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DESIGN, DEVELOPMENT AND TRIALS OF AN AIRLINE PASSENGER TELEPHONE SYSTEM

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ABSTRACT

The paper describes the design, development and trials of a satellite telephone system for airline passengers. The requirements for ground and space infrastructure are discussed and the aeronautical system is described. Design criteria for the antennas and avionic boxes are given and system operation and technical flight trial requirements are discussed, together with test methodology and development towards fully commercial trials. Finally, an indication of development requirements to achieve the desired aims of airline users is given.

INTRODUCTION

The world airline market is now being presented with the reality of providing passengers with advanced communications via satellite. These communications will include voice (telephone) and data (telex, telefax and personal data) services.

Racal Avionics have embarked on a programme of fulfilling all the communications needs of airline passengers in a series of phased developments including data only, voice only and data plus voice services [1]. The purpose of this paper is to detail the design, development and trials of a voice only passenger telephone system for airline use.

Trials are to take place on a Racal-owned British Aerospace Jetstream and also on two Boeing 747-200s belonging to British Airways.

GROUND AND SPACE INFRASTRUCTURE

Various aeronautical satellite communication systems have been proposed over the last few years [2,3], but all of the communication channel infrastructure, including satellite and ground segments, must be present before service can start. For the purposes of these trials, INMARSAT-operated satellites are to be used. The British Telecom International (BTI) Ground Earth Station (GES) at Goonhilly in south-west England has already commissioned an antenna and RF system dedicated to the INMARSAT aeronautical service. The GES also contains the ground modems and interfaces to a fixed 64kbps digital link to BTI's International Switching Centre (ISC) in London. In a manner analogous to current practice in placing credit card calls via an international operator, the ISC staff will make the final call interconnect into the international telephone networks.

This operator service will be replaced by a fully automatic world-wide service upon commissioning of the Automatic Control and Signalling Equipment at Goonhilly in mid-1989[4].

AERONAUTICAL SYSTEM DESCRIPTION

The satellite link requirements for the INMARSAT aeronautical system are well defined [5], and are summarised here for the voice service in Table 1, together with other pertinent system parameters.

The Racal trials programme was instigated before the 12dBic antenna gain figure became standard, making use of 10dBic gain, limited coverage, antennas for the first trials. Although not fulfilling the final system requirements, these antennas present a reasonable compromise in terms of performance and installation simplicity.

Also under development is a full coverage, 12dBic gain antenna, designed specifically for aeronautical satellite communications. This antenna will be used during the trials on British Airways Boeing 747s.

AIRBORNE TERMINAL DESIGN AND DEVELOPMENT

Antennas

Two antenna types are to be used during the trials. Both are of the blade form containing electronically-steerable microstrip phased arrays.

10dBic Gain Antenna. This antenna was designed specifically for sideways satellite viewing, being suited to British Airways route structures between Europe and the eastern seaboard of the USA.

The antenna consists of two vertical back-to-back phased arrays in the same radome, each of 3 x 3 elements, the resulting beam being steerable to three azimuth positions at fixed elevation. Array coverage is portrayed in Fig.1. Coverage is a minimum of 10dBic gain over azimuth angles 50^{o} to 130^{o} (relative to forward) and 20^{o} to 50^{o} in elevation. The antenna is narrow band, requiring separate transmit and receive units to be provided.

Mechanical performance contraints are to provide adequate sideload and stress properties whilst minimising drag. Drag has been maintained at under 5N at Mach 0.84 at 10,700m altitude.

Full lightning and static protection is, of course, also provided. Each antenna has an associated Beam Steering Unit (BSU) which provides suitably-phased RF signals for beam pointing.

12dBic Gain Antenna. In order to provide coverage of the super-hemisphere, this antenna is built on the same principle as the 10dBic unit, but with an additional horizontal "top hat" section mounted within the radome. Since the antenna has little aperture available fore and aft, coverage at 12dBic gain cannot be maintained in these directions. Fill-in radiators at a lower gain level are, however, provisioned for. Dual band (transmit and receive) operation is also accommodated.

The phased arrays comprise 16 elements for the vertical sections, and 14 elements for the upward-looking horizontal section. 3 bit digital PIN-diode phase shifters are used with each array element to provide continuous coverage as shown in Fig.2.

The antenna has associated with it a Beam Steering Unit (BSU) to convert relative angle pointing information into phase shifter settings. The BSU also contains BITE and closed-loop steering control circuits.

Free airflow drag of this antenna is 125N at Mach 0.84 at 10,700m.

RF Subsystem

Of primary importance to terminal performance is station EIRP and G/T. These parameters are influenced by the antenna, the output power of the High Power Amplifier (HPA), the noise figure of the Low Noise Amplifier (LNA) and any losses incurred in RF plumbing and diplexing.

The availability of cooling air and suitably stressed mounting positions affects the installation of the HPA, often implying a Main Equipment Centre (MEC) location and a long cable run to the antenna. Long cable runs cannot be achieved without high cable losses, resulting in the remote mounting of the HPA units. For the British Airways trial, HPAs will be mounted on specially-provided racks at STA1650 within 7m of the antenna.

The power output capability of the HPAs is 70W, operating in class C. This capability exceeds the requirement stated in Table 1, primarily to accommodate the lower gain of the 10dBic gain antenna. When used with the higher gain antenna, the HPA output is de-rated by its in-built power level control circuit.

The transmit-receive diplexing function is achieved either by transmit-receive antenna isolation combined with pre-LNA bandpass filtering (in the case of the dual antenna installation) or by a dedicated, diplexer/LNA device (in the case of the dual band 12dBic gain antenna). In either case, state-of-the-art technology is used to minimise noise figure and filter insertion loss, which, combined with the short antenna to LNA cable runs, ensure that the -13dB/K G/T requirement is met. Achieved diplexer/LNA performance is 0.8dB diplexer filter loss and 1.0dB LNA noise figure at $+70^{o}C$.

Digital Subsystem.

The digital subsystem provides the digital modem functions required by the aeronautical system as well as avionics control and monitoring.

Upconversion and downconversion are performed in a separate LRU - the Radio Frequency Unit (RFU). VHF synthesisers based on proprietary LSI devices are used to provide 100MHz and 200MHz local oscillators for up/down-conversion, frequency selectable in 1Hz steps to counteract the effects of Doppler shift due to aircraft motion. A prime requirement in the up/down-conversion process is spectral purity, particularly phase noise. This is especially relevant on aircraft where vibration effects completely dominate oscillator performance. Fig.3 illustrates the phase noise specification and results obtained from a high quality crystal reference oscillator installed on shock mounts and vibrated to standard specification [6]. Fig.4 illustrates the resulting performance from a 200MHz synthesiser, measured at 1200MHz using a x6 multiplier.

The digital modem and control functions are housed in a dedicated LRU - the Satellite Data Unit (SDU). A block diagram of the SDU is shown in Fig.5. Quadrature detection is performed in the Analogue Module, the Demodulator Module performing symbol timing recovery and AGC/AFC control. The Frame Sync Module performs unique word detection and de-interleaving. Error correction is performed in the FEC Module, (containing an LSI Viterbi Decoder) as well as de-scrambling and data/voice demultiplexing. The System Interface Module and Data Interface Module provide interfaces with other LRUs in the system (for control and BITE) and other avionic systems.

The modules described above also perform the inverse of the functions given for the transmit chain. The modulation scheme employed in both forward and reverse directions is A-QPSK as specified by ICAO's Future Air

Navigation Systems committee and the AEEC[7].

Voice Coding.

Many algorithms exist for encoding and decoding voice. The Inmarsat SDM [5] calls for a coding rate of 9.6kbps, in order to provide commercially acceptable call charges by maintaining a low channel bandwidth without compromising quality.

Both RELP and APC type algorithms have been considered in these trials, RELP being chosen as a suitable codec was available. Since the final choice of algorithm for airline use must be universal and approved by users and service providers alike, a compromise approach has been used in the design, the voice coding elements being housed in a separate LRU, the Voice Management Unit (VMU).

For the trials, both hardwired telephone type handsets (with noise reducing microphones) and cordless telephones as manufactured by GTE Airfone Inc. will be used.

TECHNICAL TRIALS

The technical trials are to be performed on the Racal Jetstream aircraft. The trials will make use of two 10dBic antennas (1 off each transmit and receive), a BSU for each antenna, and an HPA, LNA, RFU, SDU and VMU as shown in Fig.6. Additional peripheral equipment will be a Control and Display Unit (CDU), a seven channel tape recorder (Racal Store 7), a Compaq 286 PC with 14Mbyte hard disk for data logging and a headset/microphone.

The primary objectives of these trials fall into the following areas:

Verification of antenna performance (coverage and discrimination)
Compatibility (environment, electrical, mechanical and acoustic)
System tests (technical specifications and continuous and sampled)
Speech coding evaluation (evaluations of alternative algorithms)
Propagation tests (line of sight, multipath and airframe effects)
Limited user evaluation (subjective conversation tests).

The technical trials will take place over pre-planned flight profiles in different geographical locations. Trials are planned on variable headings relative to the Atlantic Ocean Region satellite over land and water and at optimum and extreme instances of satellite elevation. Test flight routes encompassing Norway, Portugal, the Atlantic Ocean, the North Sea and continental Europe will provide the test conditions listed above. In all, some 4 weeks of test flying will be involved.

COMMERCIAL TRIALS

The commercial trials will take place on two British Airways owned Boeing 747-200 aircraft starting during the summer of 1988. Each aircraft will support two simultaneous telephone channels, the user interface being 4 cordless handsets, manufactured by GTE Airfone Inc.

The first of the two 747 aircraft will utilise the 10dBic limited coverage antennas; two transmit (one per RF channel) and one receive.

The second aircraft will be fitted with the single, transmit/receive 12dBic antenna with full coverage.

The 747 trials will start with a two-week commissioning period during which technical performance will be verified. Commercial trials will then start, during which passengers will be charged (via credit card) for all telephone calls.

These trials will be used to demonstrate the commercial viability of such a system as well as continuing to provide data on antenna performance and the subjective quality of the communications link.

FUTURE DEVELOPMENTS

The world airlines expect to fit production equipment from about 1990, as the automatic GESs come on line. This requires the avionic boxes to become compatible with the internationally-recognised form, fit and function specification being generated by the Airlines Electronic Engineering Committee [7].

Further development to satisfy the requirements of Automatic Dependent Surveillance (ADS), currently under definition by ICAO's Future Air Navigation Systems committee, will also be required for the mid 1990s.

The modular approach used, both in terms of LRUs and the component modules, enables a simple upgrade approach to be a realistic and cost-effective solution for the airlines future satellite communication needs.

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Table 1.

Antenna Gain (min)	12dBic	Transmit Frequency	1626.5 - 1660.5MHz
Antenna Coverage, Az	0 to 360°	Receive Frequency	1530 - 1559MHz
, El	-20° to +90°	Transmission Rate	21000 bps
HPA	40W	Voice Coding Rate	9600 bps
Transmit RF Losses	2.5dB	Coding Scheme 1/2	Rate Convolutional + Interleaver
EIRP for MARECS	25.5dBW	Access Scheme	SCPC
" for INMARSAT-2	22.5dBW	Modulation Scheme	A-QPSK
G/T	-13dB/K		

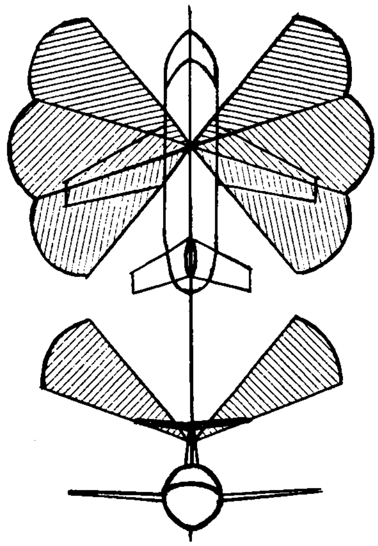

Fig. 1. 20dB Antenna Coverage

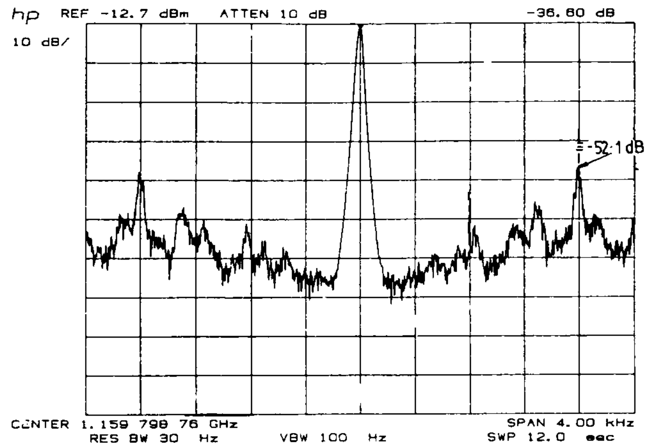

Fig. 4. Phase Noise of 200MHz Synthesiser (x6)

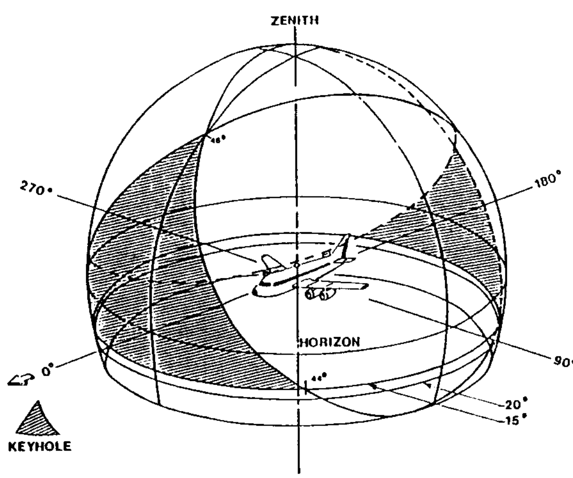

Fig. 2. 12dB Antenna Coverage

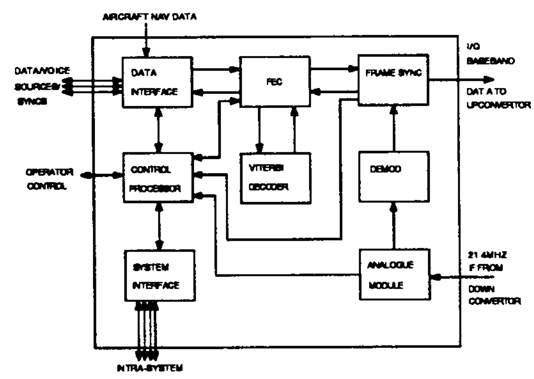

Fig. 5. SDU Block Diagram

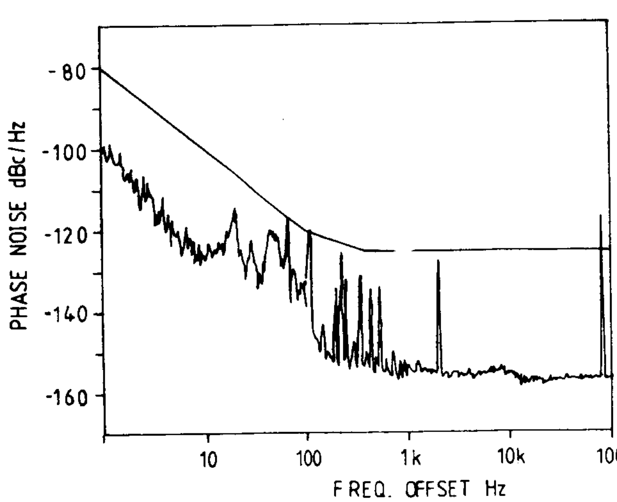

Fig. 3. Reference Oscillator Phase Noise Plot

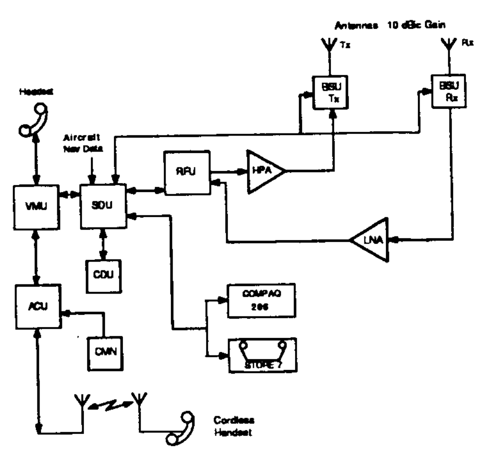

Fig. 6. Technical Trials Configuration