# BroadCast Summary Final Report

# Artes-4 Contract No. 13830/99

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*May 21, 2003*

## 1. Abstract

***This paper reports on the BroadCast project, executed by Sirius Communications NV (now part of Agilent Technologies Belgium NV) from 1999 till 2003. A flexible modem platform serving W-CDMA-like and related communications needs has been designed, implemented and thoroughly tested in the field. Target applications include S-UMTS related communications and high-end specialty terminals e.g. in wideband avionics communications. The SDR (Software Defined Radio) baseband architecture is realized through a combination of highly parameterizable hardware communication modules and a control software layer. As of today, the BroadCast platform realization has already resulted in several business opportunities for Agilent Technologies Belgium. Additional commercial exploitation is currently being prepared through further upgrades and extensions to the platform.***

## 2. Introduction

The Sirius team of Agilent Technologies Belgium is active in the field of CDMA-oriented communications targeting novel modem design and related applications. One of the long lasting strategic directions is satellite communications. Because of the increasing needs for baseband modems in this field, a strategic development was started in late 1999 in collaboration with ESTEC, in the context of the ARTES-4 program.

The next section describes the main project goals and challenges, as well as the main specification characteristics. Section 4 deals with the innovative architecture aspects; more specifically, our novel approach towards SDR architectures will be covered briefly. Section 5 describes the main implementation steps: from simulation over FPGA and PCB design and software development, towards lab tests. In section 6, the field trials results are briefly discussed. In the 7th section, links with other activities are indicated. Section 8 summarizes conclusions and next steps.

## 3. Main project goals and challenges

The initial goal was the realization of a versatile wideband CDMA-like modem as an IC. Due to various external business circumstances, as well as changes in the target markets, the final implementation target was changed in the course of the project towards an FPGA-based platform. The main project milestones, realized in this revised program, are the following:

- Detailed requirements and device specifications;
- High-level simulations, including end-to-end performance simulations;
- Detailed architectural design of the SDR modem;
- Realization of FPGA-based baseband platform, development of control software, and physical realization of the front-end interface board;
- Realistic field trials.

Besides the challenges related to the implementation target change, the main technical challenges were related to the multi-disciplinary activities combined with the high complexity. This required a design methodology with verification at the different abstraction levels:

- High-level bit-accurate performance simulations, including co-simulation of hardware and software components;
- Bit-accurate verification of the hardware descriptions (VHDL models) against the high-level models;
- 1-to-1 verification of the (near) real-time lab test results with the high-level model behavior.

The overall specification includes the following main modules:

- Hi-speed chip rate processing versatile transceiver (W-CDMA inner modem), being capable of demodulating satellite wideband links as well as terrestrial links suffering from severe fading (inner modem);
- Hi-speed symbol processing including several error correction schemes, interleaving and data formatting capabilities (outer modem);
- AFE (Analog Frond End) interface that can be connected to various RF modules (C-band, VHF-band, S-band) which have different architectures (I/Q direct up/downconversion as well as real IF superheterodyne radio's);
- Control software running on ARM7 micro-controller subsystem.

Examples of operational modes of the platform are shown in Table 1. User data rates up to 320 kbits/s are supported. Two parallel physical channels (DPDCH) are present. Turbo coding/decoding as well as convolutional coding (with Viterbi decoder) are present.

| **Test** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| **Mode** | **UMTS** | **UMTS** | **UMTS** | **UMTS** | **UMTS** | **UMTS** | **UMTS** | **UMTS** |
| **Data rate 1** | **9,6** | **57,6** | **0** | **115,2** | **9,6** | **19,2** | **38,4** | **57,6** |
| **Data rate 2** | **0** | **0** | **320** | **0** | **320** | **320** | **320** | **320** |
| DCH1 bits/frame | 96 | 576 | 0 | 1152 | 96 | 192 | 384 | 576 |
| DCH2 bits/frame | 0 | 0 | 3200 | 0 | 3200 | 3200 | 3200 | 3200 |
| CRC1 | 16 | 16 | 0 | 16 | 16 | 16 | 16 | 16 |
| CRC2 | 0 | 0 | 16 | 0 | 16 | 16 | 16 | 16 |
| L1 | 16 | 16 | 0 | 16 | 16 | 16 | 16 | 16 |
| L2 | 0 | 0 | 16 | 0 | 16 | 16 | 16 | 16 |
| Rate | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| Coding | Turbo | Turbo | Turbo | Turbo | Turbo | Turbo | Turbo | Turbo |
| | | | | | | | | |
| *Max. Coder in* | 109 | 493 | 3232 | 954 | 3341 | 3418 | 3571 | 3725 |
| *Max. Coder out* | 338 | 1490 | 9708 | 2873 | 10034 | 10265 | 10726 | 11186 |
| | | | | | | | | |
| **SF** | 128 | 32 | 8 | 16 | 16 | 16 | 16 | 16 |
| **Nr. DPDCH** | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 |
| | | | | | | | | |
| **Puncturing (%)** | 0,00 | 0,00 | 6,45 | 0,00 | 16,25 | 19,03 | 24,31 | 29,58 |
| **Input CRC 1** | 120 | 680 | 0 | 1416 | 96 | 176 | 328 | 480 |
| **Input CRC 2** | 0 | 0 | 3216 | 0 | 3216 | 3216 | 3216 | 3216 |
| **Code blocks** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **Input coder** | 136 | 696 | 3232 | 1432 | 3344 | 3424 | 3576 | 3728 |
| **Output coder** | 420 | 2100 | 9708 | 4308 | 10044 | 10284 | 10740 | 11196 |
| **Puncturing bits** | 0 | 0 | 588 | 0 | 1404 | 1644 | 2100 | 2556 |
| **2nd Fillers** | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 |
| **PHY-Data** | 420 | 2100 | 9120 | 4320 | 8640 | 8640 | 8640 | 8640 |
| **Punct. Pattern** | none | none | 2/30 | none | 2/12 | 2/12 | 2/9 | 2/6 |

*Table 1: Examples (subset) of supported operational modes*

## 4. Architecture innovations

The most important architectural innovation is the specific SDR concept that has been developed. It is a combination of hi-speed baseband processing logic (with a lot of programmable parameters) and control software running on a micro-controller subsystem. This split allows to perform significant design upgrades, air interface changes, demodulation algorithms etc. by manipulating the control software layer, rather than having to redesign the hardware components. In case the platform needs to be extended with a very different modem scheme (e.g. for backwards compatibility), the FPGA space allows to do so, in combination with the flexible interfaces and programmable mixed-signal logic.

Figures 1-3 show the block diagrams of the inner modem; Figure 4 gives an idea of the outer modem upconversion functionality.

In the inner modem, we have as examples of reconfigurability:

- Spread spectrum-related parameters: channelization code and code length, and the scrambling code initialization. There is a programmable Gold code generator and RAM space to store the channelization codes;
- Flexible support of physical channel types, and their power settings;
- Number of physical channels: when one or more transport channels are mapped on multiple physical channels, this is referred to as multi-code transmission. The technique is used to increase the data throughput per user. It is possible (but not always required) in the 384 kbits/s data rate class;
- Filter coefficients: when switching between different standards, or for co-optimization with the filter(s) in the frontend (ACLR and EVM tuning through coefficient reconfigurability);
- Rake receiver flexibility: channel estimation algorithms, flexibility for searching/tracking, control software flexibility for high Doppler circumstances, … The envisaged target applications force us to address the typical satellite channel environments as well as Rayleigh and Rice fading circumstances (e.g. for S-DMB reception!);
- Tracking loops: different tracking mechanisms can be programmed for terrestrial and satellite reception;
- Initial synchronization block (acquisition): integration time setting and flexible implementation of searching functionality;
- Selection of various interfaces for different radio front-end architectures, such as I,Q or real IF interfacing;
- Keep track of the standardization evolution through broad reconfigurability options (e.g. the S-UMTS related schemes are not yet fully standardized).

In the outer modem, flexibility has an impact on the following functions:

- Error codecs combination: convolutional/Viterbi and/or Turbo depending on the data rates used;
- Number of iterations in the Turbo decoder, as a function of the power budget and the QoS (Quality of Service) to be realized;
- Puncturing and repetition flexibility, in order to adjust user data rates to physically realizable data rates;
- Support of block lengths as defined in the different data rate classes, interleaving lengths and algorithms (sequences);

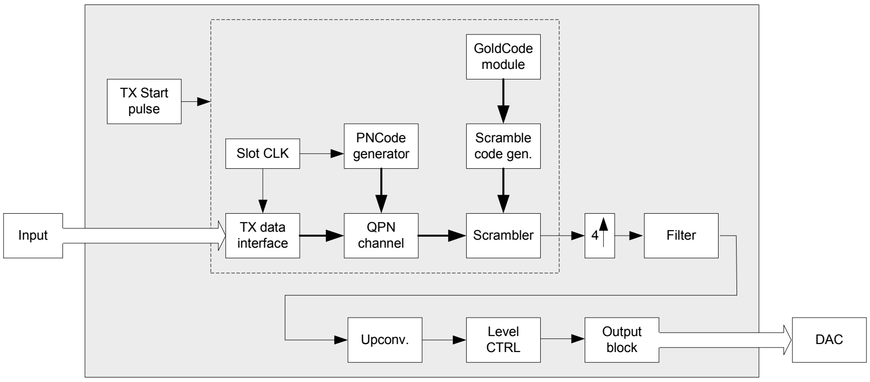

*Figure 1: Inner modem transmitter functions*

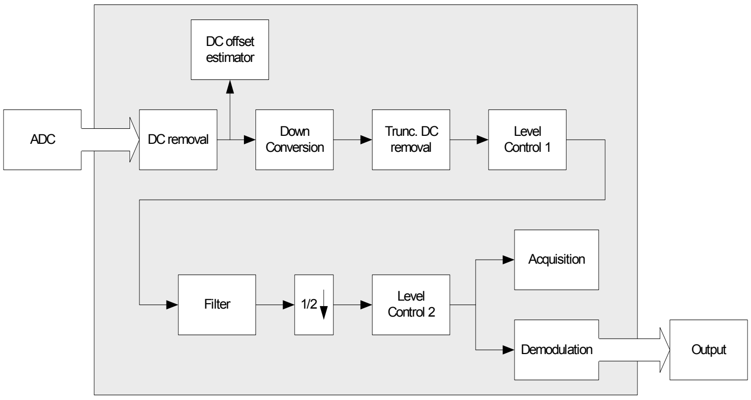

*Figure 2: Inner modem receiver functions*

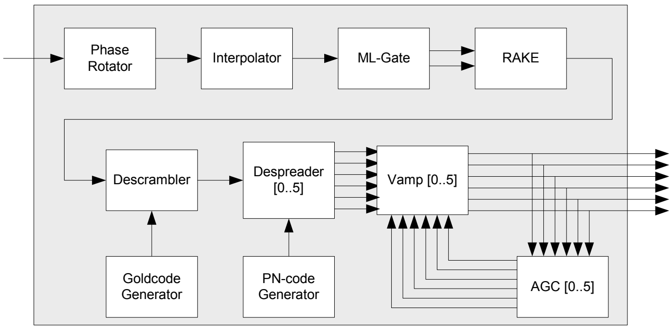

*Figure 3: Demodulation blocks in inner modem receiver*

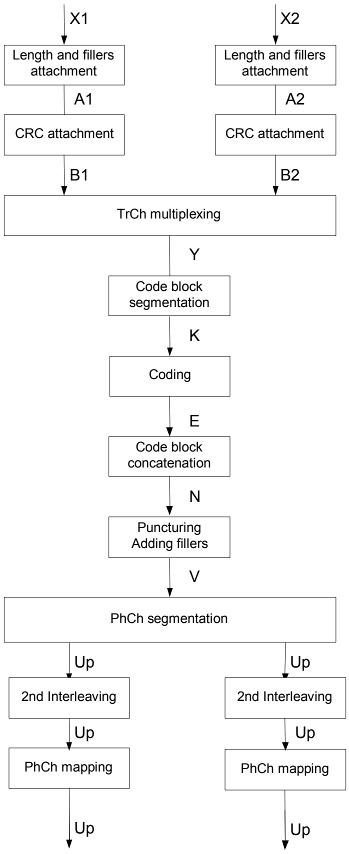

*Figure 4: Outer modem upconversion functionality*

## 5. Main implementation steps

High-level models were generated using bit-accurate C-descriptions. These were linked in a simulator environment to perform end-to-end performance simulations, involving all baseband hardware and software components. The bit-accurate detail allows for taking into account the implementation effects in the B(L)ER performance reports.

RT-VHDL descriptions for all hardware modules were synthesized towards the Altera FPGA's onboard the ARM Integrator Platform. Control software for the SDR architecture was implemented on the ARM7 processor, using eCos as the underlying RTOS (Real-Time Operating System). The main software functional blocks include:

- Rake fingers control software including Doppler management for high resiudal frewuency components;
- Power control software, including SIR (Signal to Interference Ratio) measurements and TPC (Transmit Power Control) handling;
- RF front-end control software in order to control the AGC functionality and the frequency synthesizers;
- Debugging software to support real-time analysis (see section 6).

The baseband hardware and software have been integrated with a number of prototype radio front-ends: VHF radio, C-band radio (for use in aircraft communications), and S-band (for S-UMTS tests).

Figure 5 gives a top and a lateral view on the baseband platform. In this setup, 3 FPGA boards (red) are stacked on top of each other; they contain the inner and outer modem functionality. The inner modem functions are split over two FPGA's due to the demodulator complexity. The discrete AFE board (yellow) was designed in-house (Figure 7).

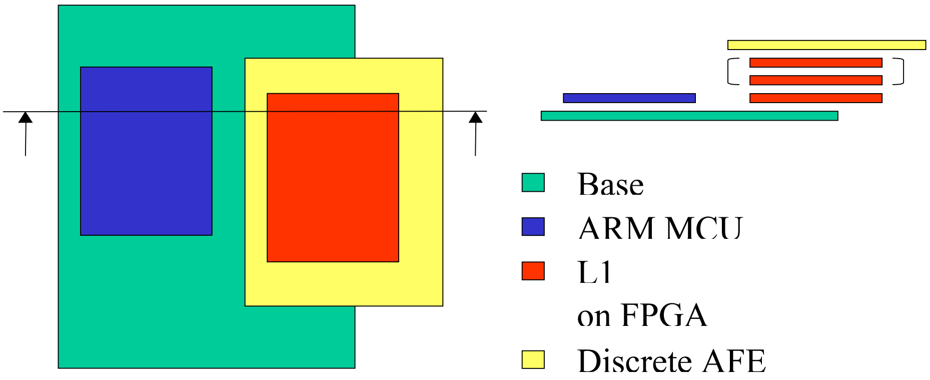

*Figure 5: Top (left) and lateral (right) views on the ARM Integrator Platform*

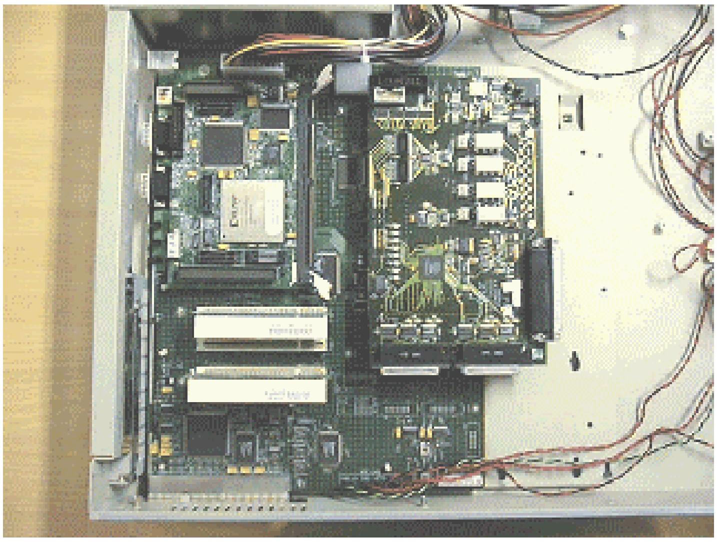

*Figure 6: Picture of the ARM Integrator Platform*

## 6. Main results

The real-time tests in the field have basically served 2 purposes:

- Validation of the baseband IP;
- Proof-of-concept tests for new emerging applications using the developed platform as a prototype modem.

The first group of field tests has been executed in the domain of ground-to-aircraft communications (Figure 9). This was an excellent opportunity to exploit the flexibility of the platform and to check some performance limits. A bi-directional hi-speed link was established between ground (modem configured as Base Station) and aircraft (onboard equipment configured as Mobile Station). The configuration with C-band radio's (both with omni-directional and directional antennas) allowed to test the link in extended Doppler fading circumstances. Links could be maintained in the case of an aircraft crossing the Base Station at speeds up to 600 km/h. The configuration with VHF radio's allowed to test the modem at the edges of its sensitivity: with +33 dBm transmit power, an error-free link over a distance of 75 km could be realized.

The second group of trials have been done in the area of S-UMTS related applications i.e. S-DMB (Digital Multicast/Broadcast over Satellite). Satellite transmission was mimicked by launching a balloon, attached to the 2 GHz directional antenna and a cable connection to the modem. Satellite simulation was possible by the right power adjustment and having the balloon positioned at a representative elevation angle. Link robustness in an open area as well as propagation into buildings have been tested.

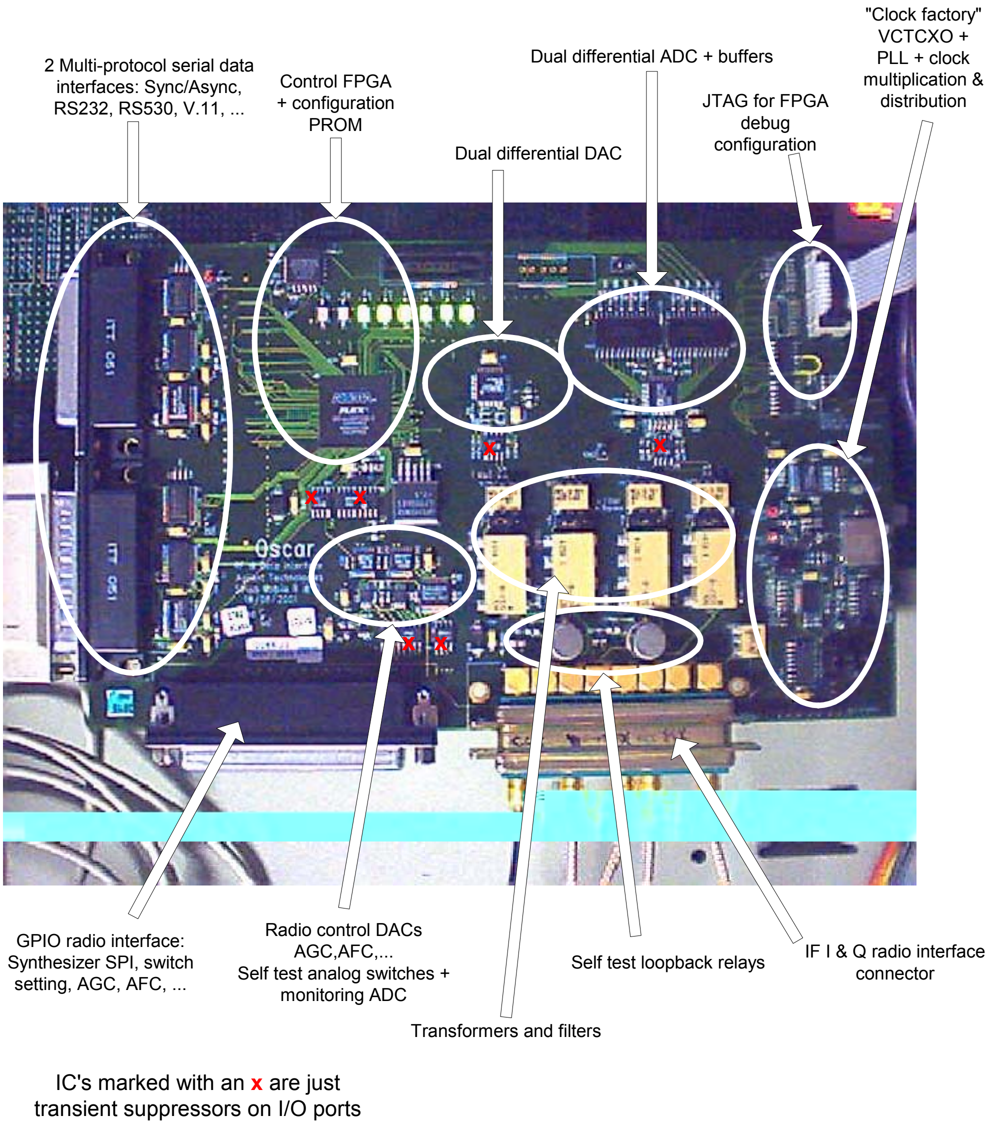

*Figure 7: Mixed-signal interface board*

## 7. Relation with other activities

In the field of S-UMTS related applications, standardization is still ongoing. We are closely involved in these efforts, as commercial success on a large scale is only possible through a uniform air interface standard.

The IST project **SATIN** (Satellite UMTS IP-based Network) started in 2000, and was successfully finalized in March 2003. The project phases of this SATIN project include the business plan for satellite-based services which are complementary to terrestrial UMTS, the architecture definition, L1 and L2 simulation and results analysis. 2 scenario's are being studied: with and without return link. The use of terrestrial repeaters for the urban environment is also considered.

The IST project **MoDiS** (Mobile Digital Broadcast Satellite) is a successor of SATIN and started in April 2002, to last for 2.5 years. It fits with the concept of broadcasting via satellite in S-UMTS.

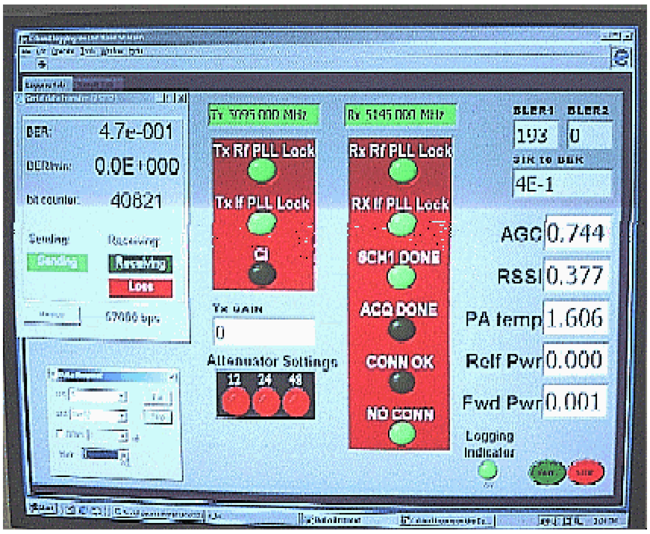
BER: 4.7e-001
BERmin: 0.0E+000
bit counter: 40821
Tx GAIN: 0
BLER1: 193
BLER2: 0
SIR to BER: 4E-1
AGC: 0.744
RSSI: 0.377
PA temp: 1.606
Rclf Pwr: 0.000
Fwd Pwr: 0.001

*Figure 8: Real-time monitoring PC screen*

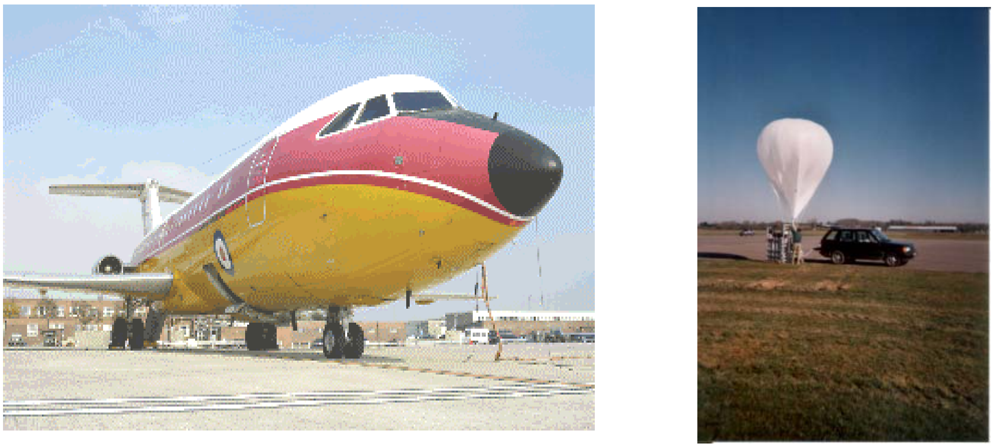

*Figure 9: Fiel trials with aircraft (left) and mimicked satellite (right)*

Purpose is to demonstrate, in the field, a Multicast layer based on a GEO satellite and terrestrial repeaters. The Multicast and the terrestrial network are tightly linked. One of the main goals of the project is to prove that the impact on terminal and infrastructure of introducing this satellite-based service is limited. The terminal platform that Agilent will use for this MoDiS demonstration is based on the BroadCast project achievements.

Sirius/Agilent is active in the SES S-UMTS WG from **ETSI**. The table below lists the different work items we are involved in.

| **Work item number** | **Version** | **Current status** |
|---|---|---|
| DTR/SES-00071 (TR 102 061) | 1.1.1 | Start of work (2001-09-28), WG approval |
| RTR/SES-00076 (TR 101 865) | 1.2.1 | TR available |
| DTR/SES-00078 (TR 102 058) | 1.1.1 | Start of work (2002-03-21), WG approval |
| DTR/SES-00079 (TR 102 059) | 1.1.1 | Start of work (2002-03-21), WG approval |
| DTR/SES-00089 (TR ) | N.A. | Table of Contents and Scope (2003-02-10) |
| DTR/SES-00090 (TR ) | N.A. | Table of Contents and Scope (2003-02-10) |

Sirius/Agilent is also a member of the **ASMS (**Advanced Satellite Mobile Systems) Task Force, which is a joined ESA/EC initiative that aims at grouping the European efforts in industry and academia in the area of future mobile satellite services.

## 8. Conclusions and next steps

The modules, platform, know-how and proof-of-concept results are of important value for our team. The developments realized in the context of the BroadCast project have already been exploited commercially in a successful way.

The support of ESA through the ARTES-4 program is gratefully acknowledged.