

# Direct Modulation of an L-band Microstrip Patch Antenna Using Integrated PIN Diodes

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# Overview

## 1. Motivation

- Application to Army comm. Systems

## 2. Direct Antenna Modulation (DAM)

- General concept
- Historical Review

## 3. DAM Experiment

- Experiment details
- HFSS simulations
- Construction and testing

## 4. Conclusion

- Recap of completed research and experimentation
- Future research plans

# 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



M577A3 Tracked Command Post Carrier [sill-www.army.mil](http://sill-www.army.mil)



Manpack Radio Set AN/PSC-3  
[www.tobyhanna.army.mil](http://www.tobyhanna.army.mil)

Typical antenna designs yield:

- *Cumbersome size*
- *Visually-compromising signature*

# Novel Concept in Antenna Design

- Antennas typically are designed to operate at resonance
  - Resonant matching network to the transmit/receive circuitry for maximum power transfer
  - Inherently narrowband system
- Antenna operation in linear but non-resonant modes gives increased bandwidth at the cost of greatly reduced efficiency
- Direct antenna modulation (DAM) uses techniques developed for high-efficiency switching amplifiers [1] to decouple the information bandwidth from the antenna resonance

- Switching diode operates in saturation not in linear mode
- May enable efficient operation over extremely wide bandwidths with electrically small antennas

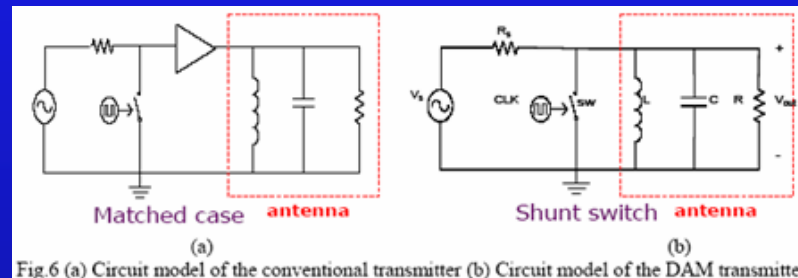
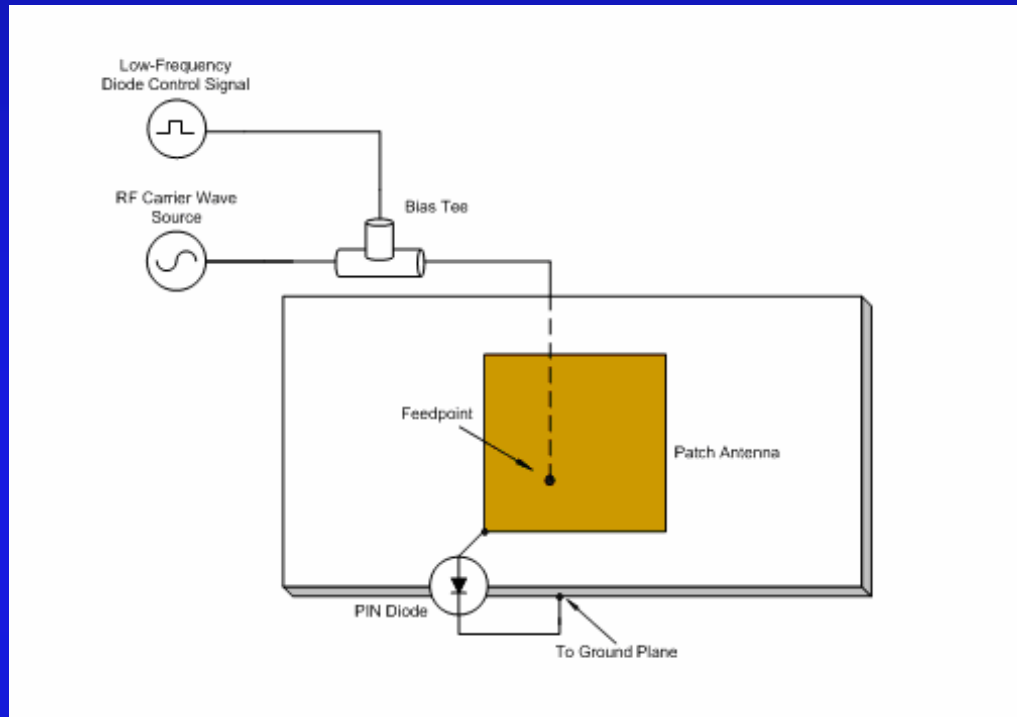


Fig. 6 (a) Circuit model of the conventional transmitter (b) Circuit model of the DAM transmitter

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# DAM General Concept

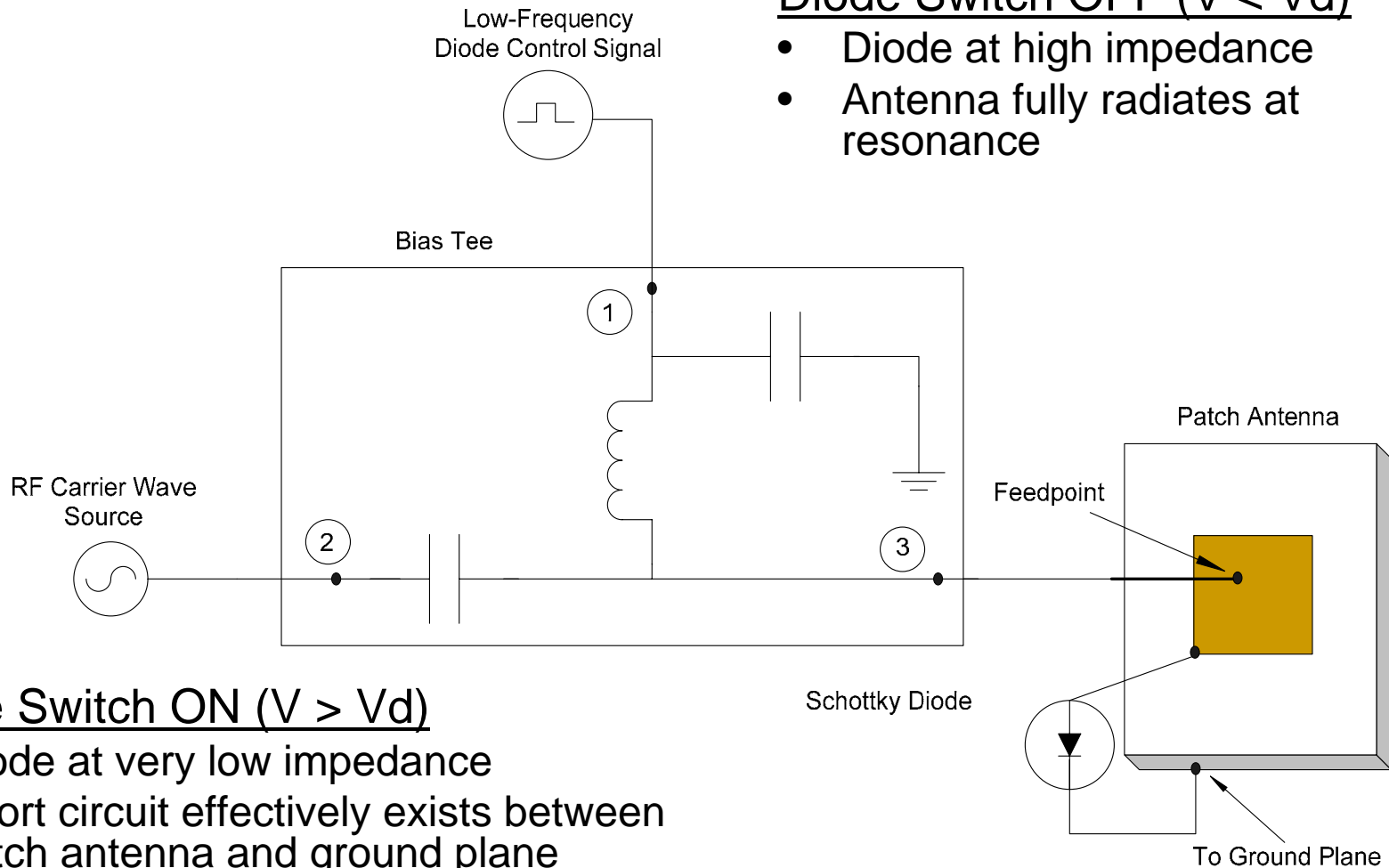


1. Fast-switching diode (e.g. Schottky or PIN) connected between antenna and ground plane
2. External carrier wave passes through bias tee and drives antenna at resonance
3. Baseband information signal passes through bias tee to feedpoint and controls diode switching
4. Diode switching directly controls antenna radiation, resulting in a modulated carrier wave signal

# Direct Antenna Modulation

## Diode Switch OFF ( $V < V_d$ )

- Diode at high impedance
- Antenna fully radiates at resonance



## Diode Switch ON ( $V > V_d$ )

- Diode at very low impedance
- 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

# DAM Historical Review

Two papers explicitly explore direct antenna modulation:

## Fusco and Chen [2]

- Designed an X-band patch antenna with integrated Schottky diode on silicon substrate
- Concluded that direct antenna modulation is possible by integrating a high-speed diode structure with an antenna and biasing it with a signal

## Yao and Wang [3]

- Designed an S-band patch antenna with discrete Schottky diodes on low-loss substrate
- Potential information bandwidth increase above 10x the resonant antenna bandwidth
- Concluded that smaller carrier lifetime (related to switching speed) of Schottky diodes could lead to improved modulation responses and further bandwidth increases

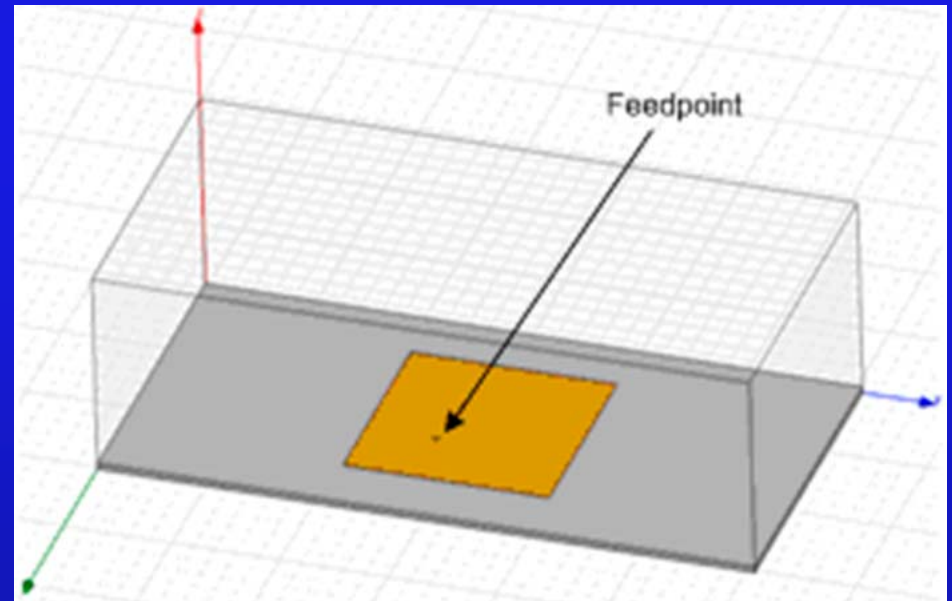
# DAM Experiment

## Objectives:

- Verify the feasibility of the direct antenna modulation technique with an L-band patch antenna
- Observe the upper limit to information bandwidth and compare the performance of a directly-modulated signal with that of an internally-modulated signal

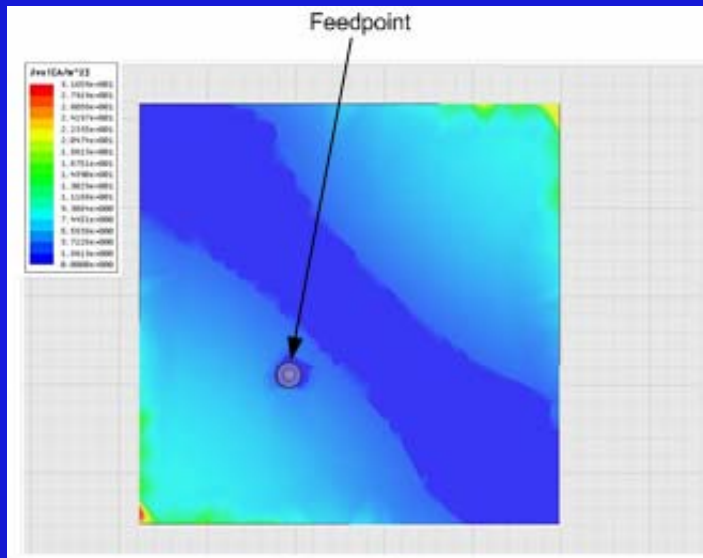
## Antenna:

- Symmetric L-band patch
- $f_r = 1.56$  GHz
- Coaxial feed
- G-10 epoxy glass substrate,  $\epsilon_r \sim 4.24$
- Modeled using *Ansoft* HFSS [4]

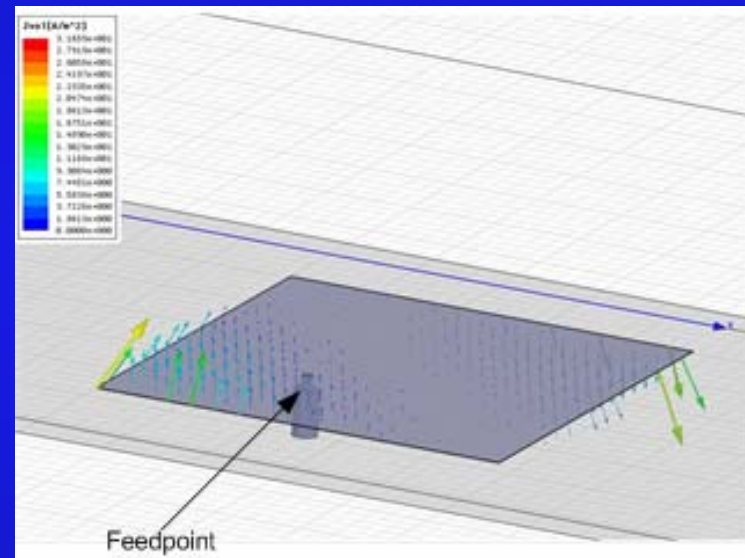


# Use HFSS To Optimize Diode Placement

- Maximum volume current density points occur at the corners along the feedpoint diagonal



$J_{vol}$  Magnitude Plot  
(Bottom View of Patch Antenna)



$J_{vol}$  Vector Plot  
(Angled Top View of Patch Antenna)

- Diodes should be placed at these points for maximum effect on radiated signal

# Diode Characteristics Are Critical

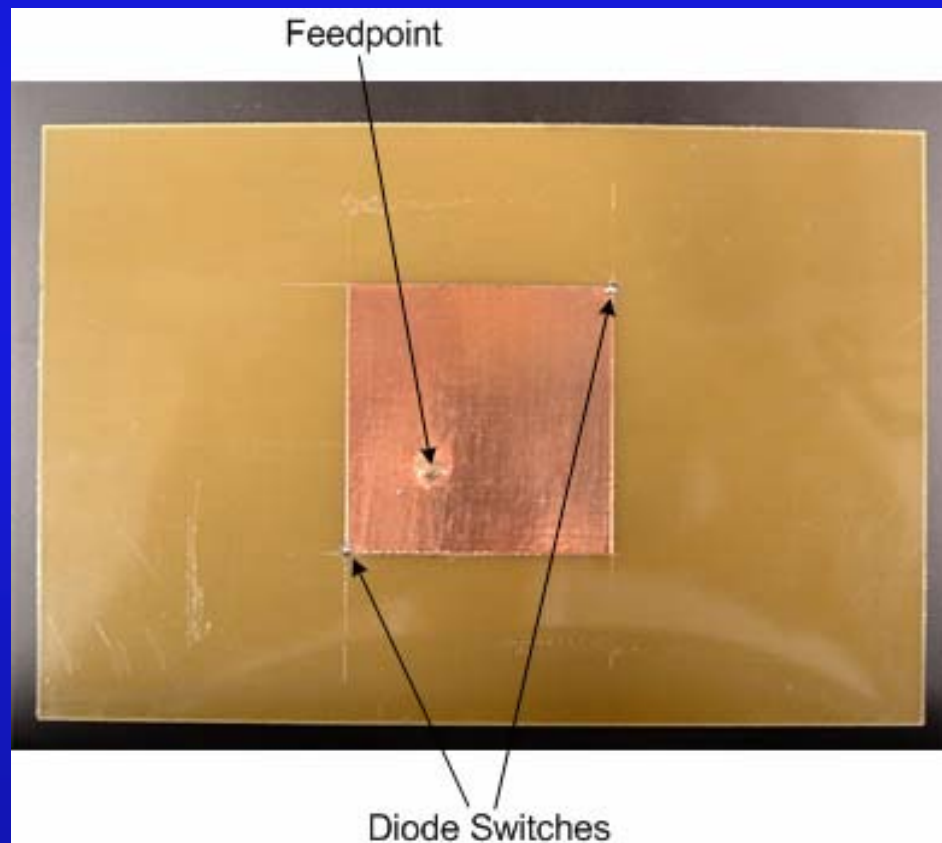
- SMP1340 (*Skyworks Solutions*) [5] has low junction capacitance (0.3pF) at 0V forward bias
  - Looks like an open circuit at 1.5GHz

$$Z = \frac{1}{j\omega C} = \frac{1}{j \cdot 2\pi \cdot 1.5 \cdot 10^9 \cdot 0.3 \text{ pF}} = j354\Omega$$

- The SMP1340 is also a very fast-switching PIN diode (short carrier lifetime of ~100ns) which enables high modulation rates

# Prototype Antenna

- Diodes soldered between patch antenna and ground
  - Located at the corners along the feedpoint diagonal

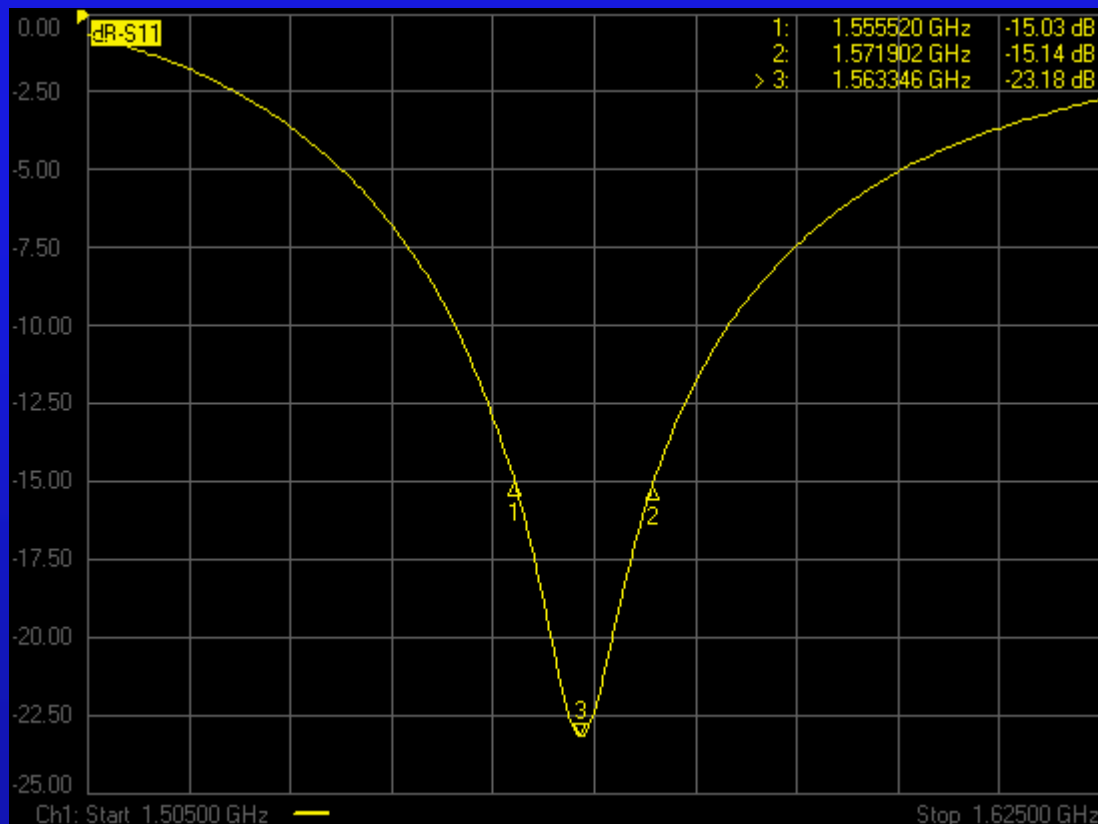


# Prototype Antenna

Center frequency: 1.56 GHz

Bandwidth: 16 MHz ( $S_{11} \leq -15$  dB)

28 MHz ( $S_{11} \leq -10$  dB)



- Narrowband system  
(~1-2% Bandwidth)

# Signal Flow

Signal Generator



Function Generator



RF Signal

Bias Tee  
Circuit



Diode Bias Control Signal

Bias Tee Output

Digitizing Signal  
Analyzer



T

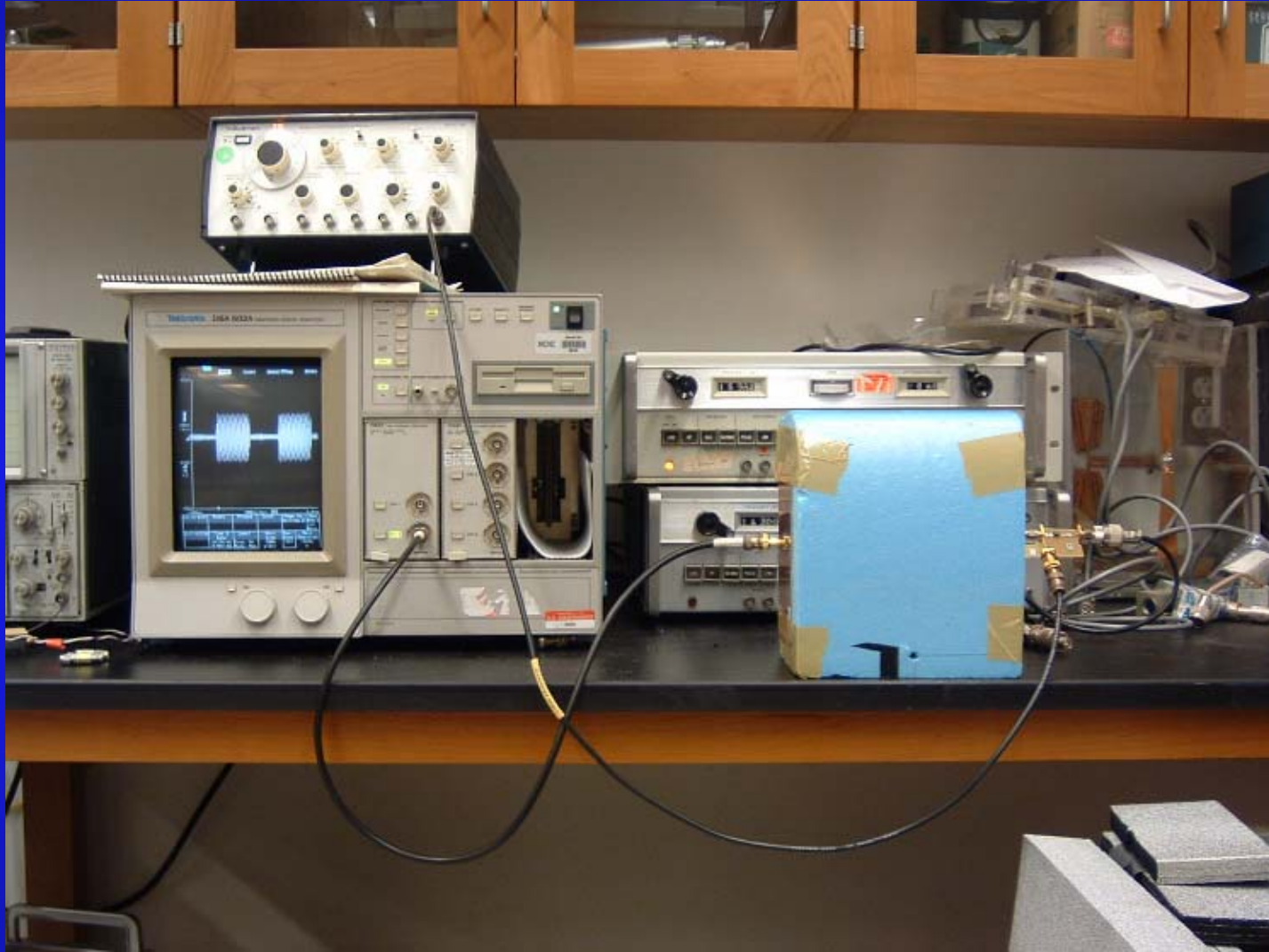
Transmitted  
Signal



R

Received  
Signal

# Experimental Setup



# Modulation Results

- Received waveform demonstrates direct antenna modulation effect



10 kHz



1 MHz



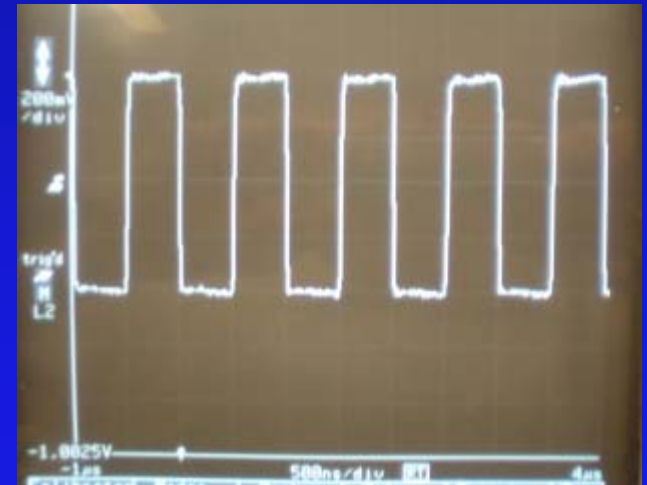
10 MHz

# Received Signal Details

## Received Modulated CW:

~ 40 mV peak-to-peak

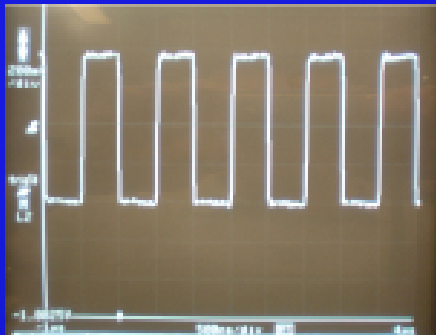
- Since diode has low, but not zero impedance when in forward bias, ~5mV received signal leakage occurs
- This leakage is minimal, however, yielding a signal peak to trough ratio of ~ 8:1



# Function Generator Limits Performance

- Above 10 MHz, received waveform is distorted by degradation in the function generator bias signal

1 MHz

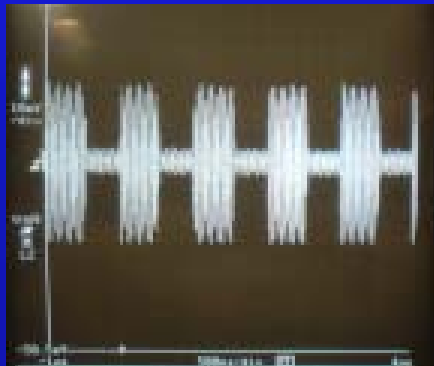


Bias  
Signal

20 MHz

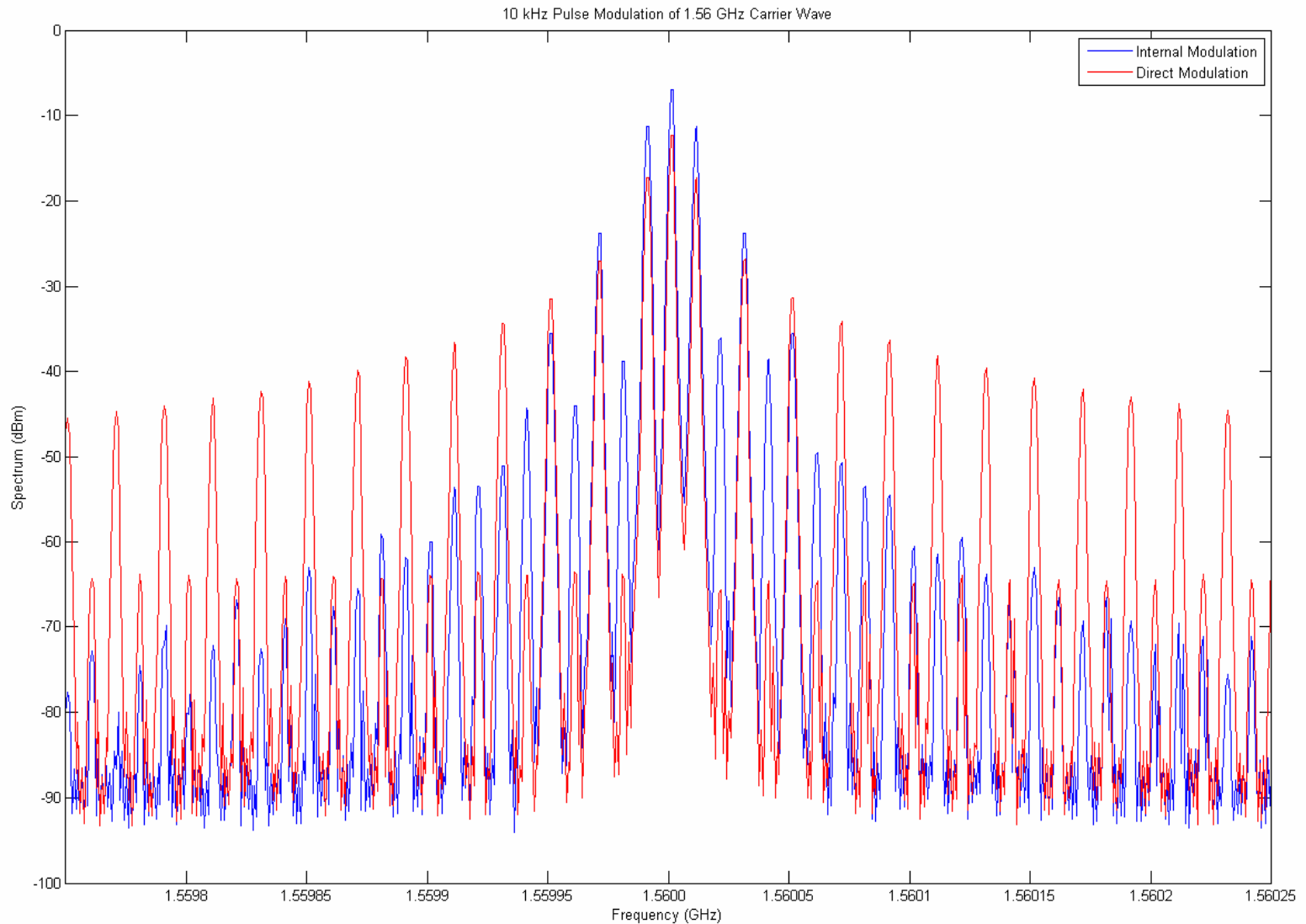


Received  
Waveform

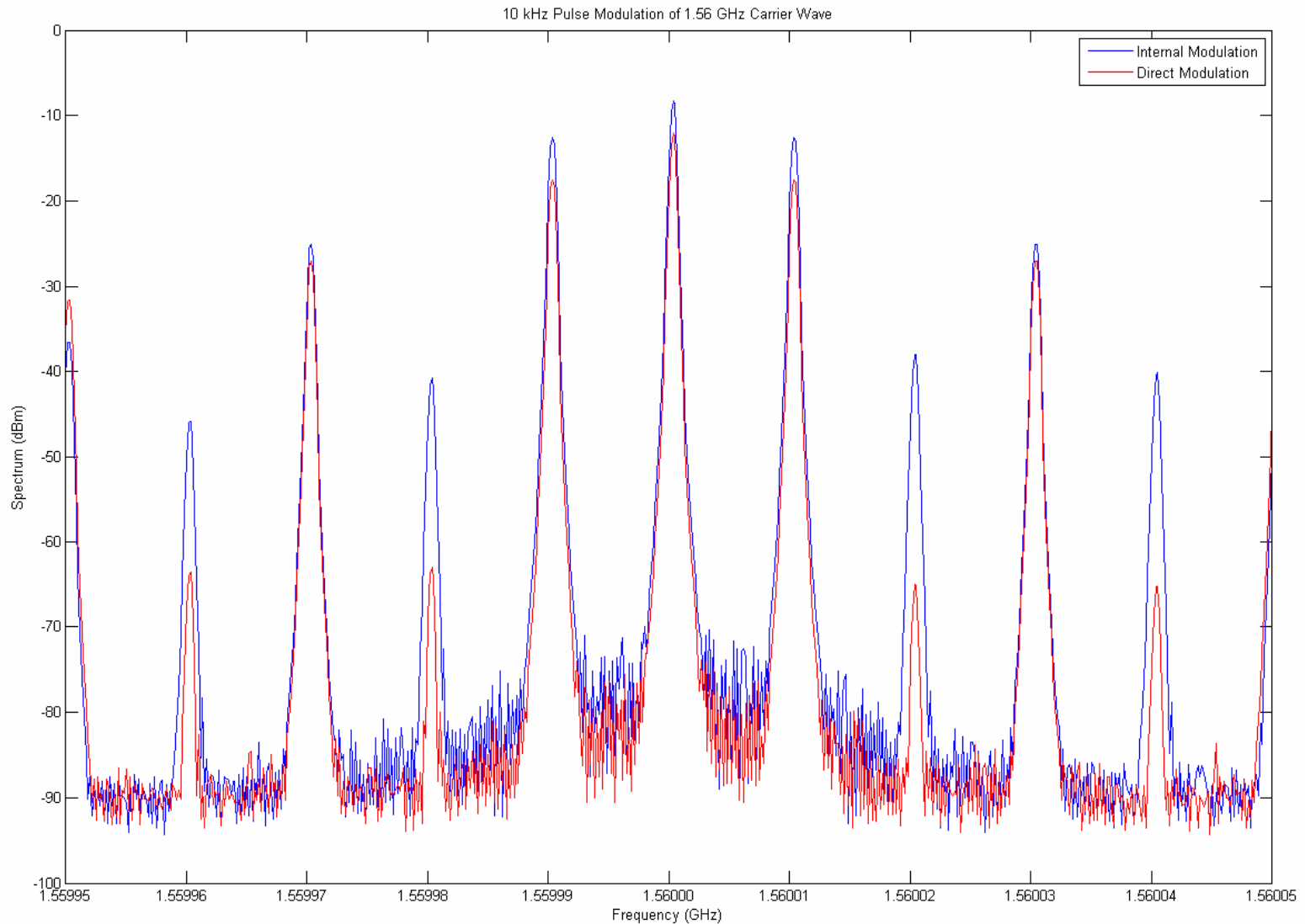


# Spectrum Analysis

- Spectrum of pulse modulated 1.56 GHz carrier wave viewed for:
  - Internally-modulated case (using signal generator)
  - Directly-modulated case
- Internal modulation limit of signal generator was 10 kHz
  - Low-frequency comparison conducted
- Analysis of spectrum data is in the early stages



- Directly-modulated carrier wave exhibits similar spectrum to internally-modulated carrier wave, but with larger odd harmonics ( $n \geq 5$ ) and smaller even harmonics ( $n \geq 1$ )



- Noise figure for directly-modulated spectrum shows improvement of  $\sim 3\text{dB}$  compared to the internally-modulated spectrum

# Future Experimental Improvements

1. Obtain improved function generator
  - Capable of providing accurate 50+ MHz square waves
2. Use wideband horn antenna as receiver instead of narrowband patch antenna
3. Incorporate diodes w/ even lower junction capacitance and faster switching speeds

# Experimental Conclusions

- Direct Antenna Modulation is an effective technique for pulse modulation of radiation from a patch antenna
- Diode selection and placement is critical
  - Fast switching speed, low junction capacitance
  - Placed at field strength maxima on the antenna for strongest effect
- Bandwidth of modulation function generator is critical for proper experimentation
- Spectrum of directly-modulated signal closely-matches that of an internally-modulated signal and seems to have an improved noise figure

# Future Work

- Develop computational and nonlinear circuit models to analyze and predict direct antenna modulation performance
  - Time-domain modeling
- Test feasibility/effectiveness of technique in receive mode
- Extend technique to lower frequencies (HF – UHF) and test applicability to Army mobile ground comm. Systems

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# References

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# Questions?

