

TRENDS IN AERONAUTICAL FLIGHT TEST TELEMETRY

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Abstract

Based on Action Item 1.5 and the relevant investigations and studies, the World Radio communication 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 by aircraft stations. The range from 5091 to 5150 MHz may be used worldwide, allowing the implication of wide band telemetry links and helping the international cooperation and standardization in flight test 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. Components and systems for either 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. Future planning to greater utilize this band is presented.

Introduction

Telemetry spectrum is required for the transmission of real-time data from a test vehicle to ground. It allows the testers to conduct safe, effective, and efficient tests by displaying and analysing data in real time. The current telemetry frequency bands, located between 1400 and 2400 MHz are vital to both commercial and military flight testing activities. By utilizing telemetry flight testers can greatly expedite testing activities. It allows real-time decisions/results that shorten the time required to complete testing, and qualify new products. This results in safer products, reaching the market faster, and reduces customer operation and maintenance cost (since customers can retire older systems faster) while also increasing supplier profits.

However, the existing telemetry bands are heavily sought after by non-aerospace industries for personal communications (e.g., wireless web and cellular telephones) and entertainment (e.g. digital audio / video broadcast) use. The existing telemetry bands, operating at capacity in several regions, are increasingly affected by encroachment

from commercial interests. Such encroachment has, in a very short timeframe, markedly reduced the already limited RF spectrum available for aeronautical telemetry.

Spectrum encroachment will continue to have a wide-ranging impact on the aeronautical test community. Many T and E programs today are operating at a less than optimal test efficiency, due to lack of real-time capability. Missions have been delayed and lost due to lack of sufficient spectrum to scheduled activities. This has resulted in increased test program delays, costs, and project risks. Examples of these impacts were documented in a U.S. National Telecommunication and Information Administration (NTIA) special publication, which quotes impacts to several military projects as a result of RF spectrum limitations [1].

Figure 1 reflects a survey conducted by the U.S. Advanced Range Telemetry (ARTM) project office [2], which indicates that the data rates for projects using aeronautical telemetry (dots) are growing at an exponential rate (upward arrow). Today, there is not enough RF spec-

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trum available to address this growing need (downward arrow).

Where are these requirements coming from? To effectively and efficiently test these sophisticated systems the tester is drawn to more in-depth analysis (systems are more complex) and a shortened acquisition cycle (do more real-time work to meet schedule and cost constraints). This drives telemetry requirements to ever-higher data rates.

Icts Preparations for the WRC'07

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 [3]. From the mid - 1990s the U.S. National Aeronautics and Space Administration (NASA) recognized 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 telecomm 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 Telemetry (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 organizations 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 helps 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 papers at international conferences, conducting workshops, and meeting with industry and government officials. Key support for the ICTS was provided by OSD's CTEIP Office, the US Navy, the US Air Force, the International Foundation for Telemetry (IFT), and the Aeronautical Flight Test Radio Consulting Committee (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 had 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.

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 test 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 [4].

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 and Africa) an additional 100 MHz are allocable in the frequency range from 5150 to 5250 MHz.

Flight Testing 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 effects, reflections/multipath, and cost/availability of hardware are different than 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. 7dB.

$$\Delta\alpha = 10 \log (\lambda S / \lambda C)^2 \text{ dB}$$

Antenna tracking in C-band is critical. The narrower beam is more difficult to track than the S-Band currently used. When leaving the antenna apertures constant (as in S-band) a 0 dB antenna (for a wide earth coverage) on-board 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.

Another point to be considered is the influence of the weather and 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 [5]. 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.

The impact of ground reflections needs also to be addressed. Most parts of test 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 $1/\lambda$ (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) [6] transmitters are not yet available in the bands 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 and 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 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 project in 2004 through the use of existing C-Band receives 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 and D is airborne qualified, spectrally efficient, telemetry transmitters. Several vendors are currently funding component developments in that area.

Current Efforts and Trends in C-Band Telemetry

The new C-bands are receiving significant attention in the United States. At the recent International Telemetry Conference (ITC 2008) held in San Diego (www.telemetry.org) several papers and presentation were made by the vendors and the iNET (integrated Network Enhanced Telemetry) project sponsored by the US DOD's Test Resource Management Centers Central Test and Evaluation Investment Program. 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 its utilization for Flight Test Telemetry. Primary developmental and testing efforts of vendors in the US concentrate on transmitters, antennas, and receivers.

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, a effort to develop a L, S multiband transmitter has made good progress and is receiving substantial procurement interest from US customers [8]. 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 4.4-4.9 and 5.091-5.15 GHz (500MHz). The end result, as least for the short term, would be to build two transmitters as this maybe too wide a gap for an effective power amplifier design.

A lower risk approach, and one which we will probably see 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 LDPC codes, currently the standard for error correction in applications like cell-phones and inter-planetary communications, were adopted by iNET [9] and will be included in the iNET Communication Links Standard with the intent to incorporate LDPC codes into new C-band airborne transmitters.

Antennas : Antennas 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 than 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.

Engineers with the iNET project have also been working with several vendors on a L/S/C band ground receiving antenna concept (Fig.2) [10].

This combined L, S, and C band Feed concept has received much interest from antenna vendors. In addition several vendors have offered to develop a single multi-band feed which would not require a secondary reflector for C-band (Fig.3). The funding of the development of a multi-band feed integrated with a prototype ground antenna system would greatly simplify ground antenna modifications to accommodate the new bands. The ability to adapt existing equipment to the new bands (no aperture/disk change) would greatly reduce the cost to telemetry ground stations and test ranges.

Receivers : Several telemetry vendors offer C-band options on their current equipment. The L3 Micro dyne RCB-2000 and DR-2000 receivers currently have slots for up to three RF tuners. Typical configurations currently accommodate 1435 - 1525 MHz, 1700 - 1850 MHz, and 2200 - 2400 MHz. Several vendors have proposed a re-

ceiver 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 vendor enter this market with the promise of new approaches and a variety of solutions.

Summary

The ICTS effectively support 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 test missions. In ITU-region 3 (India, Asia, Australia) additional usable bandwidth is available to be allocated by the spectrum regulator authorities. Components and 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 flight test community needs to occupy the new bands. Radio spectrum is now extremely valuable. The requirements of broadcasters, cellular phone and wireless broadband network providers generate an extreme pressure for acquiring more spectrums.

Conclusions

Test ranges, involved in domestic and international T and E missions, should utilize telemetering capabilities in the new bands as soon as possible, especially in the global harmonized part from 5091 to 5150 MHz. The Indian government was key to supporting AI 1.5 in the WRC-07 process. Therefore the Indian aeronautical industry is encouraged to take a lead in the next consequent step, to

implement the C-band TM capability at their test facilities and ranges.

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Fig.1 TM demand increasing while supply decreases (Bit Rate in Kbps)

Table-1 : WRC 2007 allocations for Aeronautical Mobile Telemetry (AMT)

Fig.2 iNET Multi-Band receiving antenna concept

Fig.3 Secondary reflector