Spacecraft Communications Systems

Aero 446 – Intro to Space Systems

04/22/09

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AEROSPACE ENGINEERING

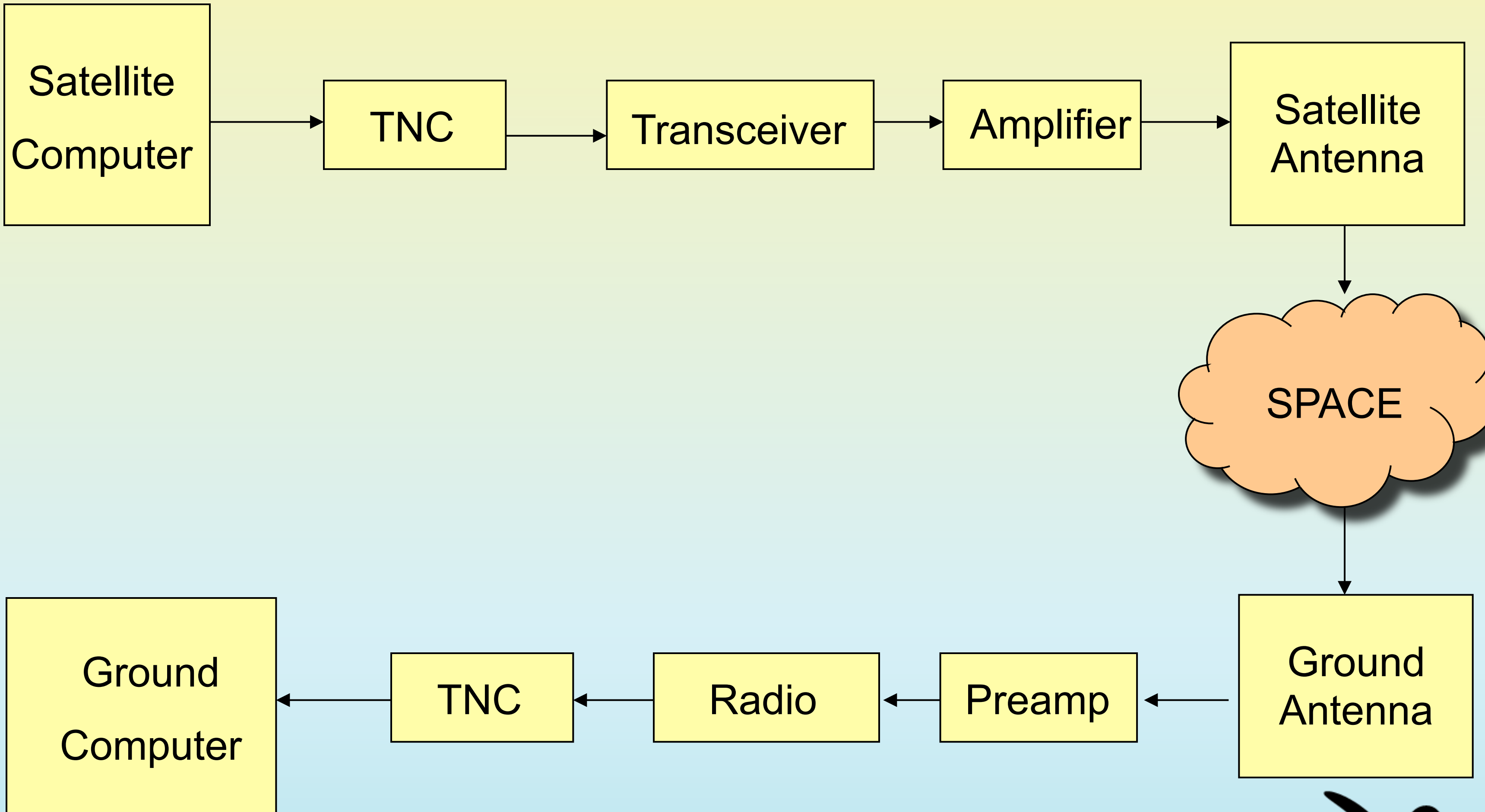
CAL POLY • SAN LUIS OBISPO

The Problem

- Data must be transferred between the satellite and the ground station
- How do we do this?

- YOU NEED THIS FOR SPACECRAFT DESIGN!!!!!

The (Down)Link



The (Down)Link

Satellite

Computer

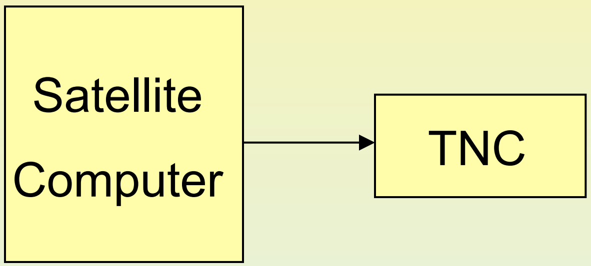
The Satellite Computer

- Processing onboard the satellite generates digital data that must be sent to the ground
- Data is stored in a digital format

The Satellite Computer Example

- Assume the satellite computer wants to send one byte of information.
- This byte is the following 8 bits
  - 1000 1001 binary
- Binary can be represented in hexadecimal
  - 1000 = 8
  - 1001 = 9
  - Therefore 10001001 = 0x89

The (Down)Link



The Satellite TNC

- Terminal Node Controller (TNC)
  - 1. Put the data to transmit into a packet
  - 2. Takes digital data and breaks it into bits to transmit

Another Processor!

Why Packets?

- Packets allow for additional routing information to be sent with the data.
  - If you hear this packet send it to Cal Poly
  - This is how the internet works with IP addresses
- Also includes extra data to ensure that if any errors occur during transmission that they are found.

Error Detection: Parity Bit

- Use parity to calculate an extra bit for error detection.
- Count the number of 1's in your data
- If the count is even
  - The parity bit is 0
- If the count is odd
  - The parity bit is 1
- Pre/Append the parity bit to the data

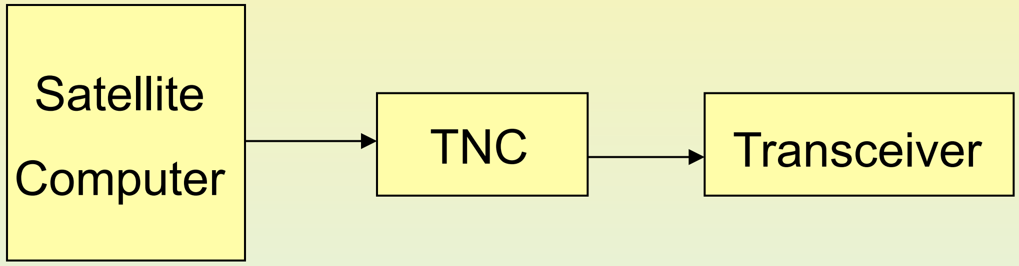
The Satellite TNC Example Packets

- Calculate the parity bit for 10001001
- There are **3** 1's in the data
- 3 is odd and therefore the parity bit is **1**
- Pre/Append this to the data so now send
  - **1**100010011**1**

The Satellite TNC Example: Break up

- The TNC with takes 100010011 and
  - Sends 1 to transceiver (Parity bit)
  - Sends 1 to transceiver
  - Sends 0 to transceiver
  - Sends 0 to transceiver
  - Sends 0 to transceiver
  - Sends 1 to transceiver
  - Sends 0 to transceiver
  - Sends 0 to transceiver
  - Sends 1 to transceiver
  - Sends 1 to transceiver (Parity bit)

The (Down)Link

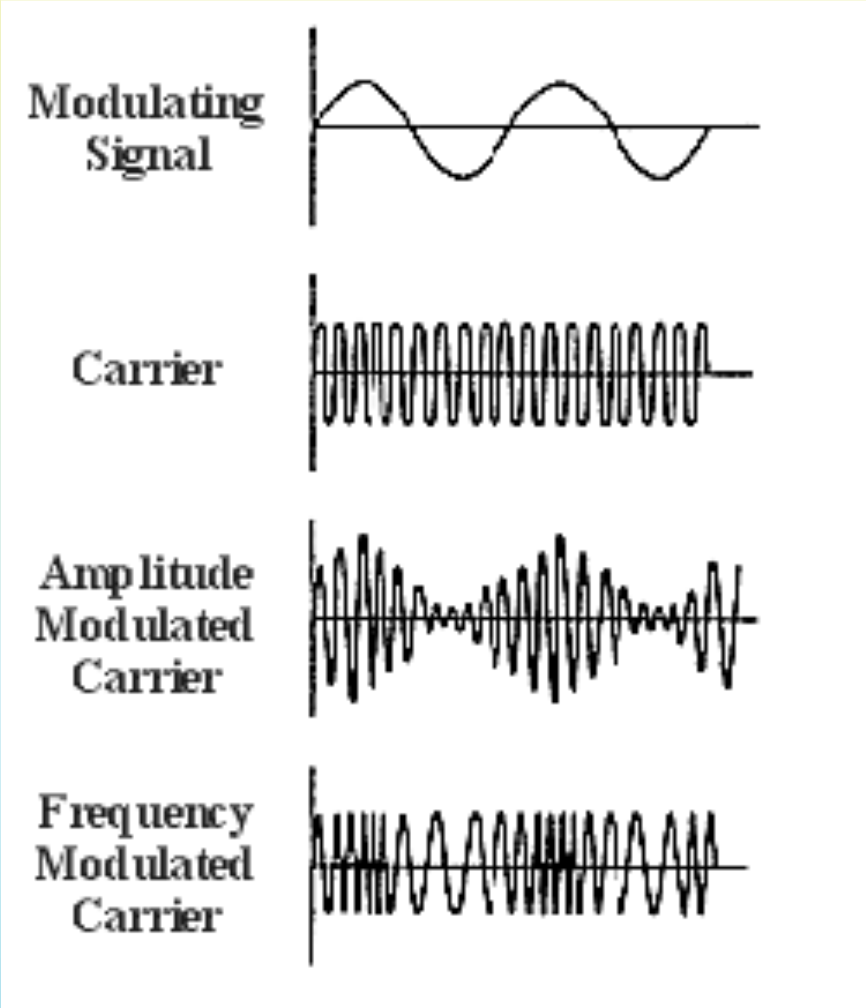


The Satellite Transceiver

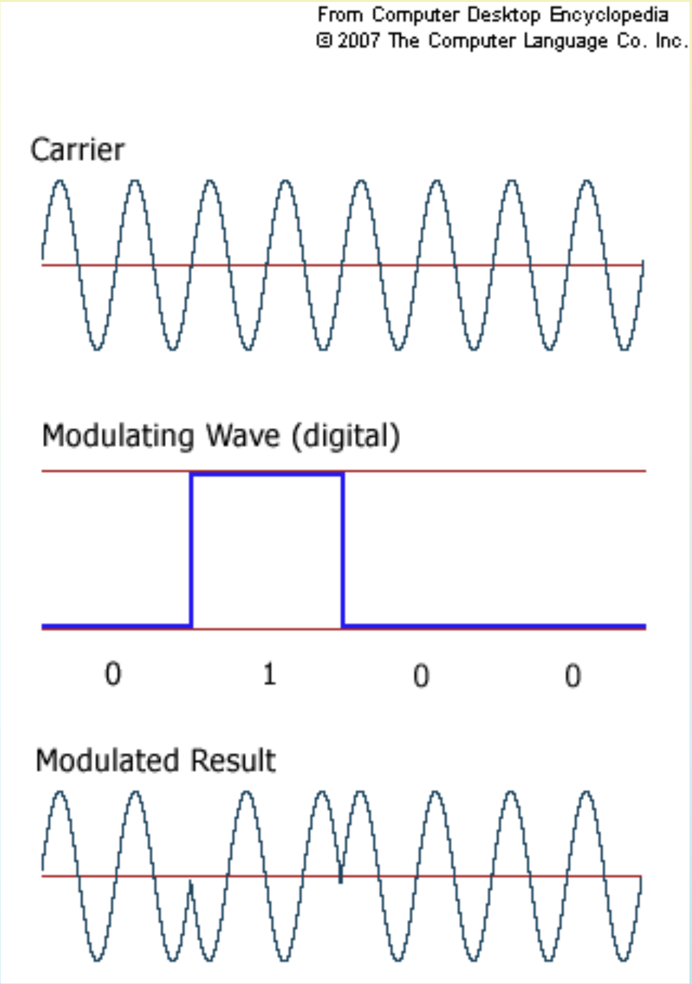
- Puts digital data onto the radio frequencies so that it can be transmitted through space
- This process is called Modulation

Analog Modulation

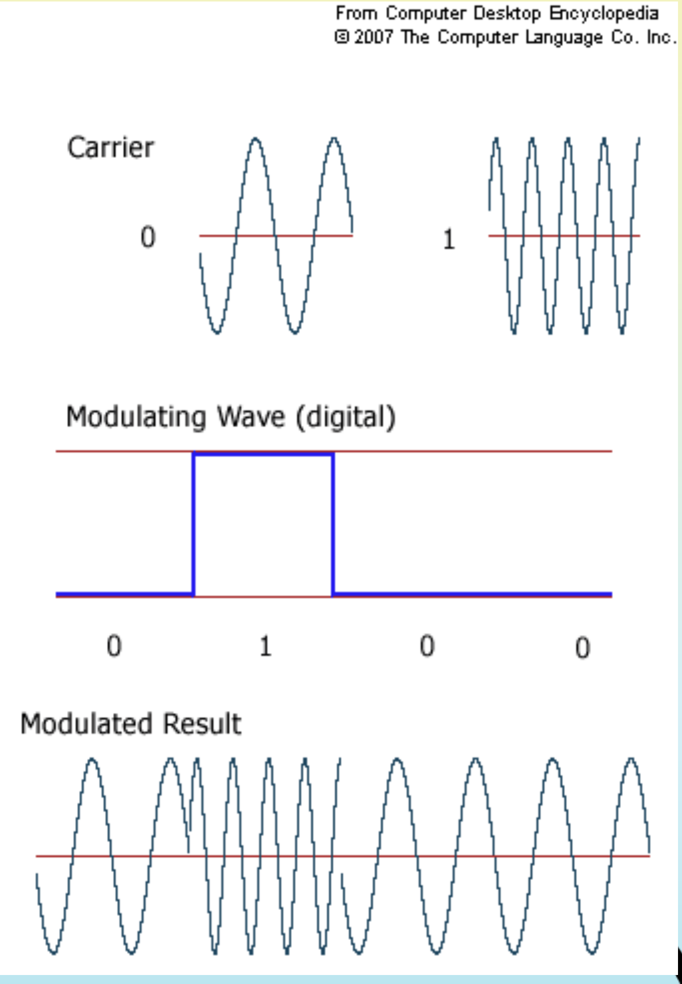
- Notice for amplitude is proportional to the signal for AM
- Notice frequency is proportional to signal for FM
- Use a constant sampling frequency to regain Modulating Signal or Information



Digital Modulation (I)

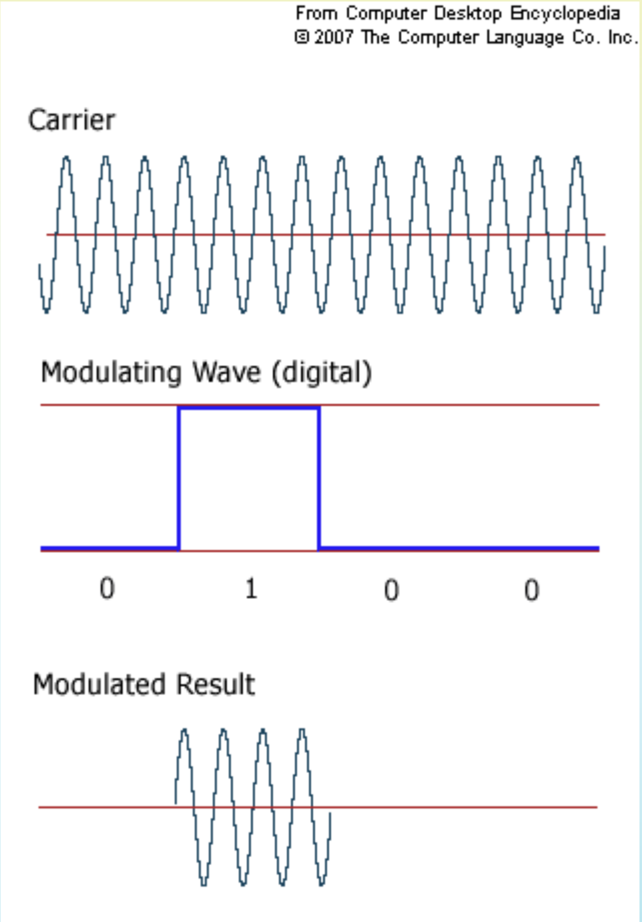


Phase Shift Keying (PSK)

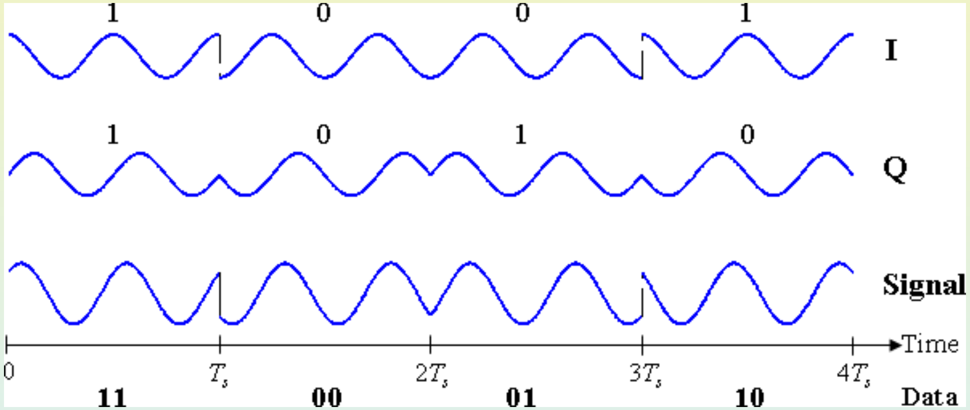


Frequency Shift Keying (FSK)

Digital Modulation (II)



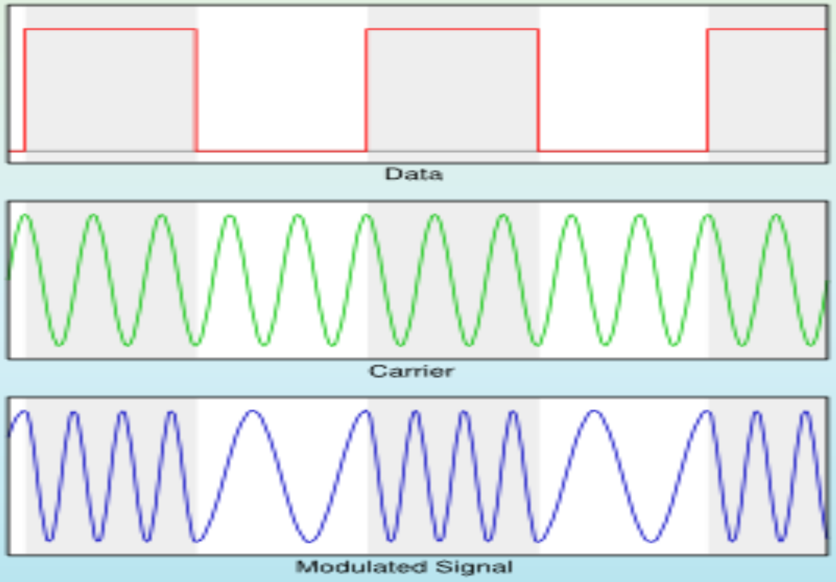
Amplitude Shift Keying (ASF)



Quaternary PSK (QPSK)

FSK Modulation

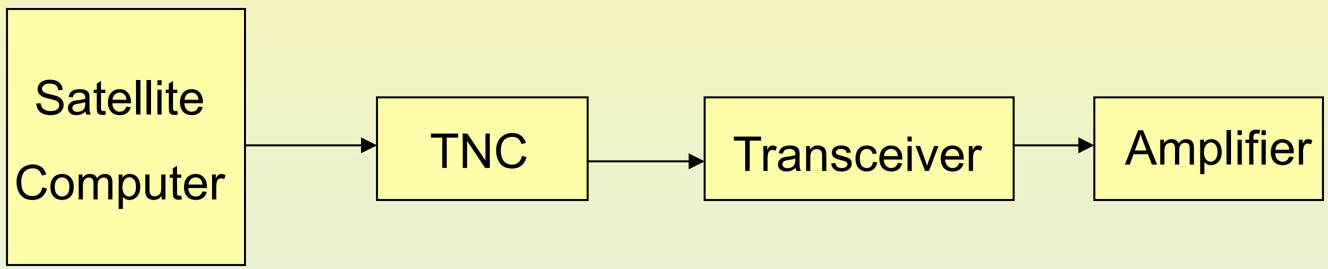
- Uses two different tones (frequencies)
- Assign one to represent a digital 0 and the other to represent a digital 1



The Satellite Transceiver Example

- Assign 437.365 MHz to be tone 1
- Assign 437.366 MHz to be tone 2
- For 1100010011
  - Generate tone at 437.36**6** (Parity Bit)
  - Generate tone at 437.36**6**
  - Generate tone at 437.36**5**
  - Generate tone at 437.36**5**
  - Generate tone at 437.36**5**
  - Generate tone at 437.36**6**
  - Generate tone at 437.36**5**
  - Generate tone at 437.36**5**
  - Generate tone at 437.36**6**
  - Generate tone at 437.36**6** (Parity Bit)

The (Down)Link



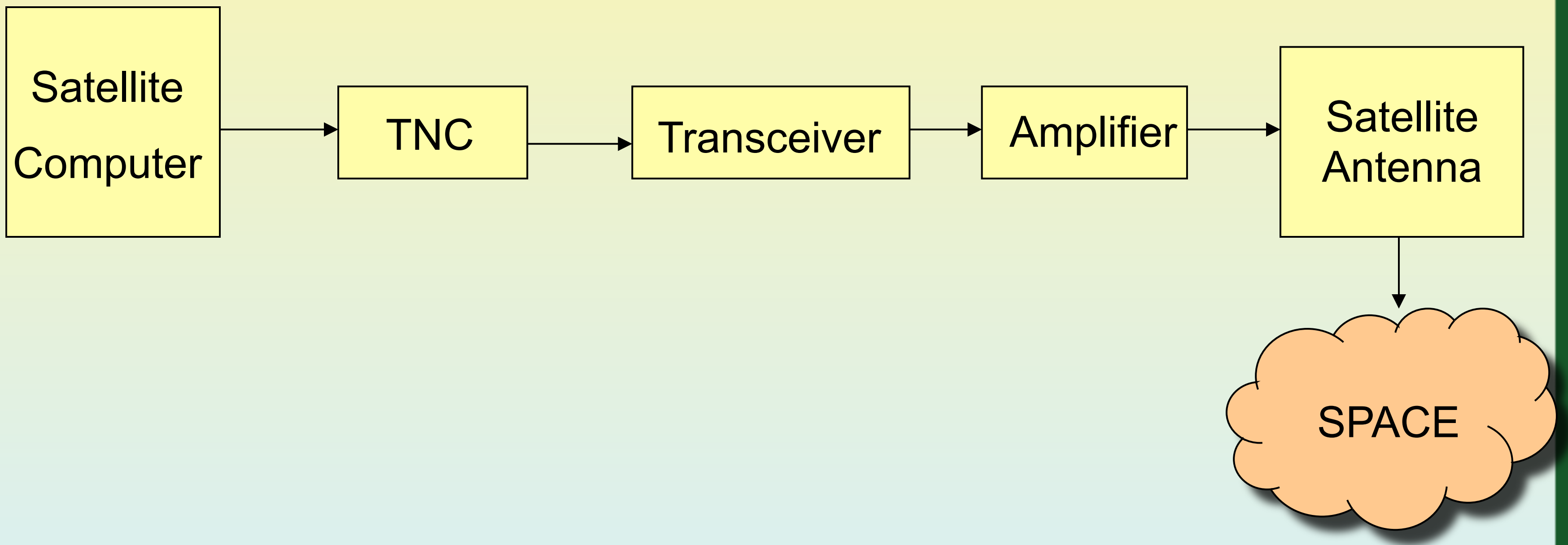
The Satellite Amplifier

- Boosts the radio signal so it can travel all the way back down to earth

The Satellite Amplifier Example

- Boost generated tone at 437.36**6** (Parity Bit)
- Boost generated tone at 437.36**6**
- Boost generated tone at 437.36**5**
- Boost generated tone at 437.36**5**
- Boost generated tone at 437.36**5**
- Boost generated tone at 437.36**6**
- Boost generated tone at 437.36**5**
- Boost generated tone at 437.36**5**
- Boost generated tone at 437.36**6**
- Boost generated tone at 437.36**6** (Parity Bit)

The (Down)Link



The Satellite Antenna

- Sends the radio energy down to earth
- If no ADCS, use an omnidirectional antenna
  - Has 0 dBs
- If can point your satellite towards earth can direct the path of RF to have a more powerful beam

What’s A dB?

- A db is a unit of referential measure
- dBs is a logarithmic scale
  - 3 dBs is double what it is referenced to

    ie. If you have a 15 dB antenna, it is twice as powerful than a 12 dB antenna
  - 10 dBs is 10 times what it is referenced to

    ie. If you have a 25 dB antenna, it is twice as powerful than a 15 dB antenna

Gain in dBs

Antenna Gain

$$G_{dBi} = 10\log\left(\frac{\text{Power Gain of Antenna}}{\text{Power from Isotropic Source}}\right)$$

Amplifier Gain

$$G_{amp} = 10\log\left(\frac{\text{Power Out of Amp}}{\text{Power into Amp}}\right)$$

Power Losses (coaxial cable insertion loss)

$$L_{coax} = 10\log\left(\frac{P_{out}}{P_{in}}\right)$$

dB Question

- How many times greater is 23 dBs?

dB Question

- How many times greater is 23 dBs?

  23 = 10 + 10 + 3

dB Question

- How many times greater is 23 dBs?

  23 = 10 + 10 + 3

  = 10 times * 10 times * 2 times

dB Question

- How many times greater is 23 dBs?

  23 = 10 + 10 + 3

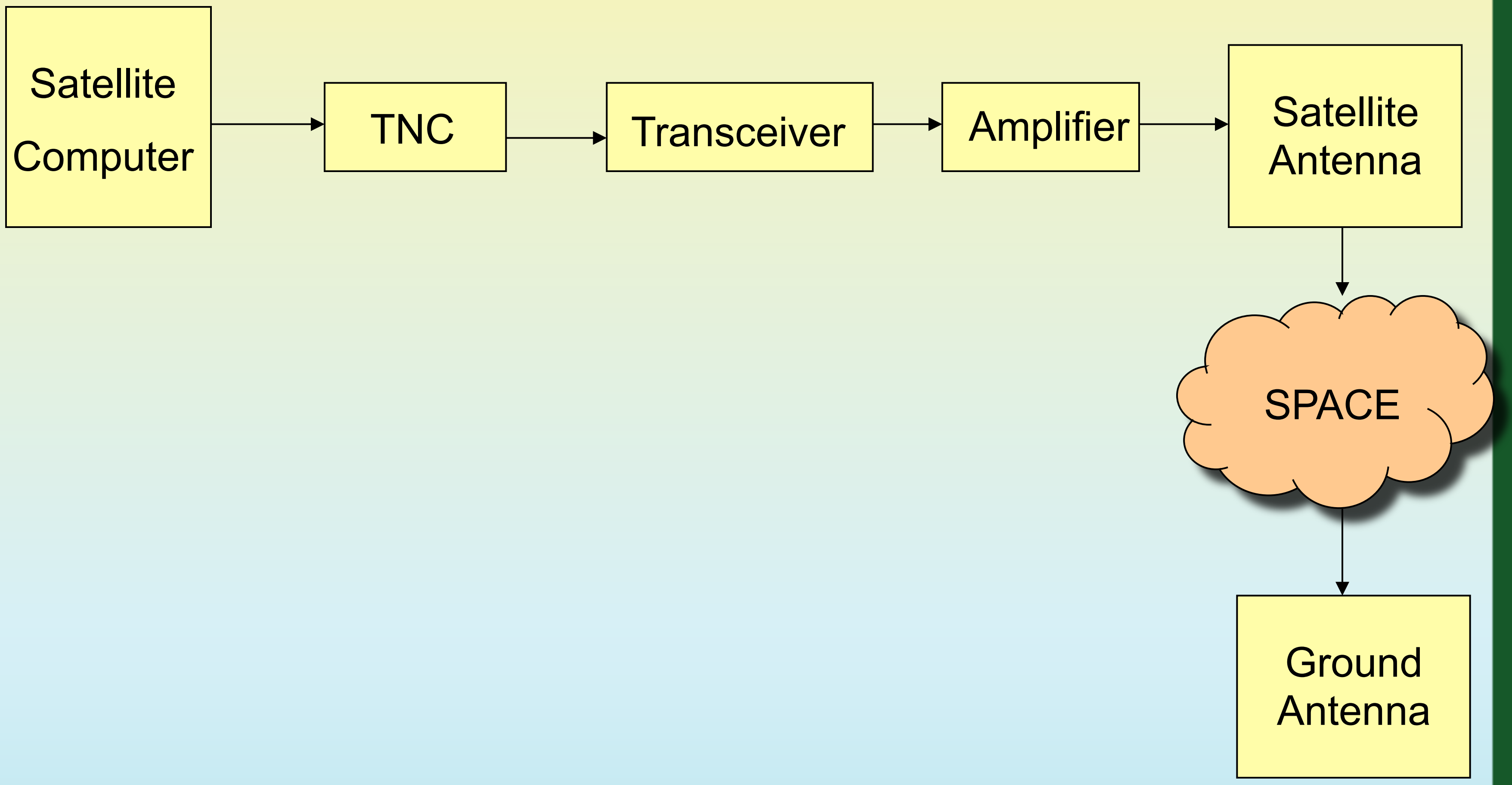
  = 10 times * 10 times * 2 times

  = 200 times greater

The Satellite Antenna Example

- Points the modulated RF signal containing the binary data 1000100011 to the ground

The (Down)Link



The Ground Antenna

- Ground antennas have more pointing capability and therefore are higher gain.
- Can increase the gain on the ground to make up for poor antennas in space

Antenna Beam Pattern

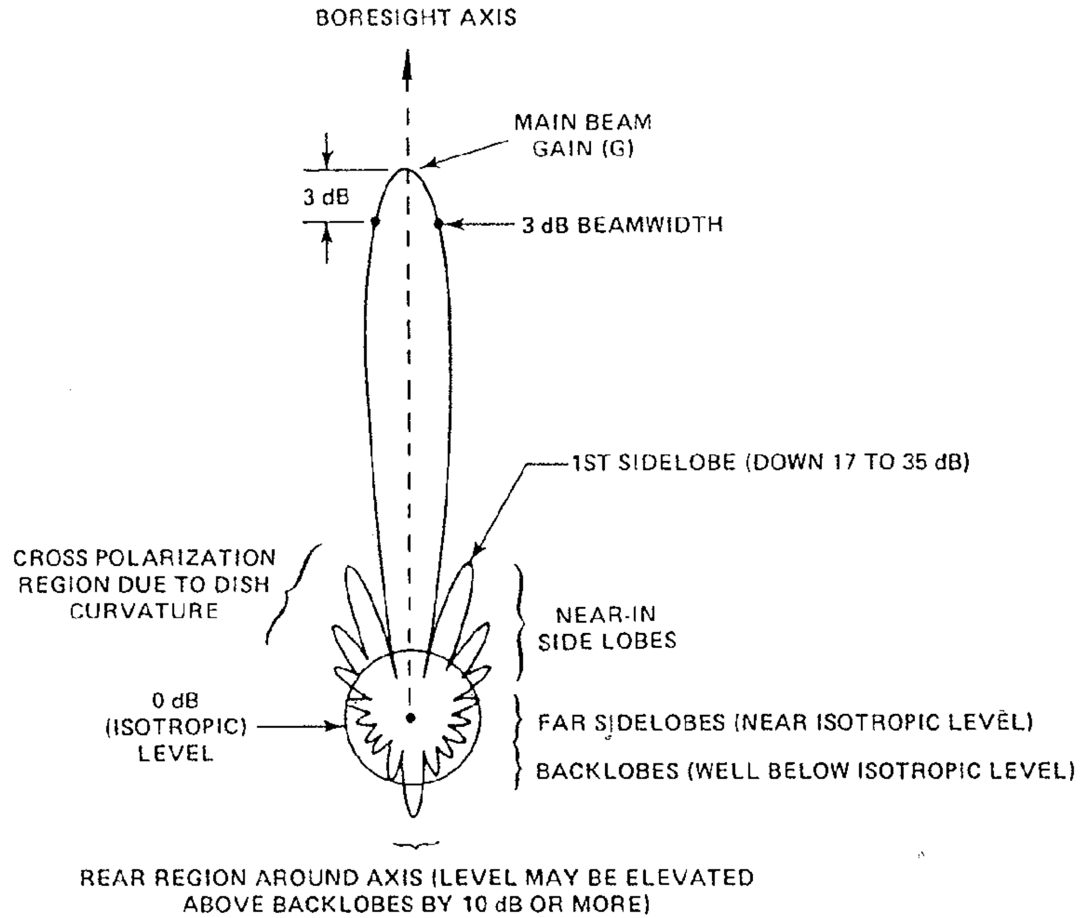
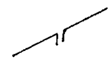
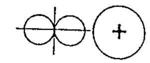
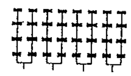
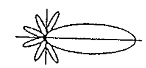
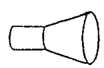
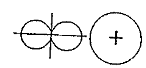
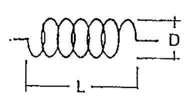
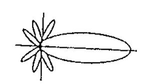
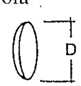
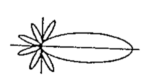
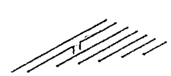
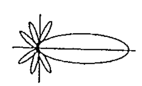


Fig. 9.12 Antenna pattern. (Copyright AIAA, reproduced with permission; Ref. 5, p. 439.)

Antenna Characteristics

Table 9.5 Antenna characteristics[5,6]

Configuration	Peak gain, dBi	Beam width, deg	Pattern
Half-wave dipole 	1.64	—	
Planar array 	$10\log\left(\frac{A}{\lambda^2}\right)+8$	—	
Turnstile 	0.6	—	—
Horn 	$20\log\left(\frac{D}{\lambda}\right)+7$ (Typically 5 to 20 dBi)	$\frac{72\lambda}{D}$	—
Bi-cone 	$5\log\left(\frac{D}{\lambda}\right)+3.5$ (Typically 5 dBi)	Typically 45×360	
Helix 	$10\log\left(\frac{D^2L}{\lambda^3}\right)+20.2$ (Typically 5 to 20 dBi)	$\frac{16.6}{\sqrt{D^2L/\lambda^3}}$	
Parabola 	$20\log(\bar{f})+20\log(D)+17.8$ (Typically 10 to 65 dBi)	$\frac{65.3\lambda}{D}$	
Yagi 	$\approx 12 dBi$	—	

Antenna Design

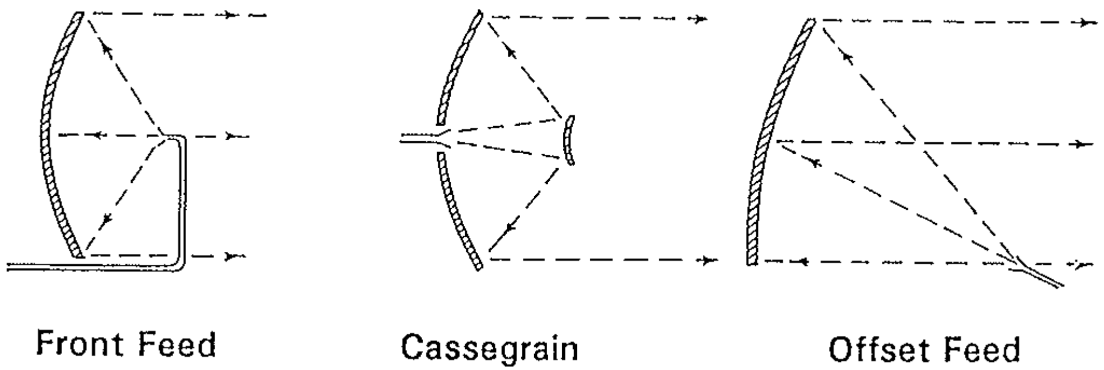
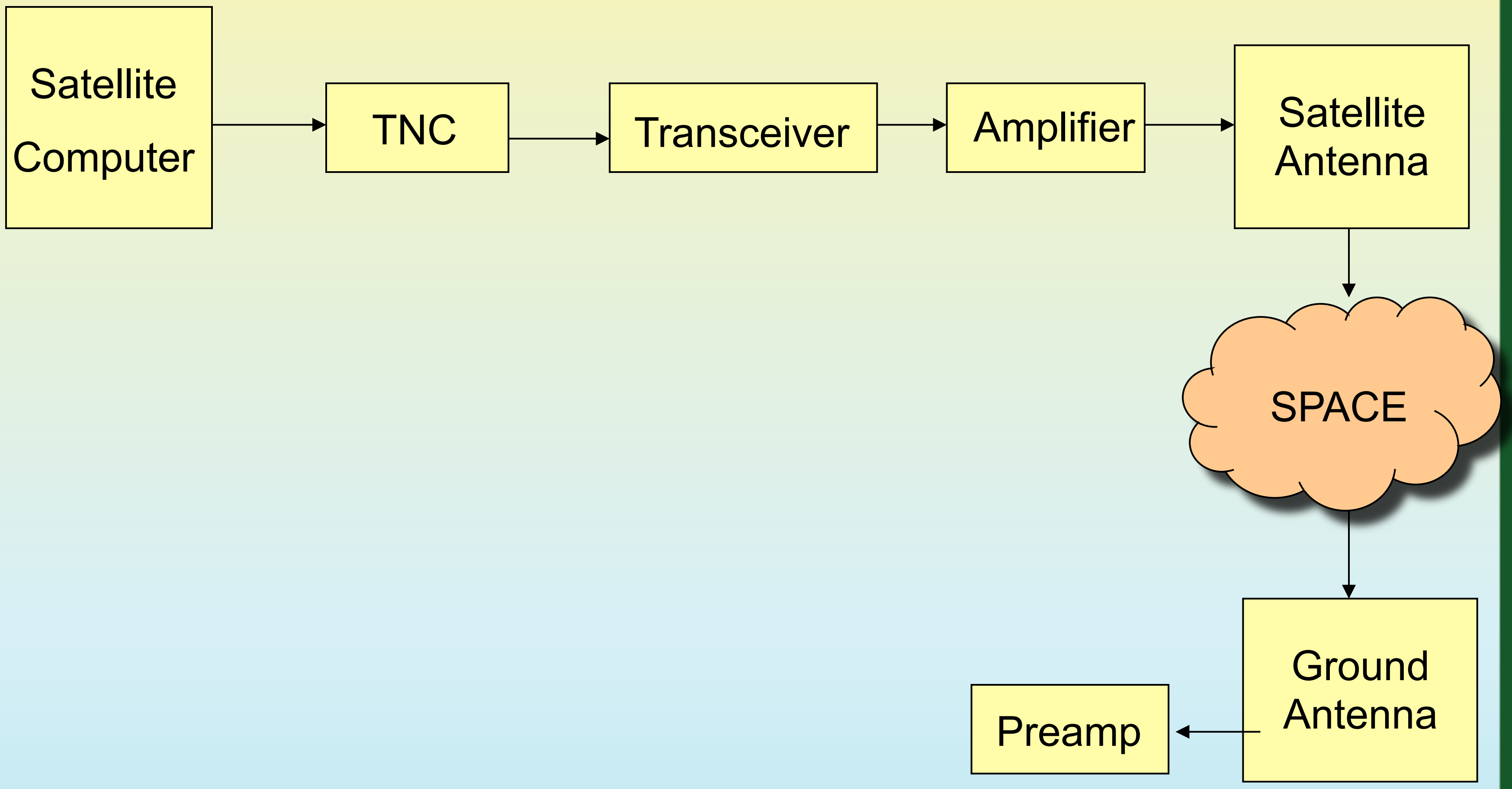


Fig. 9.13 Parabolic antenna feed systems. (*Spacecraft Systems Engineering*, Fortescue and Stark, copyright John Wiley and Sons, Ltd., 1995, reproduced with permission.)

The Ground Antenna Example

- Receives the modulated packetized data from the satellite’s antenna

The (Down)Link



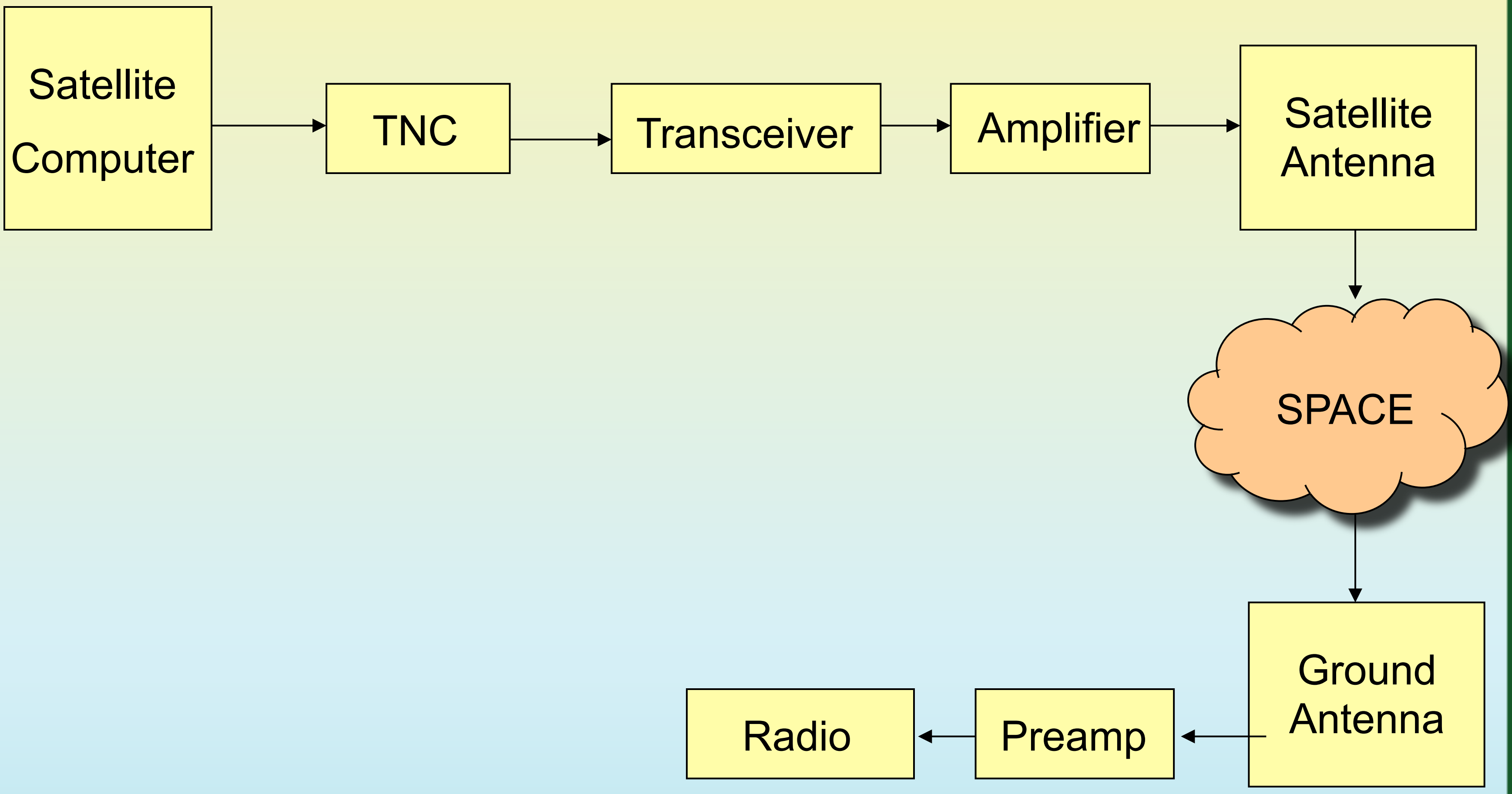
The Ground Preamp

- Boosts all the radio signals coming in from the satellite
- Similar to the boost that occurs on the satellite's amplifier

The Ground Preamp Example

- Takes the radio signal sent from the satellite and boosts the signal for later processing

The (Down)Link



The Ground Radio

- Since all radio frequencies hit the antenna, the radio selects the part of the spectrum to listen to.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

RADIO SERVICES COLOR LEGEND

AERONAUTICAL MOBILE
AERONAUTICAL MOBILE SATELLITE
AERONAUTICAL RADIONAVIGATION
AMATEUR
AMATEUR SATELLITE
BROADCASTING
BROADCASTING SATELLITE
EARTH EXPLORATION SATELLITE
FIXED
FIXED SATELLITE
INTER-SATELLITE
LAND MOBILE
LAND MOBILE SATELLITE
MARITIME MOBILE
MARITIME MOBILE SATELLITE
MARITIME RADIONAVIGATION
METEOROLOGICAL AIDS
METEOROLOGICAL SATELLITE
MOBILE
MOBILE SATELLITE
RADIO ASTRONOMY
RADIODETERMINATION SATELLITE
RADIOLOCATION
RADIOLOCATION SATELLITE
RADIONAVIGATION
RADIONAVIGATION SATELLITE
SPACE OPERATION
SPACE RESEARCH
STANDARD FREQUENCY AND TIME SIGNAL
STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

GOVERNMENT EXCLUSIVE
GOVERNMENT/NON-GOVERNMENT SHARED
NON-GOVERNMENT EXCLUSIVE

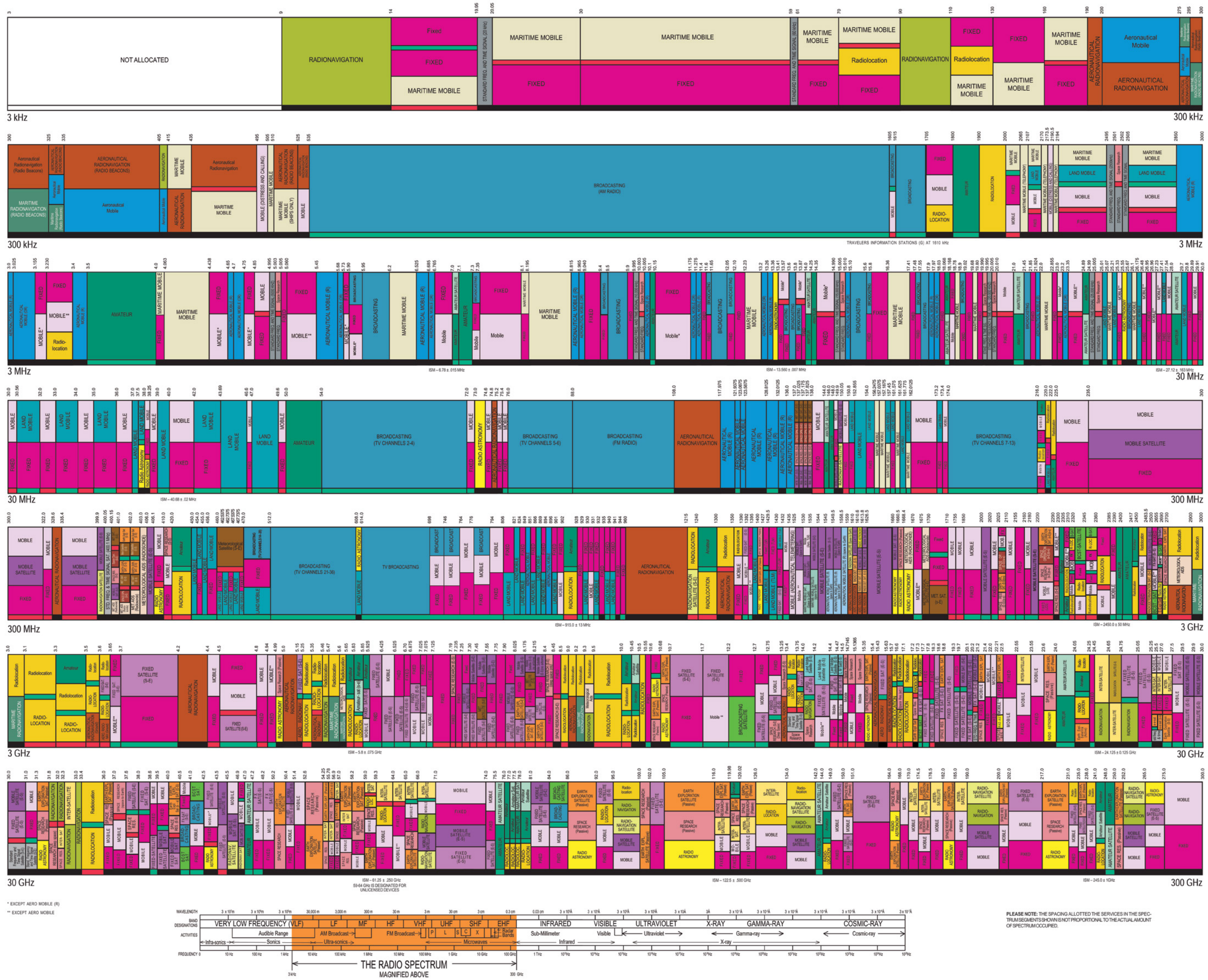
ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it does not completely reflect all aspects, i.e., footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

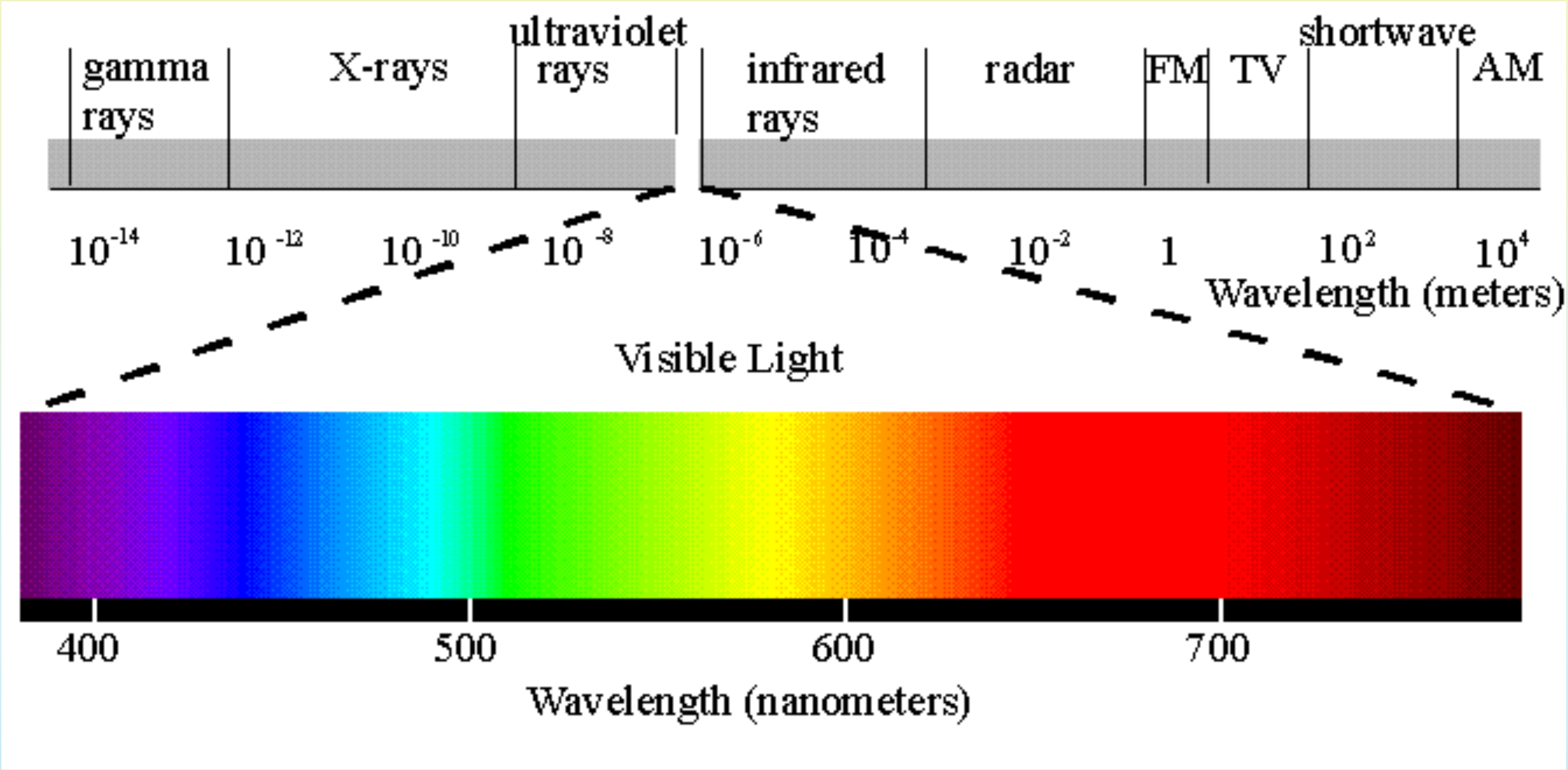
October 2003



Early Radio Bands

Band	Name	Frequency
VLF	Very Low	3-30 kHz
LF	Low	30-300 kHz
MF	Medium	300-3000 kHz
HF	High	3-30 MHz
VHF	Very High	30-300 MHz
UHF	Ultra High	300-3000 MHz
SHF	Super High	3-30 GHz
EHF	Extremely High	30-300 GHz

The Electromagnetic Spectrum

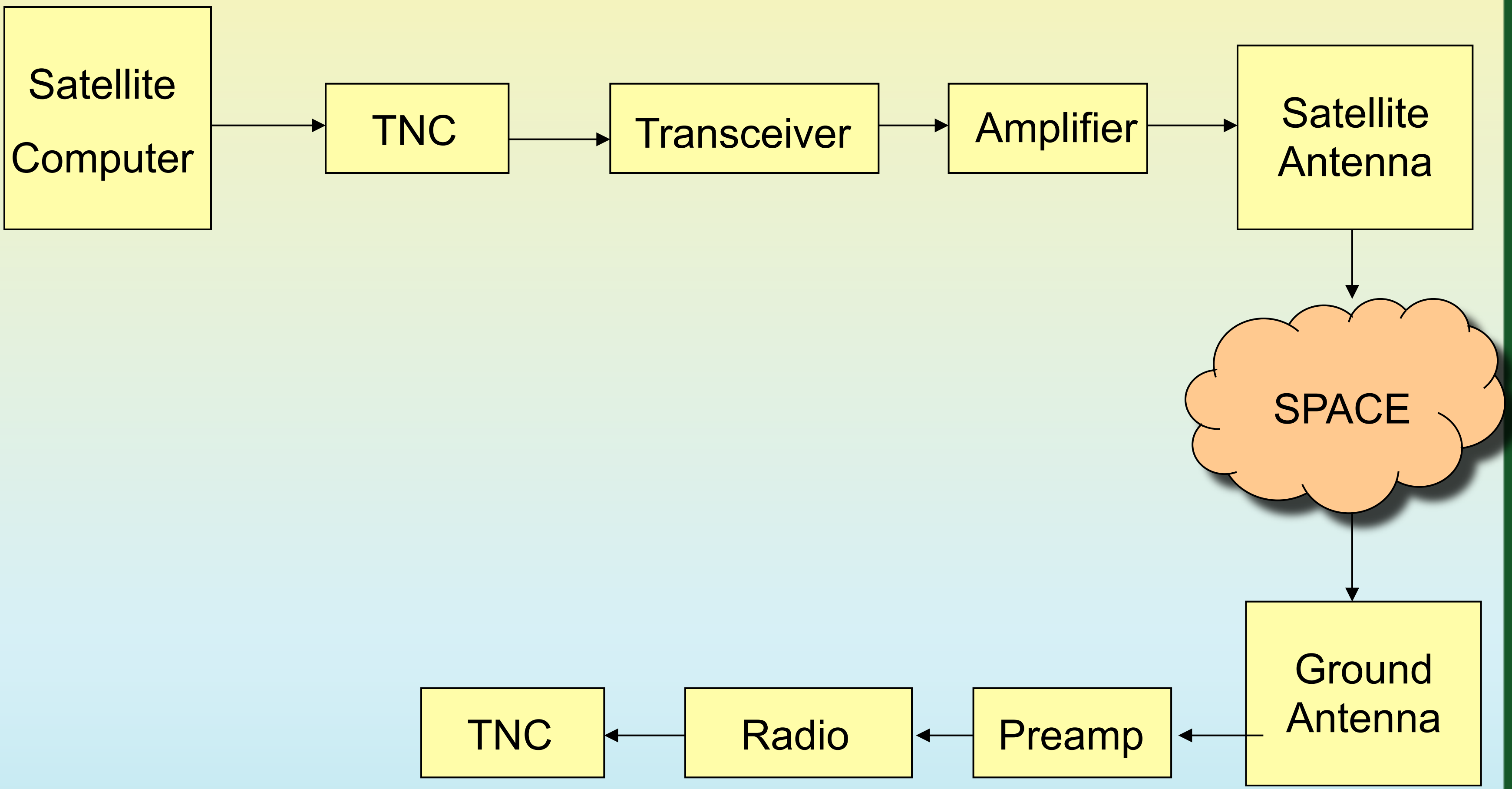


www.yorku.ca/eye/spectrum.gif

The Ground Radio Example

- Listens to the 437.365 MHz to receive the satellite signal

The (Down)Link



The Ground TNC

- 1. Demodulation
  - Converts the modulated data received back into digital data
- 2. Depacketization
  - Removes the data from the parity packet and verifies that the checksum is correct.

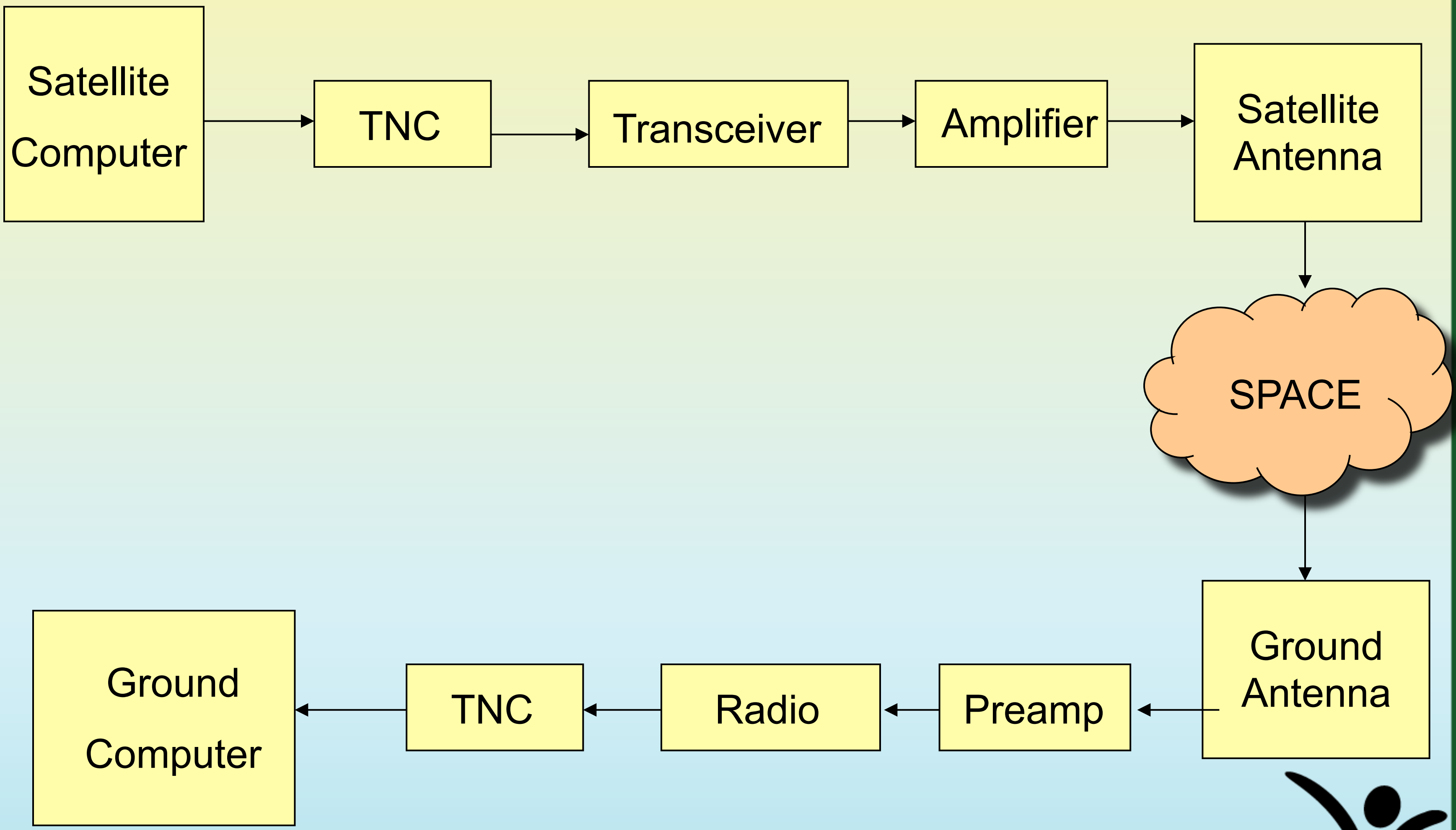
The Ground TNC Example Step 1

- Demodulation
  - Takes in the radio signal and decodes it to receive the following digital packet
  - **1**10001001**1**

The Ground TNC Example Step 2

- Depacketization
  - Verify that the two parity bits match (both at 1 in this case)
  - Recalculate parity on the original data and make sure that it makes the parity bits
  - 10001001 again gives a parity of 1 which matches
  - If different, then a bit error occurred in the transmission and the data must be resent.

The (Down)Link



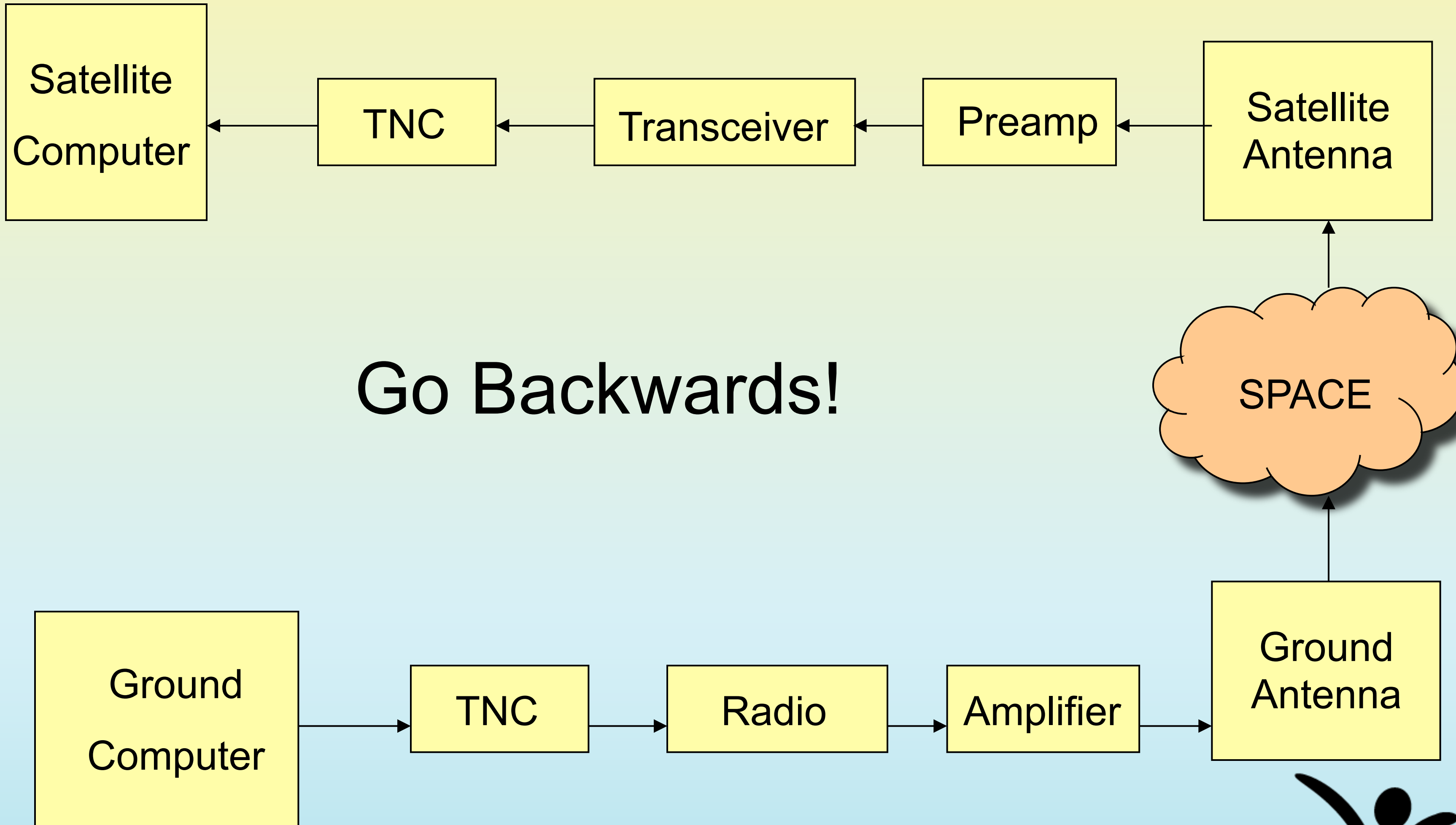
The Ground Computer

- Collects the satellite data for analysis
- Data is typically store in a log file which is timestamped
- Can also be stored in a database for easier access to data

The Ground Computer Example

- The ground computer successfully receives the transmitted byte 10001001 from the TNC!

The (Up)Link



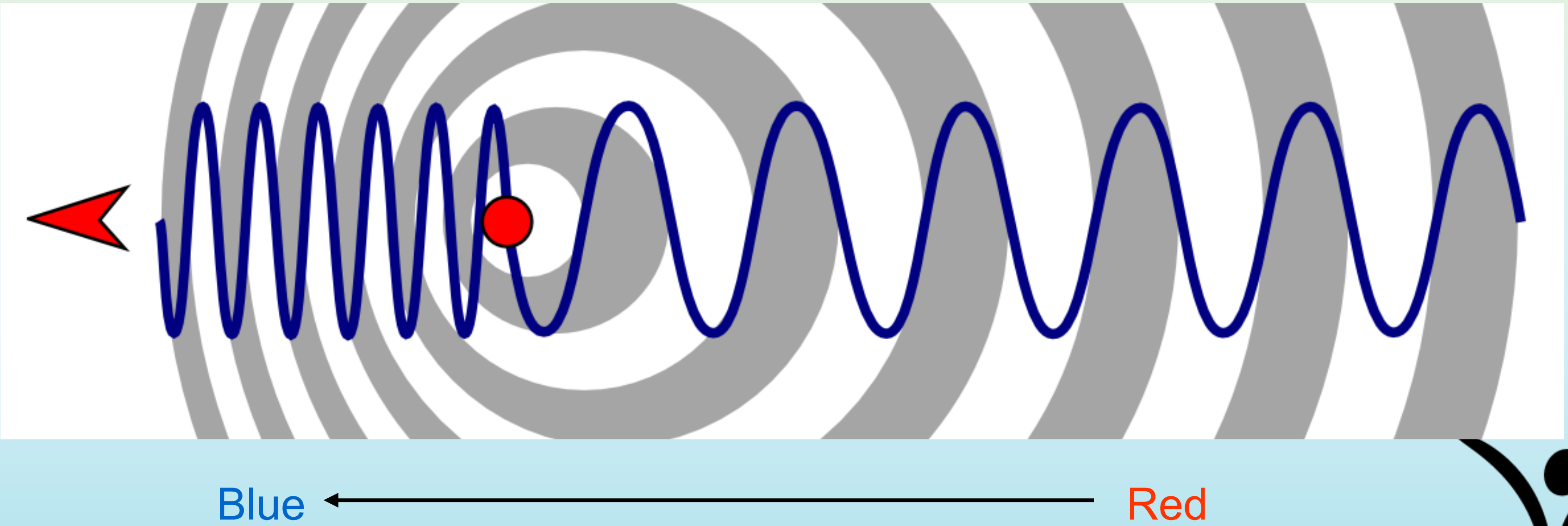
Go Backwards!

Additional Considerations

- Dopper Effect
- Software TNCs

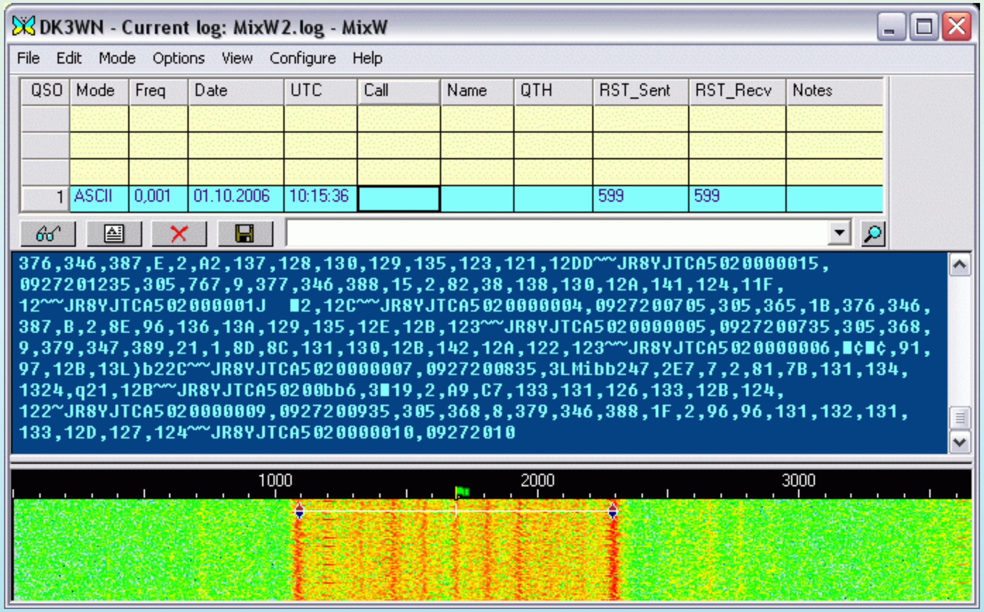
Considerations: Doppler Effect

- A shift in apparent frequency due to relative motion of transmitting or receiving object
- Can be used to measure the velocity of a spacecraft

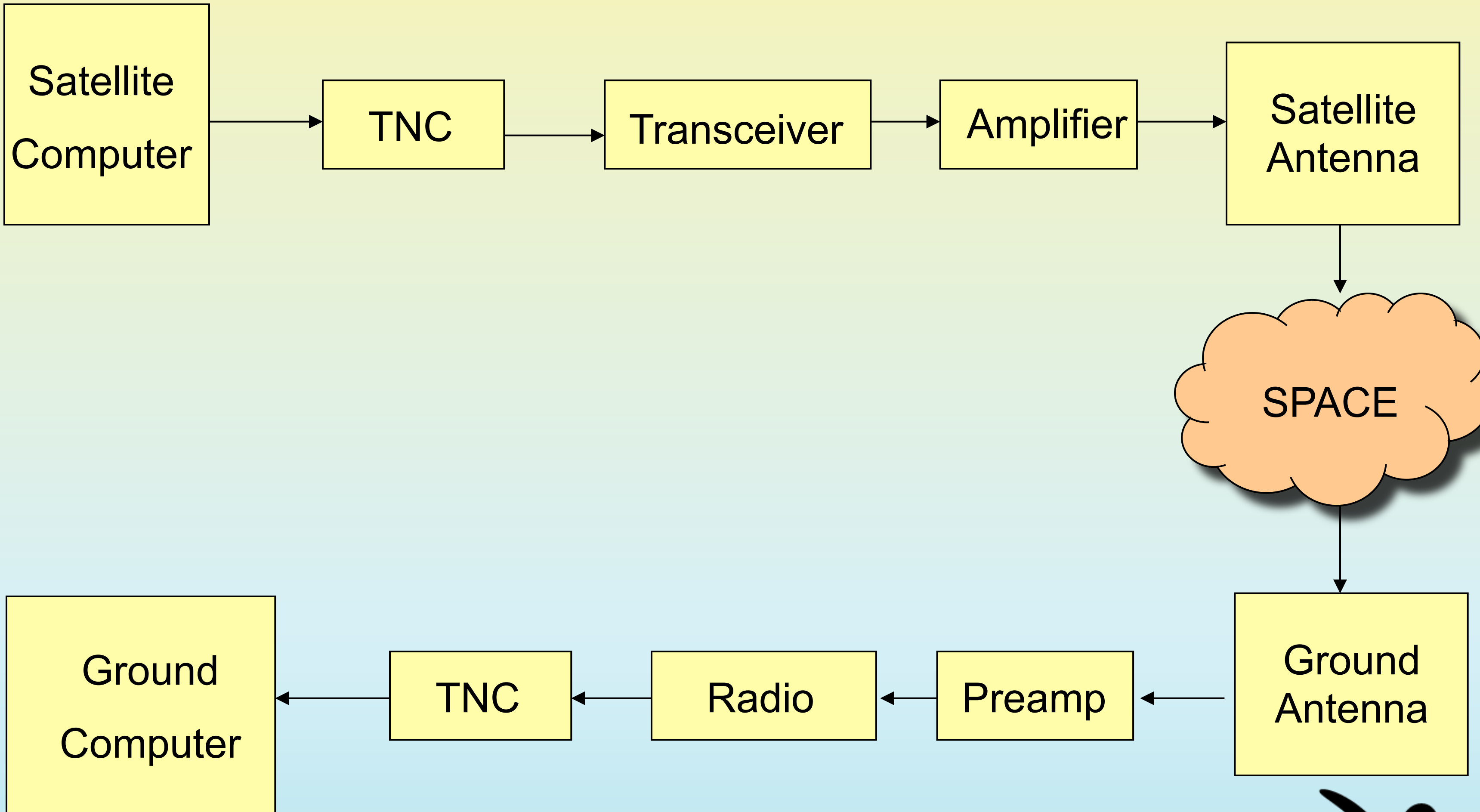


Considerations: Software TNC

- Can do demodulation in software by listening to your sound card
- More configurable and allows for exotic modulation schemes



Questions


Satellite Computer
TNC
Transceiver
Amplifier
Satellite Antenna
SPACE
Ground Antenna
Preamp
Radio
TNC
Ground Computer