TRENDS IN AERONAUTICAL WIDEBAND TELEMETRY APPLICABLE TO SCIENCE MISSIONS WITH AIRCRAFT & BALLOON

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ABSTRACT

Based on Action Item 1.5 and the relevant investigations and studies, the World Radiocommunication Conference (WRC 2007) decided upon new additional frequency spectrum allocations for Aeronautical Mobile Telemetry (AMT).

Four new frequency bands in the range from 4400 to 6700 MHz have been allocated to the Aeronautical Mobile Service (AMS) on a co-primary basis, limited to AMT for flight testing . The range from 5091 to 5150 MHz may be used worldwide, allowing the implication of wide band telemetry links and helping the international cooperation & standardisation in flight missions.

After reviewing the resolutions COM 4/2 and COM 4/7 of the WRC 2007 it is realized that C-Band becomes an attractive band for AMT. A typical C-band link inclusive wave propagation effects is being analysed.

Components & systems for either a new state-of-the-art equipment or for the upgrade of existing systems (in L-or S-Band) are already in work. One area of concern requiring an up front evaluation is tracking algorithms and mechanical tracking systems that operate specifically in C-Band.

1. INTRODUCTION

Radio Telemetry, Tracking & Command (TTC) services are an essential “real-time backbone” service for flight test missions with aircraft, balloon, satellite, sounding rocket or unattended flight systems (UAS). The tendency goes continuously to increasing data rates, due to more system complexity, an improved sensor technology with more channels and a better amplitude & time resolution.

Increased demand for telemetry spectrum parallels the demand in the general telecommunications industry. Beside the commercial flight test programmes also missions in earth sciences that use manned and unmanned aircraft and long duration balloon flights will be concerned by the increasing use of high definition video, synthetic aperture radars or wideband spectrometers.

In recognition of the expected extraordinary growth in data rates, the telemetering community was aggressively investigating various techniques which, together or in combination hold the potential to reduce the rate of growth in bandwidth needs. These include modulation and coding techniques and application of networking technologies with an increased use on-board processed and buffered data, delivered on demand only.

An international non-profit committee of aerospace telemetry practitioners, the **International Consortium for Telemetry Spectrum (ICTS)** supported a request for allocation of additional frequency spectrum for high-bit rate aeronautical telemetry [1] .
Fortunately the World Communications Conference “WRC 2007” decided to allocate additional spectrum to the Aeronautical Mobile Service (AMS) on a co-primary basis, limited to aeronautical mobile telemetry (resolutions COM 4/2 and COM 4/7). In ITU-region 1 (Europe & Africa) additional 149 MHz will be now allocable in C-band (5091 to 5250 MHz).

The exploitation process of that new C-band range was immediately initiated by the international flight test community. It may be also an attractive band to be considered for the medium and long term planning of aeronautical science missions, especially with (manned and unmanned) aircraft and balloon, having mostly flight test character.

Components and systems for either new state-of-the-art equipment or for the upgrade of existing ground and on-board (L- or S-band) systems are already available or at least, in work. The influence of wave propagation effects are already known from C-band RADAR operations. But the nature of a telemetry signal is very different from that of a RADAR. Therefore signal tracking algorithms and procedures have to be still basically evaluated.

2. PREPARING THE WRC 2007

Telemetry is critical to the international aerospace industry because it increases efficiencies and revenues, reduces product cost, decreases time-to-market, and reduces safety risks. The future health of the aeronautical Industry is reliant upon the availability of sufficient telemetry spectrum [2]. From the mid -1990’s the U.S. National Aeronautics and Space Administration (NASA)

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recognised that they would not have enough telemetry spectrum available to test the many new vehicles that were on the drawing boards at that time. They proposed that telemetry be permitted in a band somewhere between 3 GHz and 30 GHz. This proposal was eventually accepted for consideration by the International Telecommunications Union (ITU) at WRC-97. The vote on the proposal has been deferred several times and the WRC in 2003 decided (Resolution 230), to include the topic of possible additional spectrum allocations for aeronautical telecommand and telemetry as Agenda Item 1.5 for the WRC 2007.

Spectrum encroachment has become an international issue as a result of increased commercial interest. The International Consortium for Telemetry Spectrum (ICTS) was chartered under the sponsorship of the International Foundation for Telemetering (IFT). The IFT exercises oversight responsibility and authority of this consortium and provides administrative, policy, and programmatic approval. The ICTS was formed in response to the need for an international coalition of telemetry practitioners who share a common goal of ensuring the availability of electromagnetic spectrum for telemetering. Under no circumstances shall the issues within their respective organisations ICTS publish, present, or in any other way represent a position on spectrum issues. However, the information shared within the ICTS will enable telemetry practitioners to effectively respond to spectrum issues and help their national representatives develop an information position on this agenda point.

Since 2003 an extensive public relations campaign was initialized by the ICTS. This included presenting paper at international conferences, conducting workshops, and meeting with industry and government officials. Key support for the ICTS was provided by the Central Test & Evaluation Investment Program (CTEIP) Office, the US Navy, the US Air Force, the International Foundation for Telemetering (IFT), and the Aeronautical Flight Test Radio Consulting Committee (AFTRCC, commercial aircraft manufactures). Without their help, sponsorship, and funding the outreach efforts of the ICTS would have been impossible.
While the ICTS had accelerated their outreach activities, they could only effectively contact a small number of administrations. By targeting influential countries in specific regions we were able to project our power well and were approaching the 2007 WRC with a significant backing, although short of a majority. Several countries and ITU officials recommended the ICTS provide an information booth at the WRC. With funding and support from our sponsors (including several international airplane manufactures and corporations) we successfully manned a booth that have over 700 visitors during the Conference and was credited by several administrations (US, Brazil, France, Germany, UK, and others) with the successful debate and understanding of this agenda item.

3. WRC-07 RESOLUTIONS

The Resolutions COM 4/2 and COM 4/7 of the WRC-07 are summarized in *Table 1*. The indicated frequency bands are allocated to the aeronautical mobile service (AMS) on a co- primary basis, limited to aeronautical mobile telemetry for flight testing by aircraft stations.

The bands have to be shared on a non interference basis with other services (e.g. aeronautical mobile route service AM(R)S, fixed satellite services, fixed services and the microwave landing system (MLS)). This means, that a careful coordination process will be needed for any flight mission in a specific region, supported by telemetry in that (so called C-) band range. Protection zones and power spectral density limitations have to be obeyed [3].
One very positive outcome of the WRC-07 is the fact, that the band 5091 to 5150 MHz may be used worldwide. Now 59 MHz of bandwidth are globally available, helping the international cooperation in flight test missions. All test ranges should aim for their TM (on board and ground) systems upgrades to operate in this harmonized band. In region 1 (Europe & Africa) an additional 100 MHz are allocable in the frequency range from 5150 to 5250 MHz.

4. FLIGHT OPERATIONS IN C-BAND

Although this band is already used at test ranges, e.g. for fixed communication links and Radars, there is little experience with test flight telemetering. Signal quality as a function of free space attenuation, antenna tracking, weather/moisture and reflection/multipath effects, and cost/availability of hardware are different then experienced at the current L and S band systems used today. Some characteristics are worse, some are better.
When changing from the usual S-band (e.g. 2320 MHz: $\lambda_S \sim 13$ cm) to C-band (e.g. 5170 MHz: $\lambda_C \sim 5.8$ cm) the first major concern is an increase of the free space attenuation $\Delta\alpha$ in the link budget of approx. 7 dB.

$$\Delta\alpha = 10 \log (\lambda_S/\lambda_C)^2 \, dB \qquad (1)$$

Antenna tracking in C-band is critical. The narrower beam is more difficult to track then the S-Band currently used. When leaving the antenna apertures constant (as in S-band) a 0 dB antenna (for a wide earth coverage) onboard the test aircraft and an identical diameter of a dish antenna on ground, the additional attenuation could be compensated as the receiving antenna gain is proportional to $1/\lambda^2$ (same dish efficiency assumed). As free space attenuation increase so does the required gain of the receiving antenna. One consequence however is the reduction of the -3dB aperture angle of the ground antenna pattern, that is proportional to $1/\lambda$, in our example a factor of 0.45. This may be a problem for the telemetry tracking of the target and will be one area of future testing to verify if current tracking schemes are applicable in C-band.

Table 1: WRC 2007 allocations for Aeronautical Mobile Telemetry (AM T)

Frequency Band (MHz)	**Total MHz**	**Authorized Region**	**Limitations**	**Comments**
4400 to 4940 MHz	540	**ITU Region 2** (the Americas) with some exceptions that includes Brazil. Australia (in Region 3/Asia & Pacific Rim) is also authorised to operate Aeronautical Mobile Telemetry (AMT)	Non interference basis with the fixed satellite service.	
5091 to 5150 MHz	**59 MHz**	***All ITU Regions***.	Shared on a non interference basis with MLS, Satellite links & security links from aircraft.	Phase changes to introduce Air Navigation systems in this band. Band includes Airport ground links and aeronautical security transmissions.
5150 to 5250 MHz	**100 MHz**	***ITU Region 1*** with the exception of the Arab States. ***Brazil*** (in ITU Region 2) is also authorised to operate AMT in this band.	Must be operated on a non interference basis with other users.	AMT is identified as a primary user in this band.
5925 to 6700 MHz	775 MHz	***ITU Region 2*** with some exceptions that include Brazil.	Non interference basis with fixed satellite services.	
Total Bandwidth	**1474 MHz**		**Bandwidth** has to be **shared** with **other users**. Not 100% available for AMT.	**ITU Region 1: 159 MHZ to share. ITU Region 2: 1374 MHz to share**.

Another point to be considered is the influence of the weather & environment. The worst case of atmospheric loss for 5 GHz links in a wet continental weather region at 40° latitude is 3dB, compared to less than 1dB at the L- and lower S-band region [4]. To maintain the same (99.99%) signal availability as in L-band or S-band, the on-board effective radiated power (ERP) has to be doubled, either by increasing the transmitter power output or the directivity of the antenna pattern. That values have been also cross checked with the ITU-R rain attenuation prediction model [5].

The impact of ground reflections needs also to be addressed. Most parts of flight missions are seen on ground under a low elevation angle (0-10°). As the antenna aperture angle is getting smaller and the relative "roughness" of the environment is proportional to 1/λ (resulting in a conversion of the reflection rays into a more diffuse refraction pattern), their influence could be theoretically less in C-band than in S-band. But that has to be verified in experimental flight tests by doing simultaneous S-band and C-band transmissions and comparing the data.

The availability of C-band hardware is another issue. On the airborne side, small multimode (IRIG-106 standard) transmitters [6] are not yet available in the band of interest though there are existing transmitters that utilize the legacy PCM/FM modulation scheme. On the ground side, it is of the utmost interest of test ranges to utilize existing infrastructures to support C-Band AMT. This will result in existing parabolic receive antennas being retrofitted with an additional feed to support C-Band. There are multiple ways to down convert the received signal and propagate it through to the telemetry receiver. Ideally the telemetry community can concur on one common method to leverage initial telemetry receiver R&D costs as existing telemetry receivers will also need to be retrofitted to tune to the selected down converted signal. The US Range Commander's Council (RCC) is currently considering this [7].

Work has begun to add C-Band receive capability at several major test ranges in the United States. C-Band has been historically used by several agencies in a limited scope. Initial flight trials were accomplished under the Advanced Range Telemetry (ARTM) project in 2004 through the use of existing C-Band receive capabilities and existing airborne transmitters. At that time, no channel anomalies were identified which would cause concern for using

C-Band for AMT. As mentioned above, one area lacking existing products and requiring telemetry vendor R&D is airborne qualified, spectrally efficient, telemetry transmitters. Several vendors are currently funding component developments in that area.

5. CURRENT EFFORTS IN C-BAND TM

The new C-bands are receiving significant attention in the United States and in Europe. At the recent International Telemetry Conference (ITC 2008) held in San Diego [8] several papers and presentations were made by the vendors and the iNET (integrated Network Enhanced Telemetry) project sponsored by the US DOD's Test Resource Management Center's Central Test and Evaluation Investment Program [9]. Topics related to C-Band implementation address several areas such as:

- Forward Error Correction (FEC) codes.
- Ground telemetry antenna systems and C-band.
- Integration of augmented frequency spectrum into spectrum management systems.
- Multi-carrier and single carrier waveforms.
- Multi-mode, multi-band serial streaming telemetry transmitters.
- Serial streaming telemetry platform integration issues with C-band.
- Serial streaming telemetry systems.
- Serial streaming transmitter control interfaces.
- Serial streaming telemetry receiver changes that are required to support C-band.
- Using existing tracking algorithms with C-band.

The primary target C-Band frequencies for the US are 4400-4940 MHz and 5091-5150 MHz. 5972-6700 MHz has implementation difficulties in the US that may delay it's utilization. In Europe the whole allocated bands from 5091 to 5250 MHz will be target for implementation.

Transmitters. Several vendors have initiated efforts to develop a miniaturized airborne multi-band C, L, S band transmitter. Some are doing this on their own, other in association with iNET or other scientific and technology programs from the US DOD. While this is seen as mainly a high risk effort with many hurdles and technical issues to solve it would provide a significant advantage in scheduling flexibility. The ability to schedule/adjust frequency assignments in near-real and real-time can greatly increase the ability to make mission schedules and range availability times. Under a Small Business Innovative Research effort, an effort to develop a L/S multi band transmitter has made good progress and is receiving substantial procurement interest from US customers [9]. An additional effort to expand this approach. To include a C-band multi-mode transmitter is facing some severe challenges address the wide gap between 4400 - 4940 and 5091-5150 (5250) MHz. The end result, as least for the short term, would be to build two transmitters as this may be too wide a gap for an effective power amplifier design.

A lower risk approach, and one which we will probably seen near-term products, is a C-band SST transmitter. With multiple vendors looking at this, the telemetry community should see the benefits of greater competition with a significant reduction in risk. This would reduce the time to deploy C-band devices if the multi-band airborne transmitter development runs into problems.
An additional development seen in the telemetry vendor community is the implementation of standard error correction codes in telemetry devices. Low Density Parity Check (LDPC) codes were invented in the 1960's but almost forgotten about within the telemetry community until the iNET project evaluated potential free-space telemetry error correction codes. The LDPD codes, currently the standard for error correction in applications like cell-phones and inter-planetary communications, were adopted by iNET and will be included in its Communication Links Standard with the intent to incorporate LDPC codes into new C-band airborne transmitters [10].

Antennas. Antennae have also seen a lot of interest in C-Band adoption. Market Research Results at recent trade shows have been very positive with the suggestion that an airborne multi-band antenna could be constructed based on existing antennas. Vendors appear more concerned about antenna environment then RF performance. The new bands lack the airborne telemetry environmental characterization that we have with the L and S Bands and the narrow beam widths can be challenging to accommodate in a small airborne package.
Establishes multiple sources in the marketplace for antennas

Receivers. Several telemetry vendors offer C-band options on their current equipment. The L3 Microdyne RCB-2000 and DR-2000 receivers currently have slots for up to three RF tuners. Typical configuration currently accommodate 1435 - 1525 MHz, 1700 - 1850 MHz, and 2200 - 2400 MHz. Several vendors have proposed a receiver configuration that works with a down converter somewhere between 600 MHz and 2400 MHz. A new C-Band friendly receiver in this configuration may include a 680 - 1430 MHz which will tune the down-converted C-Band (680 MHz- 1430 MHz) directly as a quick approach to adapt to the new bands.

Most telemetry receiver vendors either already provide existing C-band receivers or they plan new C-band solutions that will be available in the next year. We are seeing many new vendors enter this market with the promise of new approaches and a variety of solutions.

6. SUMMARY

The ICTS effectively supported Action Item 1.5, “additional frequency spectrum for AMT”, at the WRC-07 and its decision process during the conference. We were successful. The new “WRC-bands” will allow the implication of wide band telemetry links into flight missions. In **ITU-region 1** (Europe & Africa) an **additional** usable bandwidth of **159 MHz** is available to be allocated by the spectrum regulator authorities. Components & systems for either new state-of-the-art equipment or for the upgrade of the existing system are already in work. One area of concern requiring an up front evaluation is tracking algorithms and mechanical tracking systems that operate specifically in C-Band.

The **International Science Community** with its flight missions **needs to occupy the new bands**, too! Radio spectrum is now extremely valuable. The requirements of broadcasters, cellular phone & wireless broadband network providers generate an extreme pressure for acquiring more spectrum.

The new **WRC´07 C-band allocations** provide some advantage over the S-band range:
- **More Bandwith** will be available for the telemetry data stream, allowing a transmission from wide band data sources, as synthetic aperture radars (SAR) and wide band spectrometers, where raw data rates up to 100 Mbps are common.
- **A lower Noise Environment** may be expected than in the crowded S-band range. A “conglomerate” of radio devices of different kind (e.g. amateur radio, WLANs, WPhones, microwave ovens and scientific instruments) does operate in and around the “ISM- unlicenced band (2390 – 2500 MHz). Even when the out-of-band noise emission of one single station (e.g. by spreading its intermodulation products) is marginal, the dense population of those systems generates a significant amount of non wanted emissions.
- **Less Multipath Sensitivity** is expected in C-band when tracking a transmitting target under a low elevation angle. Due to the relative higher “roughness level” of the environment (the C-band wavelength is less than half of that in S-band) a specific reflection ray may be broken up in a diffuse radiation beam and therefore causing less interference with the direct received ray.

That are good reasons to think using C-band for science missions with balloon and aircraft carried experiments.

7. CONCLUSIONS

Test ranges, involved in domestic and international T & E missions, should utilize the telemetering opportunities in the new bands as soon as possible, especially in the global harmonized part from 5091 to 5150 MHz. Besides the US most of the EU countries were key to supporting AI 1.5 in the WRC-07 process. Therefore ESA and the European aeronautical industry are encouraged to take a lead in the next consequent step, to implement the C-band TM capability.

8. REFERENCES

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