


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

**Електронні системи**

**Electronic Systems**

**Lecture #18**

**Яновський, Фелікс Йосипович**  
 професор, доктор технічних наук,  
 лауреат Державної премії України, IEEE Fellow

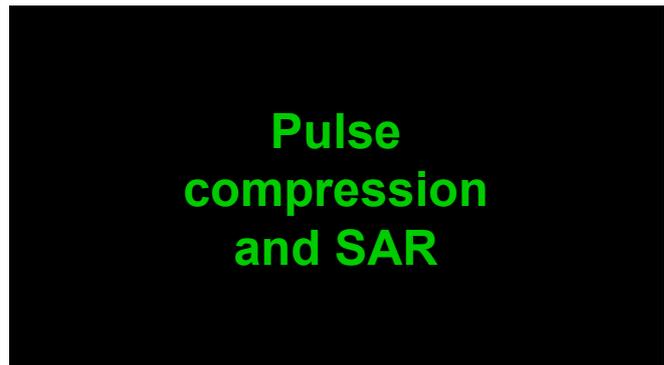
**Орієнтовний тематичний план лекцій**

**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	
<b>10. Електронні системи локації</b>	<b>18</b>	
11. Електронні системи зв'язку	8	8 семестр
12. Електронні системи авіоніки	19	
<b>Всього годин</b>	<b>63</b>	

**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
<b>8. Методи підвищення роздільної здатності і точності вимірювань.</b>	<b>2</b>
<b>18</b>	



- Contradiction between maximum radar range and range resolution.
- Wideband sounding waveforms.
- Compressing wideband signals by matched filter.
- Time-bandwidth product. Radar Equation with pulse compression.
- Range resolution at pulse compression.
- FM pulse waveform.
- Pulse-response characteristic of matched filter for FM pulse.
- Pulse compression ratio.
- Different techniques of pulse compression. Fast convolution process. Barker codes.
- Features of pulse compression in case of distributed targets.

- Why is pulse compression needed?**
- Radar range resolution depends on the bandwidth of the received signal.
  - The bandwidth of a time-gated sinusoid is inversely proportional to the pulse duration.
    - So short pulses are better for range resolution
  - Received signal strength is proportional to the pulse duration.
    - So long pulses are better for signal reception

### What to do?

- More Tx Power??
- Why not just get a transmitter that outputs more power?
- High-power transmitters present problems
- Require high-voltage power supplies (kV)
- Reliability problems
- Safety issues (both from electrocution and irradiation)
- Bigger, heavier, costlier, ...

Decision has come from MF !

### Signal compression in MF

- We could see that MF distorts the shape of the signals.
- But it maximizes SNR.
- In case of WB signals the distortion leads to USEFUL EFFECT of COMPRESSION.
- Impulse signal is named WB, if  $B \cdot \tau \gg 1$
- Broadbandness can be achieved using chirp modulation (LFM) or phase modulation (keying).

### Pulse compression, the compromise

- Transmit a long pulse that has a bandwidth corresponding to a short pulse!
- Must modulate or code the transmitted pulse
  - to have sufficient bandwidth, B
  - can be processed to provide the desired range resolution,  $\Delta R$

Example:

Desired resolution,  $\Delta R = 15$  cm; Required bandwidth,  $B = 1$  GHz ( $10^9$  Hz)  
 Required pulse energy,  $E = 1$  mJ  $E(J) = P(W) \cdot \tau(s)$

**Brute force approach**

Raw pulse duration,  $\tau = 1$  ns ( $10^{-9}$  s) Required transmitter power,  $P = 1$  MW !

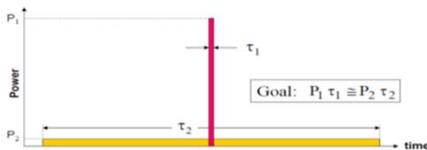
**Pulse compression approach**

Pulse duration,  $\tau = 0.1$  ms ( $10^{-4}$  s) Required transmitter power,  $P = 100$  W

### Simplified view of concept

Energy content of long-duration, low-power pulse will be comparable to that of the short-duration, high-power pulse

$$\tau_1 \ll \tau_2 \text{ and } P_1 \gg P_2$$



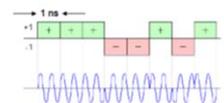
### How to create a WB pulse?

Long duration pulse is coded to have desired bandwidth.

Various ways to code pulse.

Phase code short segments

Each segment duration = 1 ns



Linear frequency modulation (chirp)

$$s(t) = A \cos(2\pi f_C t + 0.5 k t^2 + \phi_C)$$

for  $0 \leq t \leq \tau$

$f_C$  is the starting frequency (Hz)

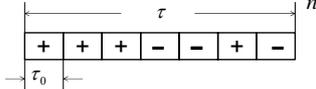
$k$  is the chirp rate (Hz/s)

$$B = k\tau = 1 \text{ GHz}$$

The choice is driven largely by required complexity of receiver electronics

### Phase-shift keyed signal (HF pulse)

- Consider phase-keying radio-pulse with duration  $\tau$  that contains  $n$  partial pulses  $\tau_0 = \frac{\tau}{n}$

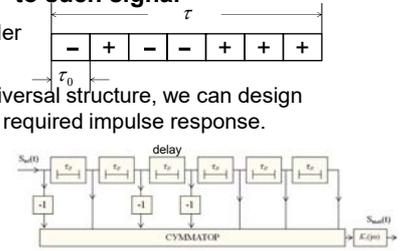


- During every interval  $\tau_0$ , the oscillations of the same frequency  $f_0$  are radiated with stable initial phase, which can be changed to  $\pi$  from partial pulse to the next partial pulse.

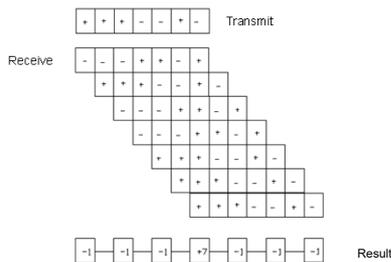
Phase-shift keying – Kluczowanie z przesunięciem fazy (фазовая манипуляция)

### Optimal impulse response $h(t)$ that corresponds to such signal

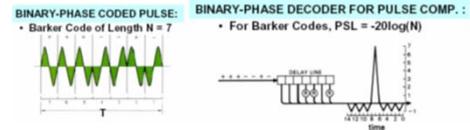
- Inverse order
- Using a universal structure, we can design a filter with required impulse response.



### Receiver signal processing



### Another example with Manchester coding phase-coded pulse compression



Correlation process may be performed in analog or digital domain. A disadvantage of this approach is that the data acquisition system (A/D converter) must operate at the full system bandwidth (e.g., 1 GHz in our example).

PSL: peak sidelobe level (refers to time sidelobes)

### Range Resolution – pulse compression

$$\Delta R = \frac{c\tau}{2} \quad \text{Contradiction between resolution and max range}$$

$$\Delta R = \frac{c\tau}{2} = \frac{c}{2B}$$

$B \cdot \tau$  Time-bandwidth product

- In general, the time-bandwidth product of an unmodulated pulse approaches unity.
- The time-bandwidth product of a pulse can be made much greater than unity by using frequency or phase modulation.

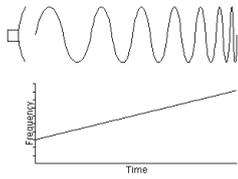
$B\tau \approx 1$  **Narrowband** sounding waveform

$B\tau \gg 1$  **Wideband** (can be compressed in receiver)

- If the radar receiver transfer function (impulse response) is perfectly matched to that of the input waveform, then the compression gain is equal to  $B\tau$ .
- Compression is a method which combines the high energy of a long pulse width with the high resolution of a short pulse width.
- The pulse compression is implemented during optimal receiving of such kind of signal (correlation receiver or matched filter do compress such signals).

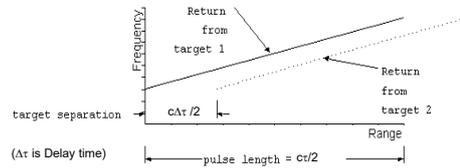
### FM Pulse Waveform (Chirp)

The pulse structure is shown below:

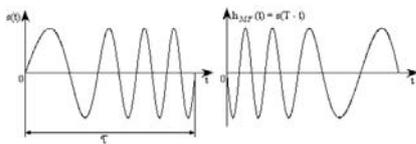


### Overlapping returns separated by FM

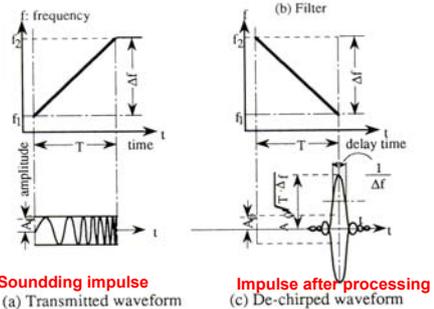
- The receiver is able to separate two or more targets with overlapping returns on the basis of the frequency. Here is a sample return showing two targets with separation less than the conventional range resolution:



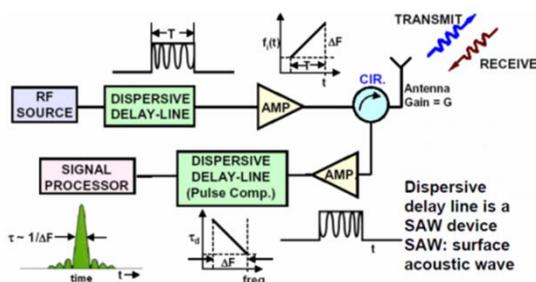
### Pulse-response Characteristic of Matched Filter for FM Pulse



### Principle of pulse compression



### Chirp generation and processing (FM pulse)



### Pulse Compression Ratio

- The ability of radar receiver to improve the range resolution over that of the conventional system is called the *pulse compression ratio (PCR)*.
- For example a pulse compression ratio of 20:1 means that the system range resolution parameter  $\Delta R$  is reduced by 1/20 of the conventional system.
- Alternatively, the factor of improvement is given by the symbol PCR, which can be used as a number in the range resolution formula, which now becomes:

$$\Delta R_{comp} = \frac{c\tau}{2 \times PCR} \quad PCR = B\tau \quad \Delta R = \frac{c}{2B} \quad B \text{ is wide!}$$

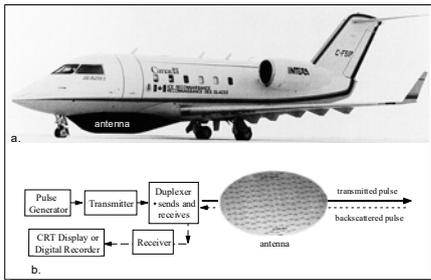
We have solved the problem of range resolution!

But what to do with low angular resolution?

- Big antenna – narrow beam  $\Theta \sim \lambda/a$
- How to install big antenna on an aircraft?
- Side-looking Radar (SLR)

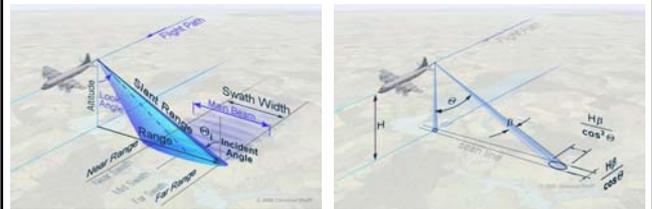
Angular Resolution – antenna beam compression

SLAR – side-looking airborne radar



SLAR = Real Aperture Side-looking Airborne Radar

Side-looking airborne radar

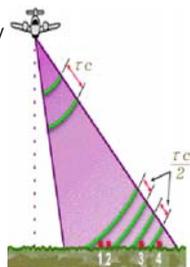


The Problem of Angle Resolution

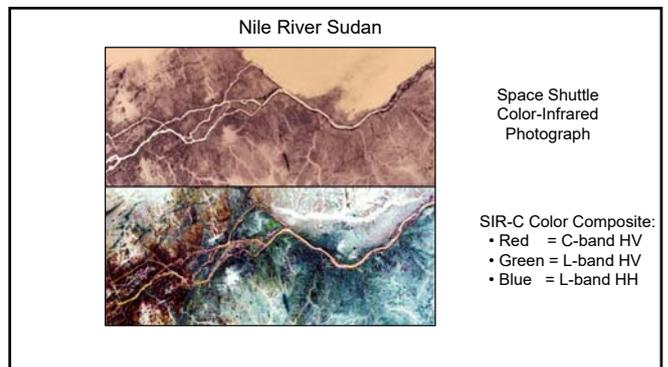
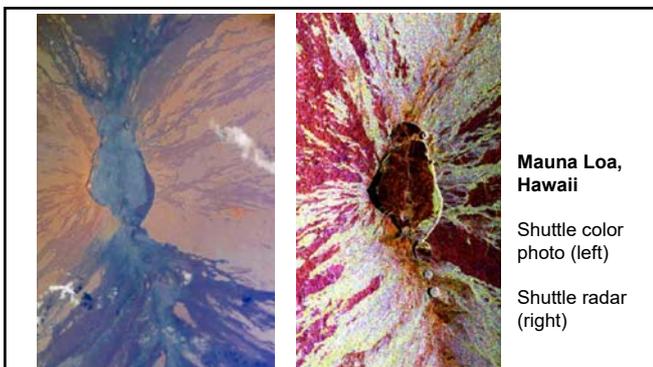
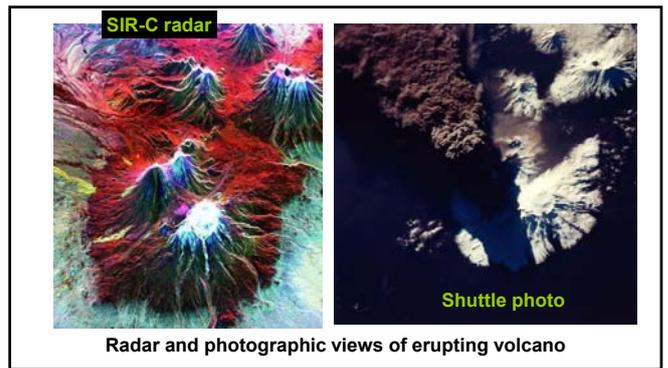
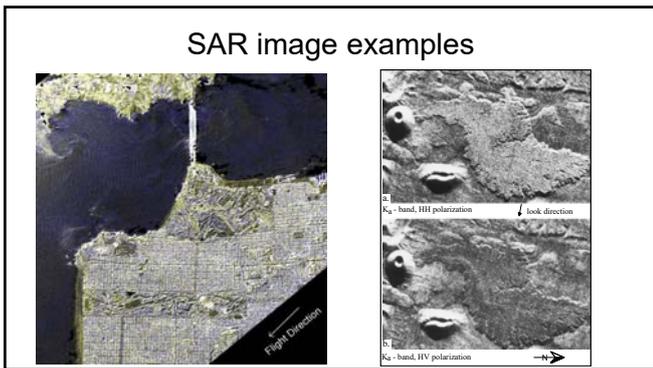
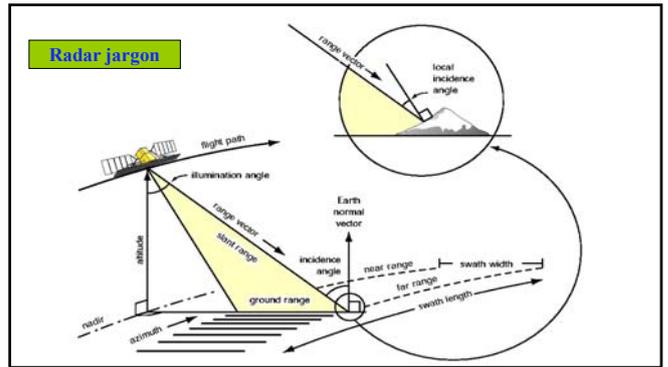
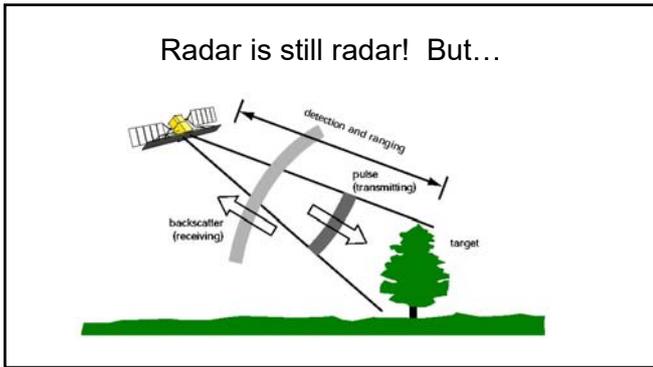
- We have already seen that the angular resolution is determined by the beamwidth of the antenna.
- At a given range, R, the ability to resolve objects in the cross-range direction, known as the cross-range resolution, is calculated by

$$\Delta R_{cross} = R\theta$$

- where  $\theta$  is the beamwidth expressed in radians.



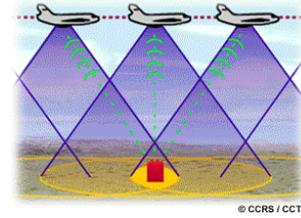
# SAR



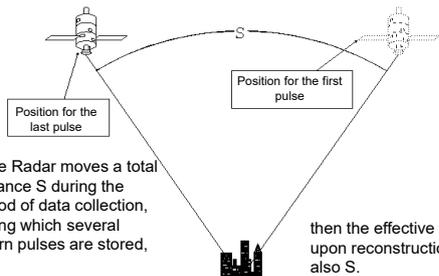
### SAR

- SAR uses the motion of the transmitter/receiver to generate a large effective aperture.
- In order to accomplish this, the system must store several returns taken while the antenna is moving and then reconstruct them as if they came simultaneously.

### SAR



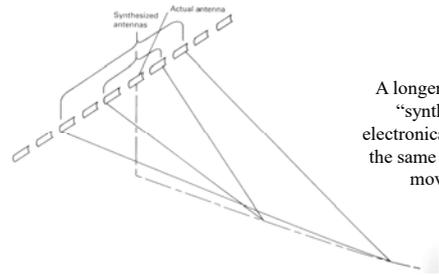
### Synthetic aperture



If the Radar moves a total distance  $S$  during the period of data collection, during which several return pulses are stored,

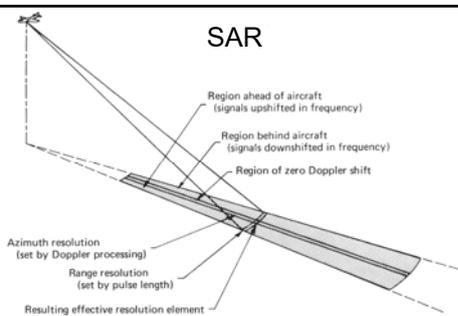
then the effective aperture upon reconstruction is also  $S$ .

### SAR



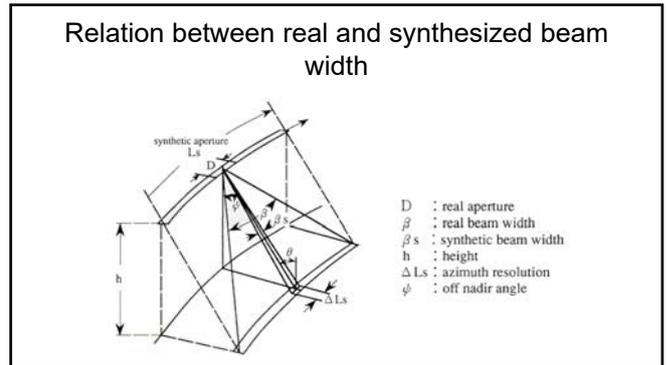
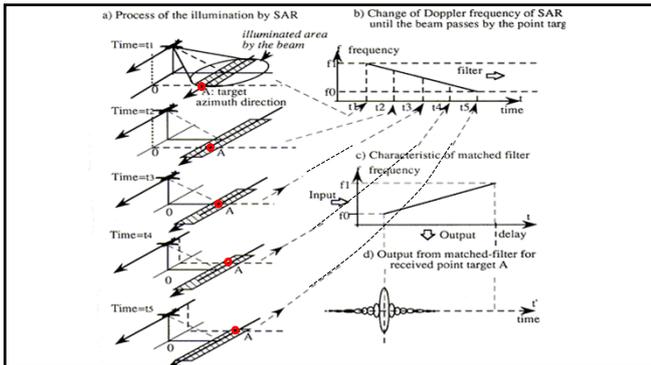
A longer antenna is "synthesized" electronically by using the same antenna but moving it.

### SAR



Doppler shift (lower frequency behind the sensor, higher ahead).

- SAR uses the technique which is similar to pulse compression as adopted for range direction.



### Spatial Resolution

Resolution volume (RV):  $V_w = \Delta R \cdot R\theta \cdot R\phi$

$\Delta R = \frac{c\tau}{2}$  Depends on waveform duration  
 More exactly, bandwidth is important  $\Delta R = \frac{c}{2B}$

$R\theta \cdot R\phi$  Depends on antenna beam width

**Pulse compression** – wideband waveforms  
 optimal processing

**Antenna beam compression** – SAR

**THE FORMATION OF A SYNTHETIC APERTURE LEADS TO HIGH AZIMUTH RESOLUTION, WHILE RANGE RESOLUTION IS GIVEN BY THE TRANSMITTED CHIRP BANDWIDTH.**

