Mobile Communications

TCS 455

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Lecture 21

Office Hours:
BKD 3601-7
Tuesday 14:00-16:00
Thursday 9:30-11:30

Announcements

- Read
  - Chapter 9: 9.1 – 9.5
- HW5 is posted.
  - Due: Feb 5 (This Friday)

Review & Clarification

- Last time
  - Synchronous CDMA
  - Walsh functions and sequences
  - Hadamard matrix and its generation

Two ways to get H_8 from H_2 and H_4

$$H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix} \qquad H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

$$H_8 = H_2 \otimes H_4$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

$$H_8 = H_4 \otimes H_2$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \end{bmatrix}$$

Chapter 4

Multiple Access

Async. CDMA: Gold codes and GPS

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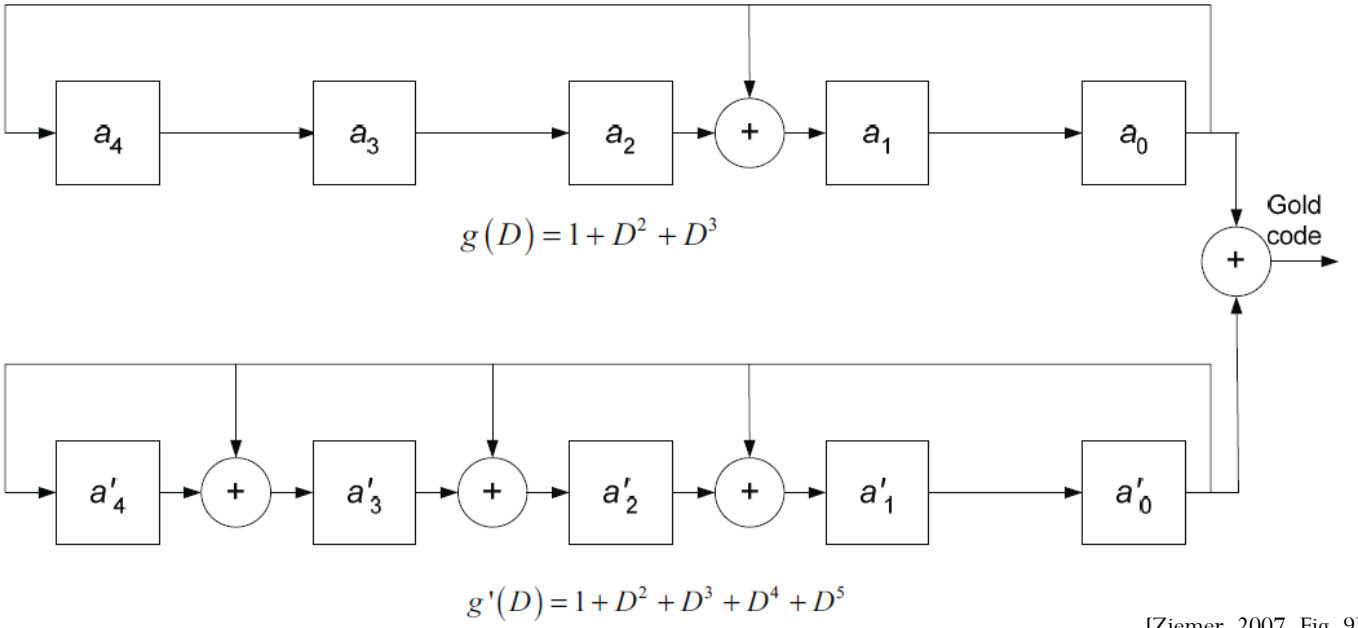
Asynchronous CDMA Model

- In cellular systems, the design of the reverse link (mobile-to-base station) is considerably simplified if the users need not be synchronized.
- It is possible to let the users transmit completely asynchronously in CDMA.
- Codes assigned to different users need to have low cross correlation with each other independent of the relative delays
- Gold codes

Gold codes

- Gold codes have worse autocorrelation properties than maximal-length codes, but better cross-correlation properties if properly designed.
- The chip sequences associated with a Gold code are produced by addition of two m-sequences.



[Ziemer, 2007, Fig. 9]

Orthogonality (a revisit)

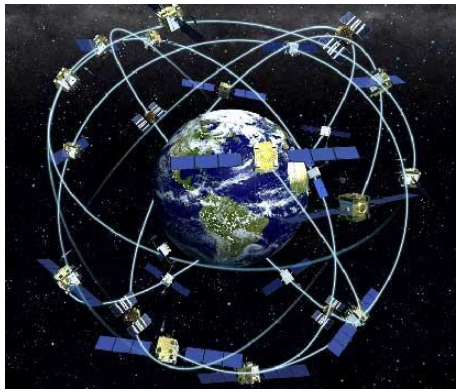
- **Downlinks**
  - May use **orthogonal** spreading codes such as Walsh-Hadamard codes
  - Orthogonality can be degraded by multipath.
- **Uplinks**
  - Generally use **non-orthogonal** codes due to the difficulty of user synchronization and the complexity of maintaining code orthogonality in uplinks with multipath.
  - Little dynamic coordination of users in time or frequency is required
    - Users can be separated by the code properties alone.
- There is a hard limit on how many orthogonal channels (orthogonal codes) can be obtained.
  - For non-orthogonal codes, there is no hard limit.
  - Non-orthogonal codes cause mutual interference between users.
    - The more users, the higher the level of interference
      - Degrade the performance of all the users.
- Non-orthogonal CDMA scheme also requires power control in the uplink to compensate for the near-far effect.

Near-far Effect

- Arise in the uplink because the channel gain between a user's transmitter and the receiver is different for different users.
- Suppose that one user is very close to his base station or access point, and another user very far away.
  - If both users transmit *at the same power level*, then the **interference from the close user will swamp the signal from the far user**.
- **Power control**
  - Make the *received* signal power of all users to be roughly the same
  - Essentially inverts any attenuation and/or fading on the channel
  - Each interferer must **contribute an equal amount of power**
  - Eliminating the near-far effect

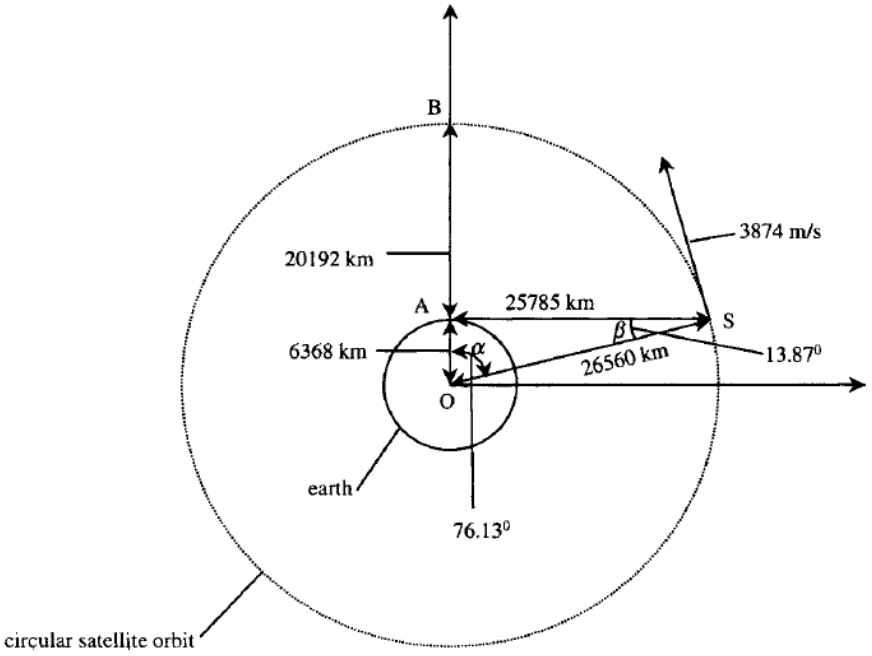
Global Positioning System (GPS)

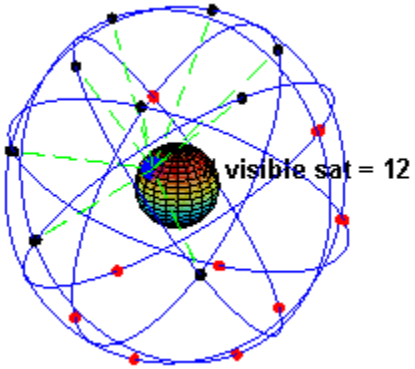
- Original application in the military
- Allow a person to determine the time and the person's precise location (latitude, longitude, and altitude) anywhere on earth.
- The potential applications of GPS are so vast that it has been called (with some exaggeration) the next utility (similar to gas, water, and electricity).



GPS Satellite

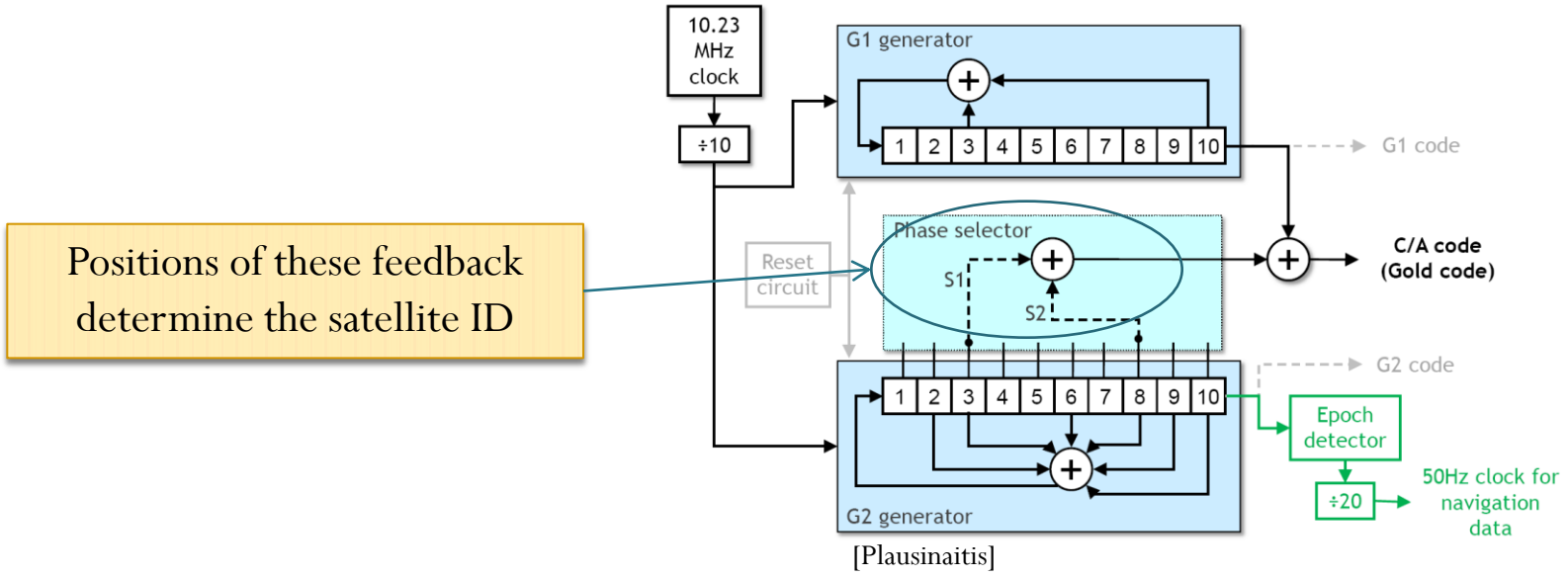
- A minimum of 24 GPS satellites are in orbit at 20,200 kilometers (12,600 miles) above the Earth.
- The satellites are spaced so that from any point on Earth, at least four satellites will be above the horizon.





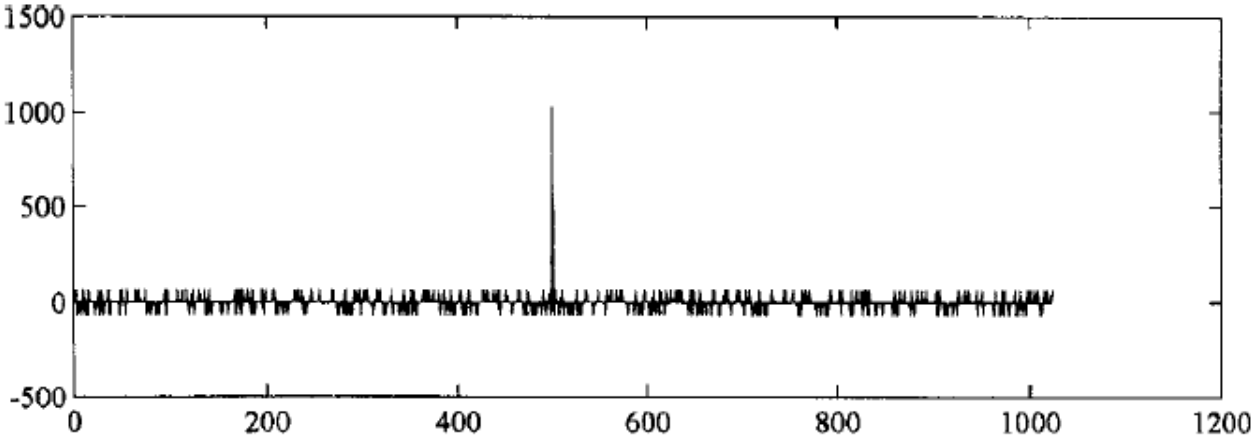
GPS and Gold codes

- Gold codes are used to distinguish the signals from different satellites
  - Coarse Acquisition code (C/A)
  - Standard Positioning Service (SPS)
- The message data is transmitted at 50 bits per second.
- 1023 bits with a period of one millisecond.

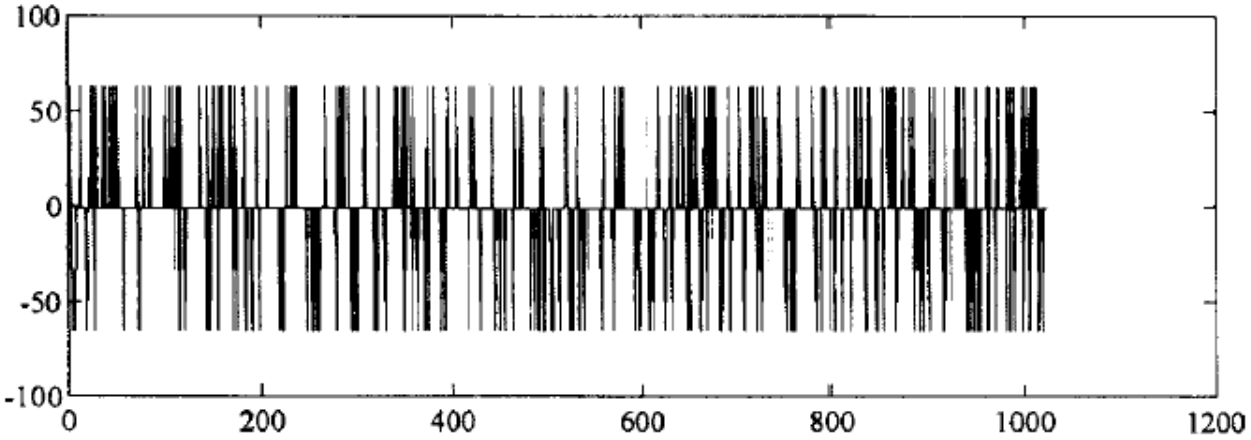


[Plausinaitis]

Auto and cross correlation of C/A code



(a) Autocorrelation of satellite 19.



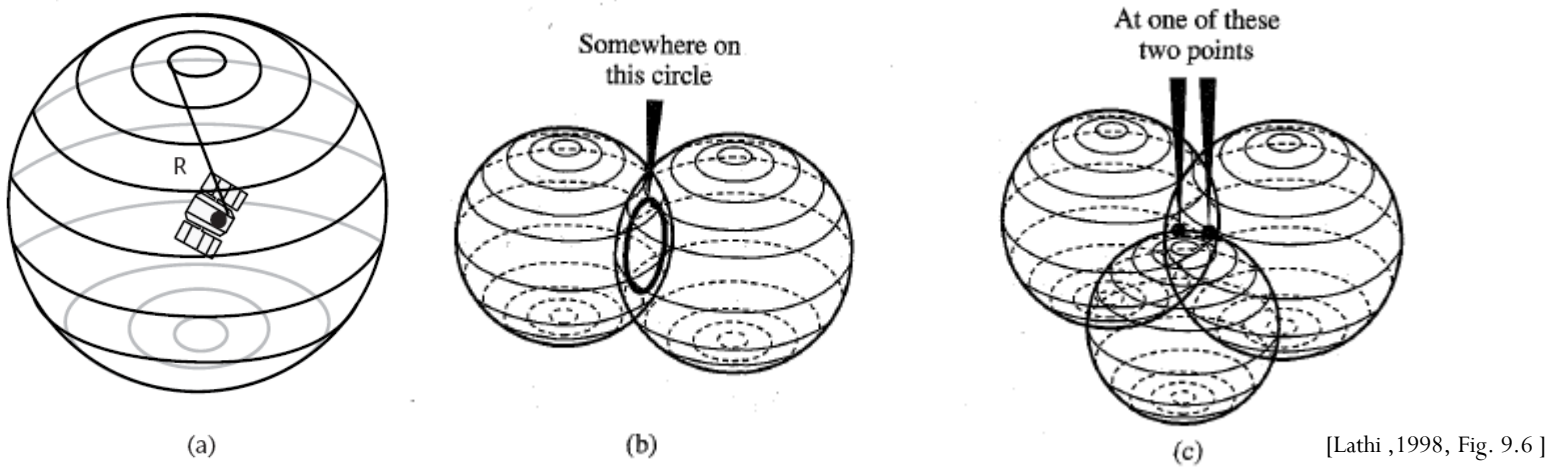
(b) Cross correlation of satellites 19 and 31.

How GPS Works?

- A GPS receiver measuring its distance from a group of satellites in space which are acting as precise reference points.
- All the satellites have atomic clocks of unbelievable precision on board and are synchronized.
- The satellite are continuously transmitting the information about their location and time.
- GPS receiver on the ground is in synchronism with the satellites.
  - Off by an (unknown) amount τ.
  - For now, assume $\tau = 0$.
- By measuring the propagation time, the receiver can compute distance d from that satellite.

GPS-Trilateration

- Intersection of three sphere narrows down the location to just two points.



[Lathi ,1998, Fig. 9.6]

- In practice, there are four unknowns, the coordinates in the three-dimensional space of the user along with τ within the user's receiver.
  - Need a distance measurement from a fourth satellite.

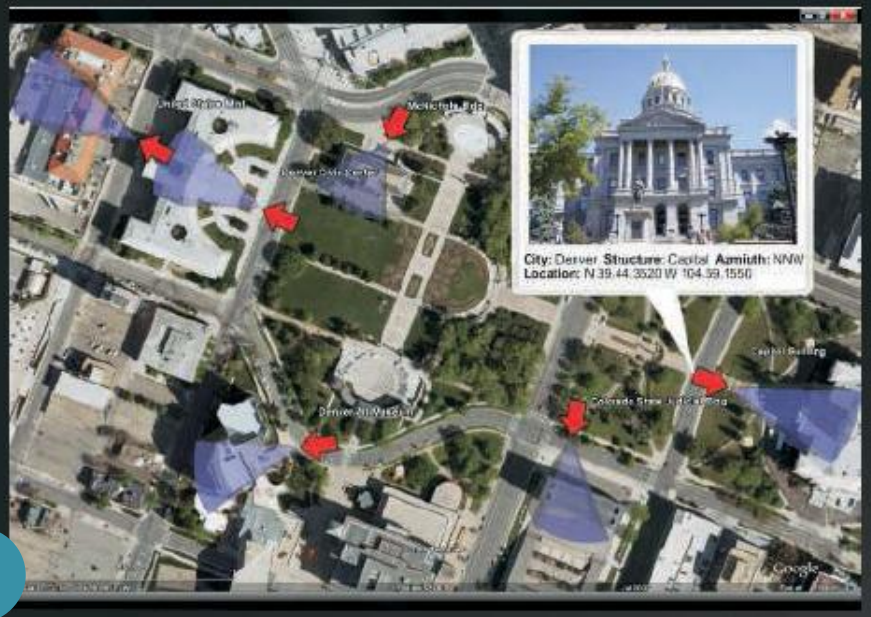

Keep left on I-90 E
S Western Ave
45
mph
0.1
Church St
W Broadway
Hudson St
TRIBECA, NY
Chambers St
350
yards
13 M
25 min
2:00 pm
2:26 pm
30 mph
Broadway
TOMTOM
NOKIA
WASHINGTON
BETHESDA
MCLEAN
ARLINGTON
ALEXANDRIA
JEFFERSON
CAMP SPRINGS
FORESTVILLE
GARMIN

Geo-Imaging Optimized

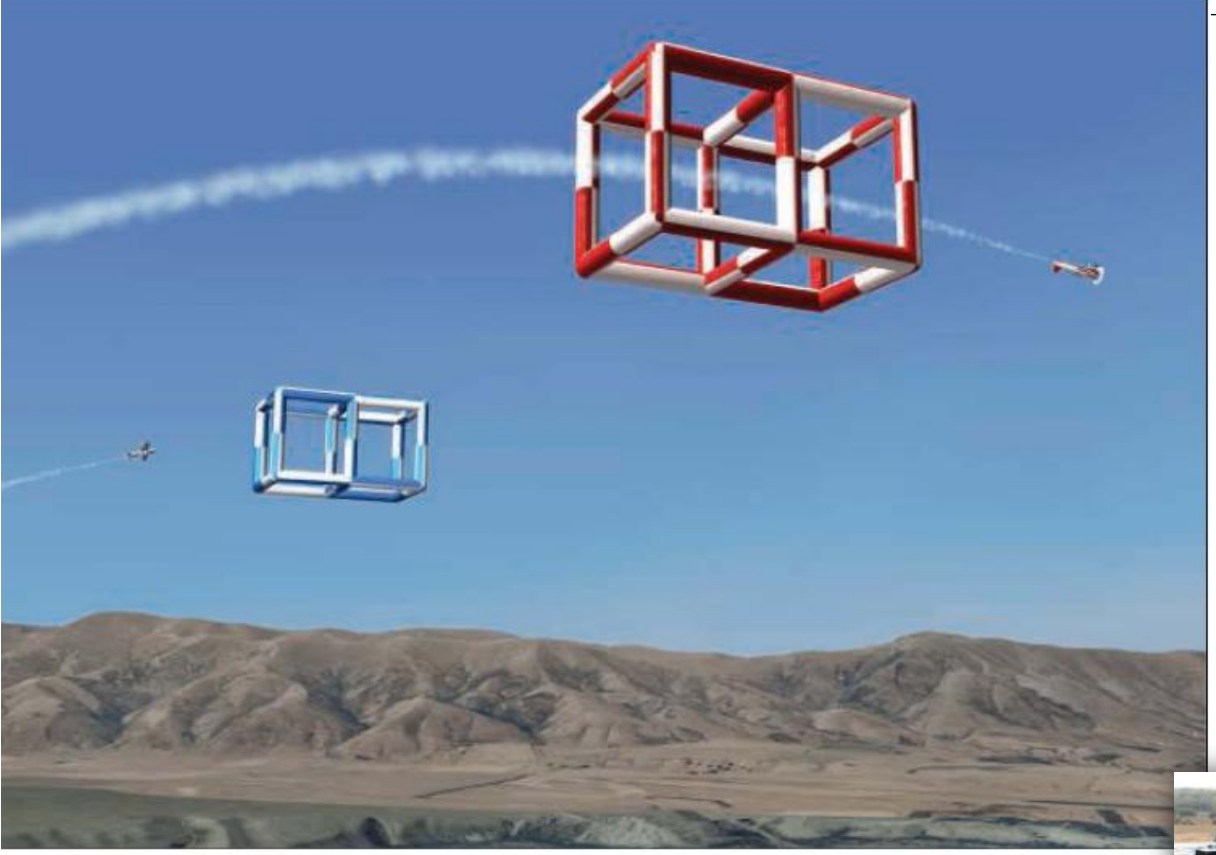
Simple, Durable, Proven.

The Ricoh 500SE GPS-enabled digital camera continues to provide the definitive ruggedized solution for integrating high quality images and video into GIS mapping applications. As easy to use as a point-and-shoot camera, the on-board GPS and data-dictionary tag images with position and workflow-related attribute data. Enhanced capabilities such as available compass and handheld GPS integration ensures the 500SE solution will deliver whenever pictures are a priority.

500SE GPS Camera
with integrated **GPS module**




"Thanks to Septentrio GPS technology, we can run 24/7 operation with 0 misplaced containers."
Stephan Gosiau,
Technical Director
PSA HNN
HESSE-NOORD NATIE
PSA

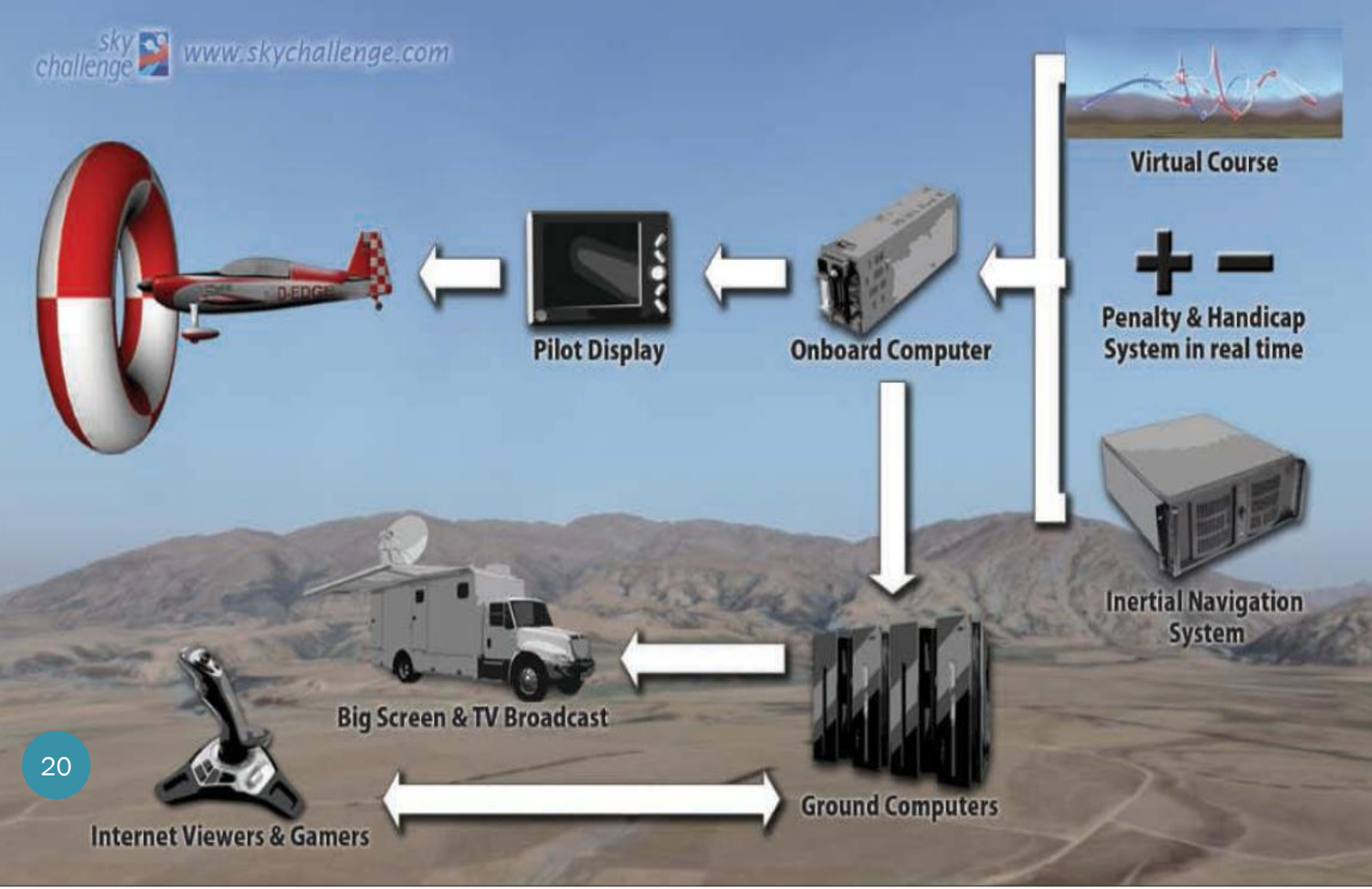


Sky-High Twists and Turns

Aerobatic racing between real and virtual aircraft poses steep positioning requirements. Real-time accuracy must reach at least 1 to 3 meters to score pilots through the course, and position must incude pitch, yaw, and roll in a high-g environment with dynamic flying maneuvers that frequently disrupt GPS signal reception.

Sky Challenge, a real-time race between real and virtual aircraft. Pilots race actual aerobatics planes through a virtual course made up of 3-D objects that do not physically exist.

Loading the course into a flight simulator on the ground and geographically linking it with the real world and simulated planes enables virtual pilots to race against real-world pilots in real time or after the race.



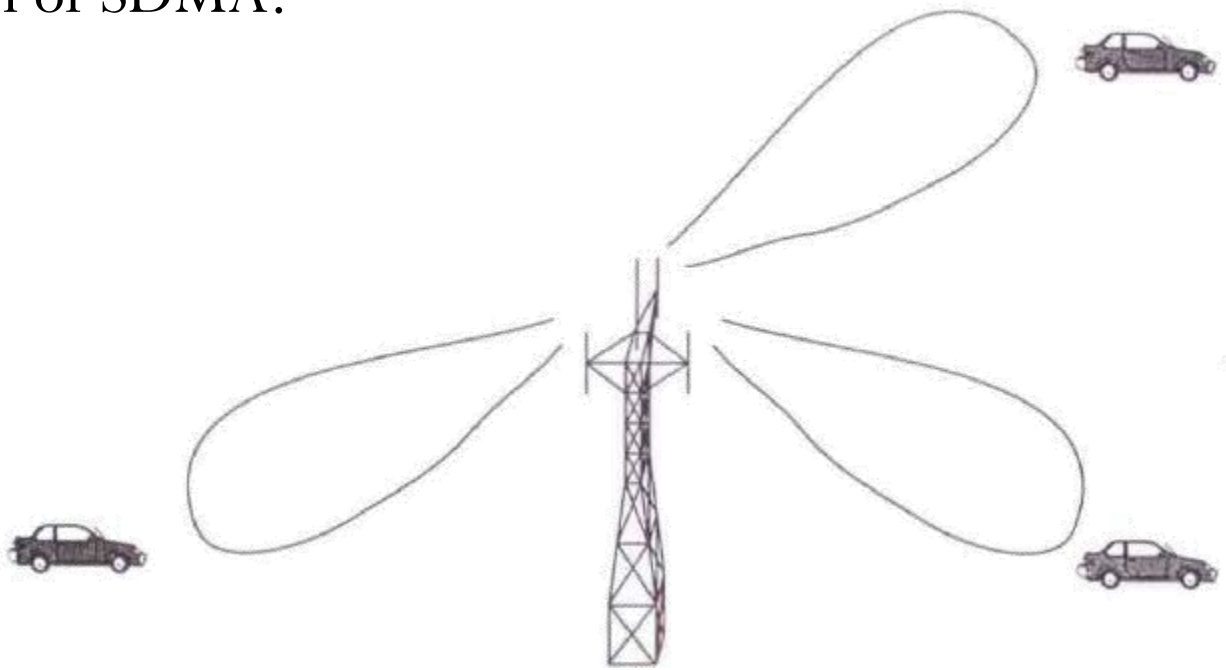
▲ **SKY CHALLENGE SYSTEM** (www.skychallenge.com) links a real-world air race through virtual objects with a live video game. Race spectators see the virtual course combined with the real world on giant outdoor TV screens. The **SKY CHALLENGE COURSE** is made up of a number of differently shaped virtual objects. Volumetric models compare the real aircraft position with the obstacles — in real time. Subsequent obstacles move away from the pilot as a penalty in the event of a collision.

FDMA never dies!

- Any CDMA or TDMA system will normally include an FDMA component, and can therefore be considered as a hybrid CDMA/FDMA or TDMA/FDMA system.
- In the relatively narrowband TDMA-based 2G systems with a small number of slots per frame
  - D-AMPS: 30 kHz carrier, three users per carrier
  - GSM: 200 kHz carrier, eight full-rate users per carrier
- FDMA still fulfills a role in providing multiple access, although not down to individual channels.

Space Division Multiple Access (SDMA)

- Control the radiated energy for each user in space.
- Use spot beam antennas.
- Sectorized antennas may be thought of as a primitive application of SDMA.



END OF CHAPTER 4

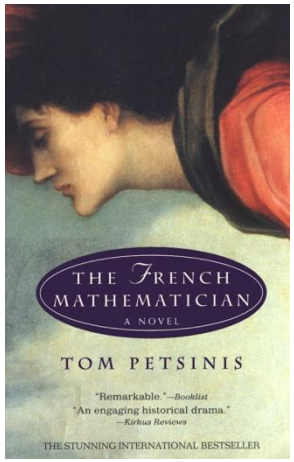
Évariste Galois

- At the age of 15, he was reading the original papers of Joseph Louis Lagrange and Niels Henrik Abel, work intended for professional mathematicians, and yet his classwork remained uninspired.
- While still in his teens, he was able to determine a necessary and sufficient condition for a polynomial to be solvable by radicals, thereby solving a long-standing problem.
- His work laid the foundations for Galois theory, a major branch of abstract algebra.
- In 1832 when not yet twenty-one years old, he was challenged to a pistol duel over a love affair and was slain.
  - Galois was so convinced of his impending death that he stayed up all night composing what would become his mathematical testament
  - "This letter, if judged by the novelty and profundity of ideas it contains, is perhaps the most substantial piece of writing in the whole literature of mankind."

Évariste Galois (2)

In the early hours of the morning of the 30th of May 1832 a gunshot was heard ringing out across the fields in the 13th arrondissement in Paris. A peasant on his way to market, hearing the shot, ran towards the scene of the shooting. On the ground he discovered a young man writhing around in agony. It was obviously a duelling wound. The young man's name was Evariste Galois, a well-known revolutionary. He was taken to the local Cochin hospital where he died the next day in the arms of his brother. "Do not cry" he pleaded "it takes all my courage to die at the age of 20."

There are lots of biographies and biographical works about Galois (e.g. by Paul Dupuy, E.T. Bell and the most recent by Lauro Toti Rigatelli). There are fictionalizations of his tragic life in novels (e..g. "Whom the Gods Love" by Leopold Infeld and "The French Mathematician" by Tom Petsinis), films ("Évariste Galois", directed by Alexandre Astruc, and "Évarist Galois", directed by Danièle Baudrier, and "Non ho tempo", directed by Ansano Giannarelli)



Chapter 5
OFDM

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Orthogonality

- Two vectors/functions are **orthogonal** if their **inner product** is zero.
- The symbol $\perp$ is used to denote orthogonality.

Vector:

$$\left\langle \vec{a}, \vec{b} \right\rangle = \vec{a} \cdot \vec{b}^{*} = \begin{pmatrix} a_1 \\ \vdots \\ a_n \end{pmatrix} \cdot \begin{pmatrix} b_1 \\ \vdots \\ b_n \end{pmatrix}^{*} = \sum_{k=1}^{n} a_k b_k^{*} = 0$$

Time-domain:

$$\langle a, b \rangle = \int_{-\infty}^{\infty} a(t) b^{*}(t) dt = 0$$

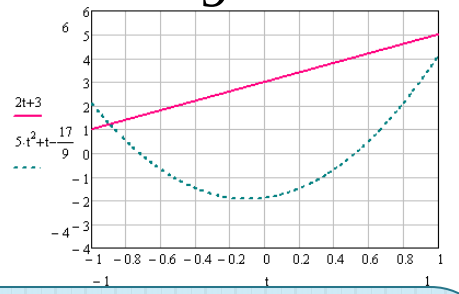
Complex conjugate

Frequency domain:

$$\langle A, B \rangle = \int_{-\infty}^{\infty} A(f) B^{*}(f) df = 0$$

Example:

$$2t + 3 \text{ and } 5t^2 + t - \frac{17}{9} \text{ on } [-1,1]$$



Example (Fourier Series):

$$\sin\left(2\pi k_1 \frac{t}{T}\right) \text{ and } \cos\left(2\pi k_2 \frac{t}{T}\right) \text{ on } [0,T]$$

$$e^{j2\pi n \frac{t}{T}} \text{ on } [0,T]$$

OFDM

- Let $S_1, S_2, \ldots, S_N$ be the information symbol.
- The discrete baseband OFDM modulated symbol can be expressed as

$$s(t) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S_k \exp\left(j \frac{2\pi k t}{T_s} \right), \quad 0 \le t \le T_s$$

$$= \sum_{k=0}^{N-1} S_k \underbrace{\frac{1}{\sqrt{N}} 1_{[0,T_s]}(t) \exp\left(j \frac{2\pi k t}{T_s} \right)}_{c_k(t)}$$

Another special case of CDMA!

Note that:

$$\mathrm{Re}\{s(t)\} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \left(\mathrm{Re}\{S_k\} \cos\left(\frac{2\pi k t}{T_s} \right) - \mathrm{Im}\{S_k\} \sin\left(\frac{2\pi k t}{T_s} \right) \right)$$