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RFI for Pointing/Tracking solutions for Ka-Band Antenna for MTG

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1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this Technical Note (TEN) is to present challenges to off the shelf solutions that may be available - at present or in the near future - to meet the stringent pointing/tracking accuracy requirements imposed on the Ka-band Antenna sub-system for the Mission Data Acquisition (MDA) stations within the MTG programme. The antenna will have a diameter of 6.3m and it will be mounted on building (TBC) having a height of approximately 20 m.
There are, at least, two particular challenges presented by this Antenna sub-system. One is that the pointing accuracy has to be better than 20 millidegrees. This is quite complicated since the 3 dB beam-width at Ka-Band frequencies for this size of antenna is very small. The other difficulty is that the satellite signal which the antenna will use for tracking has a bandwidth of approximately 400 MHz – due to the high data rate transmitted from the payload.

The scope of the document is to present an outline of the context of a Ka-Band station and the currently known relevant parameters for the Spacecraft and the ground stations with sufficient detail in order that industry can provide feasible solutions.

1.2 Document Structure

Section 1: Introduction
Section 2: An explanation of the main characteristics of the Ka-Band ground station and their possible location scenarios within Europe.
Section 3: The pointing and tracking analysis is presented using the relevant parameters for the Spacecraft and Ground station;
Section 4: An explanation of two possible solutions is given in this section;
Section 5: This chapter summarises the request to industry.

2 KA-BAND STATION ELEMENTS

This section provides an overview of the main technical characteristics of the functional elements within two of the main sub-systems forming part of the Ka-Band ground station. These are presented in Figure 2-1 below:

- Data Reception Subsystem: for acquisition and preparation of the received TM to be processed by the baseband equipment. This is briefly described in section 2.1 below;
- Antenna Tracking Subsystem, to maintain the antenna RF communication axis pointing as close as possible to the direction of maximum received power. This is briefly described in section 2.2 below.

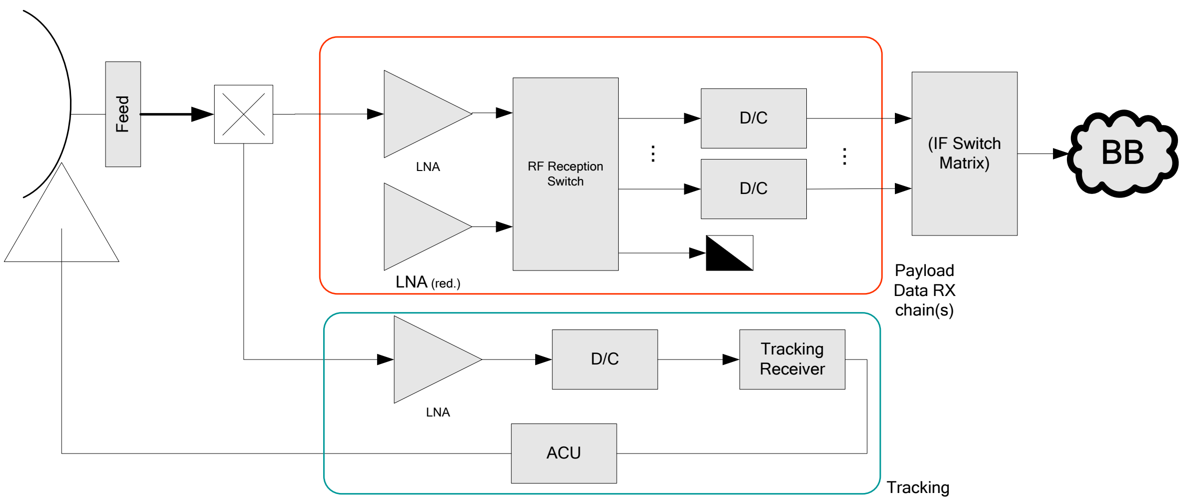

Figure 2-1 – RF architecture for the MDA Station

2.1 Data Reception Subsystem

The data reception chains, shown in the Figure 2-1 above, include at least, the following elements:

- **Low-noise Amplifiers (LNA's)**. This element follows the antenna and the feed in the reception chain and, consequently, is the driver in terms of noise imposed on the received signal. For this reason, the gain and noise figure of the LNA's shall be in line with the required G/T value for the station. The LNA's are normally installed in a hot-redundant configuration;

- **RF Switch**. This equipment selects the chain which receives signals from the antenna feed. All other signals are routed to a matched load to prevent reflection effects;

- **Down-converters**. This element is in charge of converting the RF signal into IF in L-Band and passing it to the baseband units for demodulation and processing. The frequency step required is normally, at least, 1 KHz. The station frequency reference shall be used for the synthesizer with a failover mechanism to a local oscillator;
- **IF Matrix**. The IF matrix function is capable of routing IF signals from the down-converters to the baseband units. These switches normally implement convenient redundancy and failover policies to ensure the appropriate availability at facility level.

It is important, therefore, that noise, inter-modulation and distortion are maintained as low as possible to cope with the C/No and C/I requirements in the link budget, namely in terms of:

- Harmonics and spurious
- Phase Noise
- Inter-modulation products
- Group delay

These parameters are specified for each element of the chain and contribute to the overall performance of the link. Consequently, they must be designed in such a way that the overall gain/noise is within specified limits and in accordance with [ECSS-ST-50-05C Rev1].

2.2 Antenna pointing and tracking Subsystem

In this section the components that influence the pointing and tracking performance of the antenna are discussed. The aim is not to impose any design, but to provide a high level architecture to be considered as a baseline for the specification process. The final architecture and design of the entire sub-system will rely on the current capabilities within industry involved in the development of Ka-Band antenna systems.
As stated earlier, the tracking system has to be able to cope with a signal of approximately 400 MHz bandwidth.

2.2.1 Introduction

The geostationary satellites – like MTG - move in the north-south direction over a period of 24 hours due to having non-zero inclination. Over the same period east-west and radial displacement occur due to the non-zero eccentricity of the orbit. This longitudinal drift is continuous over a long-term – either in one direction or the other - depending on the longitude of the satellite. In the case of Meteosat at 0^o longitude, this drift would be eastward. The amplitude of these overall orbital perturbations is specified by the station-keeping window. It is necessary to be able to point accurately towards this window and then to track the satellite movements within it.

2.2.2 Performance requirements

According to the relevant requirements within the MTG link budget, the Ka-Band ground station antennas are expected to have a G/T better than 34 dB/K. This value is calculated assuming that the system noise temperature has a value of 500 K. This value is achieved assuming clear sky noise temperature of 140 K – at an elevation of 30^{o} – and the gain of the antenna to be approximately 62 dBi.
The antenna is also expected to cope with wind velocity up to 110 km/h (TBC) and with wind gusts up to 130 km/h without degradation in the required pointing accuracy performance.

2.2.3 Operational requirements

It is expected that the following requirements on the performance can be fulfilled by the pointing/tracking solution considered for the MDA station:

Full mission performance for the following “typical” and “nominal” cases and degraded for the “high” satellite inclination cases:

It shall be possible to control the position of each satellite within the nominal orbital slot of +/-0.1 deg (longitude), around its assigned orbital position, and a TYPICAL inclination of +/-0.5 deg;

The mission performance requirements shall be fully met for a NOMINAL inclination up to +/- 1 deg;

The satellite shall be capable of operation with degraded performance for HIGH orbital inclination of up to +/- 2.5 deg.

2.2.4 Mechanical Considerations

It is clear, therefore, from the statements above that the Ka-Band earth station antenna sub-system has to be able to be pointed to and steered over the expected movement window of the satellite. (It is also required that the antenna can be steered at least over the *nominal longitude range of 10W to 10E* specified for MTG satellites). The ability to be able to “see and follow” the satellite at all times becomes more important as the size of the antenna and the operating frequency of the station increases. The antenna subsystem envisaged for the Ka-Band stations is expected to have a diameter of 6.3m and, therefore, the calculations presented in this TEN, an antenna of this diameter has been assumed.

As the ability to point the antenna in the desired direction is mainly influenced by the mechanical design, the following main factors have to be taken into account:

- The geometrical optics of the reflector and feed system – i.e. feed alignment;
- The antenna mount supporting this electrical assembly – usually on two orthogonal movable axes (Azimuth and Elevation);
- The driving mechanism – i.e. the motors and servos;
- Surface accuracy of the reflectors

The other factors that bear influence on the pointing accuracy (although to a lower extent) fall under the following two headings:

- Bias Error : This includes axis alignment, orthogonality and structural deformation
- Random Errors: These have a “static” component – e.g. gear backlash, thermal deformation and encoder resolution – and a “dynamic” component – e.g. variation in propagation conditions especially wind torque gusts.

Detailed analysis/quantification of these contributory factors to the overall pointing accuracy is outside the scope of this TEN.

The antennas to be used in the MDA stations may have Cassegrain (TBC) geometric configuration- based on an elevation over azimuth mount and be fully steerable. The working frequency band is within the Earth Exploration-Satellite services, between 26.2 GHz and 27 GHz, and the ground stations shall be designed to be receive-only.

The next section examines, however, how the pointing accuracy is calculated given the pointing losses assumed in the MTG downlink budget and the figures available for an existing antenna.

3 ANTENNA POINTING AND TRACKING ANALYSIS

The most relevant parameters defining an antenna are gain, radiation pattern and the polarization isolation. The gain is defined relative to isotropic gain, the radiation pattern is imposed to limit the interference to/from other satellites and the polarization isolation determines the ability of an antenna to operate in a system with frequency re-use by orthogonal polarisation – as is the case with the MTG series.

The radiation pattern of the antennas consists of main lobe and side-lobes. To limit the sidelobes – and hence interference – two reference diagram has been proposed by the ITU for 2-30 GHz systems. These recommendations are ITU-R S.580 and S.465 (for 90% of the side-lobe peaks) and are jointly defined as follows:

$$G = \begin{cases} 29 - 25\log\theta, & \theta_1 < \theta < 20^\circ, \theta_1 = \max\{1, 100\lambda / D\} \\ 32 - 25\log\theta, & 20^\circ < \theta < 48^\circ \\ -10, & 48^\circ < \theta < 180^\circ \end{cases} \quad \text{[dBi]}$$

Where D is the reflector diameter and $\lambda = c / f$ is the RF wavelength (c = 3e8 m/s and f is the frequency of the signal, in Hz).

As for the value of the beam-width corresponding to a certain reflector diameter for a standard reflector antenna, there exists a formula – see section 3.1 below.

Polarization, shall de circular – in accordance with the standard [ECSS-E-50-05]. The cross-polar isolation for all the unwanted signals shall be at least 30 dB below the co-polar component - within the 1 dB contour of the radiation pattern.

The tracking chain is similar to the other reception chains but the tracking signal is not delivered to the baseband units. The tracking signal, generated when the antenna pointing of the station is not aligned with the receiving waveguide axis, is delivered to the Tracking Rx – which generates the correction signals that are passed to the Antenna Control Unit (ACU) for adjusting the azimuth and elevation angles in order to re-point the antenna to the satellite. This is explained in more detail in section 4.2.

It is also expected that ACU shall be able to track a satellite with a drift rate of 5°/day - i.e. the ACU shall be able to steer the antenna with sufficient velocity and acceleration to cope with this value of satellite drift during the LEOP phase.

3.1 Pointing Accuracy Analysis

By definition, the pointing accuracy is the space angle difference between the direction towards which the antenna communication RF axis is pointed and the actual position shown on the display of the ACU. For maximum pointing accuracy, the antenna must receive the signal at the peak of its 3 dB beam-width (HPBW).

The HPBW of the antenna is defined:

$\boldsymbol{\theta_0 = 70\ (\lambda/D)}$, where λ is the wavelength and D is the diameter of the antenna (6.3m).

For the worse case, the frequency of MTG payload downlink is 27 GHz and this gives a wavelength of 0.0111 meter. The HPBW, $\boldsymbol{\theta_0}$, is, therefore, equal to: $\mathbf{0.12^0}$.

The loss in gain, ΔG, due to the misalignment of the antenna beam with the RF axis of the satellite is given as follows:

$\boldsymbol{\Delta G = -12\ (\Delta\theta/\theta_0)^2}$, where $\Delta\theta$ is the deviation from bore-sight and θ_0 is the HPBW.

3.2 Pointing Error budget

One of the most important parameters of any communication antenna is the accuracy with which it is able to point to the satellite. As in any complex system, this parameter – known as the pointing error budget - is derived from the several contributory factors originating from it's components. The table below shows an approximate value for the pointing loss budget for a 6.3 m antenna – taking into account all the above contributory factors. The two columns on the R.H.S show the error in each axis. The row at the end gives the total pointing error and is calculated using RSS (since the variations are uncorrelated) to be 0.01751 degrees.

Parameter	Az	El
Orthogonality AZ/EL-axis	0,00550	0,00550
Encoder calibration	0,00212	0,00212
Beam squint	0,00000	0,00000
Deformation by temperature	0,00250	0,00250
Algebraically added bias errors	0,00000	0,00300
Sum of Bias Errors	**0,00943**	**0,01112**
AZ-axis wobble	0,00003	0,00300
Backlash of drive units	0,00000	0,00500
Encoder mounting/gearing	0,00087	0,00074
Asymmetrical drive torque	0,00000	0,00000
Encoder precision	0,00140	0,00140
Encoder resolution, 19 bit	0,00070	0,00070
Servo offset & noise	0,00513	0,00513
Velocity lag	0,00008	0,00008
Acceleration lag	0,00010	0,00010
Servo loop limit cycle	0,00070	0,00070
RSS Random Errors	**0,00549**	**0,00799**
Pointing Error per Axis	0,01091	0,01370
TOTAL POINTING ERROR		**0,01751**

This gives the **total pointing loss,** using the above formula**,** to be = $-12\ (0.01751/0.12)^2$= **0.255 dB. (**Note: This value has been calculated assuming "zero wind" conditions.)

When mean wind speed of 75 km/h and gusts up to 100 km/h are taken into account, the **total pointing loss** increases to be = $-12\ (0.04364/0.12)^2$ = **1.58 dB.**

It should be noted that a tracking solution – if implemented - would result in much lower signal loss than would be achieved by pointing only.

4 TYPICAL SOLUTIONS

The Ka-band antenna will be used to accurately point and track the MTG satellite. There are some techniques that are "typically" employed to achieve this objective – and are implemented in a variety of ways. This section explains two of the most commonly used implementations for this kind of application. These are:

- Programmed tracking and
- Monopulse tracking

4.1 Programmed Tracking

With this approach, antenna pointing/tracking is achieved by providing the control system - Tracking Rx and Antenna Control Unit (ACU) – with the corresponding values for azimuth and elevation angles at given instances. These Az and El angles are calculated in advance – by taking into account the predicted apparent movement of the satellite - and these values are then stored in the memory of the Tracking Rx. The pointing is then performed in open loop without determination of the error of the space angle difference between the direction the antenna communication RF axis points towards and the actual position on the display of the ACU.

The pointing error in this case depends mainly on the accuracy with which the apparent motion of the satellite is known, the ability of the algorithms within the Tracking Rx to be able to process the predicted orbital information and the accuracy with which pointing in a given direction is achieved by the antenna system.

4.2 Monopulse Tracking

In this case, the Ka-band tracking system uses the wideband signal transmitted by the satellite as reference for precise tracking - by closing the tracking loop. This tracking allows operation of the antenna autonomously in case that the orbital vectors are not available.

The antenna normally uses a dual channel monopulse tracking chain including TRK LNA, dual TRK D/C, TRK Receiver, ACU and three axes servo system (Az, El and Pol). A monopulse Tracking Coupler located in the antenna feed is used to extract and combine in quadrature the elevation and azimuth pointing errors produced – from the higher order modes generated within the waveguide when the antenna is mispointed - into a delta channel route. This delta channel is subsequently amplified by the Tracking LNA. Both channels, the delta and the sampled of the sum channel, are routed into the dual channel tracking D/C and then to the Tracking Rx. The dual TRK Receiver demodulates and extracts the elevation and azimuth pointing errors and converts them into error voltages before sending to the ACU. These voltages are sent by the ACU to the motors that re-align the antenna to the boresight.

One of the critical factors of this system is the minimum C/No – the ratio of carrier power to the noise power spectral density - that the Tracking Rx is able to process. This value is calculated using the transmitted power from the satellite, the space loss and the gain-to-noise temperature (G/T) of the receiving antenna. It is understood that the currently available Tracking Rx require a minimum value for C/No of 35 dBHz (TBC).

A GPS system is normally used to provide time reference to the ACU and Computers and frequency reference to the Tracking Receiver.

5 CONCLUSIONS

In conclusion, it can be stated that some possible solutions to the current pointing/tracking requirement for ground stations operating in the "nominal" Ka-Band are already available. However, the MDA antenna requirements present some differences from the COTS products available in the market. These differences are the "new" frequency band (26.2 to 27 GHz) and the 400 MHz wideband satellite signal that must be used for tracking. An additional constraint that may affect the antenna performance – especially in extreme wind conditions - is that it will be mounted on the roof of a 20 m high building – see below.

It is likely that these differences may have to be resolved by tailoring or development of currently existing solutions.