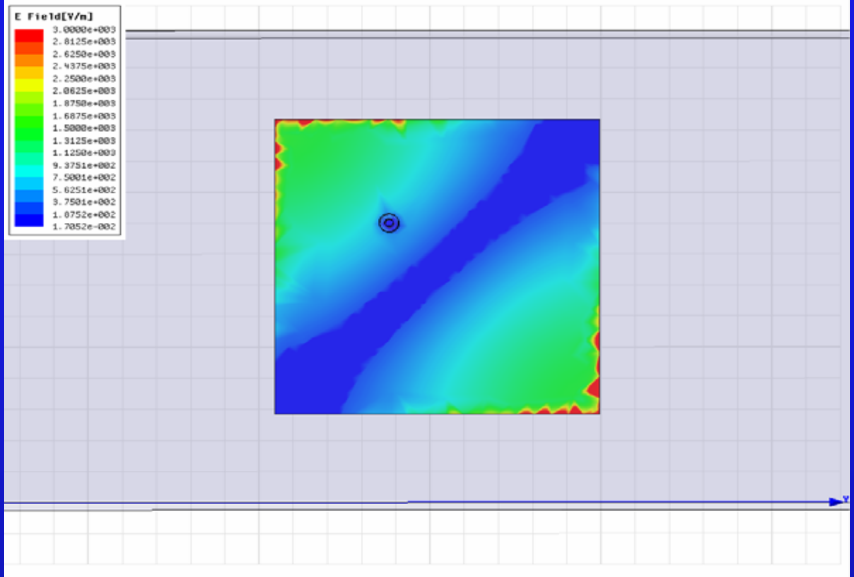


- Diodes should be placed at points of greatest electric field strength
- HFSS simulation conducted to determine the location of these points

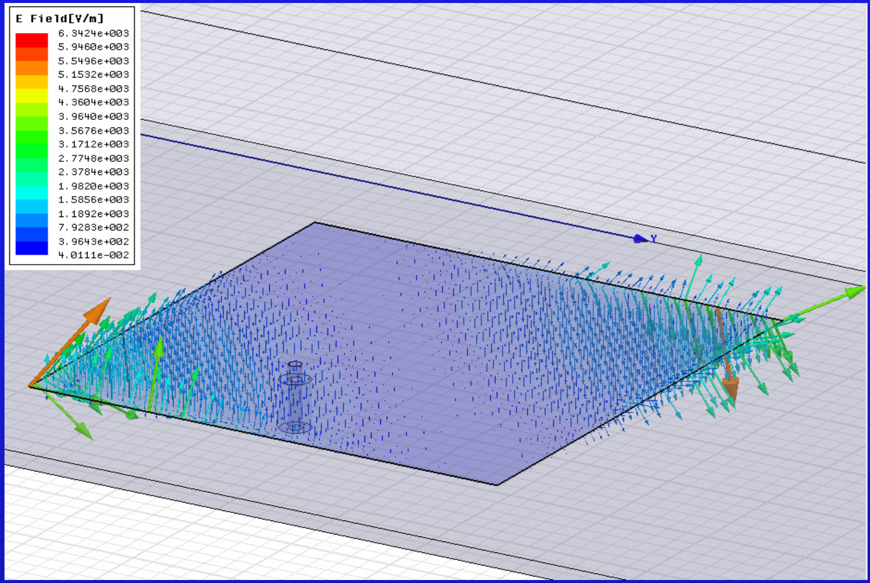
Direct Modulation of Patch Antenna

Optimal Diode Locations

- From HFSS simulations, highest electric field points occur near patch antenna corners along the feedpoint diagonal

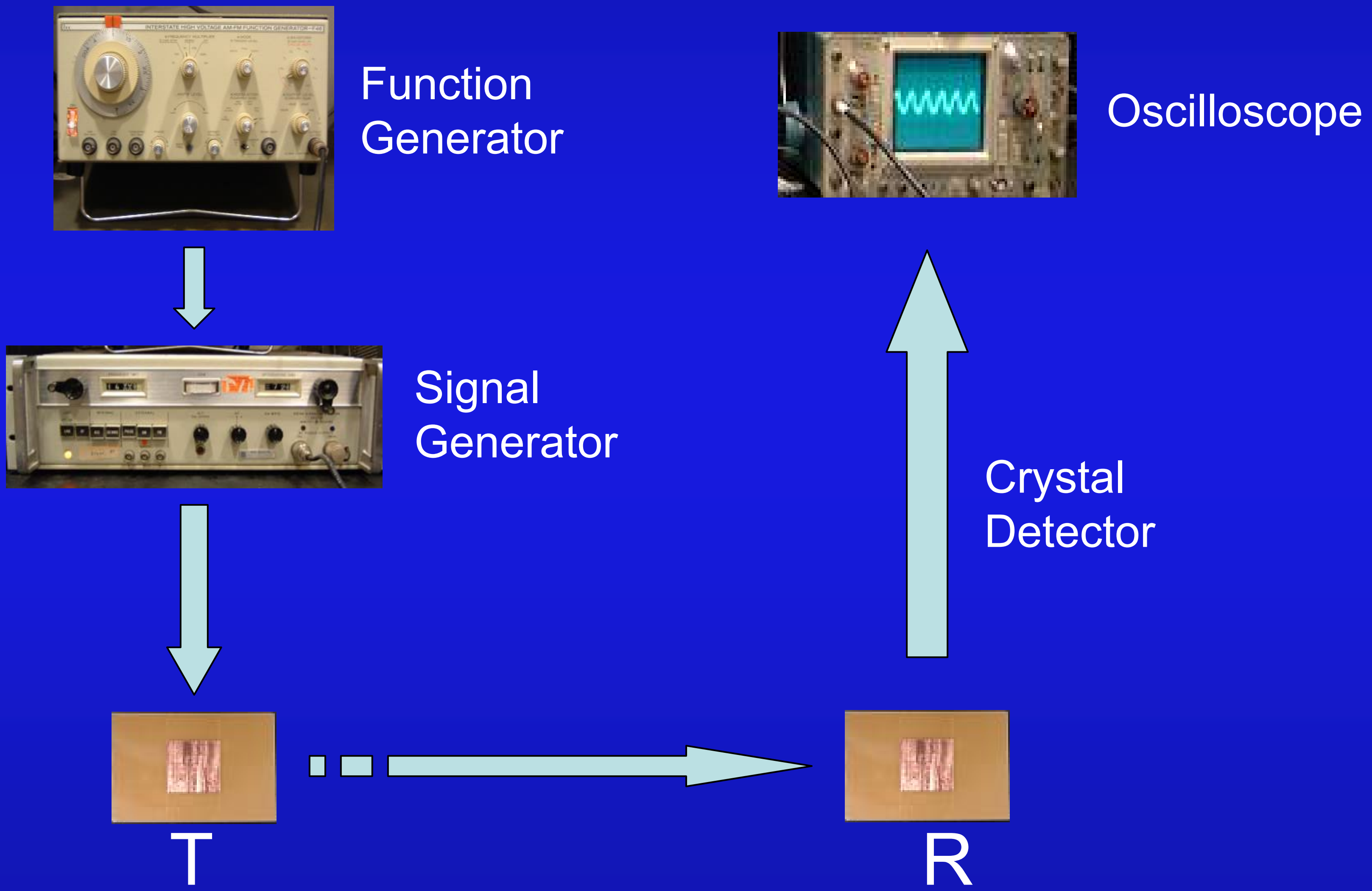


Electric Field Magnitude
(Bottom of Patch Antenna)

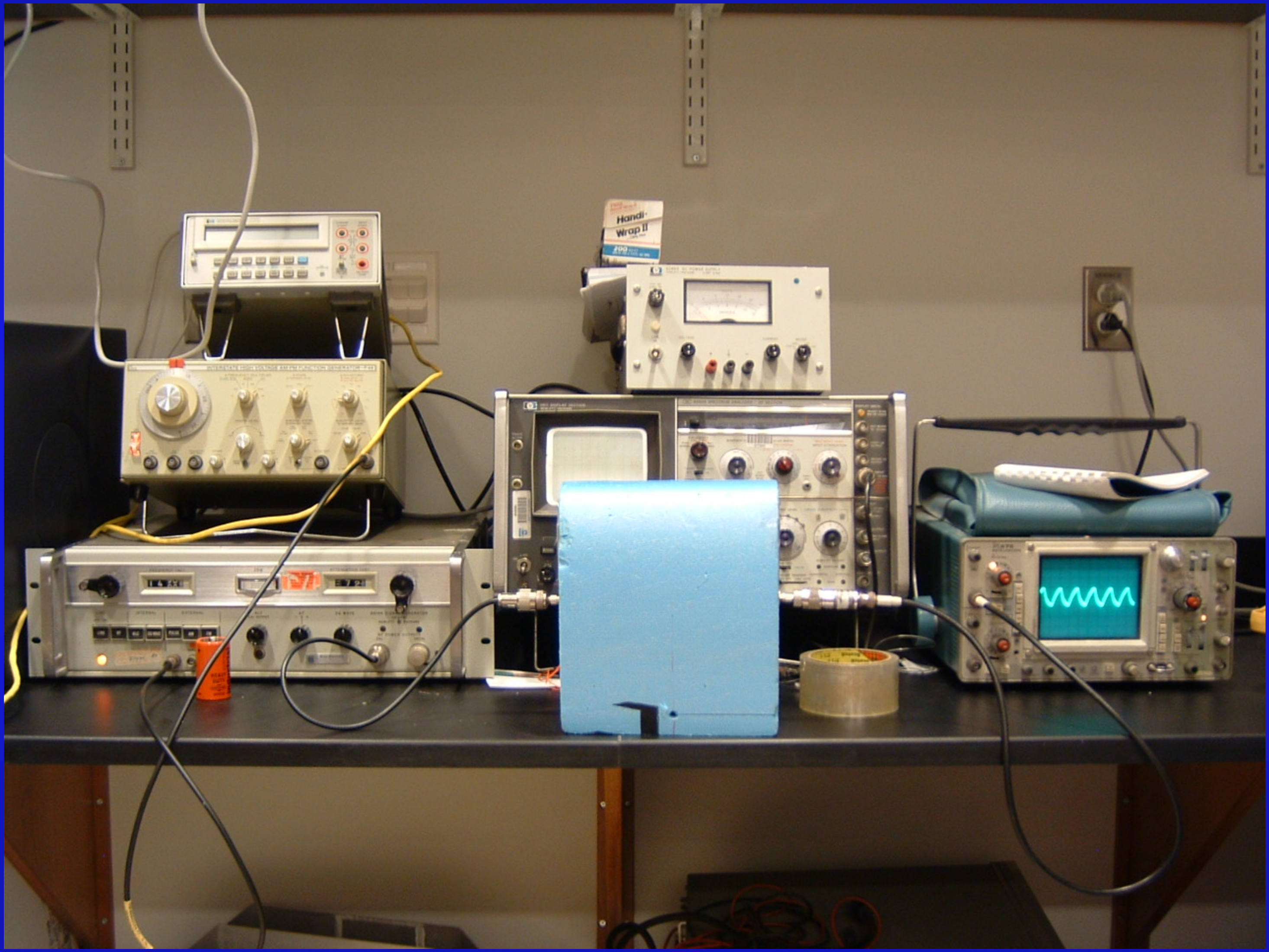


Electric Field Vector Plot
(Top of Patch Antenna)

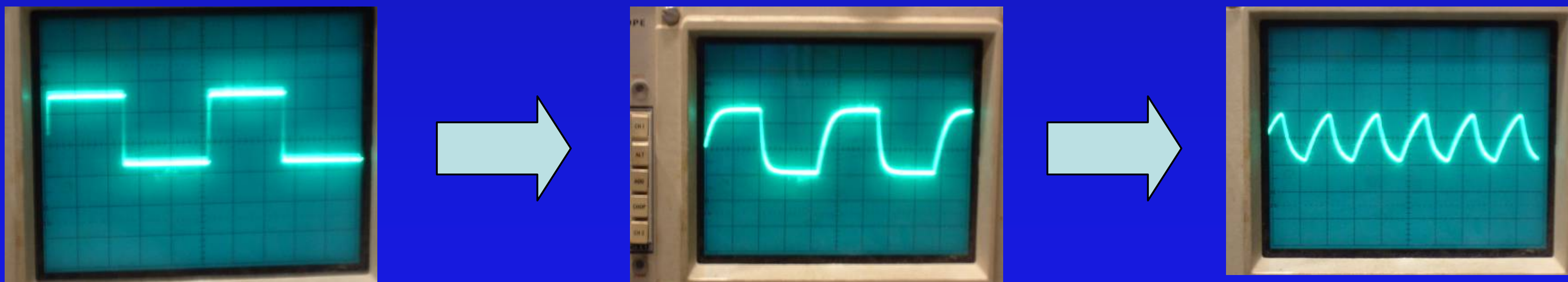
Basic Communication System



Basic Communication System



Measurement Bandwidth Limit



- As the modulating baseband information signal frequency increases, received demodulated waveform becomes increasingly distorted and peak-to-peak voltage decreases
- Currently, the signal is becoming significantly degraded with a modulating information signal frequency of just ~110 kHz
- Signal degradation is associated with the useable bandwidth of the crystal detector and is not due to the bandpass effect of the antenna

Basic Communication System

Test Equipment Modifications

- Order high bandwidth crystal detector to view demodulated received waveform
- Use sampling oscilloscope to view the modulated 1.5 GHz carrier wave

Expected Observations

- Signal will become increasingly noisy as frequency of baseband information signal increases
- For basic T/R case, information signal bandwidth will be limited by the bandpass effect of the patch antenna (should become quite noisy beyond 15-20 MHz)
- For Direct Antenna Modulation case, information signal bandwidth will only be limited by the switching speed of the diode (hope to achieve an upper bound of at least 100-200+ MHz)

Next Steps

1. Refine antenna design in HFSS
2. Construct and test final antenna design
3. Conduct basic T/R system test with two patch antennas and high bandwidth crystal detector or sampling oscilloscope
4. Apply diode switches to system for direct antenna modulation implementation
5. Test new direct antenna modulation system and compare results with standard T/R system
6. Upon successful completion of initial experiment, move on to system modeling and extension of experiment to HF/VHF/UHF Army communication systems