Radar-Embedded Communications

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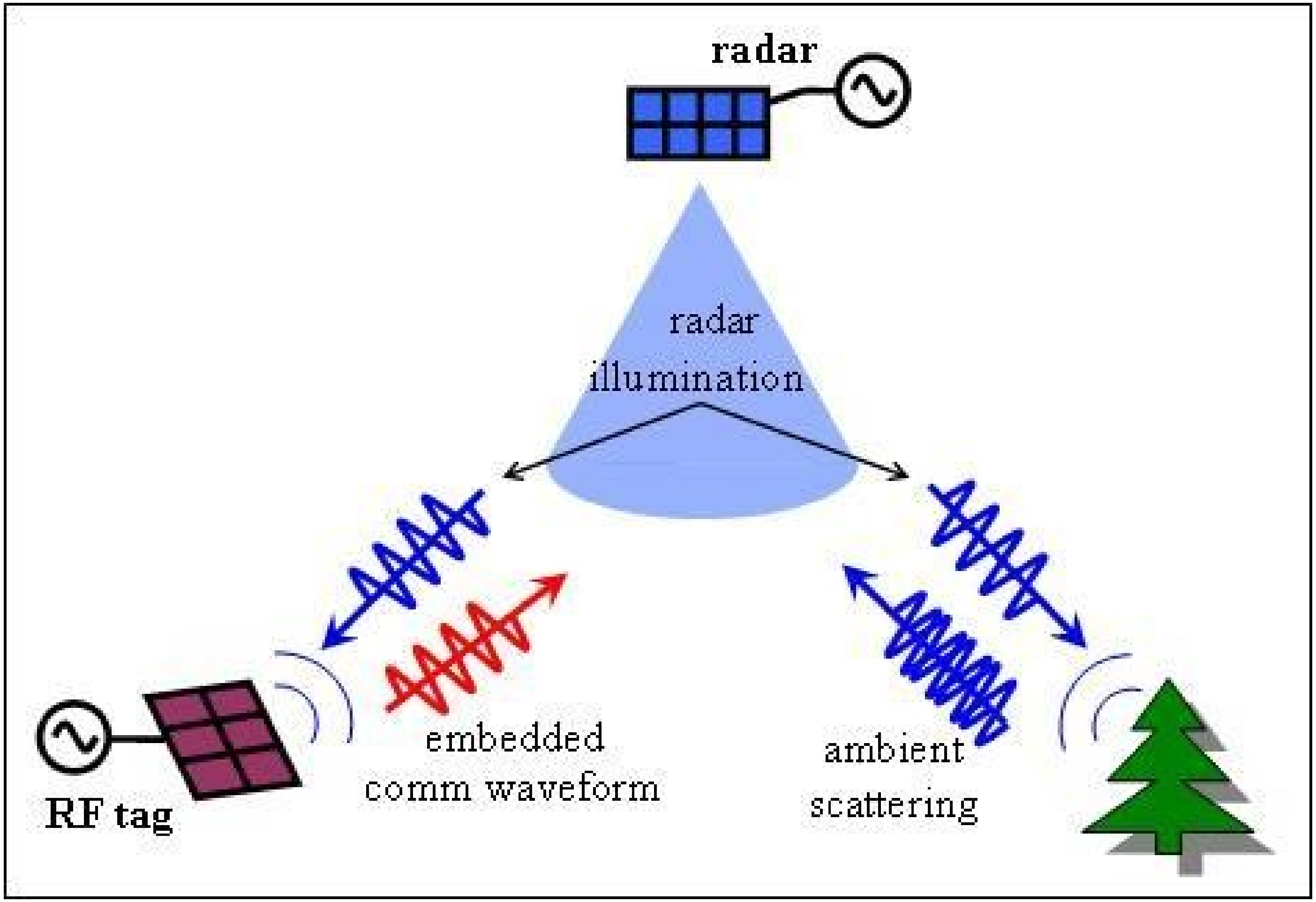
Backscatter Communications

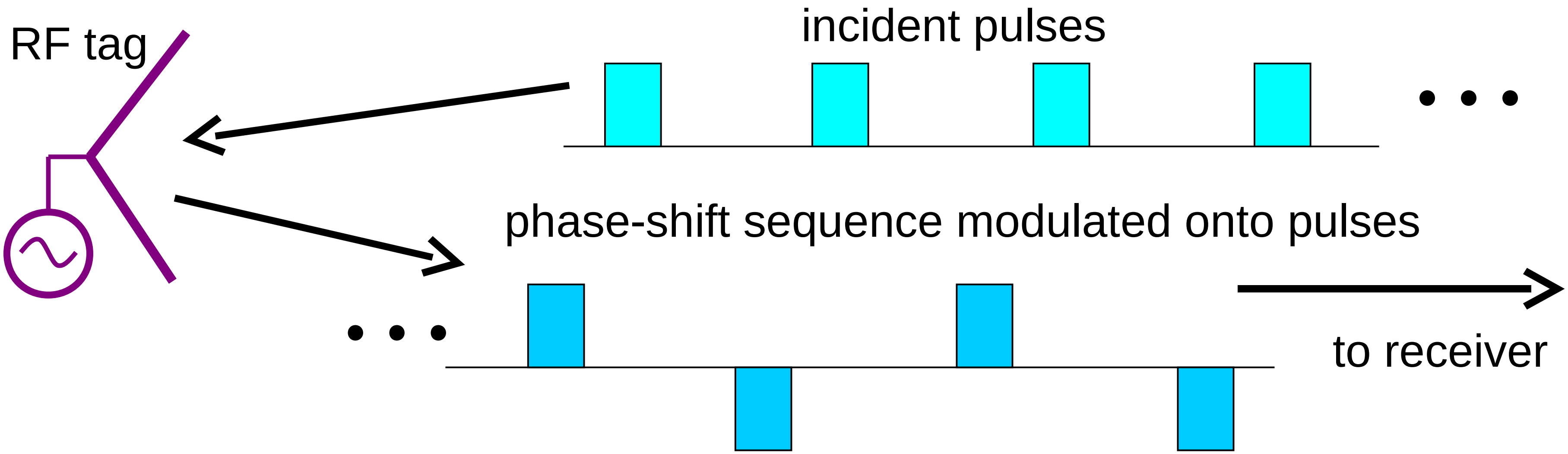


Backscatter Communications

- Exploit RF tag/transponder technology.
- Enable Low Probability of Intercept (LPI) communications
  - » prevent reception/exploitation by an adversary.
- Use the ambient radar scattering to mask the comm signal.
- How to bury a comm signal into the radar backscatter that is:
  - » invisible to an eavesdropper, yet
  - » can be extracted by the desired recipient.

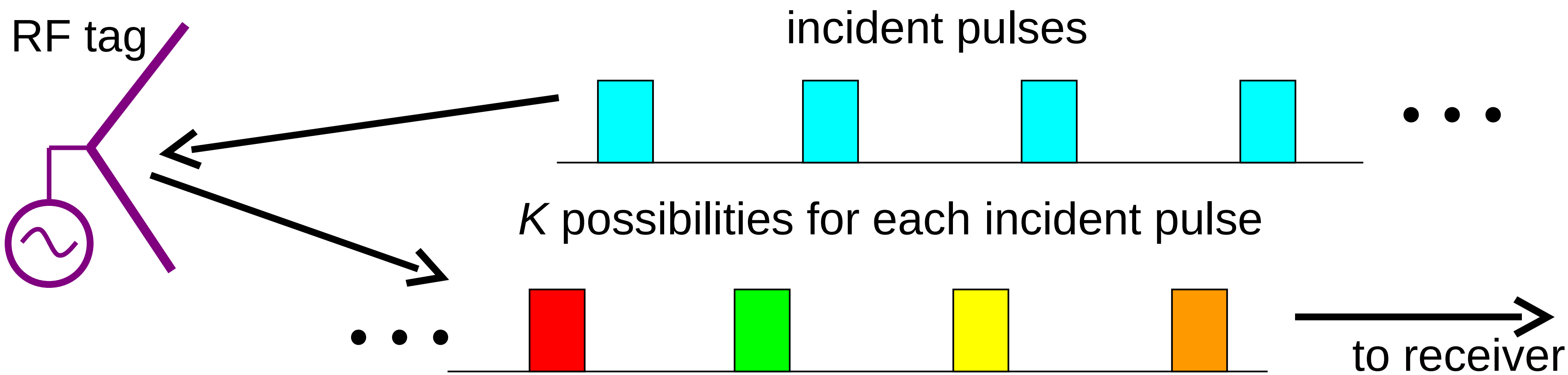
“<u>Inter</u>-Pulse” Modulation

- Previous work applied Doppler-like phase-shift sequence over numerous pulses (100s)
  - *e.g.*, Athena tag developed at Sandia National Labs.
- To be covert → very low data rate (“bits-per-CPI”) → bps
- Utilized to insert identifiers into SAR images.



“Intra-Pulse” Modulation

- Operate on each incident pulse independently.
- Incident radar waveform converted into one of *K* possible communication waveforms; *i.e.*, symbols.
- Potential for much higher data rate while still LPI
  - » $K = 4$, PRF $\geq$ 1.2 kHz → embed speech via MELP codec.



Exploiting Natural Scattering

- For $s(t)$ the incident radar waveform, $y_s(t)$ is the ambient scattered signal incident at a given receiver.
- The ambient scattered signal acts as a masking interference for one of K communication waveforms, which are denoted $c_k(t)$ for $k = 1, 2, \ldots, K$.
- To remain covert, a communication waveform must maintain a sufficient degree of similarity with the ambient scattered signal.
- The goal is to determine both appropriate comm waveforms and receiver processing structures to recover the embedded signal.

Received Response

- At a receiver (desired or intercept), the incident signal over the interval of the embedded communication signal is $y_r(t) = c_k(t) + y_s(t) + v(t)$ where $v(t)$ is noise.

- To optimally estimate the given embedded signal, the set of communications waveforms would ideally possess the following properties:

$$\int c_k(t)\, y_s^*(t)\, dt = 0$$

$$\int c_j(t)\, c_k^*(t)\, dt = 0 \quad \text{for} \quad j \neq k$$

does nothing to ensure LPI

Covert Waveform Design

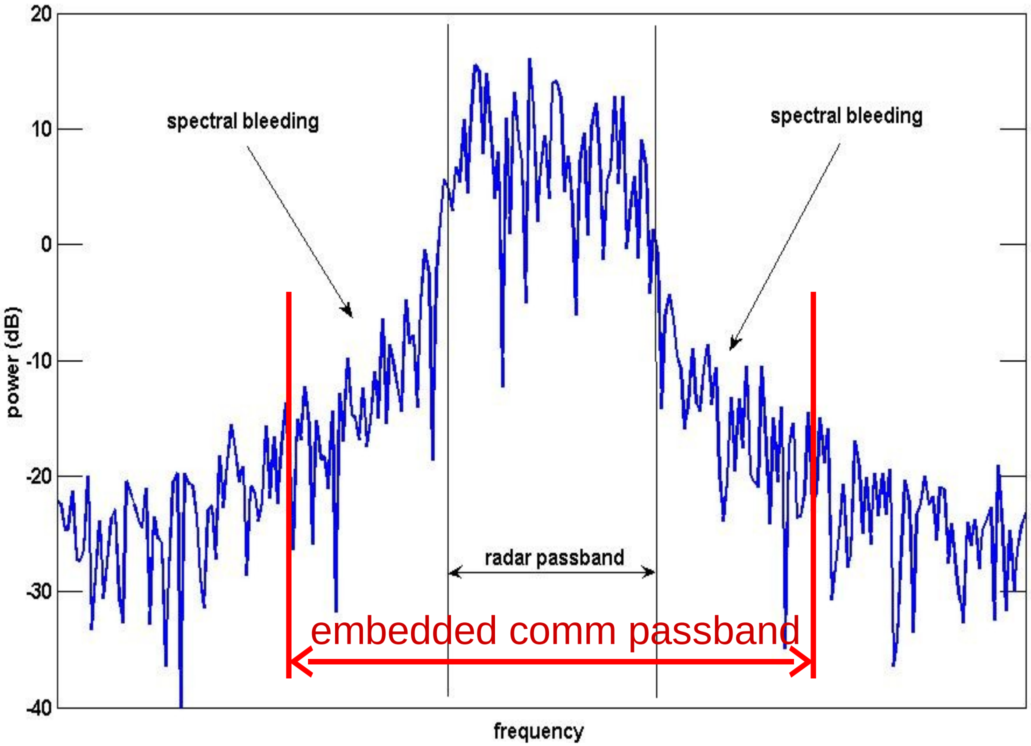
- To ensure the communications waveforms possess a low probability of intercept (LPI)
  - Comm waveforms must remain partially correlated with the natural radar scattering.
- Prevents intercept receiver from simply suppressing the radar illumination $s(t)$ in the received signal $y_r(t)$ to recover the embedded signal.
- Need to exploit the scattering phenomenology and the knowledge of the incident radar waveform to design “good” comm waveforms.

Covert Waveform Design

- Difficult to use ambient scattering to design comm signals → but may easily employ the incident radar waveform.

- Design approaches based on presumed uniform scattering of radar illumination.

- Exploits "dirty spectrum" that radars generate
  - » Allows comm signals to occupy "incremental" bandwidth surrounding the radar passband.



Receive Processing

- If the communication waveforms were designed according to "ideal" estimation criteria, coherent matched filtering as

$$\hat{k} = \arg\max_{k} \quad c_k(t)\, y_r^*(t)\, dt$$

  would enable optimal estimation of the embedded signal.

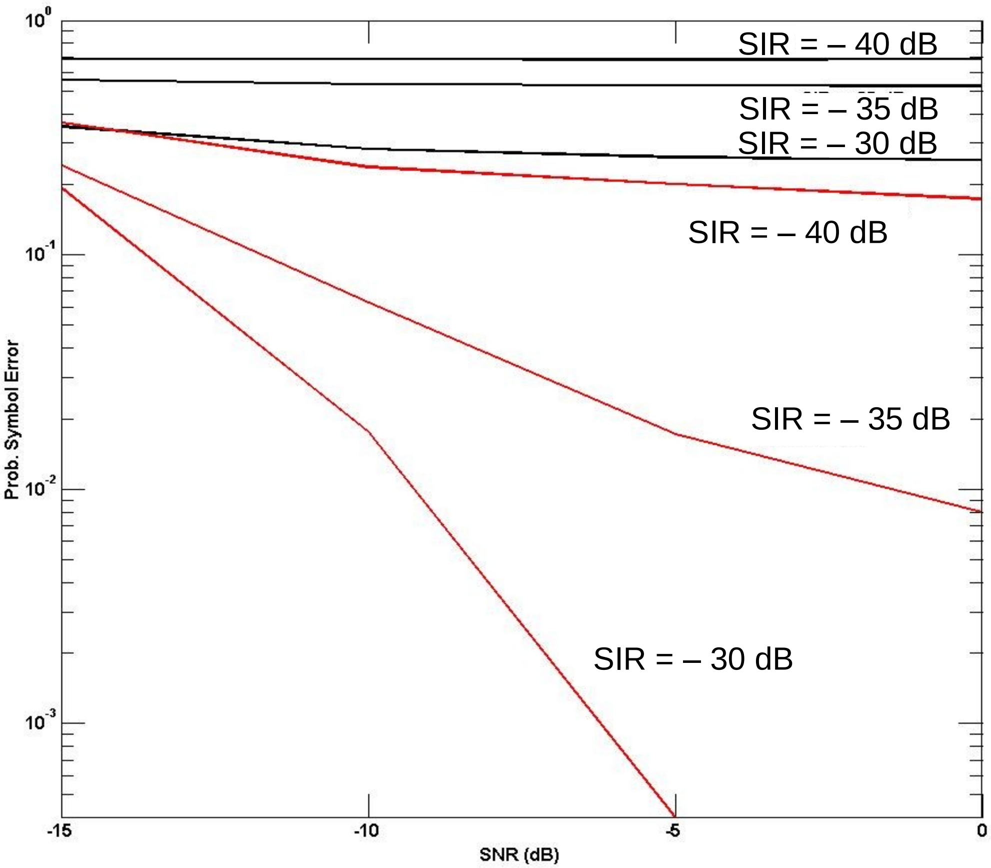
- However, some nominal correlation between the comm waveforms and the naturally scattered signal is required to maintain LPI
  - » Necessitates coherent interference cancellation to effectively extract the embedded signal from the ambient scattering.

Results from Preliminary Work

- Initial efforts have yielded promising waveform design strategies that
  - » are dependent on illuminating radar waveform,
  - » provide low communication error probability,
  - » enable data-rates on the order of (“bits-per-pulse”) → kbps.

- An indirect metric for the probability of intercept for *intra*-pulse embedded communications has been identified as well
  - » Based on a normalized correlation metric presuming the intercept can suppress the ambient radar scattering.

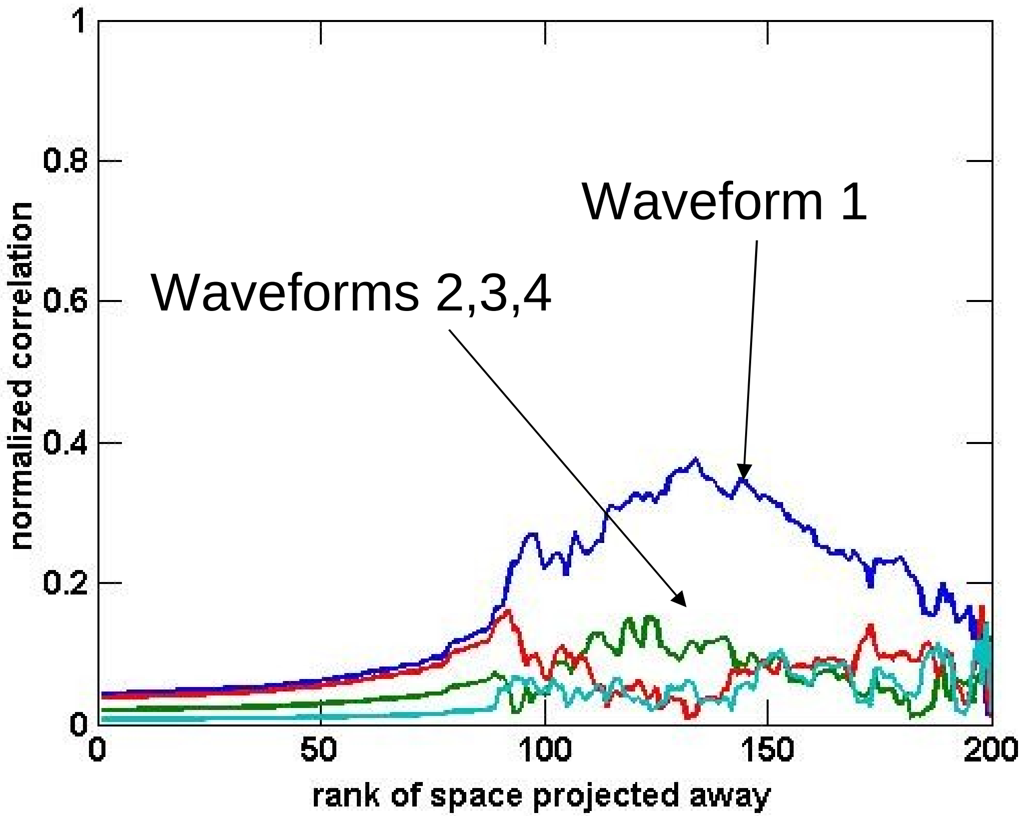
Error-Rate Performance Example



- Using *Dominant-Projection* waveform design strategy.
- Good receiver error-rate performance is attained for low SIR values when using interference cancellation.

– Matched filter
– Decorrelator

Measure of LPI



- Embed waveform 1 (of 4) and vary the rank of suppressed ambient scattering.
- Plot of correlation between suppressed residue and each of the 4 waveforms.
- Correlation-based LPI metric does not exceed 40%.
- Eavesdropper cannot obtain embedded waveform, yet intended receiver can discern among the known possibilities.

Conclusions

- Preliminary work indicates that *intra*-pulse radar-embedded communications can enable much higher data rates than previous *inter*-pulse methods while maintaining LPI.
- Necessitates the determination of appropriate comm waveforms and receive processing structures.
- Interference suppression receiver needed to maintain good estimation accuracy for LPI comm waveforms.
- Recently it has been found that comm waveform design can be made virtually immune to multipath effects.