TT&C and C&DH

1 Telemetry, Tracking and Command System

The functions of a **telemetry, tracking and command system** (TT&C) involve **carrier tracking**, **command detection and reception** and **telemetry modulation and reception**. **Telemetry** data are data that are sent by the spacecraft to the ground.

In carrier tracking, the spacecraft receives an **uplink signal** from a ground station. It then sends a **downlink signal** back. It can do this with exactly the same frequency (this is called **phase coherence**). Sometimes the frequency of the uplink signal is multiplied by a **turnaround ratio**. We are then dealing with **coherent turnaround** (also called **two-way coherent mode**). The ground station then receives the downlink signal. This frequency isn't the same as what was send out by the satellite though. A **Doppler shift** has occurred. Using the change in frequency, the velocity of the spacecraft perpendicular to the ground station can be found.

For command detection and reception, and also for telemetry modulation and reception, the satellite needs to be able to communicate with a ground station. This can be done in multiple ways. In **simplex** there is only a one way link. Either the satellite can talk to Earth, or Earth can talk to the satellite. In **half duplex** there is a two way link. However, only one link can be active at a certain time. In **full duplex** there can be a two way link all the time.

2 Command and Data Handling System

The function of the **command and data handling system** (C&DH) (sometimes also called the **on-board data handling system** (OBDH)) is, not very surprisingly, to handle commands and data. **Commands** determine the behaviour of the spacecraft. They come from the on-board computer, or from a ground station. A **telecommand** is a command sent by the ground station to the spacecraft.

Let's take a closer look at those telecommands. These commands are usually put in a **packet data field** of 434 bytes. Together with a **packet ID field**, a **packet sequence control field** and a **packet length field** (each having 2 bytes), we have a **source packet** of 440 bytes. The packet ID defines the source of the packet and defines the content of the data field.

There are also **transfer frames**. A transfer frame has a **transfer frame data field**, which contains two of the just described source packets. So this field has a size of 880 bytes. Since 1 byte is 8 bits, it has a size of 7040 bits. In the transfer frame is also a **transfer frame primary header** and a **transfer frame trailer**, each having 48 bits. So the total size of a transfer frame is 7136 bits. This frame is then part of a **transfer frame structure**. This structure also has an **attached sync marker** of 32 bits and a **Reed Solomon check symbol** of 1024 bits. So the total size is 8192 bits. And before it is send, it is also **Viterbi encoded**, making it twice as big. So to send only two commands, we need a couple thousand of bits.

When a command is received by the C&DH system, it is first validated. Are the synchronization code and the message length OK? If anything is wrong, the command is rejected. Otherwise it is executed.

The C&DH system also handles data. It keeps track of housekeeping data (like on-board temperature, current, and such). It processes and stores payload data (such as pictures that were made). It also transmits the data to a ground station when a connection is possible.

Another function of the C&DH system is to keep track of time. This time is often used by the **watchdog timer**. The watchdog timer ensures that the computer is operating normally. The computer should reset the watchdog timer every now and then. If it doesn't, the timer will be reaching a critical value, meaning that something is probably wrong. This will cause the computer to restart.

3 Analog and Digital

Most signals, like temperature and voltage, are analog. Sending digital signals has various advantage, so most signals are send in a digital form. Therefore signals need to be converted from analog to digital. This is done by so-called **AD-convertors**. This conversion is done in three steps, being **sampling**, **quantization** and **encoding**.

In the sampling step, we need to determine the **sampling rate** f_s. Theoretically, this must be at least twice the highest frequency in the signal spectrum f_m. In practice, however, a factor 2.2 is necessary. So $f_s \geq 2.2 f_m$. If f_s is higher, then the signal will be more accurate, but more data needs to be send. Using the sample rate, we can split the signal up in pieces called **samples**.

In the second step, the signal will be quantized. First the range of the signal needs to be known. Then a number of bits n needs to be chosen. The range will then be split up in 2^n parts, each having its own magnitude. Every sample will be rounded off to one of these magnitudes. This gives a certain **quantization error**. The maximum quantization error m is given by

$$m = \frac{1}{2^{n+1}}. \tag{3.1}$$

So if the error needs to be less than 5%, then $m < 0.05$ and thus $n = 4$. Also often one **parity bit** is added. So for the example this would mean that $n = 5$.

The final step is encoding. Here every sample will get a binary code, specifying its magnitude. Now the analog signal is converted to a digital signal.