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Single-channel-per-carrier access equipment for satellite business systems

P. F. Robinson

Summary International satellite business systems are now becoming an operational reality. They are designed to provide relatively high-speed digital communication between premises using small earth stations.

This article is concerned with the single-channel-per-carrier (s.c.p.c) access equipment, which interfaces the customer data stream to the earth station radio equipment.

Following a review of the major system requirements, a new equipment, which has been designed specifically for this application, is described.

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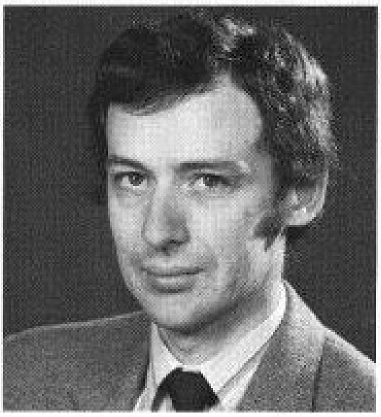

Introduction

The first fully operational satellite business system within Europe is scheduled to commence service in 1984. This is to provide relatively high-speed digital communication facilities between business premises, using small earth stations accessing the multi-services transponder[1] of the European Communication Satellite (ECS). The system is to use single-channel-per-carrier/frequency-division multiple access (s.c.p.c/f.d.m.a) techniques[2].

This article describes the design of a new equipment which implements the required s.c.p.c access function. The primary purpose of this equipment is to accept customer data via the terrestrial interfaces and to present it to the earth station radio equipment via an intermediate frequency (i.f) interface. Following a review of the major system requirements, the factors influencing the hardware design philosophy are outlined and an equipment description is presented.

This equipment is currently being supplied to British Telecom for use in its small-dish satellite service, SatStream.

System requirements

General

The Multiservice System is intended to provide a wide range of digital services via satellite, with customer bit rates from 2·4kbit/s up to 2·048Mbit/s. The s.c.p.c/f.d.m.a system allows corresponding satellite transmission data rates of 64kbit/s, and multiples thereof, generally on a pre-assigned basis. Frequency assignments are achieved by dividing the 72MHz of usable transponder bandwidth into 22·5kHz frequency slots, with each data channel being allocated a number of contiguous slots.

Further features of the satellite transmissions include the addition of a frame/multi-frame structure, an optional encryption facility, and the use of Rate 1/2 convolutional encoding together with 4-level coherent phase-shift-keying (p.s.k) modulation. These features are outlined below.

Frame/multi-frame structure

A frame structure is defined to enable the transmission of supervisory, control and signalling information over the satellite link. This frame structure is similar to that defined by CCITT Recommendation 732, as used in 30-channel p.c.m telephony for terrestrial applications. The satellite frame is divided into 64 eight-bit bytes, with all but four of these bytes dedicated to customer's data. This data is scrambled by the Modulo-2 addition of a pseudo-random sequence prior to transmission to aid energy dispersal and, additionally, demodulator clock recovery performance.

The four remaining 'overhead' bytes comprise:

Byte 0	frame alignment word
Byte 16 and 48	out-of-band signalling (if required)
Byte 32	multi-frame message

The multi-frame message byte is first used to define a 64-frame multi-frame and then carries messages concerned with the station and channel identification and, further, the synchronization of the optional encryption facility.

The overhead introduced by the frame structure results in a small increase in the transmitted data rate; for example, the basic 64kbit/s transmission rate is increased to 68·27kbit/s.

Encryption

The broadcast nature of satellite transmission, coupled with the capability of reception by relatively small earth stations, could cause some concern as to the privacy of the service for business communications. For this reason individual channel transmissions may optionally be encrypted over the satellite link.

Encryption is achieved by the Modulo-2 addition of the customer data and a key-stream, This key-stream is generated using an encryption algorithm[3] with a key variable (changed on a regular basis) and an initialization vector (generated each multi-frame). The control of the encryption function is performed by the transmit equipment, the necessary synchronization of the corresponding receive equipment(s) being achieved via the multi-frame message.

Modulation and coding

Since the system is power limited rather than bandwidth limited (due to the small earth station size), forward error correction is used to improve the overall system capacity. Rate 1/2 convolutional encoding with soft decision Viterbi decoding is applied to all channels, with differential encoding/decoding, at the terrestrial interface, for ambiguity resolution.

This powerful coding technique, in conjunction with 4-level coherent p.s.k modulation, allows a customer bit error rate of 10^{-6} to be achieved at an energy per information bit-to-noise density ratio of 6·1dB.

Design philosophy

Introduction

The s.c.p.c access equipment can be divided into two major areas: the channel equipment and the common equipment. The channel equipment encompasses the following broad functions:

a) terrestrial interfacing,
b) satellite framing and buffering,
c) (optional) encryption/decryption,
d) forward error correction (f.e.c) coding,
e) transmit and receive frequency generation,
f) 4-level p.s.k modulation/demodulation,
g) monitoring and control.

A simplified block diagram is shown in figure 1.

One channel equipment must be provided for each satellite link supported by the earth station. The common equipment is, however, shared by all the channel equipments. Since most earth stations are envisaged to support several channels, the division between common and channel equipment must be carefully considered to ensure that the degree of duplicated hardware is minimized, whilst maintaining the common equipment reliability (with the aim of avoiding the need for equipment redundancy).

In the design described here the common equipment comprises the following functions:

a) provision of a rack housing to hold the common equipment with up to five channel equipments,
b) transmit i.f path combining,
c) receive i.f path splitting,
d) reference frequency and clock generation and distribution,
e) monitoring (of the common equipment).

The design approach adopted for the equipment is heavily influenced by the three major interfaces; to the terrestrial equipment, to the radio equipment and to the monitoring and control equipment. Further major factors comprise the need for flexibility in operation, reliability and serviceability.

Terrestrial interface

The interface to the terrestrial equipment is not fully defined by the system specification due to the large number of possibilities available, depending on the location of the earth station within Europe and the proximity of the user's equipment to that earth station. This impacts on the equipment design in that terrestrial interface circuits must be implemented in a manner which results in a second 'normalized' interface internal to the s.c.p.c equipment,

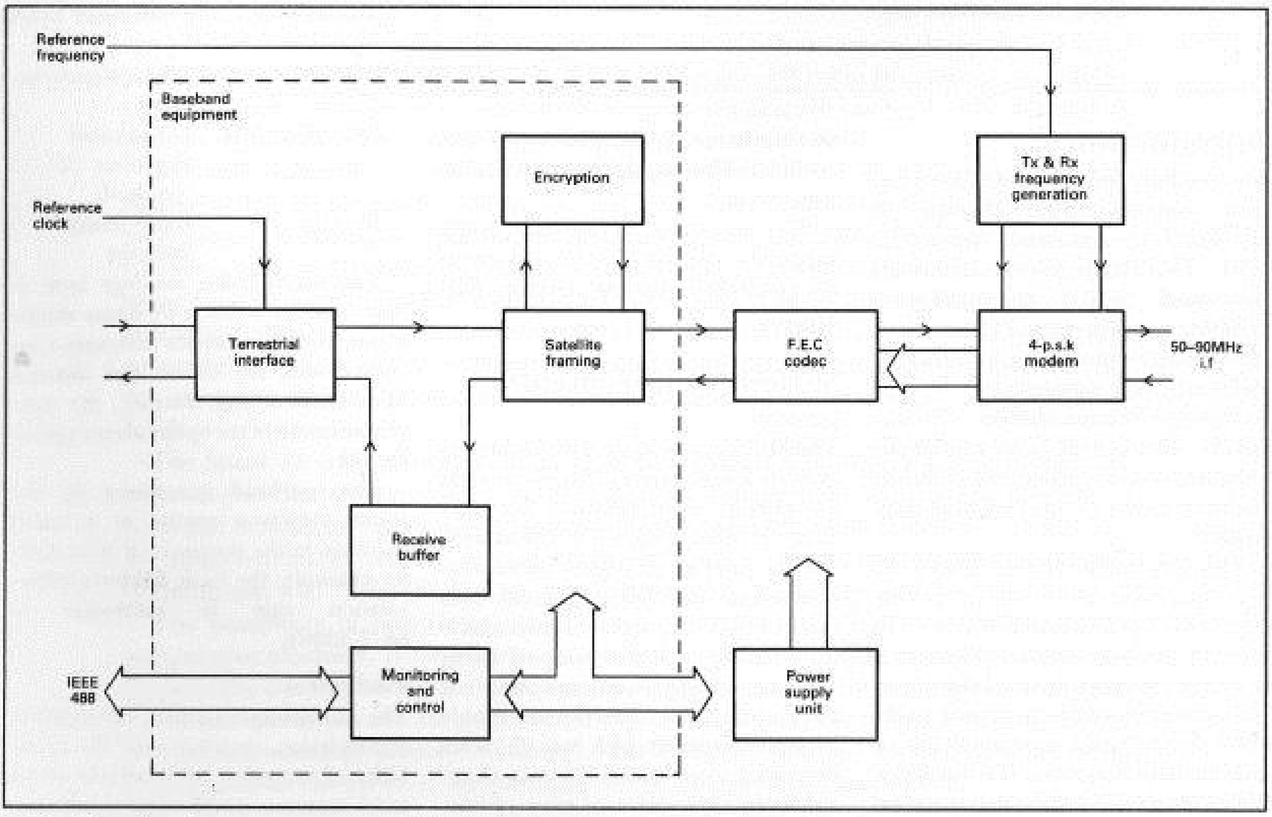

Fig.1. Channel equipment

in order that any potential terrestrial requirement may conveniently be achieved. Currently, the following terrestrial interfaces are implemented:

Type 1
For n×64kbit/s service (1<n<31) a 2·048Mbit/s interface (as defined in CCITT Recommendation G703) is provided. The frame format is similar to CCITT Recommendation G732 except that no multi-frame structure is recognized or generated. This interface provides a direct 2·048Mbit/s input and also allows direct interconnection to the Private Circuit Digital Data System[4] which is now being installed over much of the UK by British Telecom, in implementing its KiloStream service. This interface thus allows the terrestrial 'tails' to the earth station to be extended to remote user premises using a digital network, such as that provided by the KiloStream service, and further allows the use of standard multiplexing and sub-multiplexing equipment for user terminals operating at rates from 1,920kbit/s down to 300bit/s. An important further use of this interface is for the direct connection of 2·048Mbit/s user equipment providing, for example, a videoconferencing facility.

Type 2
For n×64kbit/s service a CCITT Recommendation X21 (leased circuit) interface is provided, with both DCE and DTE operating modes selectable. This interface thus allows direct connection of high-speed users' terminal equipment (e.g, computer or facsimile) close to the earth station. Additionally, connection to more remote users may be achieved via line modems and appropriate leased lines.

Type 3
For 64kbit/s service a co-directional interface as defined in CCITT Recommendation G703 is provided. This interface provides an alternative to Type 2 above for 64kbit/s service only. Its primary application is to provide a more efficient connection into digital network equipment (e.g. multiplexers or cross-connection equipment) compared to the Type 2 interface.

These three interfaces encompass a wide range of potential user requirements and location. Figure 2 shows possible terrestrial configurations.

For transatlantic applications, an alternative interface which can be offered is the T1, 1·544Mbit/s standard. This will allow easy access to the American terrestrial network via the INTELSAT satellite system.

I.F interface

The interface to the radio equipment is influenced by the modulation and frequency generation requirements.

The two major options for the i.f are 140MHz or 70MHz. Although the choice of 140MHz allows, in principle, the full 72MHz of transponder bandwidth to be covered in the s.c.p.c equipment (in association with a single 140MHz-14GHz frequency conversion system in the earth station), the penalty in s.c.p.c implementation complexity is large. The alternative is to use a 70MHz i.f, covering only one-half transponder, in the s.c.p.c access equipment. This allows existing, proven modem and synthesizer technology to be capitalized upon for this application. The penalty here is that two 70MHz to 14GHz frequency-conversion systems must be utilized to span the upper and lower halves of the transponder bandwidth, but once again the technology is well established. It is therefore contended that for a typical earth station, accommodating several s.c.p.c channel equipments, the more cost-effective choice for the i.f is 70MHz.

Monitoring and control

A monitoring and control interface is required between the s.c.p.c access equipment and a local and/or remote control device. This communication channel is used to send control messages to the channel equipment, enabling certain parts of the equipment to be programmed, and to allow status messages and alarms to be relayed from the equipment. Since the s.c.p.c equipment is intended for operation in an unattended earth station, it is a requirement that the remote facility may be extendable over the public telephone network. To implement this interface an IEC/IEEE 488 Bus is provided. This 'standard' interface has the advantages of a fully documented and proven protocol, together with the availability of proprietary control hardware. In addition the use of a single bus linking together a number of channel equipments reduces the quantity of cabinet wiring and associated controllers.

Operational aspects

Operational flexibility is provided in the s.c.p.c access equipment in the context of:

a) the number of channel units active at a given installation,
b) transmit and/or receive operation for each channel equipment,
c) encryption and/or decryption selection,
d) transmission rate (64kbit/s, or multiples thereof, up to 2·048Mbit/s).

The design approach is such that a single rack contains all the necessary common equipment for up to five channels, and the fitting, and operating-speed selection of a channel

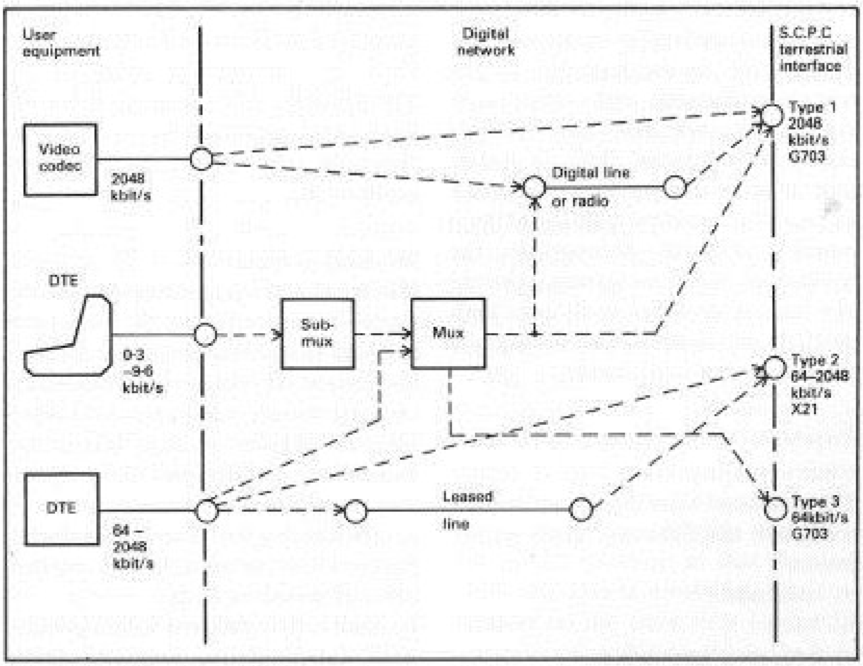

Fig.2. Possible terrestrial configurations

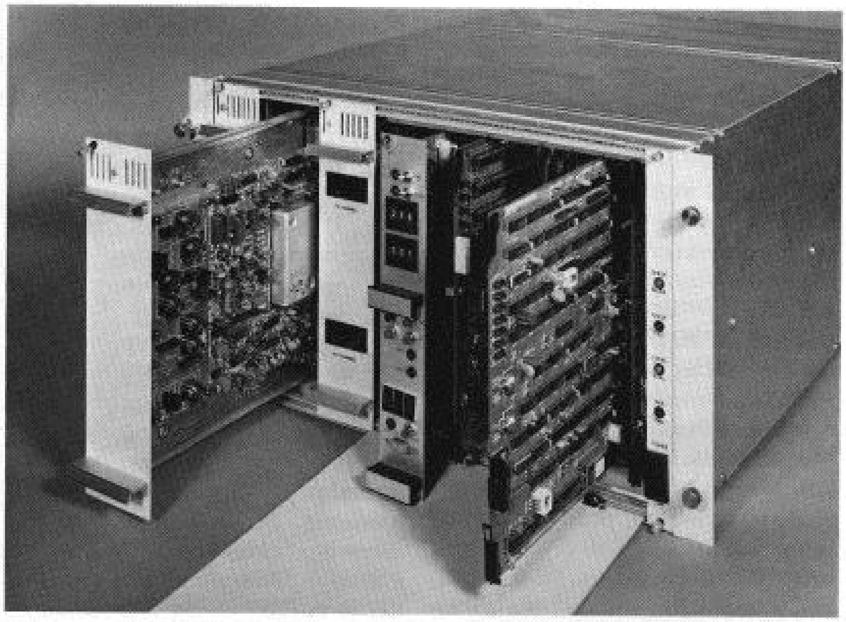

Fig.3. Prototype channel equipment shelf

equipment is a straightforward operation which may be accomplished by maintenance personnel in the field (without interruption to traffic on other channels). Operating-speed selection is effected by programming printed-circuit board (p.c.b) mounted links and/or substitute p.c.bs, with no electrical realignment procedure.

A modular design approach is adopted both for flexibility in operating configuration and to facilitate rapid fault location and restoration of service. This, together with the fact that in general readily available devices are used, contributes significantly to the equipment maintainability.

Fault location to the module/p.c.b level is indicated on the equipment and is available to be reported to the remote monitoring and control subsystem. Further test aids include removeable 'jumper' links to isolate functional blocks, to break feedback loops and to enable a number of 'loop round' functions throughout the equipment. A further feature is the use of a form of signature analysis to both partially automate factory testing and aid component fault finding.

Equipment description

Channel equipment

The channel-associated equipment comprises the following main equipments:

a) baseband,
b) f.e.c,
c) frequency generation,
d) modulation.

A basic block diagram of the channel equipment is shown in figure 1. A complete channel unit is physically housed in a single 10½in high shelf with integral power supply. Various equipment fitting options are available, dependent on the operating configuration (i.e data rate, transmit and/or receive selection, encryption and/or decryption selection).

Figure 3 shows the physical arrangement of the shelf. A 'clean' front-panel appearance is adopted consistent with the tamper-proof approach necessary for equipment which may be housed on customer premises. Front-panel indications are restricted to control settings and overall supervisories. Access to diagnostics/test interfaces and operator controls is conveniently achieved by extending the relevant module (in the case of i.f equipment) or hingeing-down the cover (in the case of digital equipment).

Baseband equipment

The baseband equipment performs the function of interfacing the terrestrial network to the modulation and coding equipment. It also provides the channel unit monitoring and control interface. In addition to these basic interfaces the major elements of the equipment comprise:

a) the framing function i.e, translating between the terrestrial and satellite network frame formats,
b) the receive (referred to the satellite link) data buffering function, which allows up to 16ms of data storage,
c) the encryption/decryption function including key management.

The baseband equipment is implemented as a number of discrete circuits as listed below:

a) terrestrial interface p.c.b,
b) satellite framing p.c.b,
c) receive buffer p.c.b,
d) monitoring and control p.c.b,
e) encryption (/decryption) module.

Items a) to d) each comprise a single double-Eurocard style p.c.b holding in excess of 100 integrated circuits. Item e) contains two p.c.bs in a physically secure unit.

The terrestrial interface circuit accommodates the various interface types. These connect to the remainder of the channel equipment via data and signalling first-in first-out (f.i.f.o) buffers, which provide a 'normalized' interface within the equipment independent of interface type.

The satellite framing circuit comprises, on the satellite transmit side, the satellite clock, frame and multiframe generator together with the scrambler. On the satellite receive side, it performs the satellite frame and multi-frame alignment functions together with descrambling and receive clock generation. The transmit satellite clock is locked to the incoming terrestrial clock; the receive clock may optionally be derived from the corresponding transmit clock, the received satellite clock or a reference clock (housed in the common equipment or from an external source).

The receive buffer circuit provides the 16ms of receive data buffering to allow for satellite diurnal movement and the plesiochronous slip strategy for the inter-connection of independent digital networks. The data buffer store is implemented using 2K×8 RAM devices.

Encryption may be implemented on the transmit and/or receive side by fitting optional encryption modules. Two identical units are required for transmit and receive operation, encryption or decryption mode being selected by an on-board link. The unit contains two p.c.bs mounted in a modular form of construction. By the use of tamper-resistant covers and a pick-resistant lock, to prevent unauthorized access to the unit, security of the encryption keys is ensured.

The monitoring and control circuit performs the function of monitoring and controlling the channel equipment. It provides an external interface for remote monitoring and control via the IEEE 488 interface bus. Via this interface, a remotely-sited operator may review the current equipment status of a number of channel equipments and, if desired, modify certain variable parameters on the equipment (namely test loop round enable, modulator output level and synthesizer frequency control).

The fault indications fed to this circuit may be classified as: alarm indications detected on incoming terrestrial signals, alarm indications detected on received satellite signals and equipment alarms. Actions consequent on one or more of these failures comprise; transmission of AIS or a 'backward' alarm condition across the terrestrial interface output port, similar action at the satellite transmit path interface, local alarm indication, and reporting of status via the remote interface.

F.E.C equipment

The f.e.c equipment performs the specified convolutional encoding and Viterbi (maximum likelihood) decoding functions. Two mechanically interchangeable single-card versions of the f.e.c circuit are used: a low speed circuit operating up to 256kbit/s and a high-speed circuit operating up to 2048kbit/s. This enables the full range of operating speeds to be accommodated in a single shelf arrangement. These units are being developed and supplied under subcontract by Signal Processors Ltd.

The low-speed version performs the required metric calculations for all paths consecutively using a single arithmetic unit to provide a relatively low-cost design, while the 2Mbit/s version performs the metric calculations using semi-custom gate array devices, and is of the same size and power consumption as the low-speed unit. Both units accept analogue inputs from which they generate 3-bit soft decision data, allowing the decoders to be interfaced directly to the demodulator outputs. A major feature of these codecs is their use of novel techniques for path storage and ambiguity resolution, which ensure that their performance is not restricted by the implementation constraints which have applied to some previous designs, particularly at low error rates. As a result they maintain full coding gain down to bit error rates below 10^{-10}, where they achieve a gain exceeding 6·1dB.

Frequency generation equipment

Frequency synthesizers are used to provide the required frequency agility in both transmit and receive channel frequency allocation. Independent units are provided for transmit and receive directions of transmission, the two units being mounted together in a single slide-in module.

The reference input to each synthesizer is at a nominal frequency of 5·76MHz. In the transmit case this is distributed to each channel equipment from the common equipment. In the receive case, the reference is derived from the associated demodulator within the relevant channel equipment. This latter arrangement enables the demodulator frequency acquisition and tracking performance to be achieved by including the synthesizer within a phase-lock loop. A single-loop synthesizer is used on the grounds of simplicity and hence low cost and high reliability (compared to a multiple-loop configuration) whilst still providing phase noise characteristics consistent with the overall link bit error rate performance. The synthesizers (and modem) operate over the band 50MHz to 90MHz.

P.S.K modem

The p.s.k modulator converts the incoming dual digital data streams from the f.e.c codec into a four-level p.s.k modulated signal with a carrier frequency in the range 50MHz to 90MHz. The p.s.k demodulator converts the received modulated carrier back into dual streams (in analogue format) for error correction within the f.e.c codec.

In the modulator, the incoming dual digital data streams are used to generate bipolar impulses. These have an essentially flat frequency response and the following baseband channel-shaping filter accurately defines the amplitude and phase response of the baseband signal. The impulse drive approach is utilized to enable identical channel-shaping filters to be used in both modulator and demodulator. In addition, it is intended to enhance the long-term amplitude and phase accuracy of the modulator. These two baseband signals are then linearly modulated, in phase quadrature, onto the carrier signal provided by the external local oscillator (the transmit synthesizer).

In the demodulator, the incoming carrier is first passed through the automatic gain control (a.g.c) circuit which maintains the signal power constant within the wanted bandwidth, by use of a control signal derived after the channel-shaping filters. This a.g.c circuit is designed to have a high intercept point so that, although it is presented with a large aggregate signal (being a wideband 50MHz to 90MHz input), the level of intermodulation products does not degrade the performance of the demodulator in a multicarrier environment. This level-controlled signal is next coherently demodulated to yield dual baseband signals. The channel-shaping filters then provide the necessary rejection of the unwanted signals and noise and complete the overall channel impulse response. The resultant analogue baseband signals are output to the f.e.c decoder.

The carrier recovery circuit comprises a non-linear device followed by narrowband filtering. The non-linear process generates a phase-error signal from the cross-talk detected on the two quadrature filtered baseband signals. A phase-locked loop is formed by applying this phase-error signal, via suitable amplification/filtering, to a voltage-controlled crystal oscillator, which in turn provides the reference signal to the v.h.f synthesizer (which generates the local oscillator for demodulation). The bandwidth of the loop is chosen to achieve an acceptable compromise between acquisition performance and cycle-skipping probability. An important aspect is the acquisition technique used in the carrier recovery phase-locked loop, where the low signal-to-noise ratio environment combined with relatively large frequency uncertainties poses significant design constraints. Swept acquisition is used in conjunction with a dual bandwidth loop. In addition, the loop incorporates a track-and-hold feature to enhance the acquisition process following a break in reception; this feature utilizes a non-volatile store.

The clock recovery circuit uses a non-linear square law process to recover a discrete clock component which is then presented to a phase-locked loop. The loop reduces the pattern noise in an analogous manner to the carrier recovery, so that the clock cycle skip rate is controlled. The constraints on the clock loop bandwidth are more relaxed however, as the possible clock frequency uncertainty is much reduced, thus easing the acquisition requirement. The loop incorporates a combined analogue and digital track-and-hold facility to allow maintenance of bit-count integrity and to alleviate pattern-dependency effects.

A significant feature of the modem design is that change of signalling rate is effected by replacement of the channel-shaping filter boards, and by link changes on the relevant p.c.bs. These changes do not require any soldering or re-alignment of the circuitry.

Common equipment

The common equipment comprises a 6ft high cabinet, wiring and items of equipment for a number of channel units, viz: i.f patching facilities, transmit i.f combining and receive i.f splitting circuitry, and common frequency reference and timing generation. The cabinet accomodates up to five channel equipments. The configuration may readily be changed in the field.

Transmit i.f combining is entirely passive, using two hybrid combiners to derive the 'low band' and 'high band' i.f outputs. The receive i.f splitting also uses hybrid networks, with similar patching facilities.

Amplifiers are used to give a small net insertion gain on any path. These amplifiers are designed to have a high reliability (since any failure in the common path would affect several channel equipments).

The reference clock oscillator/distribution circuit forms part of the common equipment and is responsible for generating and distributing the reference frequency and clock to up to five channel units. The circuit embodies a 10MHz reference oscillator, and two phase-locked loops are provided to derive 5·76MHz and 8·192MHz outputs. An IEC/IEEE-488 interface is fitted to allow communication to the external monitor and control subsystem.

Conclusion

This new generation of s.c.p.c access equipment has been specifically designed for business services in an unattended earth station environment, and features an optional encryption facility in conjunction with a powerful f.e.c technique. It further provides a large measure of operational flexibility in a physically compact arrangement.

The equipment is being developed and manufactured by Marconi Communication Systems under private venture funding, and is being supplied to British Telecom for use in its SatStream service. Although primarily designed for the European multiservice system, the equipment is equally suitable for the INTELSAT Business System. It is envisaged that the in-built flexibility will make the equipment suitable for other applications (e.g domestic systems).

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RÉSUMÉ

Les systèmes de gestion internationale par satellite sont en train de devenir une réalité. Ils sont étudiés pour permettre la communication numérique relativement rapide entre des bureaux utilisant de petites stations terrestres.

Le présent article concerne l'équipement d'accès aux systèmes à voie unique par porteuse (SCPC) qui sert d'interface entre le flux de données de l'utilisateur et le matériel radio de la station terrestre.

A la suite d'un réexamen des exigences essentielles de ces systèmes, l'article décrit le nouveau matériel spécifiquement étudié pour cette application.

RESUMEN

Los sistemas comerciales de los satélites internacionales se están convirtiendo ya en una realidad operacional. Se diseñan para proporcionar comunicación digital relativamente rápida entre locales de negocio, haciendo uso de estaciones terrestres pequeñas.

Este artículo trata del equipo de enlace monocanal por corriente portadora (SCPC), el cual establece interconexión entre el flujo de datos del cliente y el equipo de radio de la estación terrestre.

Después de una crítica de los requisitos principales del sistema, se describe un nuevo equipo, el cual se ha diseñado específicamente para esta aplicación.

ZUSAMMENFASSUNG

Internationale Satellitensysteme für die Geschäftswelt werden jetzt zur betrieblichen Realität. Diese Systeme ermöglichen digitale Kommunikation mit relativ hoher Geschwindigkeit zwischen Bürogebäuden unter Anwendung kleiner Erdstationen.

Dieser Aufsatz bezieht sich auf Zugriffgeräte mit Einzelkanalbetrieb pro Träger, womit der Datenfluß des Kunden an die Radioanlage der Erdstation angeschlossen wird.

Nach einer Übersicht der hauptsächlichen Systemanforderungen wird ein neues Gerät beschrieben, das besonders für diese Anwendung konstruiert wurde.