



Кафедра електроніки, робототехніки і технологій моніторингу та інтернету речей
Факультет авіонавігації, електроніки та телекомунікацій (ФАЕТ)



Електронні системи

Electronic Systems

Lecture #16

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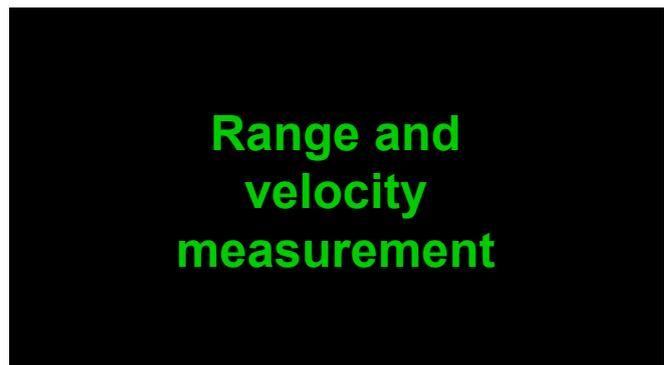
Орієнтовний тематичний план лекцій

Основи теорії систем, сигнали і первинні перетворювачі електронних систем

1. Вступ. Визначення і термінологія, класифікація	2	
2. Характеристики електронних систем	2	
3. Теорія систем, аналіз електронних систем	2	
4. Первинні перетворювачі електронних систем	4	
5. Сигнали електронних систем	2	
6. Компоненти і обробка сигналів в ЕС	1	7 семестр
7. Експлуатаційні характеристики електронних систем	2	
8. Технічні характеристики електронних систем	2	
9. Технічна реалізація системи	1	
10. Електронні системи локації	18	
11. Електронні системи зв'язку	8	8 семестр
12. Електронні системи авіоніки	19	
Всього годин		63

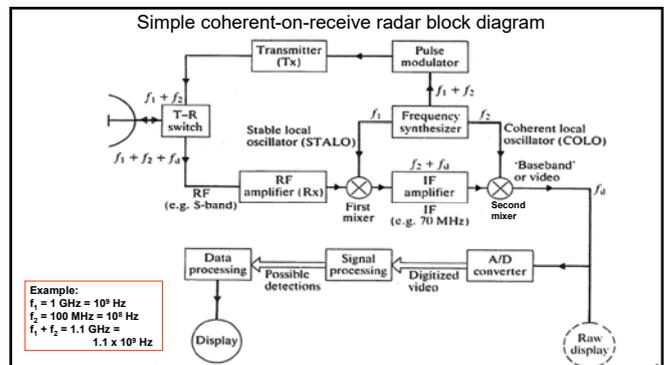
Електронні системи локації

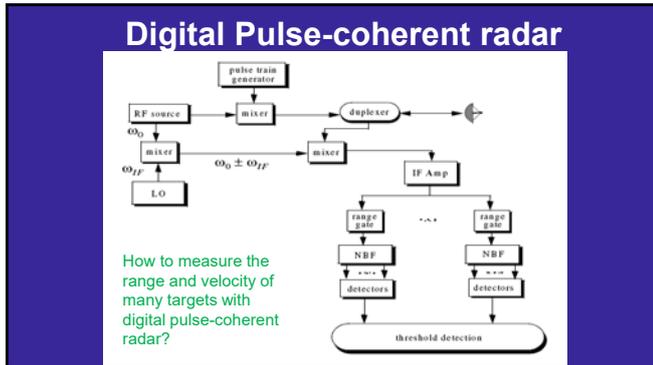
1. Основні терміни, принцип дії, класифікація та застосування.	2	
2. Відбиваючі властивості об'єктів.	2	
3. Виявлення сигналів.	4	
4. Дальність дії локаційної системи.	2	
5. Роздільна здатність локаційної системи.	2	
6. Вимірювання дальності та швидкості об'єктів.	2	
7. Вимірювання кутових координат.	2	
8. Методи підвищення роздільної здатності і точності вимірювань.	2	
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5. Potential accuracy of velocity measurement.	11. Ambiguity function for pulse train.
6. Radar ambiguity function.	12. Ambiguity contour plots.





Difference between detection and measurement procedure

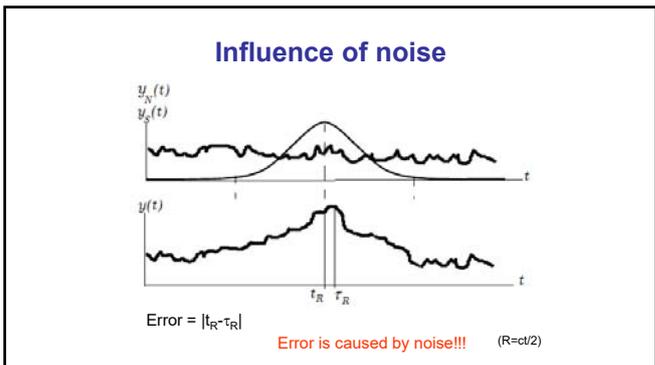
While radar detection was implemented by threshold rule that was applied to output voltage, range measuring procedure consists in **search of a maximum** of the same function .

Optimal range measurement

$$x(t) = s(t - t_{delay}) + n(t)$$

$$y(t) = y_s(t) + y_n(t)$$

$$y_s(t) = \int s(t - t_{delay})h(t - \tau)d\tau$$

$$y_n(t) = \int_{-\infty}^{\infty} n(\tau)h(t - \tau)d\tau$$


Radar Measurement

- Measurement is a separate radar task.
- Classical radar theory rigorously proves that to provide high-accuracy of measuring both target range and velocity, the waveform should be long-continued (accurate measurement of Doppler shift) and as wideband as possible (accurate measurement of time delay).
- This means using WB waveforms with $B\tau \gg 1$

Difference between detection and measurement

- Detection – comparison with threshold level
- Optimal measurement – finding maximum
- This concerns any measured value (angle, range or velocity)

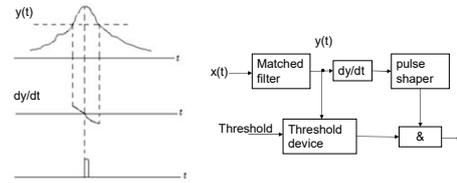
Potential Range Accuracy

- The error is less if the SNR is more
- The error is less if the width of peak is less
- The peak is narrower if the waveform spectrum is wider
- Accuracy of range measurement is characterized by rms of error $\sigma(R)=\sigma_{R_r}$, range estimation is based on time delay measurement $R=c\tau/2$

$$\sigma_{R_r}^2(R) \propto \frac{1}{\Delta\omega_{eff}^2 \frac{2E}{N_o}} \quad \Delta\omega_{eff} \propto B$$

Square of effective spectrum width
SNR

How to find maximum?



Potential Velocity Accuracy

- Velocity measurement is reduced to f_d measurement
- Accuracy is better if spectrum width narrower; The best is monochromatic waveform
- That means that the requirements are contrary
- Accuracy of velocity measurement is characterized by rms of error $\sigma(v)=\sigma_V$

$$\sigma_{R_r}^2(v) \propto \frac{\Delta\omega_{eff}^2}{2E} \cdot \frac{1}{N_o}$$

Square of Effective spectrum width
SNR

Accuracy is opposite to Error

- Potential accuracy of time (range) measurement $\frac{1}{\sigma_r^2} \propto SNR \times \omega_e^2$
- Potential accuracy of Doppler (velocity) measurement $\frac{1}{\sigma_f^2} \propto SNR \times \tau_e^2$
- Effective duration and effective spectrum width are opposite $\omega_e \approx \frac{1}{\tau_e}$

Uncertainty principle in radar

$$R \leftrightarrow t_{delay} \quad V \leftrightarrow F_{Doppler}$$

$$\sigma_t \cdot \sigma_F = \frac{1}{q^2 \Delta\omega_{ef} \cdot \tau_{ef}}$$

$$F = \frac{2V_r}{\lambda} = \frac{2V_r}{c} f_0 \quad t_{delay} = \frac{2R}{c}$$

$$\sigma_R \cdot \sigma_V = \left(\frac{c}{2}\right)^2 \frac{1}{f_0 q^2 \Delta\omega_{ef} \cdot \tau_{ef}}$$

- Equivalent (effective) spectrum width is proportional to the spectrum width of the signal itself Δf
- Equivalent (effective) duration of the signal is proportional to duration of the signal itself T_0
- Values Δf and T_0 are related between themselves by FT and their property is: $\Delta f \cdot T_0 = K = \text{const}$
K – is the basis of the signal

Reminder: At the output of MF or optimal correlation receiver, the autocorrelation function of the signal is created.

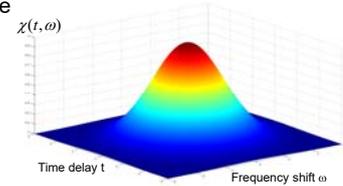
- This ACF in generalized form is named 'ambiguity function'. It plays important role in characterization of the signal.
- In complex form AF can be written as:

$$\chi(t, \omega) = \frac{1}{E} \int_{-\infty}^{\infty} \dot{s}\left(\tau + \frac{t}{2}\right) \cdot \dot{s}^*\left(\tau - \frac{t}{2}\right) \cdot e^{j\omega\tau} d\tau$$

- Module of this function $\chi(t, \omega)$ is sometimes a very complicated surface.
- But it can be also rather simple.

Example – a bell-shape pulse

- Uncertainty principle



At $\omega=0$ we get a section of this surface in the plane of time axis. In this case $\chi(t, 0)$ is just an ACF of signal envelope.
At $t=0$ – section in plane of frequency axis $\chi(0, \omega)$.

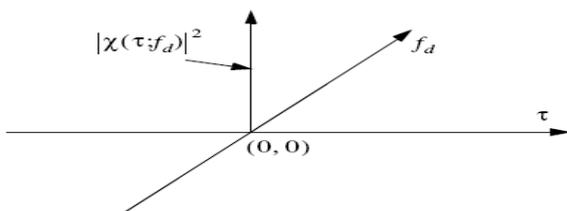
Radar Ambiguity Function

- The radar ambiguity function represents the output of the matched filter, and it describes the interference caused by range and/or Doppler of a target when compared to a reference target of equal RCS.
- The ambiguity function evaluated at $(\tau, f_d) = (0, 0)$ is equal to the matched filter output that is matched perfectly to the signal reflected from the target of interest. In other words, returns from the nominal target are located at the origin of the ambiguity function.
- Thus, the ambiguity function at nonzero τ and f_d represents returns from some range and Doppler different from those for the nominal target.

Ambiguity Diagram

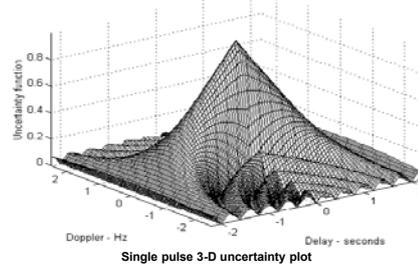
- The radar ambiguity function is normally used by radar designers as a means of studying different waveforms. It can provide insight about how different radar waveforms may be suitable for the various radar applications.
- It is also used to determine the range and Doppler resolutions for a specific radar waveform.
- The three-dimensional (3-D) plot of the ambiguity function versus frequency and time delay is called the radar ambiguity diagram.

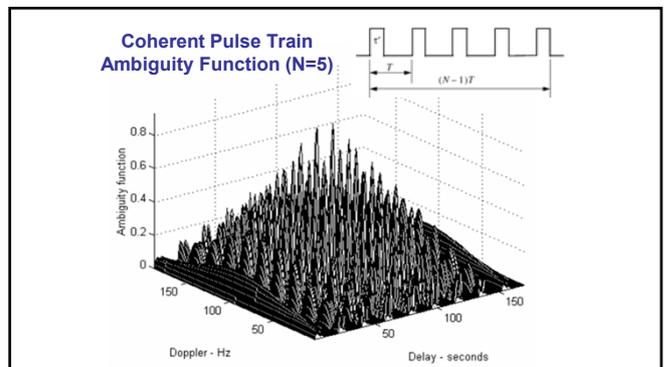
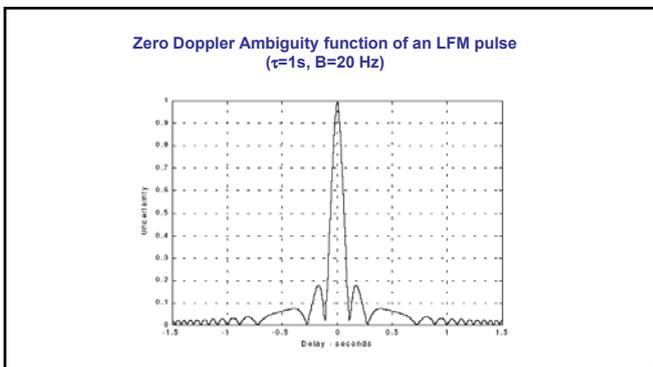
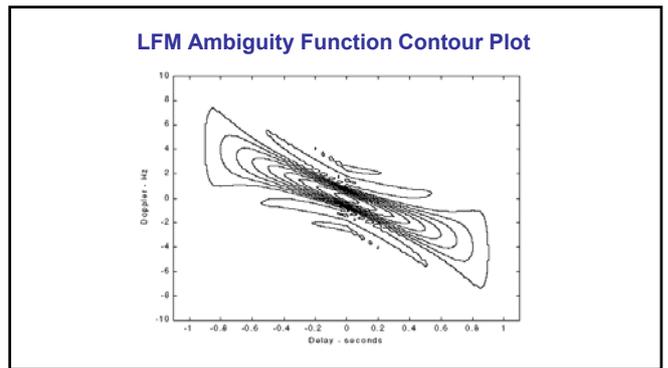
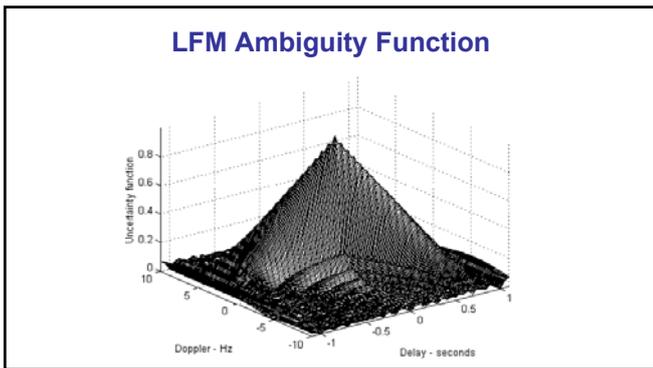
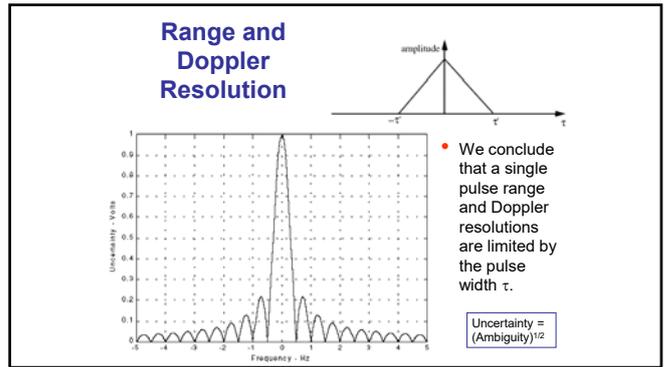
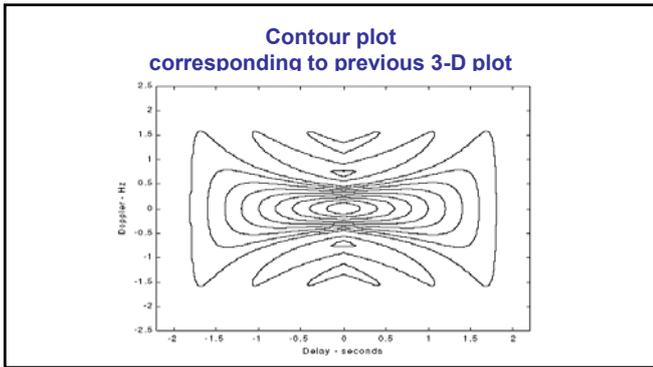
Ideal Ambiguity Function



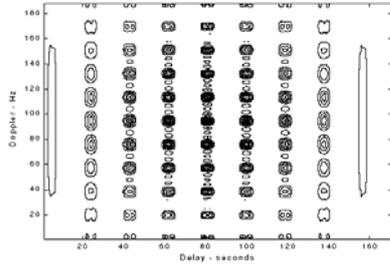
Single Pulse Ambiguity Function

Pulse width is 2 seconds

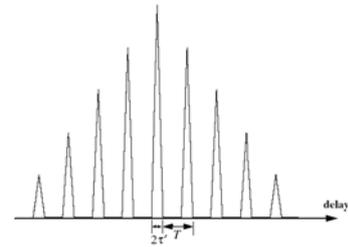




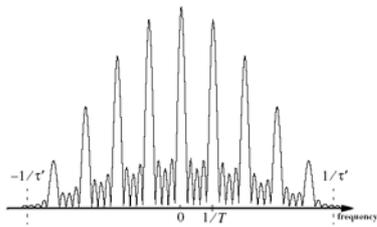
Contour plot for AF of pulse train



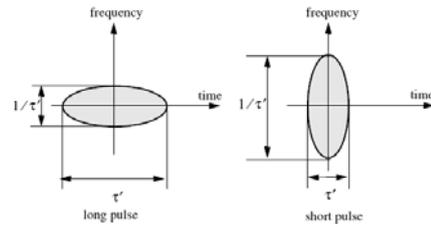
Zero Doppler cut of pulse train AF



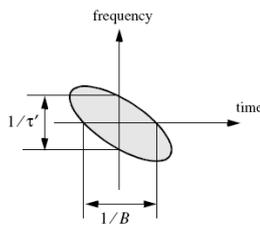
Zero frequency shift cut of pulse train AF



Ambiguity contour plot associated with a sinusoid modulated gated CW pulse



Ambiguity contour plot associated with an up-chirp LFM waveform



ЧМ-импульс с линейным нарастанием частоты

The best waveform ☺

Note that the best waveform with respect to a criterion of simultaneous measuring target range and velocity is the **ideal noise signal** because it has ambiguity function, which is similar to the delta-function located in a point of searched maximum.