Design and Development of a Long Range Modulated Scatterer Radar/Telemetry System For Proof-of-Concept Experiments

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Three Parts of Talk:

Introduction to Small-Signal CW Radar Technology

Overview of some problems encountered and solved during design and development of the latest-generation system.
My Research Radars:

1. Bistatic Synthetic Aperture Radar designed and built from scratch in grad school 1982

2. 13 cm Modulated Scatterer Telemetry proof of concept -- circa 1990

3. Near-Field Electromagnetic Scanning Microscope used to develop 220 GHz Cascade Microtech wafer probes -- 2004

4. Long Range Modulated Scatterer Telemetry -- 2009
What is a modulated scatterer Radar?

Closely related to Police Doppler Radar

Instead of modulating the Radar Signal by Speeding, modulate by rotating a dipole:

Folded path propagation study--ITS 1991

...or by switching a dipole on and off with a diode in the center

It’s like RFID, but at microwaves, and can provide much more information than just ID
The modulated scatterer (Target) is very simple:

555 timer turns on and off diode with $\lambda/2$ leads
You can easily put information on the scattered signal--for example, temperature could vary the diode switching rate.

Example of Asymmetrical Wireless Link: One station is expensive and complex the other is disposable:

We have only begun imagining the applications.....
A little Math background:

received signal

\[ a(t) \cos \left[ \omega_0 t + \phi(t) \right] \cos \omega_0 t \]

modulation

LO

multiply and low pass:

\[ a(t) \cos \phi(t) \]

baseband output
But there are a few problems:

Problem 1:

Doppler Spectrum

speeding away - red shift

Modulation Spectrum

symmetrical sidebands
Can recover Doppler (single sideband) signal with a simple direct conversion receiver.

Simple receiver can’t tell the difference between Red Shift and Blue Shift—But Policeman can.

To recover symmetrical modulation sidebands requires more advanced receiver using I Q mixer and baseband signal processing.

Problem 1: more advanced receiver needed.
Problem 2: Increasing Range

Fundamental Limitation:

\[ \frac{1}{R^4} \] spherical spreading loss

Police Doppler Radar achieves great range because the scattering cross section of your car is about 100 m\(^2\) (!)

RFID; Near Field scanning microscope; and previous telemetry applications only need very short (~1m) range
Near-Field Electromagnetic Scanning Microscope used to develop 220 GHz Cascade Microtech wafer probes -- 2004
Near-Field Electromagnetic Scanning Microscope receive Front-end:

6 GHz IQ mixer
Near-Field Electromagnetic Scanning Microscope analog baseband signal processor:
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Back to work. Take a look at Radar Equations:

\[
P_t g_t \frac{1}{4\pi R^2} S_a \frac{1}{4\pi R^2} A_e \quad \text{watts at receiver input}
\]

\[
kT_eB \quad \text{receiver input noise power}
\]
Based on measurements and equation, need $10^8$ (80 dB) improvement to increase range from 1m to 100m

Easy changes:

Increase transmit antenna gain by 16
Increase receive antenna area by 16
Increase transmit power by 100

That’s only 46 dB gain. Transmitter is above part 15 limit, antenna is getting large
Need to improve microwave receiver sensitivity by 34 dB—a receiver design problem

radar equation shows that receiver is nowhere near thermal limit

receiver noise floor is set by transmit leakage and backscattering from nearby objects

Step 1: isolate the T and R antennas

Step 2: increase the modulation frequency

Step 3: separate T and R signal paths
Block Diagram of Rev 1 local oscillator

- Noisy reference
  - VHF Frequency Reference 144 MHz
  - 72 MHz

- Noisy x78 multiplier
  - x 13
  - x 3
  - x 2
  - 5616 MHz

- Noisy x40 multiplier
  - Splitter
  - Phase locked oscillator x 40
  - 5760 MHz

- 10 mW 2nd LO output to IQ IF receiver
- 10 mW 1st LO output to superhet receiver
- 100 mW Transmit output
- 144 MHz

Until you get the hardware running in the lab, you don’t even know what you don’t know....

\[ a(t) \cos [\omega_0 t + \phi n_1(t)] \cos [\omega_0 t + \phi n_2(t)] \]

Independent T and R LO system phase noise beats together and dominates R noise floor.
Radar Rev2 overcome phase noise limitation with 2 prong attack: reduce phase noise and correlate T and R phase noise

Step 1: reduce LO phase noise with new VHF standard
New clean, stable VHF reference signal source:

(works so well, it’s been released as a commercial product)
Radar Rev2 phase noise limitation

Step 2: new LO system block diagram with highly correlated T and R LO phase noise

10 mW 2nd LO output to IQ IF receiver

VHF Frequency Reference 144 MHz

splitter

phase locked oscillator × 40

144 MHz

5760 MHz

100 mW Transmit output

5616 MHz

10 mW 1st LO output to superhet receiver
More new analog signal processing electronics designed and built for 4th generation Radar: new low-noise VHF IF for superhet receiver

schematic of VHF circuitry on upper half of PC board
New design IQ IF to baseband analog signal processing system

144 MHz IF input upper left, LO input upper right baseband output lower right
schematic of analog baseband circuitry on lower half of PC board
New Radar -- Tested September 2009
New Radar

Target at 72m
DSP signal processing of analog baseband output showing spreading from wobbling target
It Works!

Signal to noise ratio is > 20 dB in 5 Hz bandwidth from simple dipole target at 72 meters

Thank you for your time and attention.