United Technologies Research Center

Wireless Technology for Aerospace Applications

June 3rd, 2012

OUTLINE

- The case for wireless in aircraft and aerospace applications
- System level limits of wireless technology
  - Security
  - Power (self powered, remote powering, battery powered)
- Taxonomy of wireless solutions
- System integration considerations
- Summary

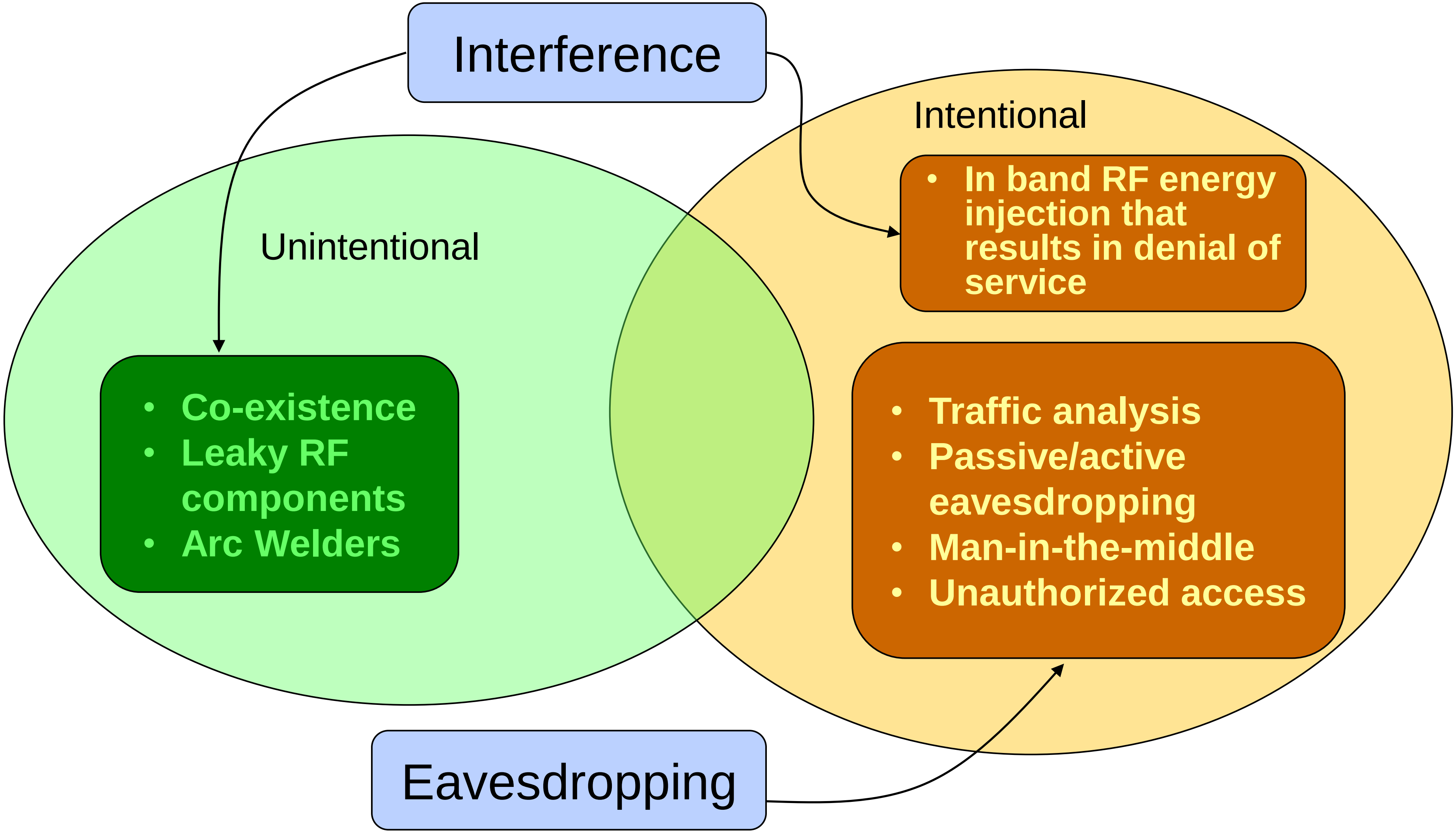
INTRODUCTION – WHY WIRELESS?

- Wireless technology has proven itself in for communications to and from aircraft (ground and other aircraft)
- Considerations for other onboard aircraft and aerospace applications.
  - Needs:
    - Long term health monitoring of the airframe and structures
    - Short term health monitoring of targeted/specific issues using peel & stick sensors
    - Security – resistance to intentional radio frequency interference and protection from eavesdropping
  - Perceptions:
    - Wireless is simply wire replacement, lower cost, weight etc.

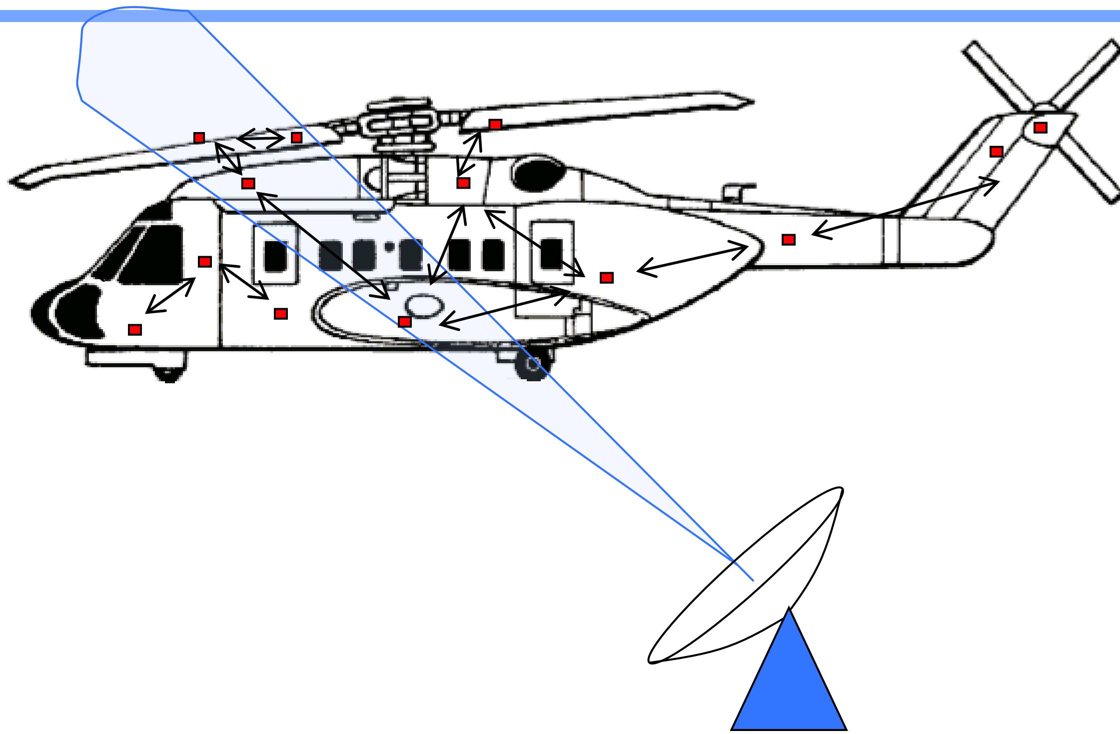
System Level Limits of Wireless Technology

Security

Securing Wireless



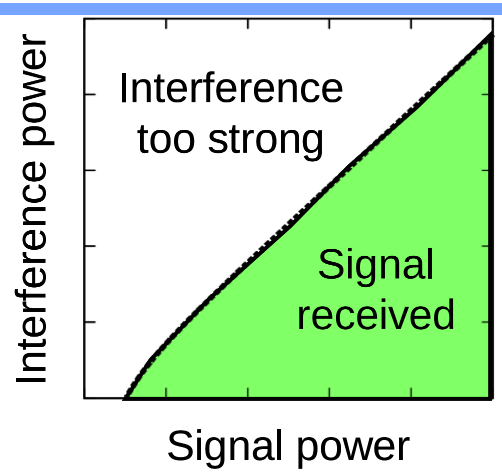
INTENTIONAL INTERFERENCE THREAT

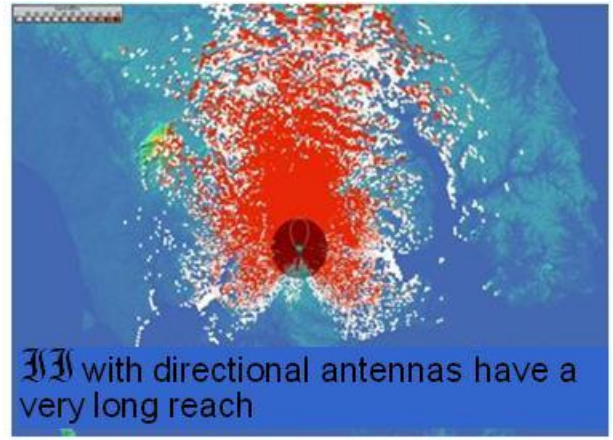


- TRADITIONAL RF WIRELESS TECHNOLOGIES ARE NOT RESISTANT TO HIGH-POWER INJECTION OF INTENTIONAL INTERFERENCE (𝔍𝔍)

𝔍𝔍 easily wins the power game =>
Opportunity for alternative technologies

JJ Overview

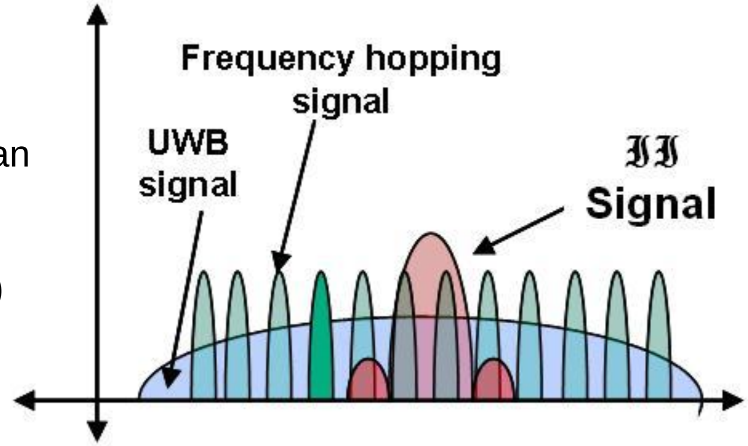


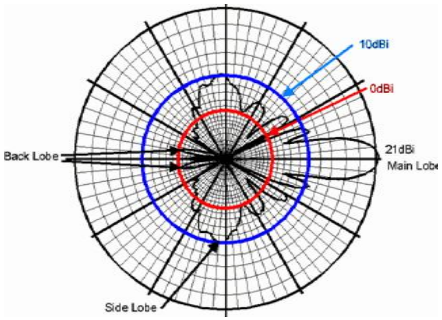


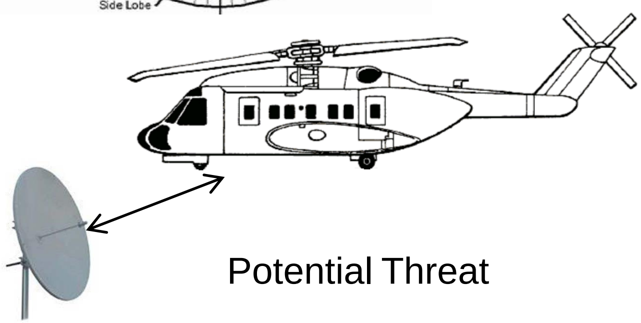
- JJ attempts to drown out the intended signal with noise
- Frequency hopping systems and wideband systems mitigate the effects of some JJ
  - Pulse-based wideband JJ are known to be effective against spread spectrum technologies
  - Example: SESP high power broadband JJ
    - Complete paralysis of RF bands (20MHz – 3000MHz)
    - 1365 W of total output power
- High gain antennas create greater challenges
- JJ characterized mostly by their frequencies, power, antenna gain and their physical space requirements

COUNTER MEASURES/TECHNOLOGIES

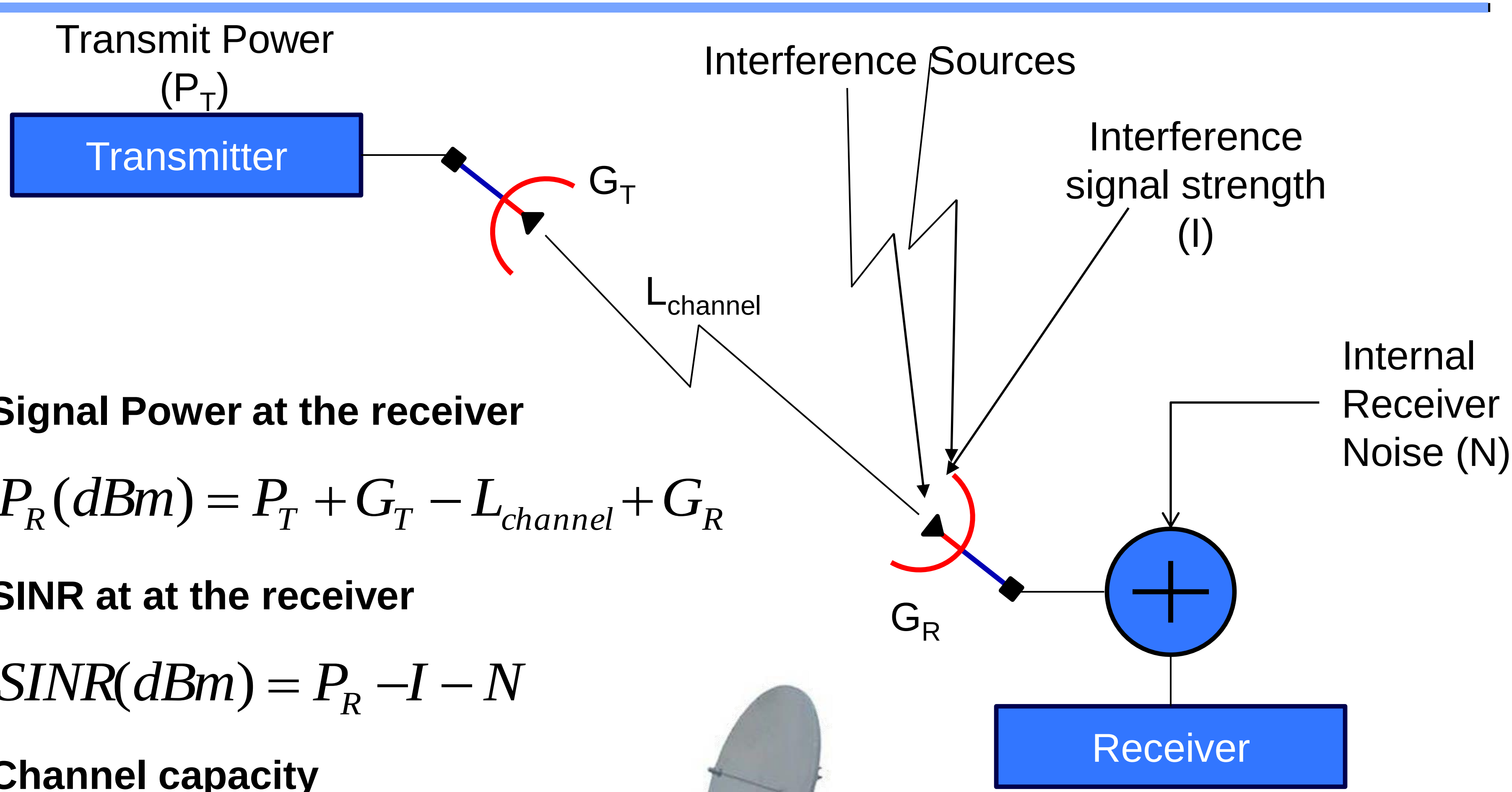
- ❖ Frequency Hopping systems over large frequency bands (>500 MHz)
  - ❑ Requires synchronization and transceiver designs that can made large bands
- ❖ Antenna Gain pattern (fixed and adaptive phased arrays)
  - ❑ Spatial nulling, frequency band nulling
  - ❑ Size can potentially increase
- ❖ Adaptive Tx power control (burn through)
  - ❑ Becomes a "power" game
- ❖ Coding
  - ❑ Coding gain can be limited depending on the SINR
- ❖ Novel Technologies
  - ❑ Magnetic communication
  - ❑ Free space optics
  - ❑ Higher frequency operation (V-band > 40 GHz)







PATH LOSS EQUATION FOR TYPICAL RF



Signal Power at the receiver

$$P_R(dBm) = P_T + G_T - L_{channel} + G_R$$

SINR at at the receiver

$$SINR(dBm) = P_R - I - N$$

Channel capacity

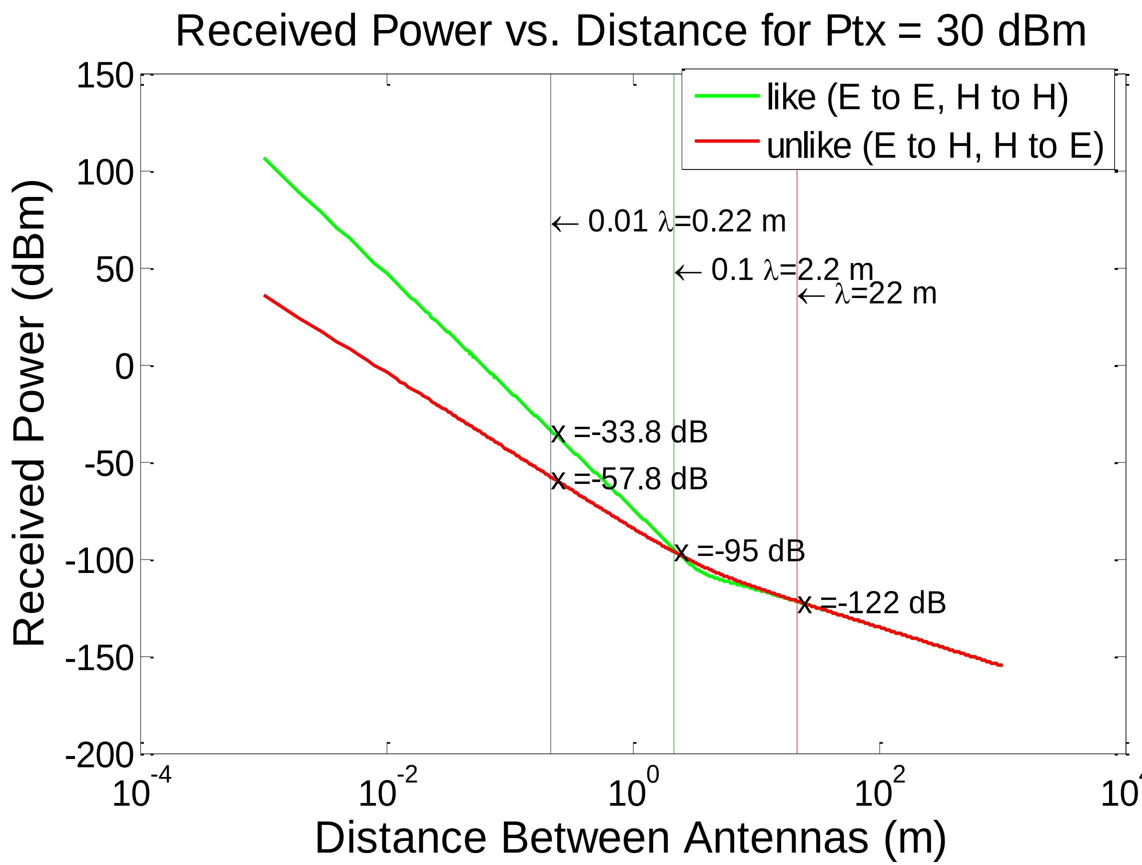
$$C = B\log_2(1 + SINR)$$

Gain of a practical parabolic dish > 40 dB

RECEIVED POWER

RECEIVED SIGNAL @ 13.56 MHZ $\lambda = 22m$

Scenario	Prx (dBm) @1 m	Prx (dBm) @10 m	Prx (dBm) @100 m	Prx (dBm) @500 m	Prx (dBm) @1 km
1	*-73.6* -83.8	-116	-135	-149	-155
2	*-43.6* -53.8	-85.6	-105	-119	-125
3	*-16.5* -6.28	-25.0	-44.9	-58.9	-64.9
4	*-17.8* -28.0	-51.0	-79.2	-93.2	-99.2



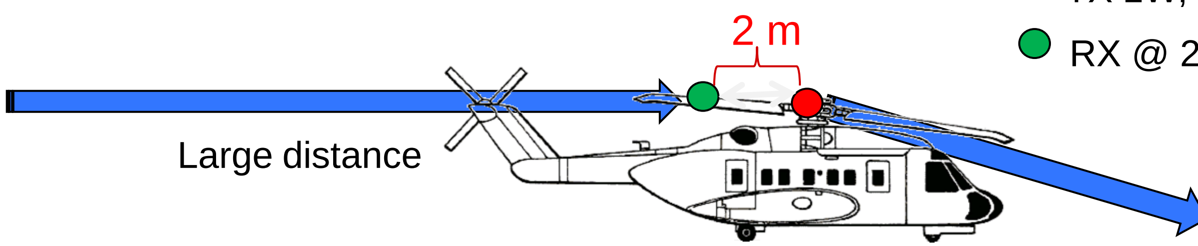
- ❖ Far field region begins at 2.2 meters
- ❖ Realistic detectable signal is -73 dBm

ℑℑ SCENARIO

How about if we’re communicating at 3 Vpp on a helicopter coil?

RF ℑℑ

63kW ERP



TX 1W, 0dBi

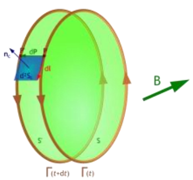
RX @ 2m = **-16 dBm**

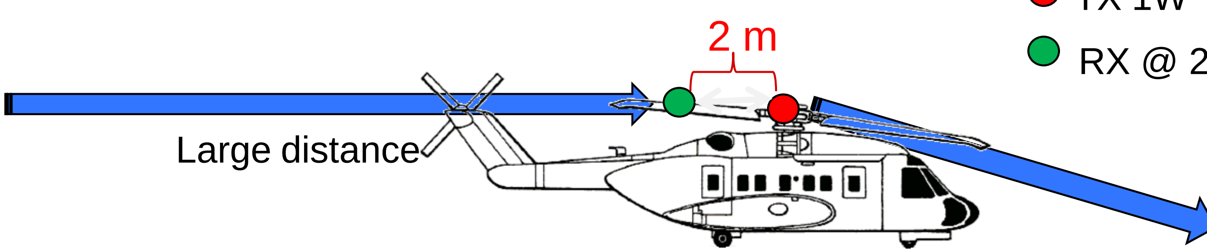
Large distance

Eavesdrop @ > 4 km

2.4 GHz 250 W(54 dBm)
24 dBi
100 cm x 60 cm

Magnetic ℑℑ





TX 1W

RX @ 2m = -2 mVpp

Large distance

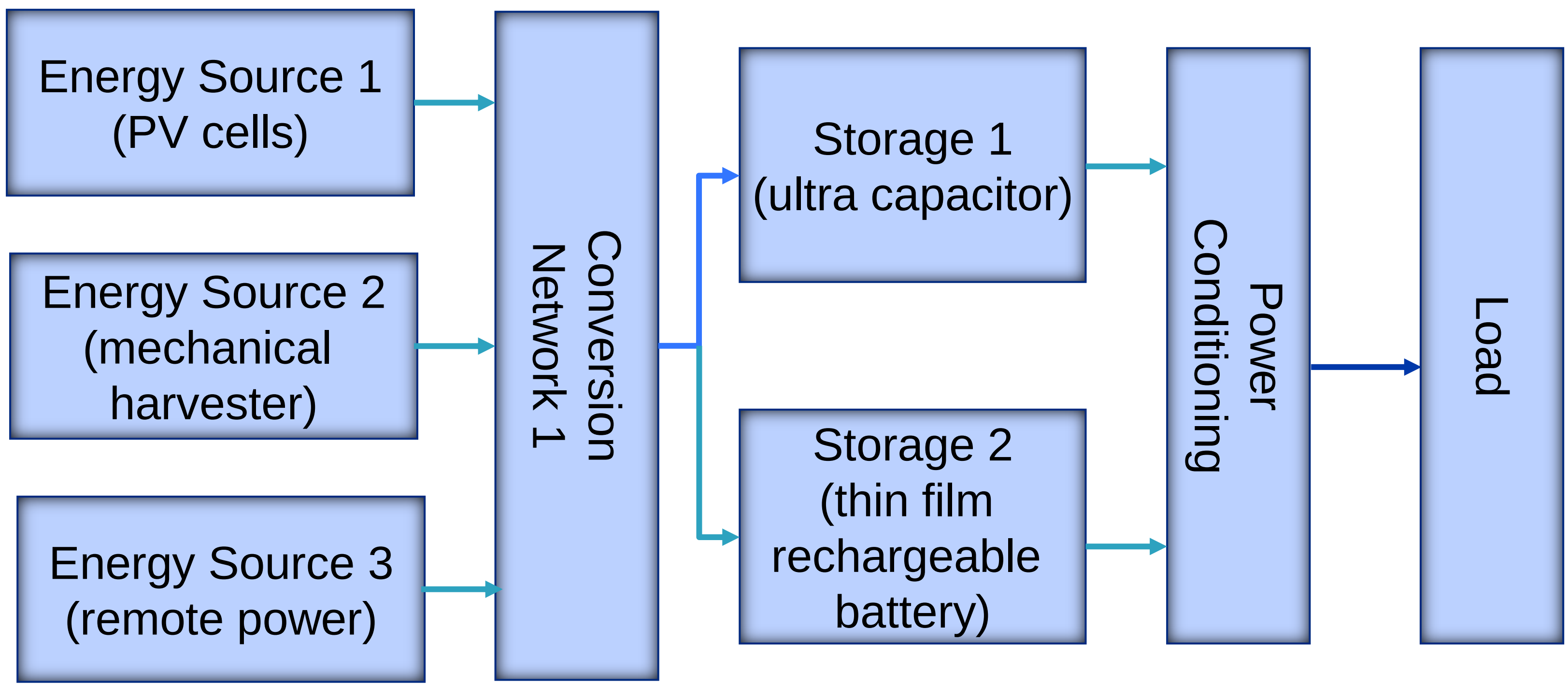
Eavesdrop @ < 4 m

125 kHz, 2m radius
0AWG, 30 Turns
5000 Amps
(Not feasible for long duration!)

System Level Limits of Wireless Technology

Power

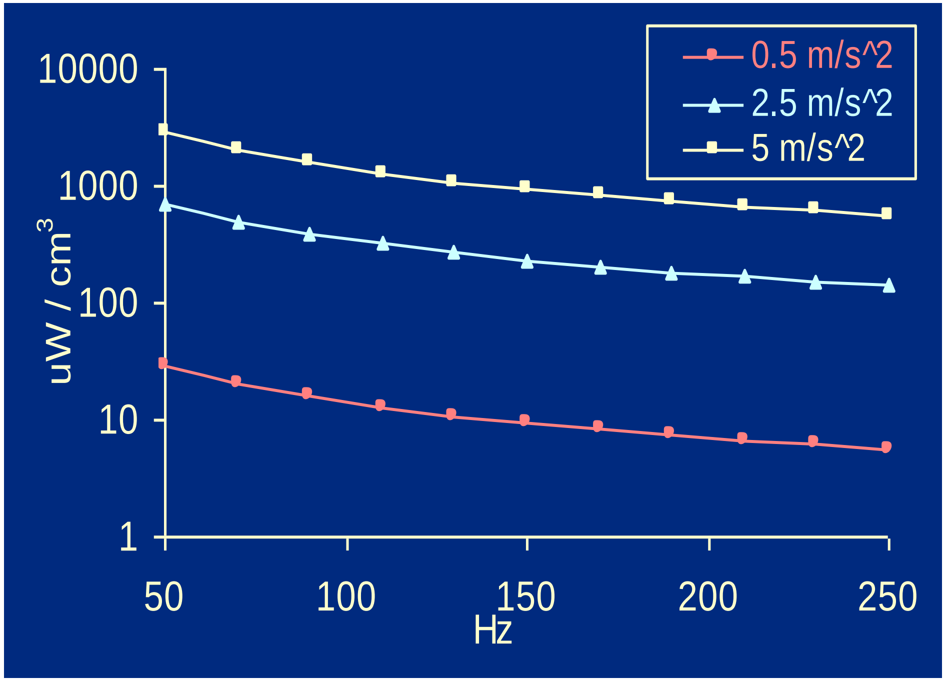
The Energy-Supply Network



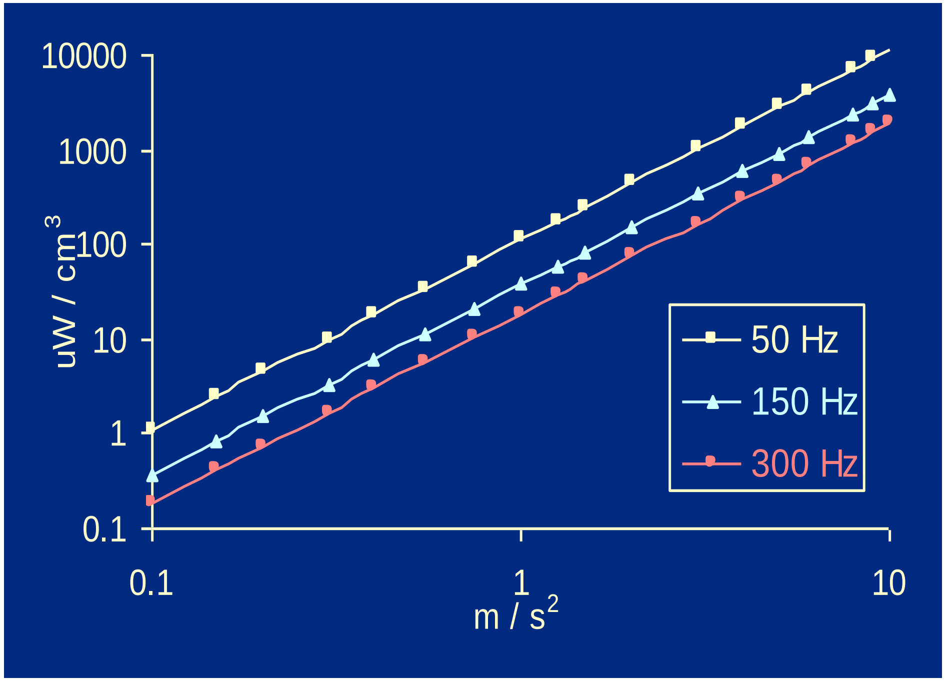
- Hybrid harvesting techniques for operational variance
- Energy storage for balancing gaps between energy source and loads

EXAMPLE: HARVESTING FROM VIBRATIONS

Fundamental limits in frequency and amplitude domains



Power density vs. frequency of input vibrations at three amplitudes



Power density vs. amplitude of input vibrations at three frequencies

Source: Dr. Shad Roundy, Australian National University

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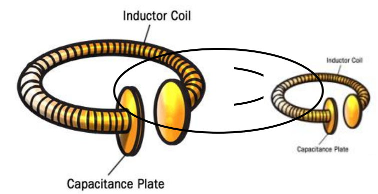
Remote Powering – Air Gap Transformer

- Factors affecting frequency change:
  - Distance change (e.g. a few millimeters can shift frequency)
  - Surrounding conductive objects: water, dirt, etc.
  - Off axis degradation: shape change, position shifting
- Weight and Size:
  - 0.5m radius (wire diameter cm's): 2.5 pound (coil only)
- Low Efficiency
  - Loop size cannot be too small (no B field)
  - Area is most powerful way to increase B field
  - More turns increase B field (linear) and losses (square)

<u>Power Transfer:</u>

Q > 900 (Typical for Power Xfer)
"Think energy storage"

$$Q \approx \frac{1}{BW}$$



$$P_{DS} \equiv -i\omega M I_S I_D$$

Similar to a transformer

$$1 >> R_r = \sqrt{\frac{\mu_0}{\varepsilon_0}}\left[\frac{\pi}{12} n^2 \left(\frac{\omega r}{c}\right)^4 + \frac{2}{3\pi^3}\left(\frac{\omega h}{c}\right)^2\right]$$

Limits Frequency/Size (**don't want to radiate**)

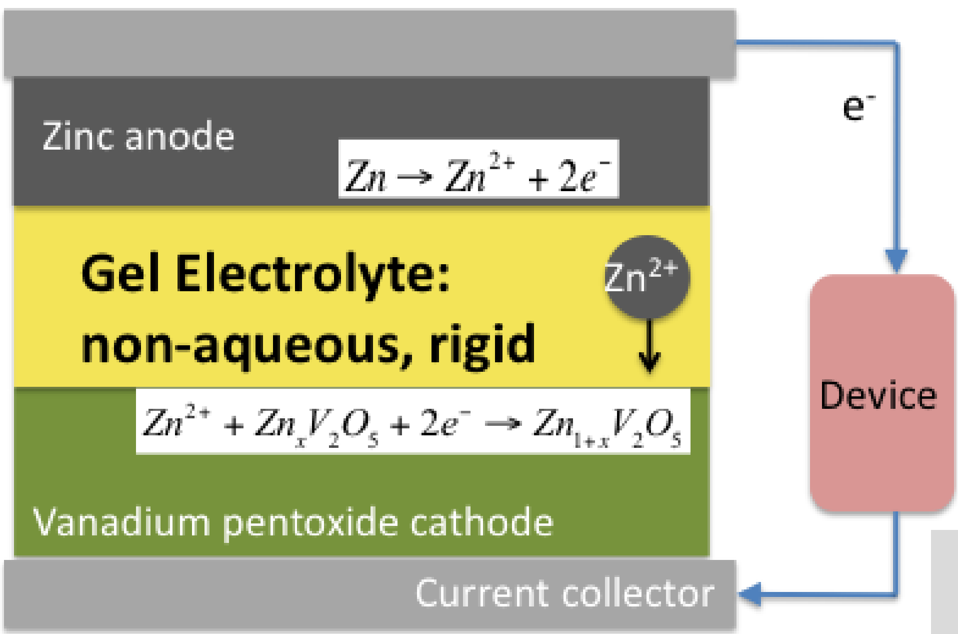
$$\frac{2}{Q} = \frac{\Delta f}{f_0}$$

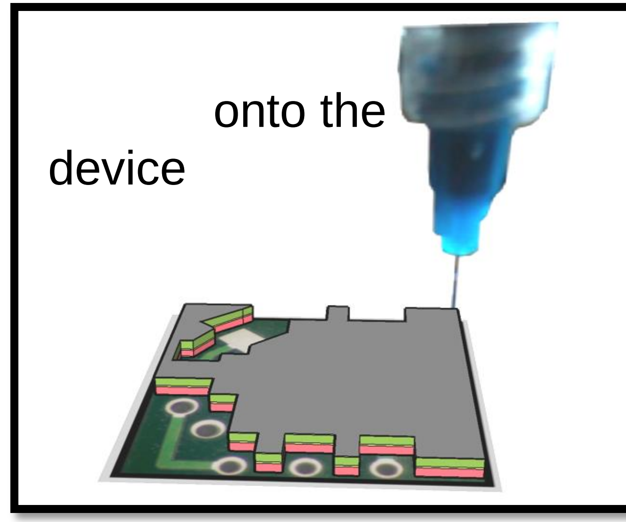
Example: For Q=900 and f0=1 MHz
Move 22 kHz and **<u>you're in the noise</u>**

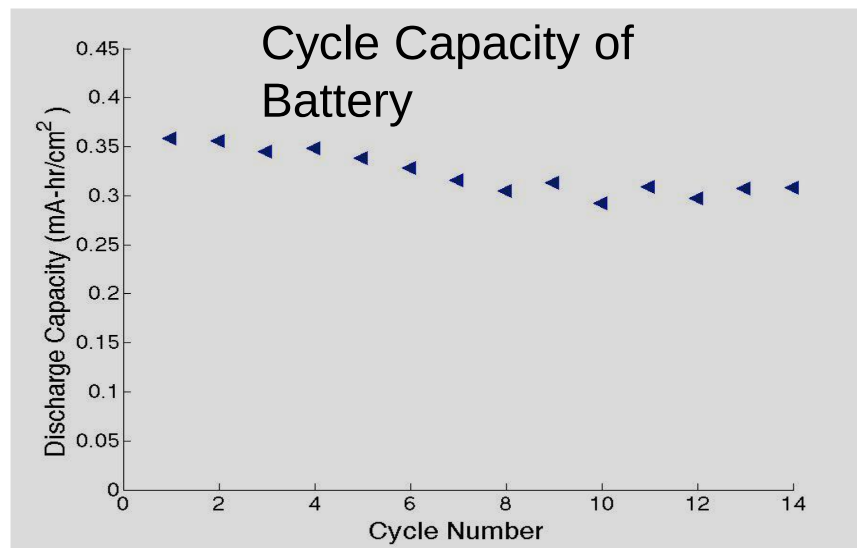
MIT Rule of Thumb

Is, I_D: currents on source and destination coils. M: mutual inductance
ω: frequency. P_{DS}: power

Printed Zinc Batteries



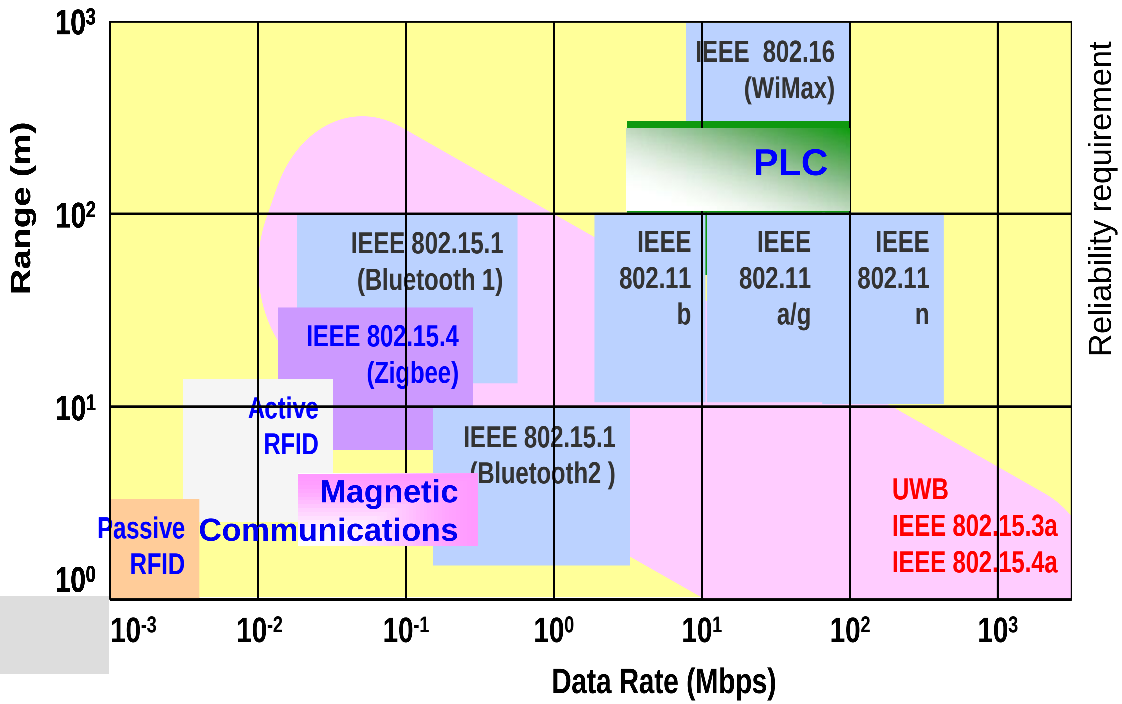




Source: Dr. Jan Rabaey, UC Berkeley

Taxonomy of Wireless Solutions

Many short range wireless technologies available



Common for multiple technologies to co-exist on a platform

- Resistance to 𝔍𝔍
- High reliability
- Security/Stealth
- Low weight and size
- EMI/EMC
- Certification
- Low power
- Data throughput

SYSTEM LEVEL INTEGRATION CONSIDERATIONS

- Communications range
  - Environment: Free space, RF absorbing, RF reflecting (multipath)
- Protocols
  - Multiple physical layers exist on a platform
    - Wavelengths: Sub GHz, ISM Bands and possible future 60 GHz
    - Modulation: BPSK, QPSK, QAM …
    - CFHSS, DSSS, proprietary,
  - Multiple SW protocol stacks
    - IEEE 802.15.4, ZigBee, IEEE 802.11, IEEE 802.16, IEEE 1902.1

Locally optimization => Plethora of point solutions for the integrator

SUMMARY

- Needs:
  - Long term health monitoring of the airframe and structures – unmet : wired
  - Short term health monitoring of targeted/specific issues using peel & stick sensors – unmet: requires an engineered wireless infrastructure
  - Security – resistance to intentional radio frequency interference and protection from eavesdropping – partially met: low power RF and encryption
- Perceptions:
  - Wireless is simply wire replacement, lower cost, weight etc. – reality: higher cost and some energy harvesters are heavy.

Opportunity! PWST addresses many of these needs