Enabling In-Flight Connectivity with the new Generation of Electronically Steered Antennas

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Abstract. In-flight communication (IFC) services offered to passengers and crew are of great importance to the air transport sector. The improvement of the satellite capacity with High Throughput Satellites (HTS) in GEO and the advent of MEO and LEO constellations will support the forecast growth of the IFC market. Antenna equipment for satellite communications will need to address multiple scenarios from G2G (Gate-to-Gate) to multi-operation under GEO-MEO-LEO systems. Under these conditions, antennas with the ability to track multiple satellites and having superior performance and reliability will play a key role. Electronically steered antennas (ESA) have emerged as a viable solution in response to these demands. The EU-funded LESAF project proposes an ESA solution of reduced size and greater efficiency for the next generation of in-flight connectivity services. This will be managed through the requirements definition, system analysis, technology assessment, prototyping and validation of ESAs. The project has successfully passed the first milestone corresponding to requirements consolidation, baseline architecture definition and candidate technology trade-offs. Multi-beam Electronically Steered Antennas, separated apertures for both transmission and reception, a flexible modular approach coupled with planar multilayer integration and an advanced beamformer design are the basis for the proposed concept. The following project phase will be focused on the design and validation of an antenna demonstrator aimed at proving the superior added value of ESAs technological solution for the aviation industry needs.

1. Introduction

Communications in the aviation sector have experienced an impressive growth in capability and use in the last decades. This course has evolved from restricted flight operation and navigation applications, between crew and control towers communications, to the "Connected Aircraft" concept that comprises additional features like passengers' connectivity and entertainment, maintenance and aircraft systems [1].

This article introduces the evolution of In-Flight Communications since the presentation of the first satellite communications system [2], "Connexion by Boeing", and proposes a solution for the future implementation of electronical steerable antenna systems on the horizon of this decade.

2. In-Flight Communications Evolution

2.1. Background

In-Flight Communications were originally conceived to provide secure flight operations and navigation, supporting crew and control towers activities. This scenario is defined as an Air-to-Ground (A2G) communication system that was characterised by slow links and limited coverage. A new scenario emerged to increase the capacity of In-Flight communications systems when satellite-based solutions appeared on the scene [2][3]. In 2004, this initiative was demonstrated through “Connexion by Boeing” (see Figure 1) with the participation of several airlines, among others Lufthansa, SAS and JAP. With the aim at providing global network mobility (see Figure 2) and high-speed links (up to 20 Mbps forward / 1 Mbps return), this solution offered new services and applications to passengers and airlines while onboard.

Figure 1. Connexion by Boeing® in-flight demonstrator in 2004.

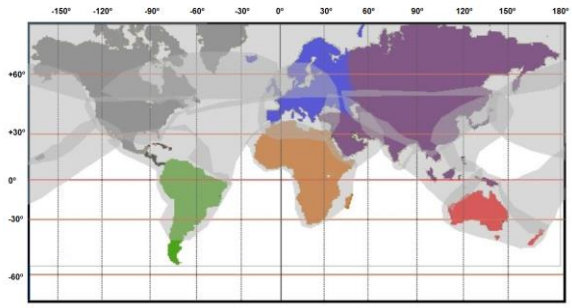

Figure 2. Connexion by Boeing® coverage in 2004.

The desire for connectivity to internet/e-Mail/eCommerce and entertainment for passengers was fulfilled, which improved the flight experience and generated ancillary revenue to airlines. Additional services and applications that airlines benefited from, were focused on the following aspects: flight operations, cabin crew and maintenance. Next table summarizes the most representative ones.

Table 1. Services and applications offered by Connexion by Boeing® in 2004 [3].

Passengers	Airlines		
	Flight Operations	**Cabin Crew**	**Maintenance**
Internet	Electronic Flight Bag	Passenger Data Base/Reservations	Maintenance documentation
e-Mail	Charts and Maps	Electronic LogBook	Aircraft Health Monitoring
Personal/Corporate Communications	Access to Flight Information services	Cabin Inventory	Electronic LogBook
eCommerce	Performance Data	Quality Monitoring	Data loading
VPN Support	Operational Checklists	Security	Flight Operations Quality Assurance download
	Security		Equipment List

However, the Connexion by Boeing was not a success story [4]. An impressive investment, close to one billion dollars failed to create a completely new market for satellite services, including years of effort gone into securing regulatory authorizations, creating a new global network infrastructure and developing terminals for the service. Very high operating costs per aircraft (satellite transponder lease, ground infrastructure, satellite terminals), high price and low usage rate (between 5-10% of passengers) slowed down the deployment of the system, impacting seriously on the revenues. The business case did not reach the expectations and two years later, in 2006, the service was interrupted.

At that point, the companies involved reoriented their efforts to provide onboard connectivity at low cost to users while a rapid deployment and financial return could be achieved [5]. Two main approaches were considered. First, OnAir (supported by SITA and Airbus) and AeroMobile (supported by ARINC and Telenor) proposed to deploy in-flight cellular roaming services using Inmarsat satellite equipment for backhaul, in the European and Asian territories respectively. Second, AirCell presented a system based on Air-to-Ground communications to provide connectivity to laptops on domestic US flights.

In early 2010s, in-flight connectivity was in service for more than 1000 aircrafts with a clear dominance of the Air-To-Ground approach. An increasing usage rate per flight (50-80% of passengers) and lower running costs favoured these A2G solutions. The launch of new satellites with superior performance enabled the development of the satellite-based solutions where service cost decreased significantly to be competitive. Initiatives like Row 44 and LiveTV Kiteline joined the chase and the market experienced a growing demand of onboard connectivity and the airlines bet markedly on these services. Millionaire grants encouraged airlines, satellite operators, service providers and terminal providers to create step-changes in in-flight services including connectivity and entertainment for passenger, and flight operations, maintenance and aircraft systems for airlines.

As an example, in 2015 the company Gogo covered most of the market with A2G systems (see Figure 3). Meantime, its satellite-based system started to take-off in American, Japanese and European airlines (see Figure 4).

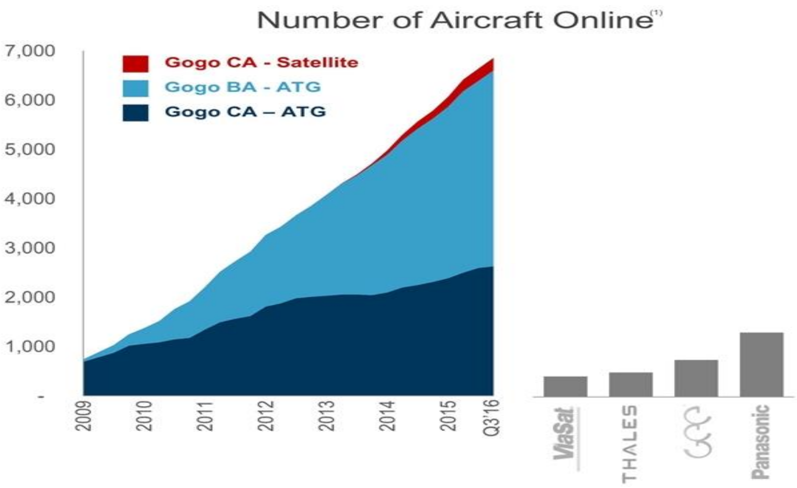

Figure 3. Connected aircrafts overview by 2015, Gogo®.

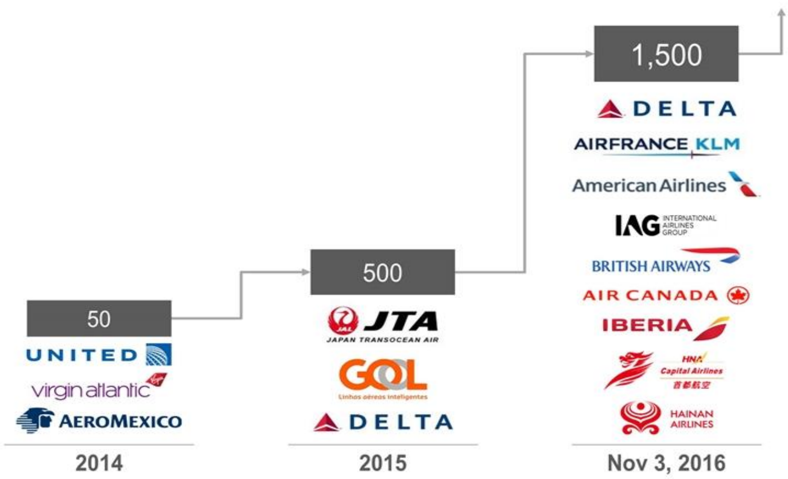

Figure 4. Gogo's deployment overview - satellite-based systems by 2016, Gogo®.

2.2. Airborne SATCOM Terminals Consolidation

Throughout the 2010s, a greater development of in-flight connectivity services was achieved following combined ATG and SATCOM solutions. With regard the satellite-based approach, the adoption of the industry standard ARINC-791 [6] allowed several companies to offer their terminals with the following objectives:

- Reference functional architecture
- Compatible interfaces
- Compatible mechanical integration
- Mitigation of profile/drag – Fuel consumption

Two main options gained traction in the market: Gimbaled terminals and Electromechanical flat phased arrays. The gimbaled terminals include moving parts where a single rectangular aperture is oriented according to the electro-mechanical control (see figure 5). It is characterised by an acceptable performance in link budget, bandwidth and consumption across the scanning range while it is limited in aspects like slow beam agility, equatorial operation, reliability and profile/drag. This solution was offered by companies like Viasat, TECOM and Panasonic.

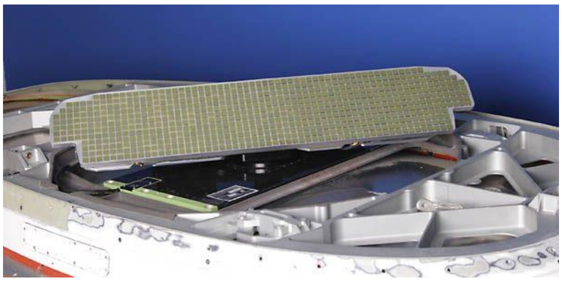

Figure 5. Electromechanical solution, by Panasonic®.

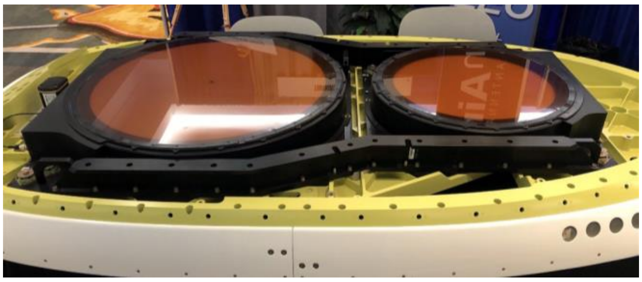

Figure 6. Electromechanical solution, VICTS® by ThinKom®

In contrast, the patented VICTS® (Variable Inclination Continuous Transverse Stub) phased array technology (see Figure 6) from ThinKom offered a different electro-mechanical flat and low profile/drag terminal integrating two independent apertures with the ability to provide rapid beam agility, wide bandwidth, equatorial operation, low consumption and high reliability. It is considered the state of the art of electro-mechanical phased arrays for SATCOM terminals.

2.3. Market Trend and Initiatives under IFC

The deployment of high throughput satellites (HTS) in Ku band as well as the advent of LEO/MEO constellations in the 2020s will expand the capacity of IFC systems at lower costs. Satellite operators like Inmarsat, SES or OneWeb, are collaborating with airlines, aircraft manufacturers and equipment manufacturers to enable improved communications and entertainment for passengers on one hand, and advanced services and applications for flight operations, cabin crew and maintenance of the other hand.

IFC as a global market has been in exponential growth since 2015 (see Figure 7). However, the COVID-19 pandemic caused an important limitation in mobility and the associated braking in the market. A higher demand of connectivity and more competitors with the satellite capacity because of boosted satellites and new constellations operating in Ku and Ka band, are reducing the operating costs of the service and increasing the revenues (see Figure 8). Several advisors in the sector have announced an updated prediction for the 2020 decade with an impressive expansion [7][8].

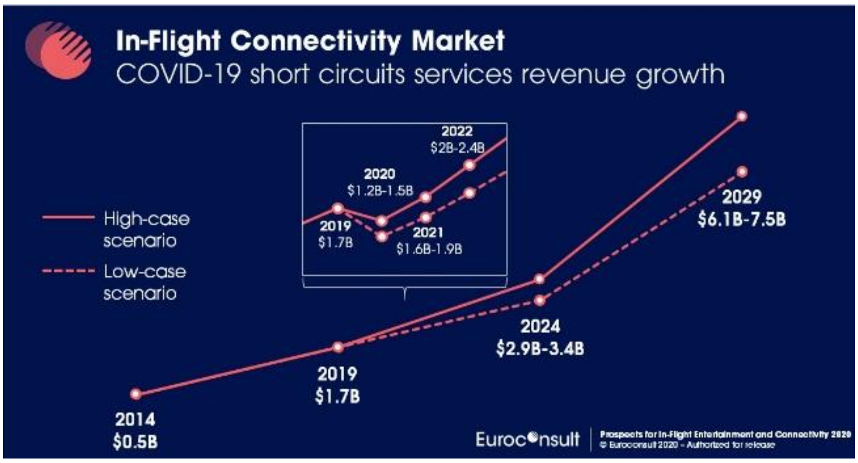

Figure 7. IFC market prediction in 2020 decade, EuroConsult®.

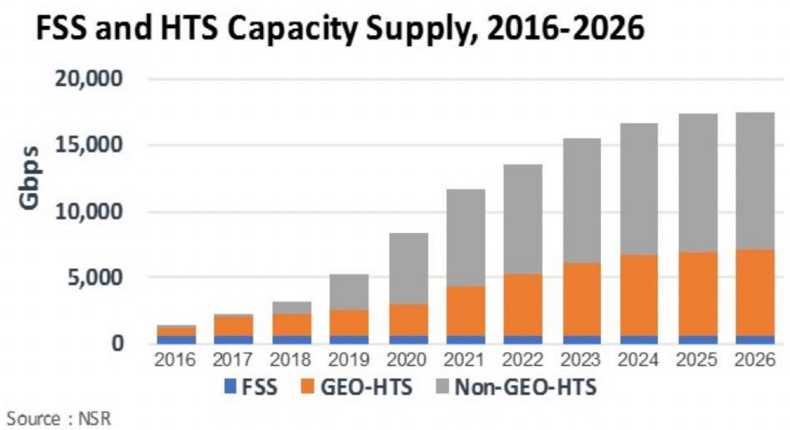

Figure 8. Installed satellite capacity in 2020 decade, NSR®

In the field of satcom equipment, there is an important push to develop Electronically Steered Antennas (ESA) that can be the best solution for the new scenarios with multiple satellites. This solution enables a low profile/drag terminal, with rapid beam agility, wide bandwidth, equatorial operation and high reliability. Additionally, it enables multibeam capability for interoperability in different situations, covering satellites in geostationary and low/medium orbits.

European Space Agency and Clean Sky Joint Undertaking are two drivers in Europe towards the development of this technology. In combination with private investment, the coming years will offer ESA terminals under different approaches (RF beamformers, transmit arrays, lens technology or metamaterials) to cover not only the In-Flight connectivity markets but also the ground equipment for users and operators in a wide variety of sizes.

3. Project LESAF

Project LESAF [9] is a Clean Sky [10] initiative that proposes a low-profile and highly efficient ESA solution for the next generation of In-Flight Connectivity services in the 2020 decade. This is achieved through the next breakdown of activities:

- Definition of requirements and System analysis
- Technology assessment
- Prototyping and Validation

As an outcome, two demonstrators of the proposed ESA systems will be developed to validate they can meet the strictest requirements imposed by the aviation market while bringing superior benefits over alternative technological solutions.

3.1. Key Requirements

In-Flight equipment presents inherent challenges associated with airborne applications, for example, environmental conditions as listed in the applicable standard RTCA DO-160G. In addition, to keep compatibility and interoperability between manufacturers and facilitate the installation, the industry standard ARINC-792 has been adopted and these guidelines are being followed in the development of satcom terminals under ESA solutions.

The following characteristics are considered as the key requirements:

- High Reliability, High Performance, High Efficiency
- Low Drag Coefficient – Fuel Savings
- Gate-to-Gate Operation, GEO/MEO/LEO scenarios, Multibeam, Seamless handovers
- ARINC-792 compatible (architecture and integration guidelines) [11]
- FCC 25.218 compliant (antenna radiating pattern) [12]
- RTCA DO-160G compliant (environmental conditions) [13]

A direct impact on running costs is expected according to next advantages: low drag to lead fuel savings; high efficiency antenna to provide higher capacity at lower cost per bit; and high reliability to minimize maintenance actions.

Aero antennas based on gimbaled solutions have a radome with a typical profile of 30-40 cm. In contrast, in electronically steerable antennas it will be approximately 15-20 cm. The presence of the radome causes a drag coefficient increase, that also depends on airplane and particular location. The impact can be estimated in next parameters: aerodynamic equivalent drag penalty (AEDP) and CO_2/NO_x emissions. A previous work [14] made an assessment on A350 airplane case and typical flights in comparison to reference performance without radome. Estimations in the optimal location showed low impact, as depicted below:

- High profile, optimal location. AEDP = +227 kg, +0.13 % fuel/CO_2, +0.30 % NO_x emissions
- Low profile, optimal location. AEDP = +159 kg, +0.01 % fuel/CO_2, +0.02 % NO_x emissions

However, integration constrains might require a worse location and results would be multiplied by 8-10 to reach significant impact on fuel consumption and emissions with high profile radomes. A clear benefit on low profile integration is, therefore, achieved to contribute to reduce OPEX and CO_2/NO_x emissions.

3.2. Technical Approach

An electronically steerable antenna solution is proposed in project LESAF following the ARINC-792 guidelines. Figure 9 presents the baseline architecture as proposed in LESAF.

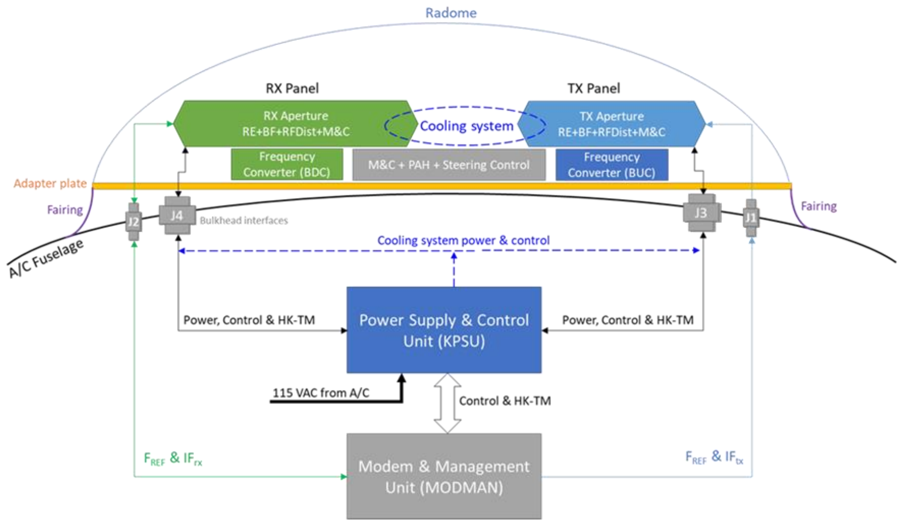

Figure 9. Baseline architecture according to ARINC-792.

The baseline configuration presumes that the antenna system, including the main RF components, local monitoring and power supply are installed externally under a radome. Also accommodated under the radome is the cooling system for the active RF components that are the most power consuming elements. Inside the aircraft fuselage, the main power supply and control units are installed with the modem and management unit.

The electronically steerable antenna is based on a flat phased array panel with RF beamformers, where each single radiating element embeds phase and amplitude control. Figure 10 presents a modular approach that enables a flexible construction of the aperture. A basic module, called a tile, is composed by a group of radiating elements and their associated RF beamformers. The replication of the tile builds the aperture with full electronic scan capability.

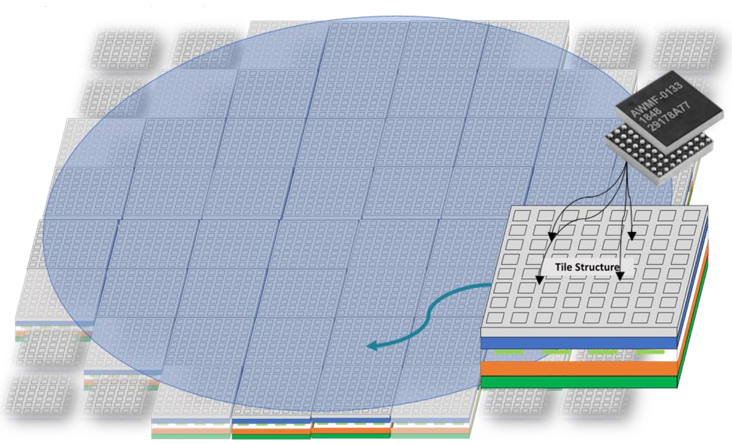

Figure 10. Modular approach and scalable construction under LESAF.

Two separated TX and RX apertures are considered to maximize the performance and mitigate the integration constraints and interferences between the electronics. For example, the transmitter antenna must observe regulatory constraints while the receiving antenna requires the multibeam capability in order to support multi-satellite tracking and seamless handovers. Figure 11 depicts the integration concept and multibeam approach.

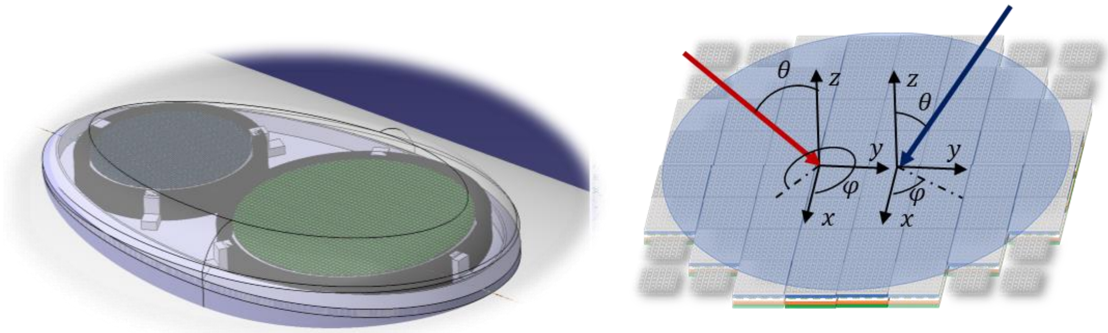

Figure 11. Implementation approach (left). Multibeam capability (right).

3.3. Status and Next Steps

The first phase of the project dealt with requirements consolidation, baseline architecture definition and candidate technology trade-offs. The detailed study of the requirements was carried out with active participation from a forefront service provider (Thales UK and Thales IFEC). The assessment of key technologies was also completed, by paperwork as well as by breadboarding, with the aim at defining in detail the final architecture and technological solution. The following key technologies have been validated:

- Radiating element.
- RF beamformer
- Monitoring and control
- Thermal breadboard based on a phase transition cooling system.

The second phase is intended to design, manufacture, integrate and test antenna demonstrators: one TX and one RX antenna panels with radiating elements plus RF beamformers including RF conditioning, monitoring and control, and power supply. Detailed validation by test campaigns in an anechoic chamber and in an RF laboratory will be used to prove the applicability of the proposed solution.

4. Conclusions

The present paper has introduced the evolution of in-flight connectivity through satellite-based systems. Considering the deployment of high throughput satellites and mega-constellations in low/medium orbits, electronically steerable antennas are proposed as the most convenient technology to provide a superior solution for the aviation industry needs. Project LESAF, a Clean Sky Joint Undertaken initiative, approaches the in-flight connectivity needs with a low-profile and highly efficient electronically steerable antenna.

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Disclaimer

The present work reflects only the authors' view and the European Commission and Clean Sky 2 JU are not responsible for any use that may be made of the information contained in this paper.

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