Electronic Support Sensors

Short Course on Radar and Electronic Warfare

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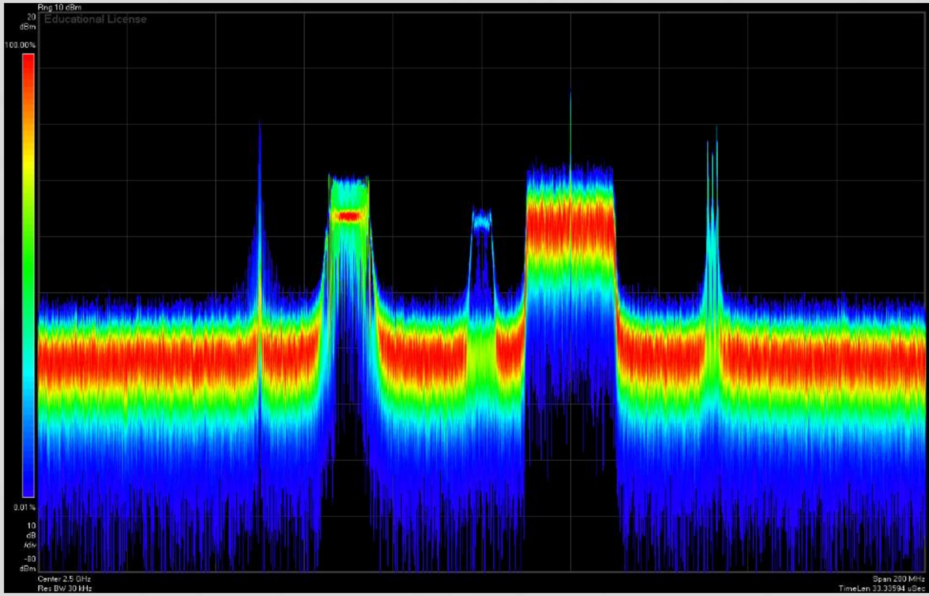
Classes of ES Sensors

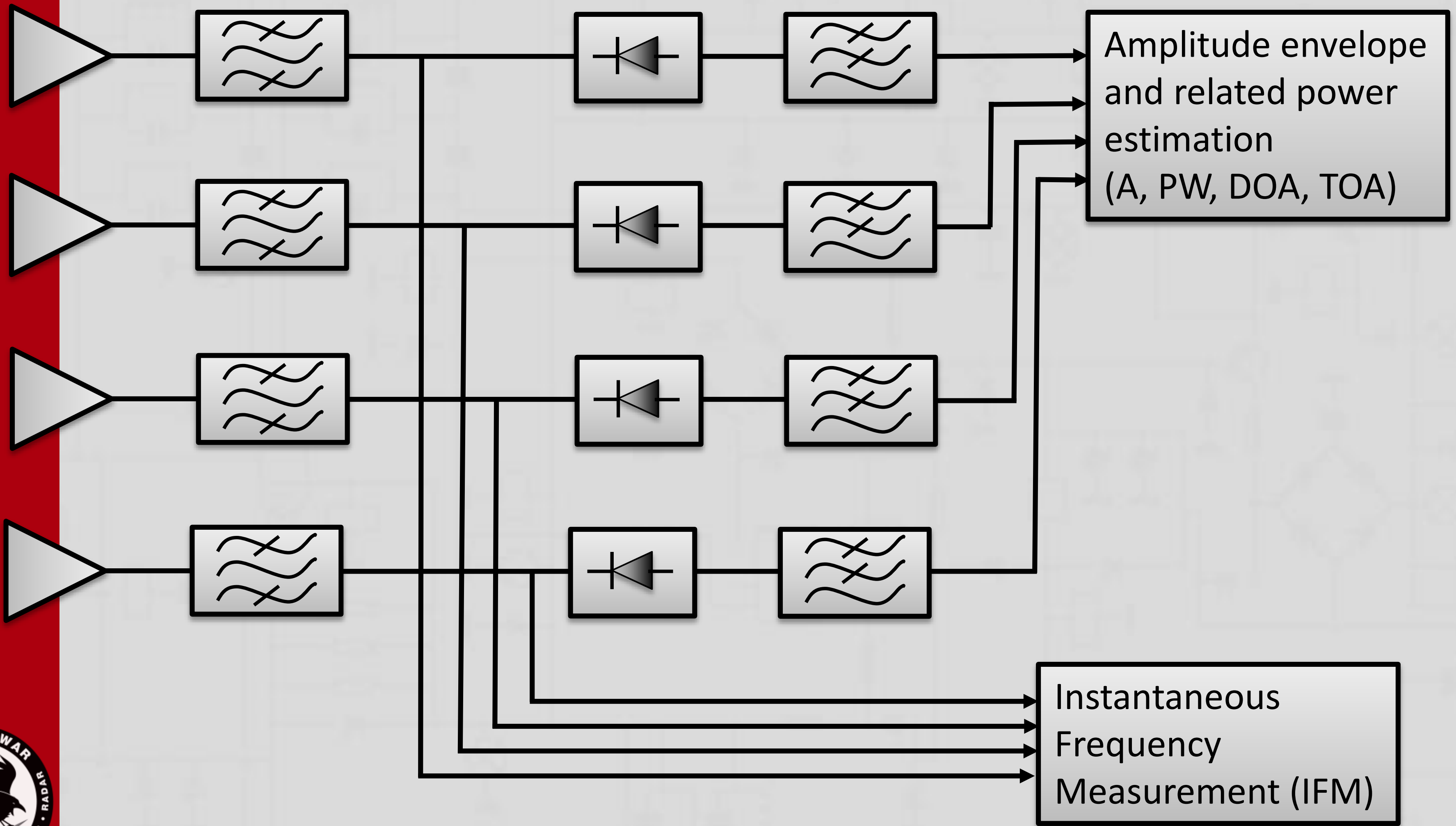
- Radar Warning Receiver (RWR)
- Electronic Support Measures (ESM)
- Electronic Intelligence (ELINT)

What are the challenges?

- Receiver sensitivity
- Probability of
  Intercept (POI)
- Ability to discriminate an emitter within spatial and frequency coverage



Wide Open Receiver



Crystal Detector

- Crystal/square law detector allows detection of the entire RF bandwidth, but eliminates any phase or frequency information
- Performs the following measurements:
  - Pulse amplitude
  - Pulse width
  - Direction of arrival (DOA)
  - Time of arrival
  - Antenna scan type
  - Antenna scan period

ESM Architectures

ESM Receiver

- Typically super heterodyne
- Often uses a wideband IF switching amongst channels
- Compromise between POI and resolution

ELINT Receiver

- Focus is on a single signal at a time
- Selectable IF with a sample and hold receiver
- High gain antenna

POI vs Receiver Architecture

1. Omni directional UWB antenna, with a wideband receiver covering the entire RF bandwidth (100 % POI)
2. WB antenna with a narrow band receiver swept quickly across the RF spectrum (≈ 10 % POI)
3. Rotating high gain wideband antenna, with narrowband, selective receiver (≈ 2 % POI)

Who sees the other first

- Range Advantage Factor (RAF)

$$RAF = \frac{R_e}{R_r} = 1 + a$$

- $R_e \equiv$ RWR detection range
- $R_r \equiv$ radar detection range
- Closing velocity

$$v_c = v_e + v_r$$

- Warning Time

$$R_e = R_r + v_C T_w$$

Understanding RAF

- Received Power

$$P_R = \frac{P_t G_t}{4\pi L_t R^2} \frac{\sigma}{4\pi R^2} \frac{G_r \lambda^2}{4\pi L_r}$$

$$P_e = \frac{P_t G_t}{4\pi L_{t_e} R^2} \frac{G_r \lambda^2}{4\pi L_e}$$

- Assume a $P_D = 90\ \%$ or $P_{FA} = 10^{-6}$

$$\Rightarrow \mathrm{SNR}_0 \geq 13\ \mathrm{dB}$$

- For a good DOA assessment , $\mathrm{SNR}_0 \geq 18\ \mathrm{dB}$

Understanding RAF

- Required radar receiver power

$$P_{r_0} = P_r \times \mathrm{SNR}_0 = (kTB_rF_r)(\mathrm{SNR}_0)$$

- B_r = equivalent noise bandwidth

$$B_r = B_T/G_P$$

- B_t = transmitter bandwidth
- G_p = processing gain
- Required EW receiver power

$$P_{e_0} = P_e \times \mathrm{SNR}_0/G_{pe}$$

Range Equations

$$R_r = \sqrt[4]{\frac{P_t G_t G_r \lambda^2 \sigma G_p}{(4\pi)^3 L_t L_r (kTB_t F_r) SNR_0}}$$

$$R_e = \sqrt{\frac{P_t G_{t_e} G_e \lambda^2 \sigma G_{pe}}{(4\pi)^2 L_t L_r (kTB_t F_r) SNR_0}}$$

- Note the radar antenna main lobe may not always be pointed at the target

$$G_{t_e} = G_t / SLL$$

Range Advance Factor

$$\frac{R_e}{R_r} = \left[\frac{kP_t\lambda^2 {G_t}_e^2 G_e^2 {G_p}_e^2 B_t}{4\pi G_t^2 G_p B_e^2 \sigma}\right]^4$$

$$k = \left(\frac{F_R}{F_e^2 L_e^2}\right)\left(\frac{1}{kTSNR_0}\right) = 83 \text{ dBm/MHz}$$

- Assumes the following
  - Monostatic
  - Transmitter and receiver losses are equal
  - $SNR_0 = 13\,dB = 20$
  - $F_E \approx 5F_r$

Case 1: Prior Gen EW & Radar

- Radar characteristics
  $P_t = 100\ kW = 80\ dBm; G_t = G_R = 35\ dBi; B_t = 1\ MHz = 0\ dBMHz; \lambda = 0.1; G_p = 13\ dB; F_R = 3\ dB; L_t = L_r = 2\ dB; RCS = 5\ m^2 = 7\ dB_{m^2}$
- RWR characteristics
  $G_e = G_{pe} = 0\ dB; B_v = 20\ MHz; B_{RF} = 16\ GHz; F_e = 10\ dB; L_e = 2dB; B_e = (2B_vB_{RF})^{1/2} = 800\ MHz$
- With the above parameters $R_r = 188.4\ km$ and $R_e =$ 3548 km in the main lobe and 64 km in the side lobe

Case 2: LPI Radar

- Radar characteristics

$P_t = 100\ W = 80\ dBm; G_t = G_R = 35\ dBi; B_t = 500\ MHz;\ \lambda = 0.03; G_p = 30\ dB; F_R = 3\ dB; L_t = L_r = 2\ dB; RCS = 1000\ m^2$

- RWR characteristics

$G_e = G_{pe} = 0\ dB; B_v = 20\ MHz; B_{RF} = 16\ GHz; F_e = 10\ dB; L_e = 2dB; B_e = (2B_v B_{RF})^{1/2} = 800\ MHz$

- With the above parameters $R_r = 40\ km$ and $R_e =$ 35.5 km in the main lobe and 0.63 km in the side lobe

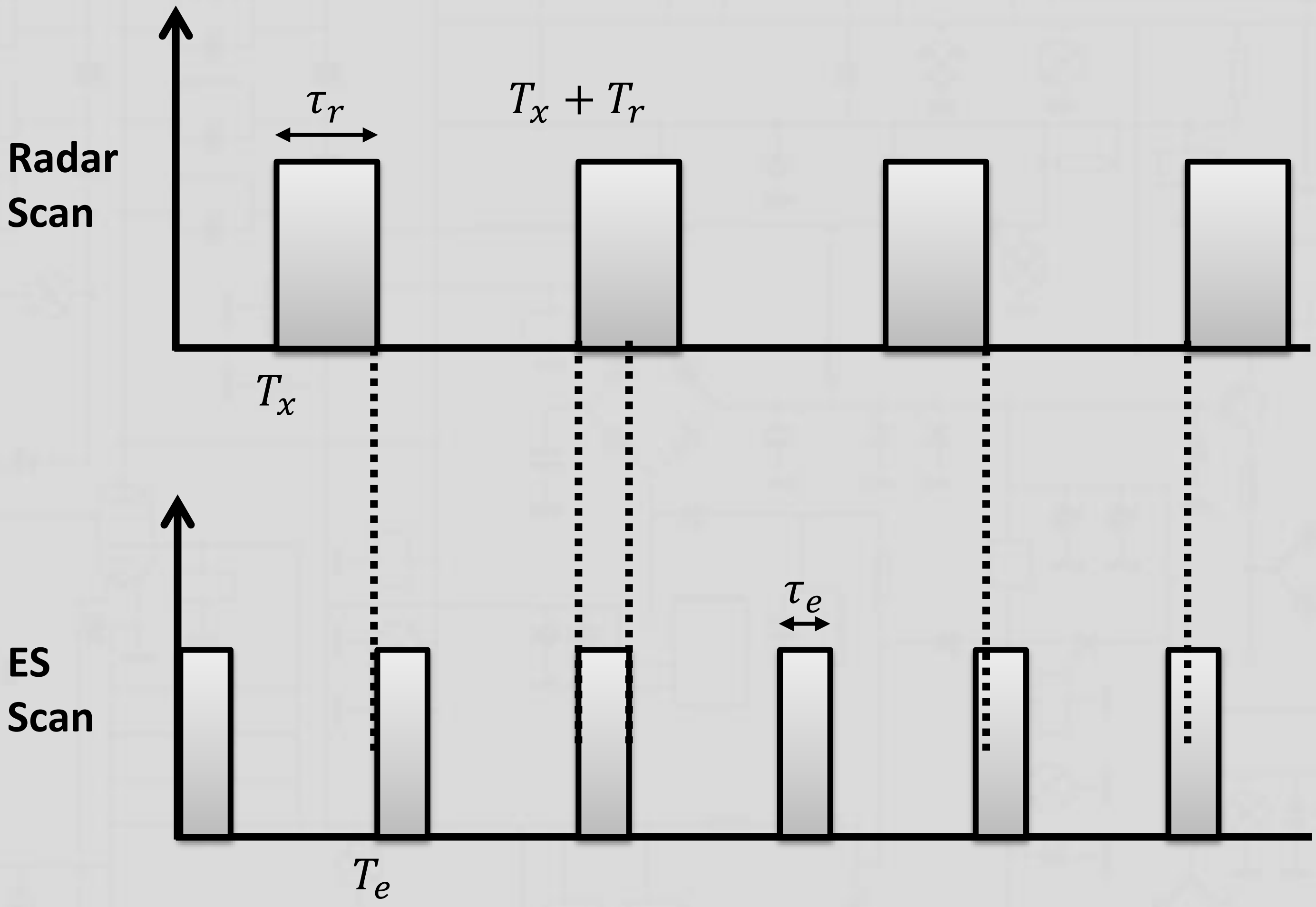
Pulses Received

- Number of pulses per unit time:

$$M = N_r PRF_{avg}$$

- Where N_r is the number of radars

Chance of Coincidence



Probability of Coincidence

$$mT_e + T_x = nT_r$$

- Need to find the least common multiple of m and n to find the coincident period
- For a common window duration

$$C = \tau / T_p \text{ where } T_p = lcm(T_e, T_r)$$

Coincidence Metrics

- The case of different window durations can be deduced by setting $\tau_r = \alpha T$ and $\tau_e = \beta T$
- It can be shown that the coincidence fraction for different window widths is

$$C(T_e, T_r) = \frac{\alpha\beta}{hk} = \frac{\tau_e \tau_r}{T_e T_r}$$

- The mean period between coincidences is

$$T_p = \frac{T_e T_r}{\tau_r + \tau_e}$$

- The average duration of the coincidence is

$$\tau_p = \frac{\tau_r \tau_e}{\tau_r + \tau_e}$$

Probability of Intercept

- Assuming the probability of coincidence, $p(t)$, is independent from observation to observation
- The probability of a coincidence at time $t + \Delta t$ is increased with respect to $p(t)$ by the ratio of the increment in time, Δt, to the mean period between coincidences T_p

$$p(t + \Delta t) - p(t) = \frac{\Delta t}{T_p}[1 - p(t)\Delta t]$$

Probability of Intercept

- Taking the derivative this gives

$$\frac{dp(t)}{dt} = \frac{\Delta t}{T_p}\left[1 - p(t)\Delta t\right]$$

- This can then be solved for the probability of coincidence

$$p(t) = 1 - (1 - C)e^{t/T_p}$$

Example of POI

- An EW sensor with a wide beam antenna and a fast stepped scan frequency receive able to cover 1 GHz of bandwidth in 100 MHz search steps, at a 10 ms duration per step.
- The targeted radar is a surveillance radar with a 2 degree beam width, rotating at 10 rpm

Example of POI (continued)

$\tau_e = 10\,ms$ and $T_e = \left(\frac{1000\,MHz}{100\,MHz}\right)(10\,ms) = 100\,ms$

$T_r = 6\,s$ and $\tau_r = \frac{2^\circ}{360^\circ}(6\,s) = 33.3\,ms$

The coincidence fraction is then:

$$C(T_e, T_r) = \frac{\tau_e \tau_r}{T_e T_r} = \frac{0.033 \times 0.01}{0.1 \times 6} = 0.55 \times 10^{-3}$$

Mean period between coincidences

$$T_p = (0.1 \times 6)/(0.033 + 0.01) = 13.86\,sec$$

Average duration of coincidences

$$\tau_p = (33.3 \times 10 \times 10^{-3})/(33.3 + 10) = 7.7\,ms$$

Time of Intercept

$$TOI = 2.3T_p = 31.9\,sec$$