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C Band Telemetry Tests Results.

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ABSTRACT

The purpose of this paper is to show how Airbus Defence and Space has developed its initial C Band Telemetry capabilities for Flight Test and the final results and conclusions obtained during the C band telemetry campaign. New dual transmission and reception telemetry chains have been validated both capable to work in S or C Band. Also, a new telemetry model in C band has been assessed in order to predict telemetry behavior and quality of the link (coverage, bit error rate...) taking into account different modulations and data rates.

The first modified telemetry station in order to receive in C band has been the Telemetry Mobile Station of Airbus Military, with an antenna of 5 feet diameter and with a new dual band feeder.

The main objectives of the C band test campaign are:

• Optimize the antenna alignment to the target in order to meet the thinner reception lobe in C band, about 2.8 degrees, compared to the 5 degrees previously used in S Band.

• Test new scenarios combining PCM/FM (Pulse Code Modulation / Frequency Modulation is n used in all the tests in S band up to today) and SOQPSK modulation with new data rates from 4 Mbps up to 20 Mbps.

• Link Budget model characterization and validation.

This paper describes the starting point (theoretical mathematical model of the C band Link) and the arrival point (real and validated mathematical model based on the results).

Key words: C Band, SOQPSK, Telemetry, PCM/FM, Feeder, Coverage, Antenna

New Rules on Frequency Spectral Range.

New rules on frequency spectral range arose from Resolution 418 passed in the World Radiocommunication Conference 2007 in Geneva.

C Band from 5091 to 5250 MHz is allocated for Aeronautical Mobile Telemetry, limiting its application to flight test "of aircraft for non-commercial flights for the development, evaluation and certification of aircraft".

Current Status of Telemetry Systems.

Airbus Defence (Spain) offers a complete Telemetry System consisting of 2 interconnected Telemetry Main Centers (Getafe and Seville) and 4 remote Telemetry Stations hanging from Seville Telemetry Center.

Telemetry Band and Modulation used by Airbus Military prototypes is:

Prototype	Band	Modulation
A310 Aerial Refueling Boom System	2.3 – 2.4 GHz	PCM / FM
A330 Multi Role Tanker Transport		
Eurofighter (IPA4 & ISPA3)		
A400M	2.7 – 2.8 GHZ	COFDM

Table 1. Airbus Military Prototypes, Telemetry Band and Modulation.

C Band Migration Plan.

C Band Migration Plan must meet the current legislation and be compatible with the use of 2.7-2.8 GHz band (unknown real date end of A400M tests).

Airbus Defence decided to implement an incremental movement to dual S&C Band. Incremental acquisitions of new receivers in C Band will cause higher costs.It is possible a fully alignment with the upgrade of the fleet of prototypes in C band.

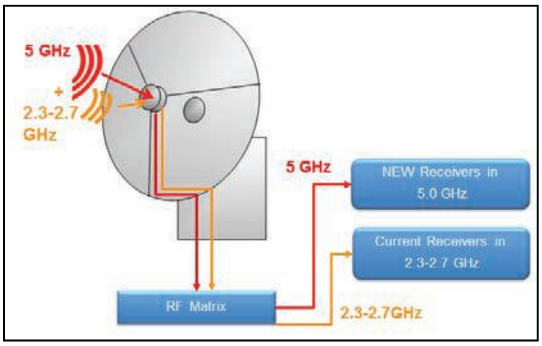

Fig.1.Airbus Military C Band Upgrading.

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Dual Band Antenna Design

An initial upgrade of the 5 feet Telemetry Antenna of the Mobile Station will be implemented in order to receive in S & C Band simultaneously.

It involves a new design of the feeder and the integration of new control systems. Emphasize the idea of creating a new design of S&C band taking into account the risk of the designation of this project to a Spanish telemetry supplier (PRODETEL) in collaboration with the Carlos III University. The upgrading of the rest Telemetry Systems will be incremental once the S&C model is validated.

First preliminary designs of a dual band antenna were *printed dual band antennas*. Printed antennas are very attractive elements in the RF and microwave frequency region because of their friendly manufacturing, low cost, polarization purity, and low-profile properties.

The following constraints must be satisfied at the time of designing the new antenna:

- 3 bands must be covered (2.3 to 2.4 GHz, 2.7 to 2.8 GHz,5.0 to 5.3 GHz)
- S11 < - 10 dB (< -15 dB desirable).
- Suitable radiation pattern to illuminate a parabolic reflector.
- High G/T.
- Lobe angle as wide as possible.
- High Isolation between ports.
- Gains around 30 dBi in C Band and maintaining S Band current gain (around 29 dBi).

After several iterations needed, the third simulated prototype, a printed Coplanar Antenna was the best design with the best theoretical results.

Different measurements, carried out in the anechoic chamber, enable us to optimize the focal length. Not only will the focal length be fixed, also the reception of the antenna in far field will be simulated.The results obtained from the anechoic chamber bring us new values of the reception lobules and gains at different RF Bands. Due to C Band high frequency and current parabolic reflector shape, main beam amplitude in degrees is very narrow, 2.8 degrees at 1.5m reflector, compares to 5 degrees in S Band. This will impose a very good pointing mechanism/algorithm..

In order to reuse the S band receivers a downconverter step has been included in the reception chain. It includes a Phase locked Coaxial Resonator Oscillator which downloads the whole band from 5.091 - 5250 MHz to 2200 – 2380 MHz with a traslation frequency of 2850 MHz.

Link Budget.

Link budget is a relatively addition and subtraction of gains and losses within an RF link. a formal way of calculating the expected received signal to noise ratio (SNR).

To be able to predict telemetry behaviour and quality of the link (Signal to Noise Ratio, coverage, bit error rate...) it is neccesary to validate the Link Budget Model.

Link budgets begins with the transmitter power and sum all the gains and losses in the system accounting for the propagation losses to find the received power. Then the noise level at the receiver is estimated and SNR is taken.

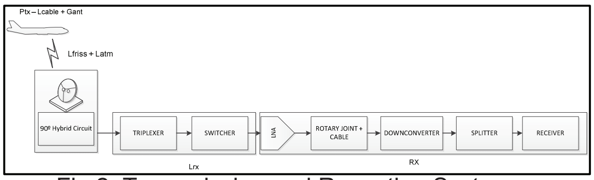

Fig.2 Transmission and Reception System.

$$P_{rx} = P_{tx} - L_{cable_{tx}} + G_{tx} - L_{txFriss} - L_{atm} + G_{rx} - L_{rx} + G_{LNA} - L_{cable_{rx}} + G_{DC} - L_{splitter} - L_{margin}$$

Most values of the above equation are known and have been measured but some of them depend of several factors.

- Path Losses (LFriss):

LFriss (dB) = 20 log (d km) + 20 log (f GHz) + 92.45

Fade Margin becomes necessary to account for the unpredictable changes in RF signal levels at the receiver. This value will be a precise measurement of the robustness of our Link. The higher this value is higher margin to ensure system quality, in this case measured by the BER.

The radiation pattern of both transmitter antennas have been implemented in our link budget taking into account the angle of the beam between the antenna located on board and the telemetry reception antenna on ground. Pith, Roll and Yaw position are measured in real time and sent via telemetry link to ground, the beam between transmission and reception antennas will point the aircraft in a different angle according to the 3 values of these parameters and the

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transmission gain (or loss) will change in real time. Due to this condition it is necessary predict this transmission gain and incorporate its value to calculate the radio-electrical coverage in real time.

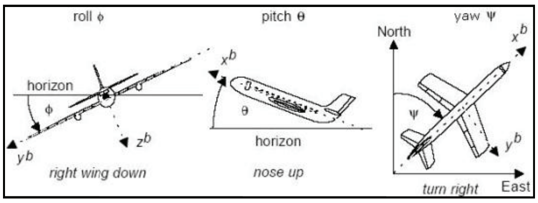

Fig.3 Pitch, Roll and Yaw parameters.

Some values of different variables of this equation have been measured, anothers must be calculated. Thanks to all the estimated behaviour and measured values of the transmission and reception chain it will be possible to calculate our theoretical Signal to Noise Ratio (SNR) in function of the distance from the aircraft to our base station. This theoretical SNR value will be compare with the real SNR value obtained from our measures on ground.

$$SNR_{dB} = S - N = \frac{Eb}{No} \times \frac{Bit\ Rate}{BW} = \frac{Eb}{No} \times \frac{1}{\eta}$$

where BW = η x Bit Rate

Eb/No must ensured BEP <1E-05.

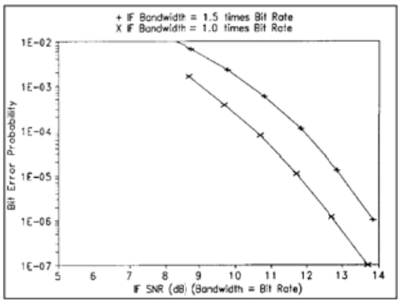

Fig. 4 (Eb /No) vs Bit Error Probability

SNR= (Eb/No) x (Bit Rate / BW) = (Eb / No) / η (dB) = S - N (dB)

Where:

- η is the spectral efficiency of the modulation. (1,16 for PCM.FM and 0.78 for SOQPSK)
- S = Prx = f (distance, fade margin)
- N: Noise Power at the input of the receiver. Given by the noise of all the equipment of the reception chain. It must be calculated and this value is fixed for our system.

Scenarios:

- Fade Margin and BEP (Eb/No) fixed → Maximum theoretical radio electrical coverage (distance between target and ground station) is calculated.
- Fade Margin and Distance fixed → Different BEP (Eb/No) zones are estimated.
- Maximum effective coverage is reached for a fixed value of BEP → Fade Margin value is calculated.

FM - Banda C Móvil	
Concepto	Valor
Banda (Ghz)	5,131
Modulation	FM-PCM
EficienciaEspectral	1,16
Eb/No - 10-5 BER	11,8
TX Power (dBm)	43
TX Antenna Gain	0
TX Chain losses	0,3
RX Antenna Gain	31
RX Chain losses	1,15
Receptor Noise Figure	2,14
Bit Rate	4000000
Fade Margin Rqst (db)	15
BW=Bit Rate · Eff Espectral	4640000
SNR = Eb/No * (Bit Rate/BW) = Eb/No * 1/Eff Espectral	11,15542
Ntotal (Nc + Fr)	-103,64299
S (Signal Power) = SNR + Ntotal	-92,487565
Prx=Ptx-Ltx+Gtx-Lmg+Grx-Lrx+Grx	151,18756
KM : Lfs =20Log(f, Ghz) + 20Log(d, km) + 92,45	168,52962
Millas náuticas	90,998713

Fig. 5 Link Budget Calculation.

Analysis Tools.

On board the aircraft will send - telemetry link - IENA packets related to:

GPS data to point with accuracy towards the target. Roll, Yaw and Pitch position of the aircraft to simulate the transmission gain according to the beam between the telemetry reception antenna and the aircraft.

Status and Control of the transmitters and multiplexer like controlling power transmission, modulation, rate and frequency of the transmitters.

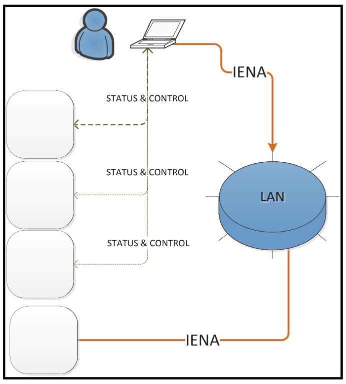

Fig.6 On board Analysis Tools.

On ground several software tools have been developed to log and to send in real time IENA packets like:

- Status of the receiver (Signal Strength Meter and rate configured.

- Status of the De-multiplexer (CRC errors).
- Level of the RF Signal received. Spectrum Analyzer connected to our LAN and sending IENA packets with the status of SNR values.
- Link Budget tool. Simulates according with the Position (Roll, yaw and pitch) of the aircraft and the distance from it the theoretical Radio-electrical Coverage.

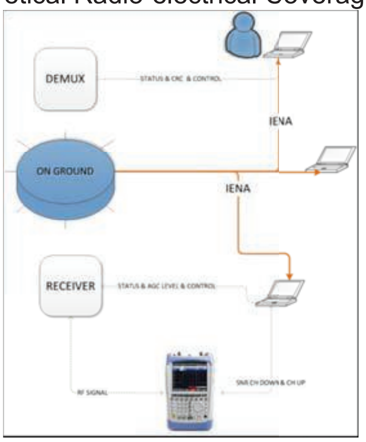

Fig. 7 On ground Analysis Tools.

C Band Test Campaign.

At the moment, C Band Telemetry Campaign is still on going and only 5 flights have been dedicated to C band study. Main goals are:

- Test new scenarios combining PCM/FM and SOQPSK modulation with new data rates from 4 Mbps up to 15 Mbps.
- Characterize and validate the theoretical model Link Budget of the C Band System.
- Validation of Transmission Antenna Radiation Pattern.

A C-295 instrumented aircraft is equiped with a dual S&C transmission chain to cover this campaign. The first measures of the frequency spectrum in C Band with our Telemetry S&C antenna located in the facilities of Airbus Defence in Seville presents a noisy spectrum.

Due to this noisy frequency spectrum around the mobile station in Seville, the frequencies 5131 & 5167 MHz were assigned to use in our campaign are located inside the zones where the noise is under -90 dBm for all azimuths.

Six different scenarios are scheduled in this campaign to complete the characterization of the new S & C Telemetry System.

SCENARIO	Freq	MOD	RATE
0	2306 & 2355 MHz	FM	4
1	5131 & 5167 MHz		4
2			6
3			12
4		SOQPSK	12
5			15

Fig. 9 Scenarios.

For each of the above scenarios, the aircraft must move away from the base station at highest possible altitude (to avoid line of sight limit) and following a constant radial.

The trajectory (pitch < 5º and roll around 0º) must be a racetrack that will begin once is reached the 60% of the theoretical radio-electrical range and will not end until we reach the maximum radio-electrical coverage. For each scenario 2 tracks should be performed to verify the actual radio-electrical range with higher reliability.

Within the scenario number 1 (see the table above) and already known the theoretical radio-electrical coverage for this scenario we must check the consistent of the reception level according with the Antenna Radiation Pattern. The Aircraft must perform a couple of “lazy eight maneuver” always within the radio-electrical range and at different bank angles of 15 and 30 degrees, in order to record possible zeros in magnitude (in reception).

Results.

Different tests will be developed to validate our system. Tests to validate Antenna Radiation Pattern logging in real time Signal to Noise Ratio values at both channels and compare it with the theoretical SNR according to specific values of Pitch, Roll and Yaw of the aircraft and tests to validate our Link Budget Model. Finding out the maximum radio-electrical coverage and comparing it with the theoretical coverage, once a link margin is established.

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We are in the period of validation of our system until the end of summer and we continue with tests in C band. To date only 5 flights have been dedicated to test C Band System, 4 and 6 Mbps have been tests, and PCM-FM and COFDM modulation has been tested.

The results cannot be cataloged yet conclusive, but indicate how will evolve the following tests and robustness of the telemetry system.

Three of the five tests of C295 performed will be detailed below.

FLIGHT F1109-C295

4 Mbps // PCM-FM

Slots: S Band: 10:17 → 12:25 UTC

C Band: 12:25 → 12:53 UTC

All the way back to the base station holds SNR levels above the minimum B.E.R. of 1E-5.

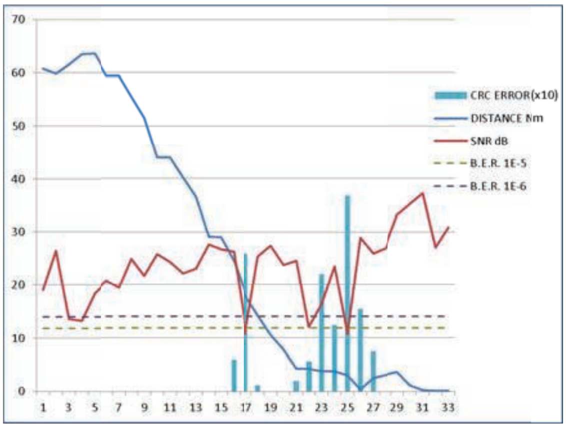

Fig. 10 SNR vs CRC (Cyclic redundancy check)

CRC errors arise once SNR is under 11.8 dB (limit 1E-5 B.E.R.) due to Pitch, Roll and Yaw values, where critical lacks of transmission power comes in a shadow zone.

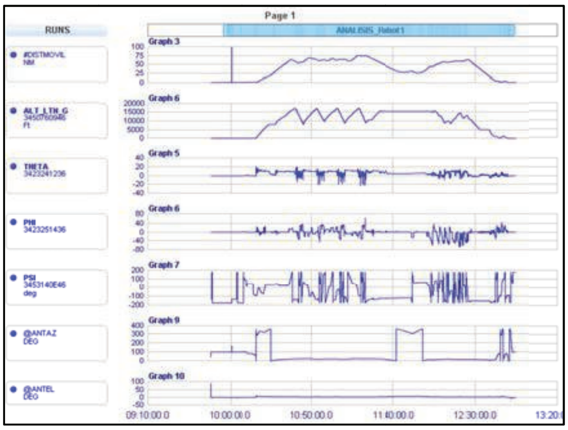

Fig. 11 Pitch Yaw and Roll values

Areas where the transmission losses were not significant, due to the correct position of the aircraft, signal to noise values were high enough to be continuously in areas with bit error rate (B.E.R.) less than 1E-6.

FLIGHT F1110-C295

4 Mbps // PCM-FM

Duration C Band period: 06:17 → 06:55 UTC

Ferry to Berlin from Seville. During the flight the aircraft got its back to the base station so the upper antenna of the aircraft was in line of sight of the reception antenna and the reception from the lower antenna was very poor as we can check at the graphics below.

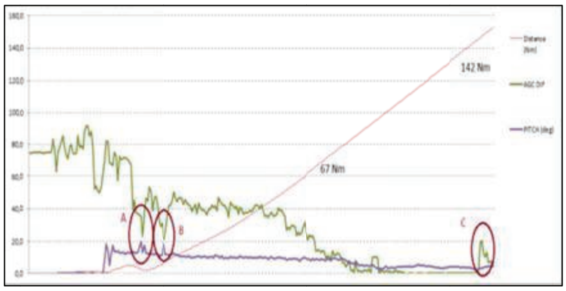

Fig. 12 AGC Level versus Pitch degrees.

At the figure above we can check the correlation between high Pitch values and falls of the AGC signal. At A, B and C points the beam from the reception antenna towards the radiation pattern causes some dB losses and integrating this losses values into our Link Budget model we find out a theoretical maximum radio-electrical coverage of 65 Nm and the telemetry was lost at 67Nm.

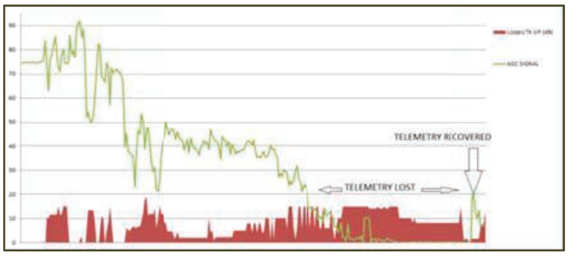

Fig. 13 AGC Level vs.Upper Antenna losses

At the picture above it is possible to check the period when telemetry is lost, losses of the transmitter (caused by the Pitch of the Aircraft) are very high, around 15 dB. Once these losses get down to values around 3 dB telemetry is recovered at a distance of 142 Nm, but some miles after when the losses increase again telemetry is lost.

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FLIGHT F1112-C295

4 Mbps // PCM-FM

Duration C Band period: 07:59 → 10:28 UTC

"Approach to stall" dedicated Flight at low altitude, what implies severe changes in Pitch, Yaw and Roll values of the target and high changes in the transmission gain (losses).

Due to low altitude during a period of time there is a lack of telemetry link, under 3000 feet of altitude (see next picture).

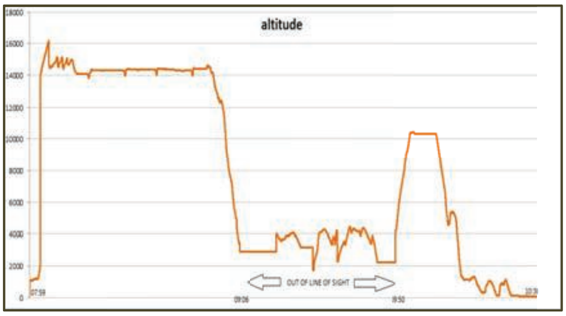

Fig. 14 Altitude

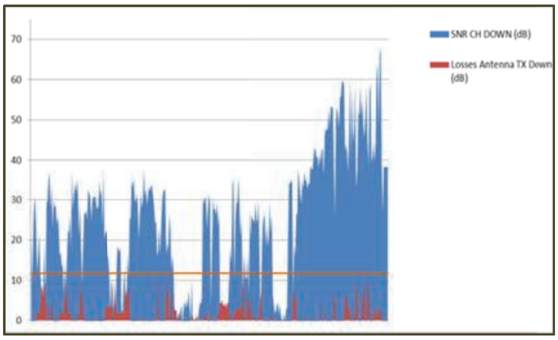

Fig. 15 SNR CH DOWN versus Losses CH DOWN

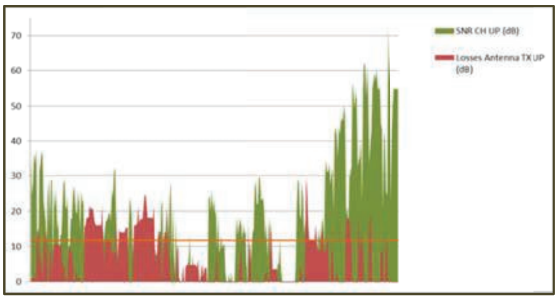

Fig. 16 SNR CH UP versus Losses CH UP

During all the flight (except the period with altitude under 3000 feet) the combiner of the receiver switch (when necessary) to the high level of the receiver signal (from upper or lower antenna). As you can see at the picture below during the period above 3000 feet always SNR were above 11,8 dB, limit of the 1E-5 B.E.R.

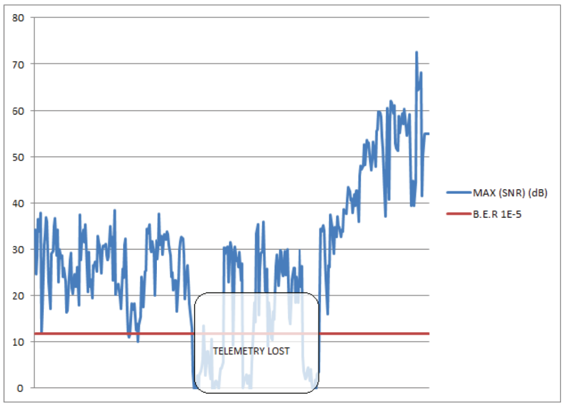

Fig. 17 SNR COMBINED

Preliminary Conclusions.

- Inside line of sight and with the target in position of usual values of pitch, yaw and roll, the behavior of the reception telemetry system is very acceptable with Signal to Noise values above the minimum require for a B.E.R. < 10^{-5}.
- Rates of 6 Mbps only has been tested during short slots of some flights back to the base station with similar good behavior of the system.
- Some dedicated flights, one per each scenario, has been re-schedule to June 2014, due to some delays. During those flights maximum coverage will be checked and compared to the theoretical radioelectrical coverage obtained from our Link Budget.
- To date, **142 Nm** has been achieved with the configuration of 4 Mbps and PCM/FM.
- Note: the first flight followed by our Telemetry System was a ferry of the A400M from Toulouse to Sevilla and started to receive COFDM signal **162 Nm** far from the base station.

Glossary

B.E.R.: bit error rate

C.R.C: cyclic redundancy check

SOQPSK: shaped offset quadrature phase-shift keying

PCM: Pulse Code Modulation

SNR: signal to noise