Satellite Technology (20EC81)

V-Sem,ASE&IT, A.Y: 2024-25

Unit-III B
BUS Electronics

Presented by

Mr. M.Sivasankara Rao

Sr.Assistant Professor in ECE

Lakireddy Bali Reddy College of Engineering, Mylavaram

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TTC&M

- Stands for Telemetry, Tracking, Command & Monitoring
- Telemetry is the onsite collection of measurements or other data at remote points and their automatic transmission to receiving equipment for monitoring.
- The word is derived from the Greek roots *tele*, "remote", and *metron*, "measure".

TTC&M

- Systems that need external instructions and data to operate require the counterpart of telemetry, tele-command.
- A tele-command or tele-control is a command sent to control a remote system or systems that are not directly connected

TTC&M

- The TTC&M system is essential to the successful operation of a communications satellite.
- It is part of the satellite management task, which also involves an earth station, usually dedicated to that task, and a group of personnel.

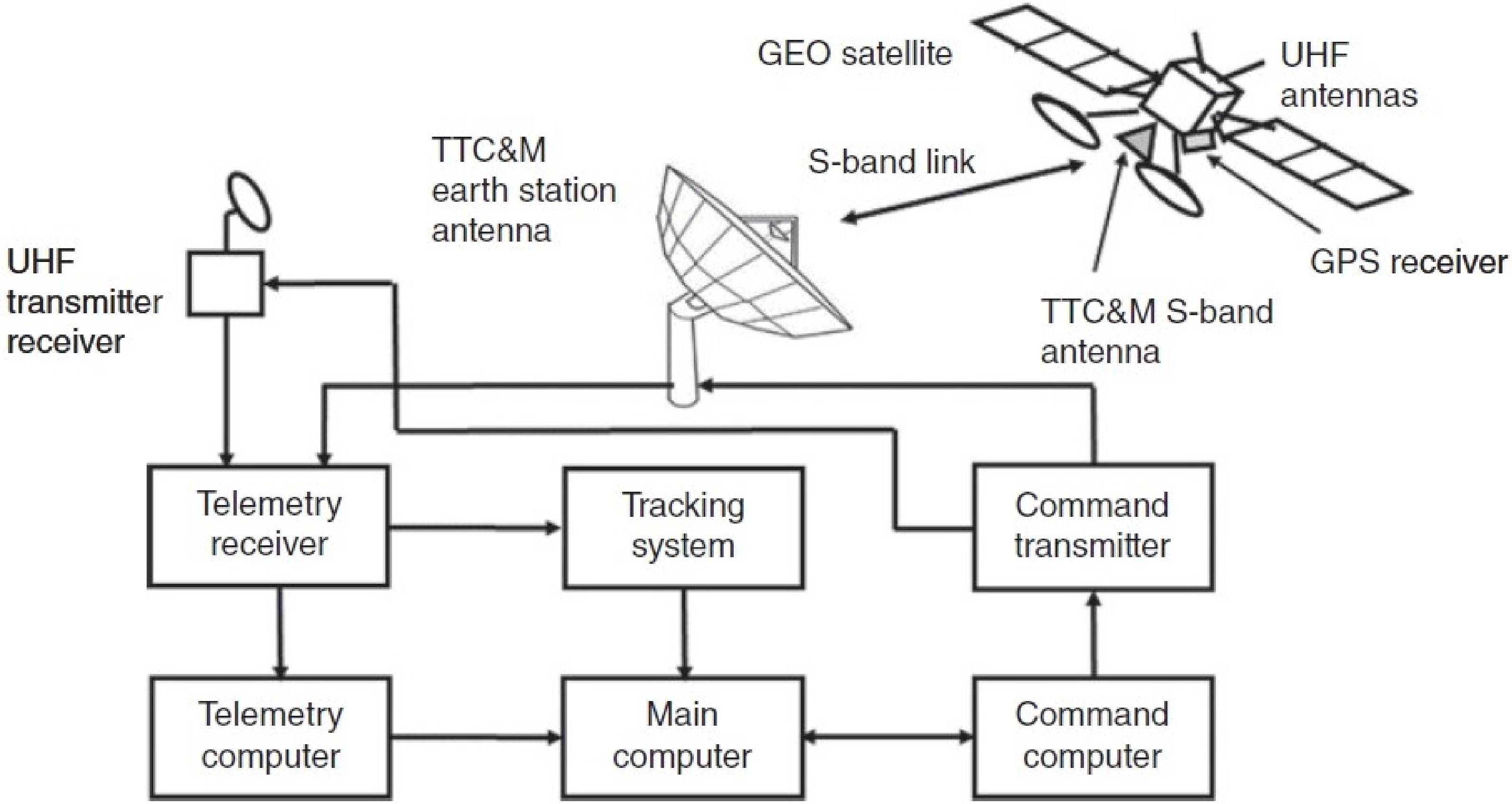
TTC&M

- The main functions of satellite management are to control the orbit and attitude of the satellite, monitor the status of all sensors and subsystems on the satellite, and switch on or off sections of the communication system.
- The TTC&M earth station may be owned and operated by the satellite owner, or it may be owned by a third party that provides TTC&M services under contract.

TTC&M

- On large geostationary satellites, some re-pointing of individual antennas may be possible, under the command of the TTC&M system.
- Tracking is performed primarily by the earth station. Figure illustrates the functions of a controlling earth station.

TTC&M


GEO satellite
UHF antennas
TTC&M earth station antenna
S-band link
GPS receiver
TTC&M S-band antenna
UHF transmitter receiver
Telemetry receiver
Tracking system
Command transmitter
Telemetry computer
Main computer
Command computer

TTC&M

- Simplified diagram of the earth based control system for a GEO satellite.
- The main computer receives telemetry data from the satellite's attitude and orbital control systems, as well as all the many sensors on board the satellite.
- Commands for station keeping maneuvers and changes to switch settings originate in the main computer and are translated to command codes by the command computer.

TTC&M

- The UHF command and telemetry system is used during the launch phase when the satellite orientation has not been stabilized.
- Once on station, TTC&M communications are switched to the main frequency, S-band in this example.
- All telemetry data is stored for later analysis to determine aging trends in critical components such as transponders.

Telemetry and Monitoring System

- The monitoring system collects data from many sensors within the satellite and sends the data to the controlling earth station.
- There may be several hundred sensors located on the satellite to monitor pressure in the fuel tanks, voltage, and current in the power conditioning unit, current drawn by each subsystem, and critical voltages and currents in the communications electronics.

Telemetry and Monitoring System

- The temperature of many of the subsystems is important and must be kept within pre-determined limits, so many temperature sensors are fitted.
- The sensor data, the status of each subsystem, and the positions of switches in the communication system are reported back to earth by the telemetry system.

Telemetry and Monitoring System

- The sighting devices used to maintain attitude are also monitored via the telemetry link: this is essential in case one should fail and cause the satellite to point in the wrong direction.
- The faulty unit must then be disconnected and a spare brought in, via the command system, or some other means of controlling attitude devised.

Telemetry and Monitoring System

- Telemetry data are usually digitized and transmitted as phase shift keying (PSK) of a low-power telemetry carrier using time division multiplexing (TDM).
- A low data rate is normally used to allow the receiver at the earth station to have a narrow bandwidth and thus maintain a high carrier to noise ratio.

Telemetry and Monitoring System

- The entire TDM frame may contain thousands of bits of data and take several seconds to transmit.
- At the controlling earth station a computer is used to monitor, store, and decode the telemetry data so that the status of any system or sensor on the satellite can be determined immediately by the controller on earth.
- Alarms can also be sounded if any vital parameter goes outside allowable limits.

Tracking

- A number of techniques can be used to determine the current orbit of a satellite. Velocity and acceleration sensors on the satellite can be used to establish the change in orbit from the last known position, by integration of the data.
- The earth station controlling the satellite can observe the Doppler shift of the telemetry carrier or beacon transmitter carrier to determine the rate at which range is changing.

Tracking

- Together with accurate angular measurements from the earth station antenna, range is used to determine the orbital elements.
- Active determination of range can be achieved by transmitting a pulse, or sequence of pulses, to the satellite and observing the time delay before the pulse is received again.

Tracking

- The propagation delay in the satellite transponder must be accurately known, and more than one earth station may make range measurements.
- If a sufficient number of earth stations with an adequate separation are observing the satellite, its position can be established by triangulation from the earth station by simultaneous range measurements.
- With precision equipment at the earth stations, the position of the satellite can be determined within 10m.

Tracking

- Some satellites carry GPS receivers that report the satellite’s position over the telemetry link.
- GEO satellites orbit at a higher altitude than GPS satellites requiring a somewhat different operating mode to calculate position.
- The availability of the L5 signal on later GPS satellites makes possible dual frequency measurements with accuracy better than 5m.

Command

- A secure and effective command structure is vital to the successful launch and operation of any communications satellite.
- The command system is used to make changes in attitude and corrections to the orbit and to control the communication system.
- During launch, it is used to control the firing of the AKM(Apogee Kick Motor) and to extend the solar arrays and antennas of a three-axis stabilized satellite.

Command

- The command structure must possess safeguards against unauthorized attempts to make changes to the satellite's operation, and also against inadvertent operation of a control due to error in a received command.
- Encryption of commands and responses is used to provide security in the command system.

Command

- The command and telemetry links are usually separate from the communication system on a GEO satellite, although they may operate in the same frequency band, often C-band (6 and 4GHz).
- Two levels of command system are used in some satellites; the main system operates in the 6 GHz band, in a gap between the communication channel frequencies; the main telemetry system uses a similar gap in the 4 GHz band.

Command

- During the launch phase and injection into geostationary orbit, the main TTC&M system may be inoperable because the satellite does not have the correct attitude or has not extended its solar arrays.
- A backup system is used at this time, which controls only the most important sections of the satellite.

Command

- A great deal of redundancy is built into this system, since its failure will jeopardize the entire mission.
- Near omni-directional antennas are used at either ultra high frequency (UHF) or S-band (2–4 GHz), and sufficient margin is allowed in the signal to noise ratio (SNR) at the satellite receiver to guarantee control under the most adverse conditions.

Command

- The backup system provides control of the AKM, the attitude control system and orbit control thrusters, the solar sail deployment mechanism (if fitted), and the power conditioning unit.
- With these controls, the satellite can be injected into geostationary orbit, turned to face earth, and switched to full electrical power so that handover to the main TTC&M system is possible.

Command

- When ion thrusters are used to raise the satellite to geosynchronous orbit, the antennas and solar arrays can be deployed during the orbit raising process, allowing full operation of the satellite and main TTC&M system.
- This allows all the satellite’s systems to be checked out by the time the satellite reaches GEO.

Command

- In the event of failure of the main TTC&M system, the backup system can be used to keep the satellite on station.
- It is also used to eject the satellite from geostationary orbit and to switch off all transmitters when the satellite eventually reaches the end of its useful life.

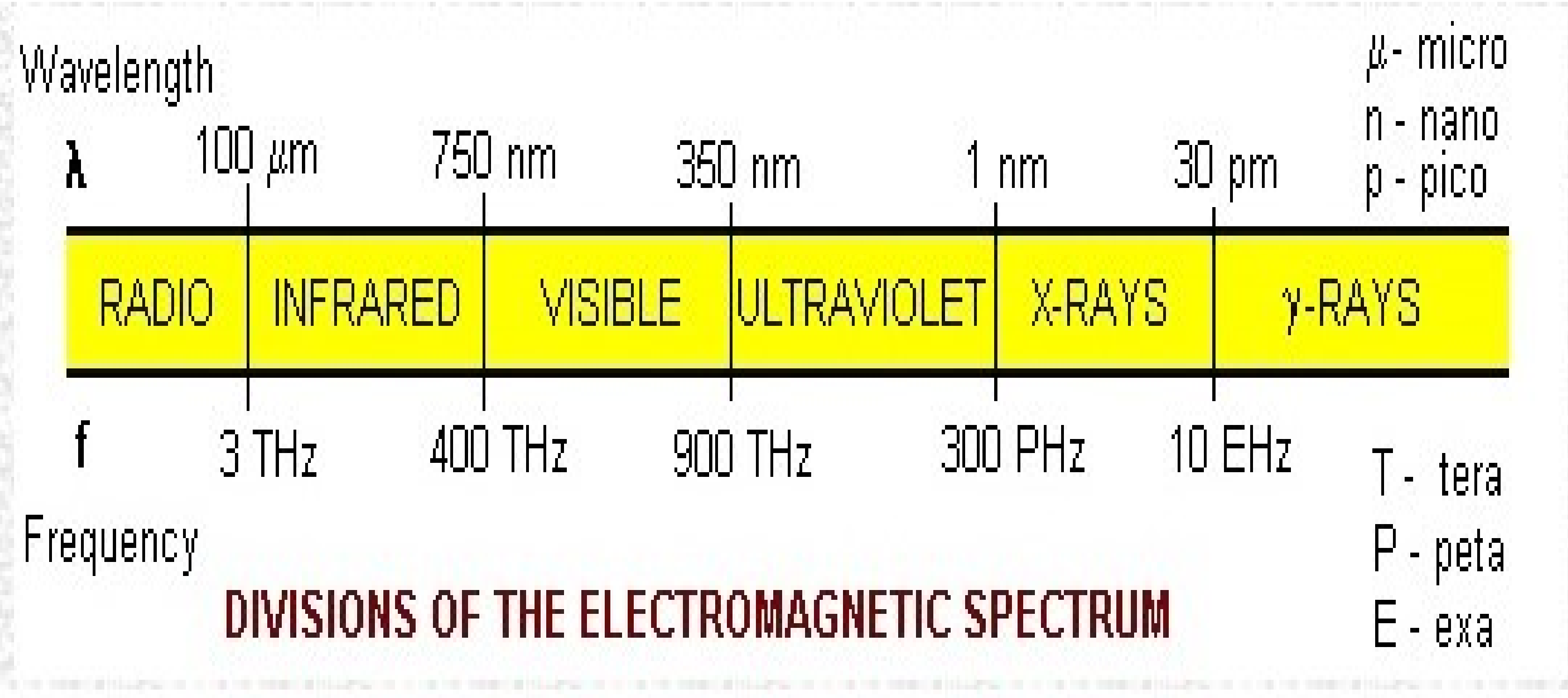
Generally Employed Communication Bands

- Most satellite communication is accomplished by radio part of the electromagnetic spectrum.
- Radio frequencies must be shared with terrestrial radio services, and international frequency assignment is essential to avoid interference between all the different uses made of the radio spectrum.

Generally Employed Communication Bands

- The International Telecommunications Union (ITU) is the global body that assigns radio frequency allocations. In doing this they divide the world into three regions, regions I, II and III.
- The radio spectrum is a subset of the electromagnetic spectrum. It extends from frequencies below 1 Hz up to around 3000 GHz or 3 THz

Generally Employed Communication Bands



Generally Employed Communication Bands

- Microwave is a term that was historically applied to signals with wavelengths less than one foot (30 cm), and this region has been subdivided into letter bands. However, there are several schemes of designation for microwave bands. Two of these, which we shall call traditional and new, are given below.

Generally Employed Communication Bands

Traditional	f range(GHz)	New	f range(GHz)
L	1 - 2	D	1 - 2
S	2 - 4	E	2 - 3
C	4 - 8	F	3 - 4
X	8 - 12	G	4 - 6
Ku	12 -18	H	6 - 8
K	18 - 27	I	8 - 10
Ka	27 - 40	J	10 - 20
V	40 - 75	K	20 - 40
W	75 - 110	L	40 - 60
mm	110 - 300	M	60 - 110
sub-mm	> 300		

MICROWAVE RADIO BANDS

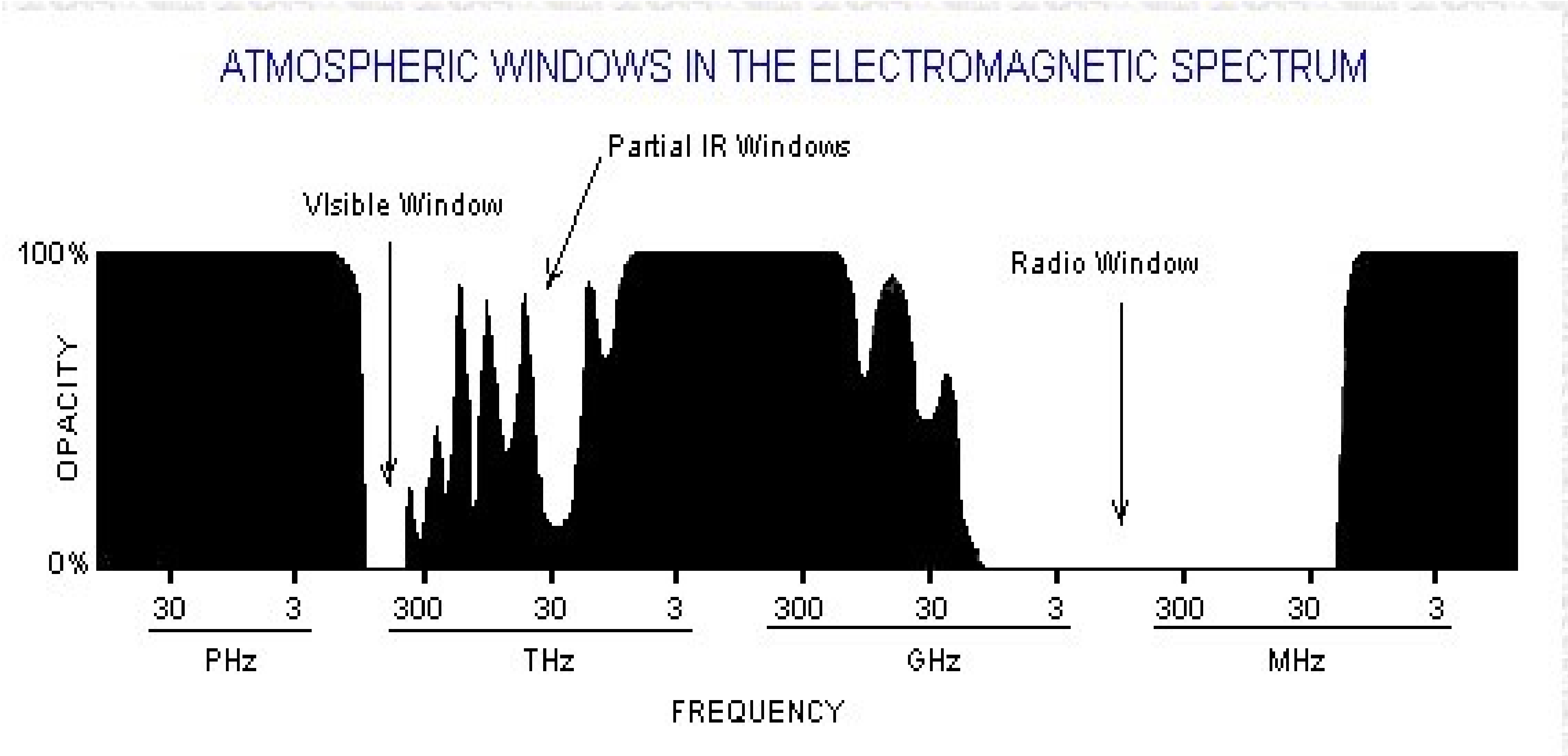
Generally Employed Communication Bands

- Not all of the electromagnetic spectrum can pass through the Earth's atmosphere. There are in fact only two main windows of the EM spectrum that are open to space. One is the visible spectrum and the other is the radio spectrum.
- However, not all of the radio spectrum is useable for space communication. The available window spans from about 30 MHz to 30 GHz, although these are not absolute end frequencies.

Generally Employed Communication Bands

- Below 30 MHz, the ionosphere, at altitudes from around 100 to 500 km, absorbs and reflects signals. Above 30 GHz, the lower atmosphere or troposphere, below 10 km, absorbs radio signals due to oxygen and water vapour. Even between 20 and 30 GHz, there are some absorption bands that must be avoided.

Generally Employed Communication Bands



SPACE COMMUNICATION BANDS – characteristics & Applications

- VHF Band
  - 136 - 138 MHz
    This band was used heavily by many different types of satellites in the past. From (2012), most activity is restricted to 137-138 MHz and consists of meteorological satellites transmitting data and low resolution images, together with low data rate mobile satellite downlinks (eg Orbcomm)

SPACE COMMUNICATION BANDS – characteristics & Applications

- VHF Band
  - 144 - 146 MHz
    One of the most popular bands for amateur satellite activity.
  - 148 - 150 MHz
    This tends to be used for uplinks of the satellites for downlink in the 137 - 138 MHz band.
  - 149.95 - 150.05 MHz
    This is used by satellites providing positioning, time and frequency services, by ionospheric research and other satellites.

SPACE COMMUNICATION BANDS – characteristics & Applications

- VHF Band
  - 240 - 270 MHz
    Military satellites, communications. This band lies in the wider frequency allocation (225 - 380 MHz) assigned for military aviation.
- UHF Band
  - 399.9 - 403 MHz
    This band includes navigation, positioning, time and frequency standard, mobile communication, and meteorological satellites.

SPACE COMMUNICATION BANDS – characteristics & Applications

- UHF
  - 432 - 438 MHz
    This range includes a popular amateur satellite band as well as a few Earth resources satellites.
  - 460 - 470 MHz
    Meteorological and environmental satellites, includes uplink frequencies for remote environmental data sensors.

SPACE COMMUNICATION BANDS – characteristics & Applications

- L Band
  - 1.2 - 1.8 GHz
    This frequency range includes a very diverse range of satellites and encompasses many sub-allocations. This range includes the GPS and other GNSS (Global Navigation Satellite Systems - Russian Glonass, European Galileo, Chinese Beidou). It also hosts SARSAT/COSPAS search and rescue satellites which are carried on board US and Russian meteorological satellites. It also includes a mobile satellite communication band.

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SPACE COMMUNICATION BANDS – characteristics & Applications

- L Band
  - 1.67 - 1.71 GHz
    This is one of the primary bands for high resolution meteorological satellite downlinks of data and imagery.
- S Band
  - 2.025 - 2.3 GHz
    Space operations and research, including 'deep space' links from beyond Earth orbit.

SPACE COMMUNICATION BANDS – characteristics & Applications

– This encompasses the Unified S-band (USB) plan which is used by many spacecraft, and which was also used by the Apollo lunar missions. It also includes military space links including the US Defense Meteorological Satellite Program (DMSP). Many Earth resources (remote sensing) satellites downlink in this band.

– 2.5 - 2.67 GHz
Fixed (point-to-point) communication and broadcast satellites, although the broadcast allocation is only used in some Asian and Middle-eastern countries.

SPACE COMMUNICATION BANDS – characteristics & Applications

- Ku band
  - 10.7 - 11.7 GHz
    Fixed satellite services (FSS)
  - 11.7 - 12.2 GHz
    Broadcast satellite service (BSS) downlinks. This band is used for domestic TV programs.
  - 14.5 - 14.8 GHz
    The uplink for the previous Ku downlink band.
  - 17.3 - 18.1 GHz
    An alternate 'Ku' band BSS uplink.

SPACE COMMUNICATION BANDS – characteristics & Applications

- 'Ka' band
  - 23 - 27 GHz
    A region that will be used increasingly by a variety of fixed link, broadcast, environmental and space operations satellites in the future as more bandwidth is required than can be provided in the lower bands. The disadvantage of this band is the increased absorption due to water vapour and rain. Not very useful for tropical regions of the Earth.

On-Board Computer (OBC)

- The On-Board Computer (OBC) is the brain of the satellite.
- OBC is responsible for implementation of control law, processing associated with payload, data packeting activities associated with communication, monitoring load health status, handling of data storage etc.

On-Board Computer (OBC)

- The processor needs to interface with various sensors, actuators present onboard to acquire data to perform its activities and responds accordingly through actuators.
- Scheduling of the activities of the processor is essential due to the number of tasks it has to perform.

OBC - Data Budget

- Data budget is tabulated calculation of data being generated in a system, data being stored and memory allocation for the same.
- The amount of data to be processed in every iteration of the processor or one loop or sequence of all the activities can be known from data budget.

OBC - Data Budget

- In case of the satellite, the data budget will include data generated by payload instrument, health monitoring parameters, housekeeping data, process variables, status variables, sensor data, etc.
- We need to ensure that sufficient data storage is available for them. Also, the processor selection is guided by the amount of data it has to process every iteration or cycle.

OBC - Data Budget

- Typically, image processing involves higher computation needs due to high data rates which need to be processed in a cycle.
- Data budget will also involve calculations on how much data is downlinked.
- All the data generated in orbit is not downlinked as it may not be possible due to available bandwidth, speed of communication and time available for downlink.

OBC - Clock Selection

- The majority of clock sources for microcontroller can be grouped into two types:
  - those based on mechanical resonant devices, such as crystals and ceramic resonators, and
  - those based on electrical phase-shift circuits such as RC (resistor, capacitor) oscillators.

OBC - Clock Selection

- Silicon oscillators are typically a fully integrated version of the RC oscillator with the added benefits of current sources, matched resistors and capacitors, and temperature compensation circuits for increased stability.

OBC - Clock Selection

Comparison of various clock sources [1]

Clock Source	Accuracy	Advantages	Disadvantages
Crystal	Medium to High	Low Cost	Sensitive to Electromagnetic interface(EMI), vibration and humidity. Complex circuit impedance matching.
Crystal oscillator Module	Medium to High	Insensitive to EMI, vibration and humidity. No additional components or matching issues.	High cost, high power consumption, sensitive to vibration, large packaging.
Ceramic resonator	Medium	Lower Cost	Sensitive to EMI, Vibration and Humidity.
Integrated Silicon Oscillator	Low to Medium	Insensitive to EMI, vibration, and humidity. Fast startup, small size, and no additional components or matching issues.	Temperature sensitivity is generally worse than crystal and ceramic resonator types; high supply current with some types.
RC Oscillator	Very Low	Lower Cost	Usually sensitive to EMI and humidity. Poor temperature and supply-voltage rejection performance

OBC - Processor

- A processor is needed for the different subsystem that can execute the onboard programs in a reasonable way. The compulsory tasks of the satellite (power control, communication, attitude control, etc.) could be managed by a quite humble processor or microcontroller.

OBC - Processor

- Selection of a Processor
  - **Space Grade Tested/ Used in Another Satellite**
    - f the processor has been already used in space it will tell us about the reliability of the processor in space and then the matching of other specifications to our requirements generally helps finalize that processor. If a processor satisfies all requirements, but hasn't been tested in space before, there will always be some doubt about its reliability creeping in now and then.

OBC - Processor

– **Operational Temperature Range**
  - The thermals subsystem maintains the temperature of the satellite within a specific range. If the microcontroller can work well in that temperature range, it can be used for the satellite. On an average operational temperature of an off the shelf micro-controllers is -40 to 80 degrees Celsius.

OBC - Processor

- **Digital and Analog I/O Ports**
  - All sensors and actuators need access to the processor via the I/O pins of the processor, it is preferable to have sufficient I/O pin in order to connect all the peripherals.
- **Communication ports and protocols**
  - processor will be required to interact with various sensors and other processors it is of utmost importance that the processor has sufficient number Communication ports and protocols. A microcontroller having UART, SPI and I2C channels will be better than a microcontroller with only UART channels.

OBC - Processor

– **Peak and standby power consumption**

- satellite will have only limited power supply so it is necessary that the processor has low power consumption. Also it is possible that during some stage in mission some subsystem’s processor might not be in use so it is also important that processor has low standby power consumption. Values of peak and standby power consumption can be easily seen from datasheet of the processor.

OBC - Processor

- Interfacing a Processor
  - microcontroller should have various types of communication ports supporting various communication protocols such as :
    - **Universal Asynchronous Receiver-Transmitter (UART):** UART is used to send or receive serial data. A PC uses UART to communicate. Really useful for debugging.
    - **Serial Peripheral Interface (SPI):** It is a synchronous, full duplex serial communication interface specification. It communicates using master-slave structure.

OBC - Processor

- **I2C:** The I2C bus uses a bi-directional Serial Clock Line (SCL) and Serial Data Lines (SDL) and due to its two-wire nature can only communicate half-duplex. It is a multi-master, multi-slave, packet switched, single ended serial computer bus. Data and clock are sent from master.
- **Controller Area Network (CAN):** The CAN bus is a balanced (differential) two-wire interface. This bus use NRZ encoding to ensure compact messages with a minimum number of transition and high resilience to external disturbance.

OBC - Processor

- **SpaceWire:** The Spacewire bus provides a bidirectional serial interconnect which builds a scalable parallel system using a pair of unidirectional lines. IEEE 1355 defines the Physical and Data Link Layer. The electrical interface is specified as standard Transistor-Transistor Logic (TTL).

OBC – Memory Selection

- There should be enough memory on board to store flight software, payload data, health monitoring data,etc. And enough RAM to execute all the software.
- Different type of memories can be classified as follows :-
  - **Volatile memory:** It requires constant power to maintain the stored information.
    Example: SRAM(Static Random Access Memory)

OBC – Memory Selection

– **Dynamic Memory:** It is a volatile memory which also requires constant power to store information, it is periodically refreshed, or read and rewritten without modifications. Example DRAM (Dynamic Random Access Memory). DRAM is less expensive than SRAM, but SRAM is much faster than DRAM

– **Non-volatile memory:** It will retain the stored information even if it is not constantly supplied with electrical power. For example Flash, EEPROM (Electrically Erasable Programmable Read-Only Memory) and magnetic memory (HDD).

OBC - OS

- An operating system (OS) is system software that manages computer hardware and software resources and provides common services for computer programs.
- Sometimes it might be possible that the tasks of satellites cannot be dealt with a simple scheduling algorithm. In that case it might be necessary to use an Operating System to handle the software part of satellite.

OBC - OS

- Some of the Operating Systems that have been already used in satellites are:
  - **eCos:** The Embedded Configurable Operating System (eCos) is a free and open source real-time operating system intended for embedded systems and applications which need only one process with multiple threads.
  - **µClinux :** µClinux is a variation of the Linux kernel, previously maintained as a fork, that targets microcontrollers without a memory management unit (MMU).

OBC - OS

– **VxWorks :** VxWorks is a multi-thread and real-time operating system. VXworks is the world leader of the optimization of software for peripherals.
– **FreeRTOS :** FreeRTOS is a popular real-time operating system kernel which has small memory footprint, low overhead and fast execution.

OBC – Flight Code

- The flight code of the satellite is expected to perform the following functions:
  - **Scheduling**
  - **Control Law Implementation**
  - **Power Management**
  - **Data Handling for Communications**

Ground Checkout System

- Purpose:
  - To establish and evaluate the operational effectiveness and reliability of the integrated satellite system, it is necessary to confirm that every subsystem is functioning according to the technical specifications laid down.

Ground Checkout System

- The ground checkout equipment provides a means for assessing the overall performance of the integrated satellite through checks carried out during various stages of the satellite assembly and after every mechanical operation, such as transportation to the technological position (TP), interfacing the satellite with the rocket and also during pre-launch operations at the launch pad (LP).

Ground Checkout System

- It is imperative that the checkout system should be able to test all the subsystems extensively in as short a time as possible.
- The ground checkout system essentially processes telemetry data through a radio frequency link, power and various necessary stimuli being provided through a cable link.

Ground Checkout System

- The checkout system consisted of
  - control panel,
  - cable checkout system,
  - tape recorder test console and
  - spin test console which were connected to the satellite through cables and
  - the telemetry data processor, PDP-11 computer with associated input/output devices and
  - telecommand encoder with transmitter to simulate up and down r.f. link of the satellite.

Ground Checkout System

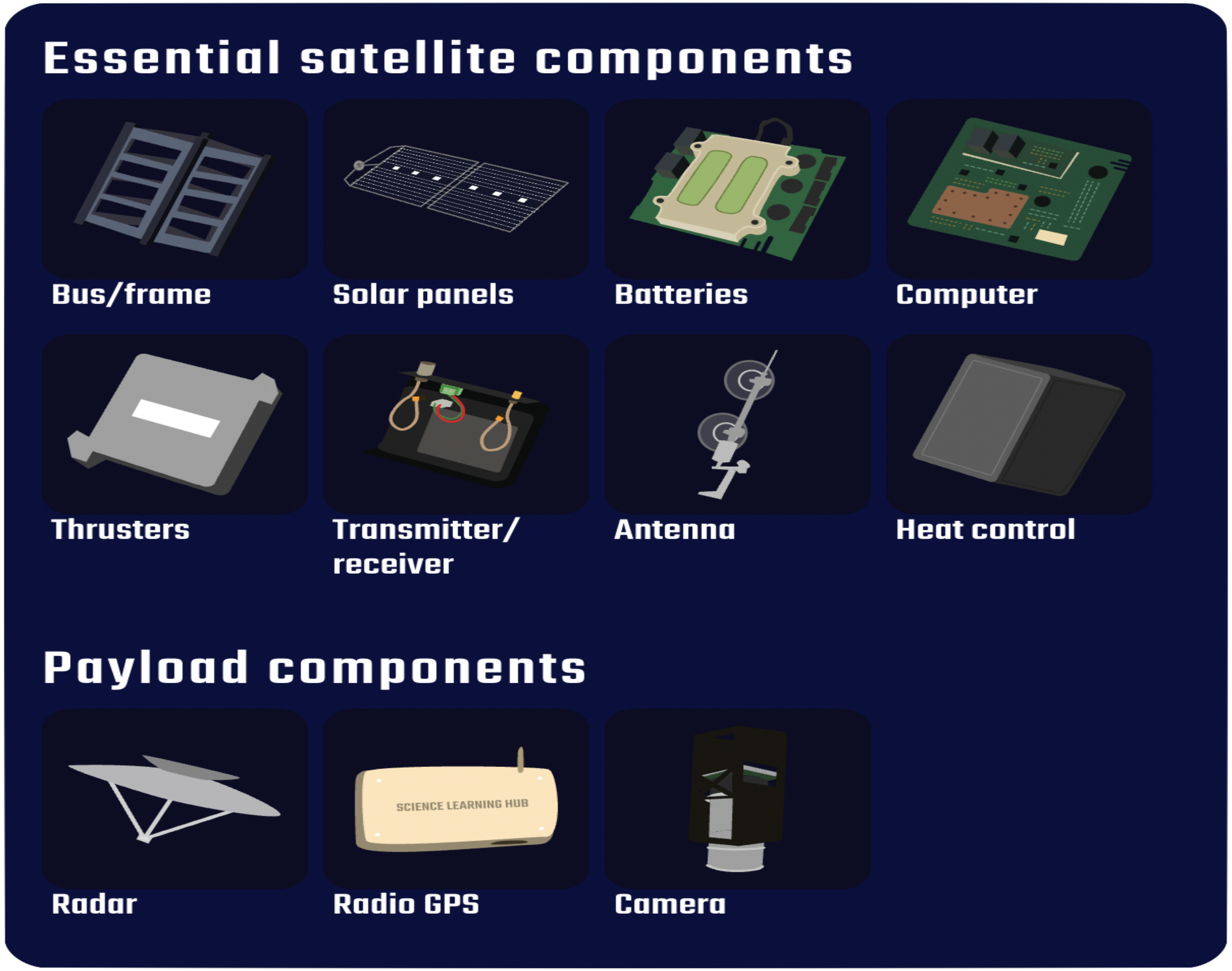
- System Description
  - Cable system
    - Control panel
      - Control board
      - Satellite simulator
      - Solar array & chemical battery simulator
      - Battery charger
      - Real time clock
    - Cable checkout system
      - DC measurement Unit
      - Stimulus Generators
      - Signal obsewrvation unit
      - Tape recorder and spin test consoles

Ground Checkout System

- RF Checkout System
  - to make an arrangement for identifying the frame synchronisation code
  - to monitor all incoming words of the telemetry format and print
  - to compare the input information with reference data and then process and analyse the data according to subsystem requirements
  - to monitor the command status
  - RF Checkout system comprises of
    - Telemetry Data Processor
    - Computer System

Ground Checkout System

- Test Philosophy:
  - To qualify the spacecraft for launch worthiness and to enhance the acceptance level of its performance, it has to be tested again and again, after every mechanical operation or transportation or after each stage of integration. The entire testing sequence was well documented and followed rigidly prior to launch. Essentially the test was carried out in two phases:
    - in the disassembled mode and
    - in the assembled mode.


Essential satellite components
Bus/frame
Solar panels
Batteries
Computer
Thrusters
Transmitter/ receiver
Antenna
Heat control
Payload components
Radar
Radio GPS
SCIENCE LEARNING HUB
Camera

Thank You