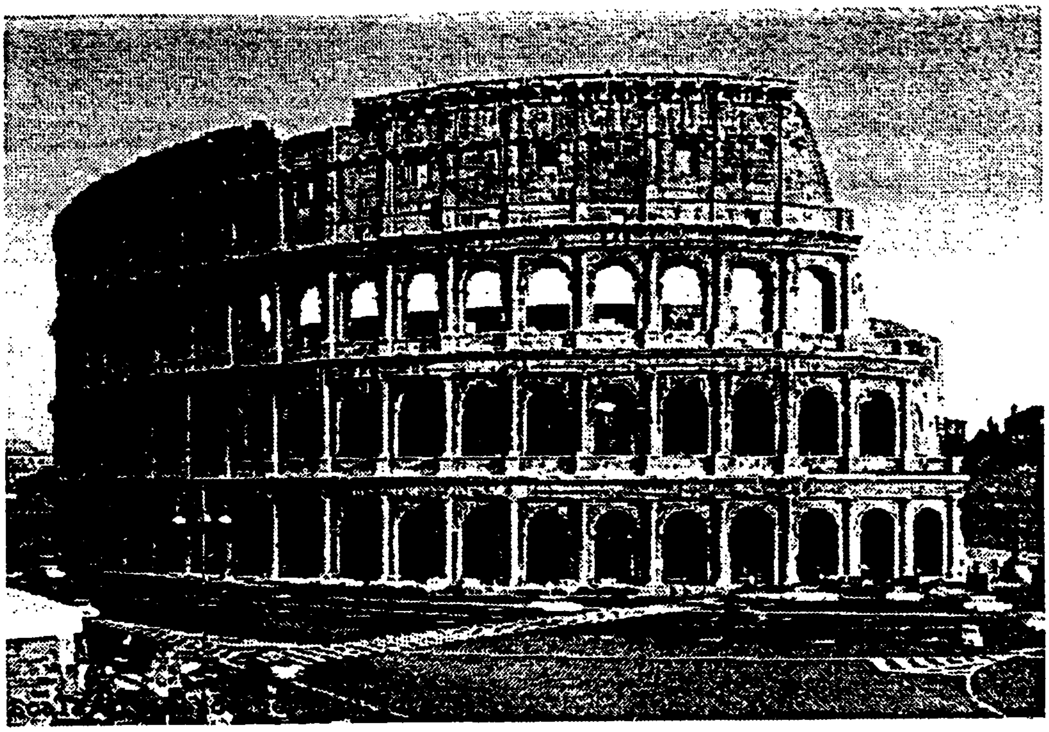

Ka BAND UTILIZATION CONFERENCE

October 10 - 12, 1995
Rome, Italy

Under the auspices of:

Ministero delle Poste e Telecomunicazioni, Italy
Agenzia Spaziale Italiana - ASI, Italy
National Aeronautics and Space Administration - NASA, USA
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THE ITALSAT PAYLOAD

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ABSTRACT

The second flight unit of the ITALSAT telecommunication satellite will be placed in geostationary orbit in early 1996, making operative the ITALSAT telecommunication system after the experimental and preoperational phase performed by ITALSAT F1, which was launched in January 1991 by the Italian Space Agency.
A general view of the ITALSAT payload is presented with emphasis on the design, the telecommunication mission, the new technologies and the protocols with the ground segment.

THE ITALSAT MISSION

The ITALSAT F1 satellite is placed at 13.2° east in geostationary orbit; the communication mission is accomplished by three packages: the multibeam national coverage, the global national coverage and the extra high frequency (EHF) propagation experiments.
The mission, which includes the most innovative characteristics, is carried out by the multibeam payload. Six beams are linked for the coverage of the whole national territory. This is achieved through a switching matrix in baseband on board the satellite. The access to the ground stations is of the time division multiple access type and the transmission rate is 147 Mb/s.
The Global National Coverage payload capable of a coverage of the entire Italian territory with a single beam and three transparent channels is located beside the multibeam.
The two payloads (multibeam and global) together make up the ITALSAT telecommunication system whose block diagrams, frequency plan and coverages are shown in Figg.1, 2, 3 respectively.
The two payloads differ one from the other in their technical-operational, systemwise and performance features. The 'multibeam' payload, together with the ground-based units, is part of a satellite numeric network integrated with the ground-based network; the interface with the ground network is at the switching centres level. The 'global' payload can perform various different tasks: from the single end-to-end links with small ground stations sited close to the user, to the implementation of closed-loop networks having *ad hoc* characteristics and performances, to the transmission of data and analog video signals as well as telephone links up to 24.5 Mb/s.
ITALSAT F1 includes also 40 and 50 GHz beacons, radiated by two dedicated antennas, that allow propagation experiments in the millimetric wavelengths for Europe. The 50 GHz beacon is radiated without any modulation in linear polarization. The polarization plane can be set, by means of telecommand, in fixed vertical mode, fixed horizontal mode or switching between vertical and horizontal mode. Absolute attenuation can be measured as well as polarization purity and attenuation parameters as functions of the polarization.
The ITALSAT F2 telecommunication mission foresees a multibeam payload and a global beam payload (as in the precursor ITALSAT F1) plus the European mobile system (EMS) payload (which substitutes for the experimental propagation payload of ITALSAT F1). The EMS payload will provide communications between mobile users (in L band) and fixed earth-stations (in Ka band) within Europe, managing telephony and data traffic with three 4 MHz transponders.

THE TELECOMMUNICATION SYSTEM

Multibeam coverage payload

The mission. The ITALSAT multibeam mission was conceived to establish point-to-point and point-to-multipoint connections via satellite between stations deployed on Italian territory, providing maximum flexibility and reconfiguration of connections and of their assigned capacity.

To this end, the surface of the Italian territory has been divided into six service areas, each served by a spot beam having high directivity. The six areas covered have been formed into groups of three by using two TX/RX independent antennas which point towards the desired direction with a tracking system which can ensure an overall error less than 0.03°. The communications system adopts vertical polarization carriers in both the 30 GHz (ground-to-board) and 20 GHz band (board-to-ground).

Each coverage is associated with a transmitting channel with a bandwidth equal to 110 MHz which can carry the QPSK modulated signal at 147 Mb/s.

The peculiarity of the multibeam payload is to work regeneratively on packet signals received from the various stations operating in TDMA, to switch them, and to then organize them into a continuous binary flow which, when modulated in QPSK and amplified, can be sent to ground in one or more spots as required by the ground-programmed traffic plan. This operating mode is defined as the SS-TDMA system (satellite switching time division multiple access) and the ITALSAT multibeam payload is its first application in orbit.

To better understand how the ITALSAT network operates, we must bear in mind that the analog audio channels are processed by the ground station so as to obtain a synchronous binary stream (e.g. at 32 kb/s). Such streams, in accordance with the capacity needs of the stations, are sent at the ITALSAT satellite network speed of 147 Mb/s. In accordance with the traditional TDMA access, the resulting speed compression is such that each station occupies the satellite channel for short and well defined time periods, so as to allow cyclic access of all stations of the network according to a periodic organization known as a frame, which is described later on in this paper. From the above, it is clear that the resulting capacity is given by the ratio between the satellite network speed and that of a single service, e.g. with a 32 kb/s coding of an audio signal, the spot capacity of the ITALSAT system is 2000 circuits/spot, or 12,000 total circuits. The regenerative channel was dimensioned so as to have on board a G/T equal to about 10.0 dB/K and bit error rate better than 10^{-6} with an Eb/No ratio of 13.3 dB. Channel e.i.r.p., within the beam, is equal to about 54.0 dBW.

The multibeam mission success was designed to be better than 87 per cent and the mass and power envelope of the payload are 110 kg and 580 W, respectively.

The frame and type of services. The advantage offered by the SS-TDMA system is that of satellite system capacity and connectivity reconfiguration in times which are practically neglectable. For TDMA operation, however, the stations must be synchronized with the time reference used on board by the payload baseband switching section.

Effective management of access implies that the times and duration of transmissions assigned to single stations by the master station are organized cyclically within a periodic structure lasting 32 ms, called a frame and shown in Figure 4. The ITALSAT frame has been organized into 3000 minimum contiguous switching units (SU) each lasting 10.5 μs.

Station synchronization with the satellite reference is obtained by monitoring the RB packet (reference burst), which the on-board switching matrix sends every 32 ms to all spots, allocating the first 3 SUs of the down-link. The time of receipt of the RB is used by all stations as the time origin for the calculation of the time of transmission of each packet. The ITALSAT frame can be divided into four regions:

(a) *Service area.* This is a fixed area used as a signaling and command channel between the master station and the on-board switching matrix. The commands are sent from the ground (master station) on the CH packet which occupies SU n° 4, 5 and 6 of the uplink frame. The command channel has an information stream equal to 64 kb/s gross through which it is possible to reconfigure on-board traffic and connections in a few minutes. The on-board switching matrix reacts to the commands delivered and replies according to the exchange protocol on the FMC packet, allocated to the next-to-last SU of the down-link frame.

(b) *Permutation area.* This area can be dimensioned by the master station by setting frontier F1. Here the permutation traffic is set, assigned in an almost stable mode to the stations of the network. Within the permutation area it is possible to access only with 32 μs packets occupying three consecutive SUs, and therefore providing a 128 kb/s stream per packet.

(c) *Videoconference area.* This region too can be modified by selecting appropriate values for frontiers Fl and F2 shown in Figure 11. Access to this region is through blocks of sixteen 32 μs packets, so as to occupy, therefore, 48 consecutive SUs. The stream which results is equal to 2 Mb/s per block, which supports the videoconference service.

(d) *Switching area.* This region, settable by changing frontier F2, supports access with 10.5 μs (1 SU) packets, which therefore provide a capacity of 32 kb/s per packet.

If required, the entire frame may eventually be organized to carry a TV channel at about 147 Mb/ s, re-broadcast on one, more than one or on all six regions of the multibeam coverage.

The burst format. The burst, shown in Figure 5, has a preamble with a fixed content, equal for all types of burst and a useful data field which can host 512 symbols (1024 bits) in 10.4 μs single channels bursts or 2048 symbols (4096 bits) in the case of 32 μs four-channel bursts. The useful data area is coded (scrambled) by the traffic stations so as to ensure the correct number of transitions of the four states of the QPSK carrier under any circumstance. The efficiency obtainable with the single channel packet is equal to 66 per cent; efficiency reaches 87 per cent with the four channel packet and reaches about 100 per cent for TV service at 147 Mb/s. It can be readily understood from the above that maximum efficiency of the system is achieved by allocating maximum capacity in the permutation area on the basis of the average traffic requirement of each station. The low efficiency switching area must, on the contrary, be used jointly with all stations to manage the peak traffic situations and must be assigned on request and released as soon as the peak traffic situation has ended.
The starting part of the burst provides the data required for the carrier and clock recovery circuits of the on-board coherent demodulator, so as to obtain correct absolute frequency and clock and carrier phase with which the data was modulated on the ground.
The acquisition process must be completed before the last preamble field arrives: the unique word (UW) which has the task to let the on-board and ground baseband stages correctly decode the data organized in positional form. The 40 service symbols between the UW and the data field can be used as service channels between the various stations of the network.

The network. The Italsat telecommunication network operates with the multibeam payload of the satellite, which makes available a 147 Mbps transmitting capacity for each of the six areas covered. The main scope of the network is to provide the capacity for additional connections to the ground telephone network, integrating with the National Telephone Network and with the other types of circuit switching networks (data network). The Italsat network can offer resources useful for two types of services:

- Permutated Traffic with a point-to-point connections between two stations, where each circuit has an origin and destination defined in the present time scale and is unchanged till there is a timeplan variation.
- On Demand Assigned Traffic so that the resources available to achieve communications are defined in the traffic plane, but circuits are assigned dynamically on a case by case basis, depending on the call requests.

The telecommunications network consists of a set of ground stations through which it is possible to obtain a full mesh connection among a number of sites using the on-board controller switching capability. The ground stations have access to the satellite according to a TDM/TDMA protocol, using a frame lasting 32 ms., divided into 3072 Switching Units (S.U.) which in turn are grouped into bursts according to their use: those made up of 3 S.U. dedicated to permutated traffic and those of a single

S.U., used for the Demand Assignment Multiple Access (DAMA). All stations configured in the network can give way to traffic and they are indicated as Traffic Stations: one of such stations at Fucino acts as a control station for the network traffic (and is hence called the Master Control Station) and supplies the data necessary for the switching matrix on board the satellite, so that it is regulated in the most appropriate manner for administering its own switching resources. This station, which is also linked directly to the telephone network, is connected to two computers: one is dedicated to administering the satellite network and the other the traffic.
The Fucino control center also controls the 'beacon' stations at Cagliari and Courmayeur near Aosta. They have the task of supplying the satellite with two signals on differing frequencies (28 and 29 GHz) which serve as a reference to maintain the antennas' radiation bands aimed at the center of the determined geographical area. The two beacon stations also transmit a third signal based on a cesium sample. The system which generates it is also flanked by a very reliable quartz oscillator, which allows synchronization of the times of the network activity with those of the innovative switchboard installed on board the satellite, the baseband matrix which switches up to 12,000 telephone calls simultaneously. When working according to a timeswitching technique, this deals with the incoming signals from the ground stations which have already been organized according to a precise cadence of 32 thousandths of a second.

Design and performance. The SS-TDMA multibeam payload relays the traffic between the six zones, in Italy, covered by spot beams having 0.4° of aperture. The spot beams are generated by two single offset antennas having reflector dishes of 2 m diameter providing very high gain (about 50 dBi). The high data rate (147 Mb/s) implies an e.i.r.p. of about 57 dBW and a G/T of about 17 dB°K, obtained with a 20 W TWTA and 4 dB noise figure receiver. The satellite body attitude control is not adequate to maintain the antenna pointing accuracy necessary because of the high gain slope at the edge of coverage; the antenna pointing system is then required. The linearly polarized narrow beams are pointed by means of two lobe switching antenna pointing systems locked on two ground beacon signals.
The repeater input section includes wideband 30 GHz low loss multiplexers and low noise 30 GHz parametric amplifiers. The signal is then down-converted to 12 GHz and fed to the burst mode QPSK demodulators. The baseband signal is routed by the high speed 6x 6 S type switch matrix and fed to the 20 GHz QPSK modulator bank. These two are direct modulators based on the reflection of signals by transmission lines end loaded by PIN diodes. The 20 GHz modulated signal is amplified by 20 W / 20 GHz TWTAs. The microwave filters at 12 GHz and 20 GHz are realized in thin wall invar and silver plated to achieve high thermal conductivity and good dimensional stability.
The multibeam regenerative payload can be made a transparent one by using a transponder (mounted to perform the in-orbit test) which bypasses the baseband section.
Table I shows the comparison among specified G/T and e.i.r.p. values, the on-ground measurement results and the in-orbit performances. In addition the bit error rate performance in both up and downlinks is shown: the BER performance includes the contribution of the ground modem. The in-orbit performance shows margin versus the specifications.

National coverage payload and telemetry beacon

The mission. The global national coverage payload has access to all points of the national territory, performing point-to-point and multipoint services with possible on-request assignment. Emergency connections with disaster hit areas and TV signal broadcast are also made possible. To this end the payload includes three transparent repeaters with a 36 MHz useful bandwidth. Each repeater is compatible with the following types of access and modulation:

(a) QPSK modulated digital signals with TDMA access to the satellite at a 24.576 Mb/s transmission speed;

(b) analog signals such as standard TV signals, frequency modulated (FM-TV) with a 27 MHz bandwidth;

(c) signals with multi-carrier digital modulation (SCPC/FDMA).

In this last case, the payload can vary the TWTA working point by desired back-off values by means of commands from the ground, allowing linear operation of the TWTA to cut back the intermodulation products.
Coverage of the Italian peninsula and islands is obtained by means of a single transmit/receive antenna with a beamwidth of 1.06° x 1.55°. Vertical polarization is used for the up-link and down-link. The payload adopts the radio-frequency band in up- and down-link assigned exclusively to fixed services via satellite by the international regulations to avoid possible interference with ground radio links, at 29.5-30 GHz up and 19.7-20.2 GHz down. Under eclipse, one receive/transmit chain alone is activated to optimize power consumption of all payloads as a function of battery capacity.
At the package output is connected the 20 GHz beacon which transmits telemetry signals towards earth when the satellite is set in its geostationary orbit.
The 20 GHz beacon is also used as a tracking signal for the communication ground stations. The beacon is fully operative even in an eclipse situation.

Design and performance. The package is divided into a low noise receiver, a channeling intermediate frequency section, high power amplification and a TX/RX antenna.
National coverage is assured by a single TX/RX antenna of subreflector type which provides an elliptical beam with an aperture of 1.06' X 1.55' with vertical polarization. The repeater input section includes a medium band front-end with low noise parametric amplifier, single balanced passive mixer for down conversion at 12 GHz and FET amplifier. The channeling section separates the three 36 MHz channels with a demultiplexer, amplify and up-convert to 20 GHz, where the signals drive the TWTAs into saturation or backed-off in the linear mode. The wide band intermediate frequency amplifiers have two operating modes:

(a) limiting mode: to drive the TWTA in saturation by means of an automatic level control circuit

(b) fixed gain: to drive the TWTA with the desired back-off by means of a gain commandable from ground in linear conditions.

The up-conversion at 20 GHz is performed by a resistive mixer followed by a bandpass filter. The 20 GHz power amplifiers use TWTs of the helix and three stages collector type, with 20 W in saturation.
The telemetry beacon consists of a 18,685 MHz carrier is phase modulated by a sub carrier (65 kHz) in turn PSK/ SPL modulated by the digital telemetry signal at a transmission speed equal to 1024 b/s.
The three global package channels, together with the telemetry signal coming from the 20 Ghz beacon, are combined in the output multiplexer before being radiated to the ground.
Table II showes a comparison among the specified values, the on-ground measurements and the in-orbit performances which have margins versus the specifications.

ITALSAT F1 European propagation experiments

Connections via satellite in the millimetric wavelengths require in-depth knowledge of propagation characteristics at such frequencies. The 40/50 GHz transmitters carried on board the ITALSAT satellite form a realistic model of a radio link operating at such frequencies for experimentation and tests over the entire European territory.

40 GHz propagation beacon. The 40 GHz propagation beacon is adopted for propagation experiments in the European coverage, supporting also attenuation measurements, attenuation and differential phase and polarization purity. The 40 GHz carrier, radiated to ground in right-hand circular polarization, is phase modulated by a 505 Mhz coherent sinusoid subcarrier, in order to compare the amplitude and the phase of the three signals transmitted (carrier and the first side frequencies) in a 1 GHz band. The radiated total EIRP is 28 dBW and the power consumption is 40 W.

50 GHz propagation beacon. *The* 50 GHz propagation beacon is radiated in the european coverage without any modulation and with a linear polarization. The beacon is polarization-modulated by a switch which rotates the polarization plane by 90•, resulting in a transmission with alternate H/V polarization at a switching rate of 933 Hz. To increase flexibility during experiments, there is a possibility to freeze the beacon on one of the H or V polarizations by means of telecommands from ground. This way we can perform absolute attenuation and polarization purity measurements. The radiated EIRP is 27 dBW with a power consumption of 25 W.

ITALSAT NEW TECHNOLOGIES

The on-board regeneration and the baseband switching adopted for the multibeam payload was the first implementation for space communication programs. The SS-TDMA access, adopted for the system, with variable burst technique, had to be interfaced with the public switching telephone network using dedicated software at the terminal ground station. The signal bit rate of 147 Mb/s required components with high degree of integration which were not available and qualified for space application.
The high gain Ka band antennas required an antenna pointing system having 0.03° of accuracy to avoid unacceptable e.i.r.p. and G/T degradation. Thus, a careful design and development program for the communication payload and the ground stations was at the highest priority.

On-board processing equipments

The on-board regeneration and switching represents the innovative feature of the ITALSAT multibeam payload. In fact it was the first in-orbit implementation of a regenerative payload with high speed baseband switching. The entire ITALSAT multibeam system is, for a good part of its switching resources, a TST network node where T (timing) stages are distributed among the ground stations, the S (space) stage is on-board, and management is entrusted to the ground telecommunication control center.
The on-board processing equipments are the demodulators, the baseband switching matrix and the remodulators.

The *demodulator* is of burst mode type and its key features are the fast acquisition (carrier and clock recovery within 112 symbols) to maintain the system synchronization, the high input dynamic range (30 dB) due to rain attenuation, and antenna gain variation from peak to end of coverage.
The demodulator input signal at 12 GHz is down-converted at 700 MHz and then filtered amplified and level stabilized at the output. The carrier is recovered from IF signal through multiplication by 4, narrow filtering, a limiter and division by 4, and inserted later in the demodulation section. The demodulated signal is then regenerated and ready for on-board switching. The carrier phase is stabilized by a feedback loop which acts on the VCO frequency. The lock-in range of the demodulator is about 2. MHz.
The implementation of the demodulator makes extensive use of microstrips and is characterized by microwave (2.8 GHz) carrier recovery circuitry, DRO filters, ASICs for baseband signal processing and feedback phase loop.
The *baseband switch matrix* (BBS) allows the connection, in any combination, of the traffic terminals located in any of the six coverage areas. The baseband switch matrix handles the commutation of nine streams of 147 Mb/s, six of which in current duty and three in cold standby.
The BBS is constituted by two essential sections: switching matrix and controller. The matrix contains high-speed circuits to manage, in real time, the signals in baseband, the controller is in charge of the switching matrix management by means of available signaling channels, as well as functional control of the unit. The controller recei[illegible] instructions for its operation from the TT&C station and/or from the master control station. All the ti[illegible]ng functions are derived from a highly stable external clock generated from an on-board master clock. The switching basic function is performed by six multiplexers: each one can route the bursts coming from the demodulators and the service bursts generated within the BBS.
Each multiplexer is provided with a bit synchronizer circuit to resynchronize the bursts with the on-board clock to recover the instantaneous frequency differences (due to the Doppler effect and the different stability of the ground terminal equipment) between the up-link data stream clock and the onboard

clock. The BBS is implemented using 7 ASIC ECL gate arrays. These are of two types (MUX, timing) having 2500 and 3500 gates, respectively.
The 20 GHz QPSK *remodulator* is fed by two data streams (I, Q) at 73 Mb/s acting on two cascades biphase modulators to obtain the 147 Mb/s QPSK signal. The input logic selects data streams (1, Q, CK) coming from the two switching matrixes: ECL 10k logic is used. This logic generates a suitable signal to phase shifters (0÷180°) and (0-90°) which are manufactured in a waveguide WR 42 section, using PIN diodes as commutation devices. The modulator can handle carrier power levels up to 500 mW and operates directly at the microwave transmission frequency. The reference carrier at 20 GHz is generated (inside the unit) by an oscillator stabilized with a dielectric resonator.

The technology accomplishments of the regeneration section are summarized in Table III.

Multibeam antenna pointing
The two SS-TDMA payload multibeam antennas are very narrow beam antennas, so that the pointing accuracy achievable by the satellite body control is not sufficient to meet the requirements. For this reason the two antennas are controlled by a lobe switching closed loop antenna pointing system (working at Ka band). The two beacon ground stations are located in the cities of Cagliari (Sardinia) and Aosta (Northern Italy) and are associated with the East and West spot beam antennas, respectively.
The on-board equipments includes the RF sensor, the antenna rotation mechanism, the motor drive electronics, the control unit and the tracking receivers. Many operating modes ensure the proper control and operation of the subsystem. The autotracking sequence automatically sets the subsystem in beacon tracking mode through initial repointing and angular acquisition. The in-orbit test has demonstrated the full achievement of the design objectives. The resulting pointing errors summary is shown in Table IV.
Besides, the master/slave back-up mode has been actuated, simulating the outage of one beacon: the affected antenna has been correctly driven by the control of the other antenna and negligible variations have been found on the e.i.r.p. of the slave beams.

ACKNOWLEDGMENTS

The work reported in this paper was possible thanks to the effort of many colleagues of Alenia Spazio and ASI involved in the ITALSAT project.

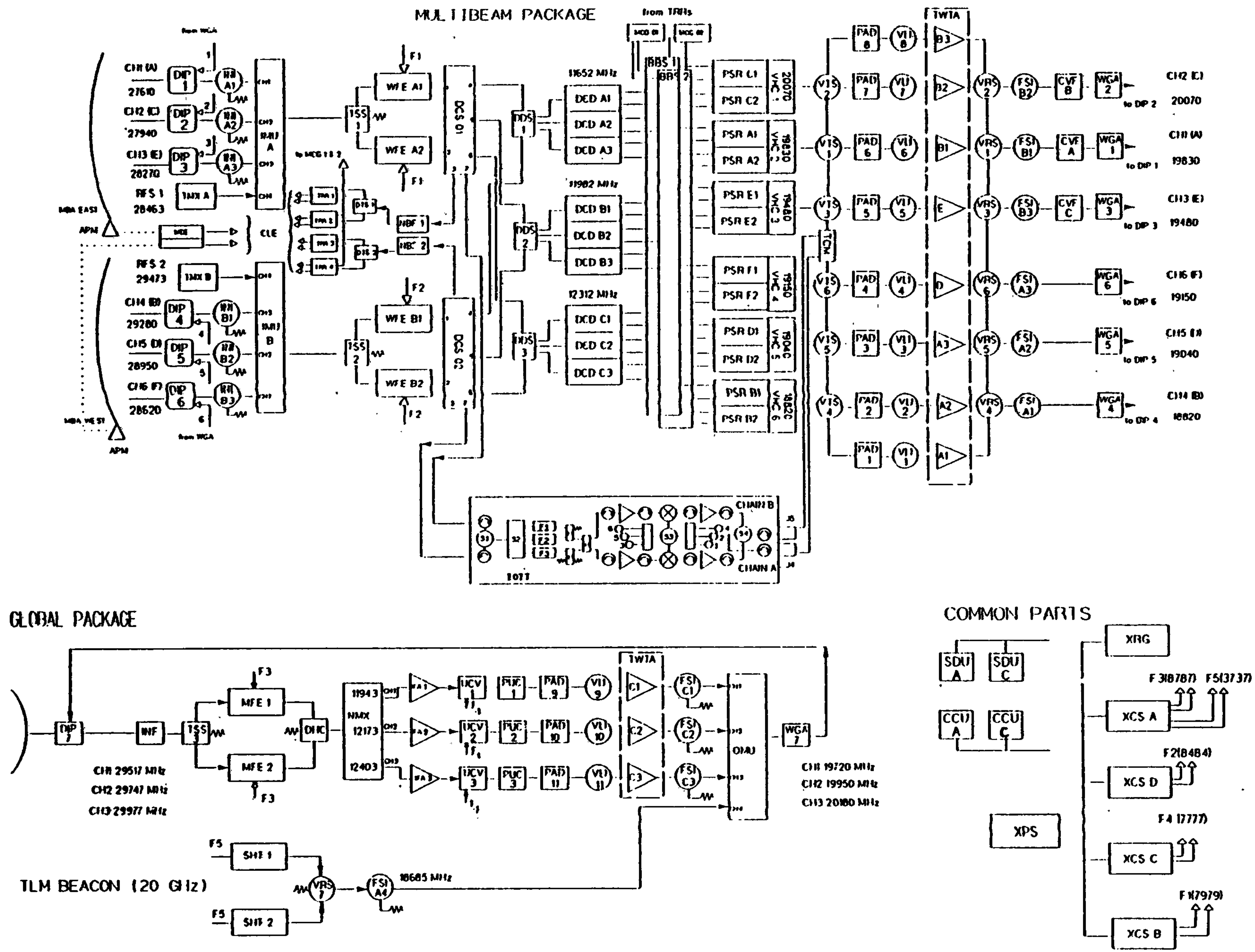

Fig. 1 - ITALSAT Multibeam and Global Payloads Block Diagram

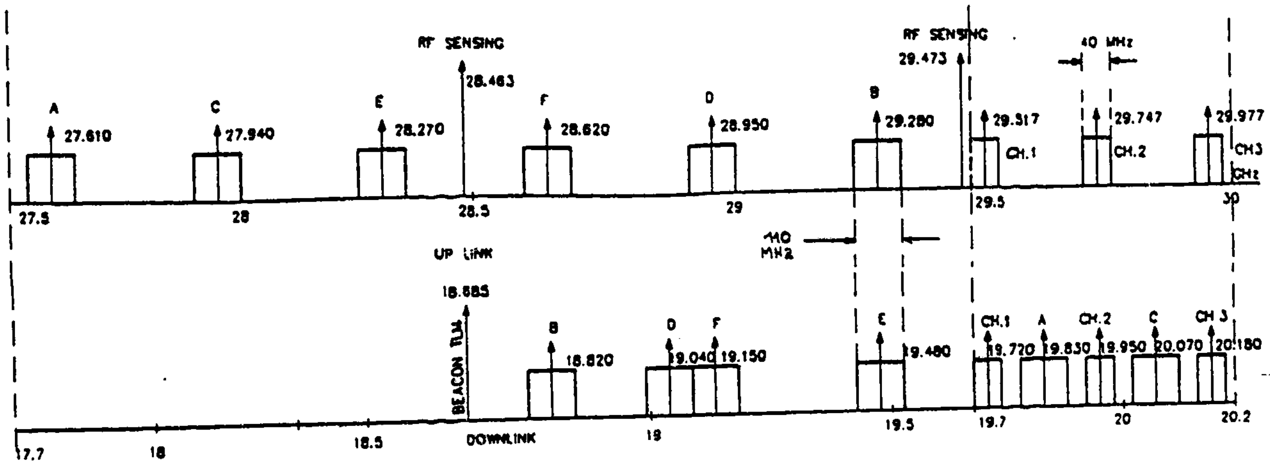

Fig. 2 - ITALSAT Multibeam & Global Payloads Frequency Plan

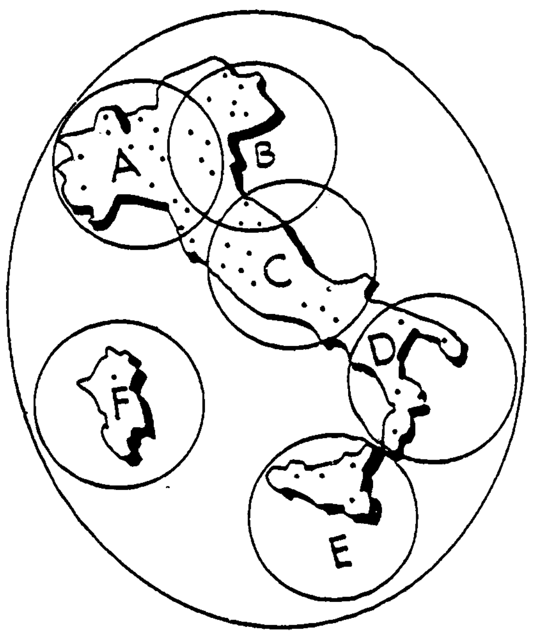

Fig. 3 - ITALSAT Multibeam & Global Coverages

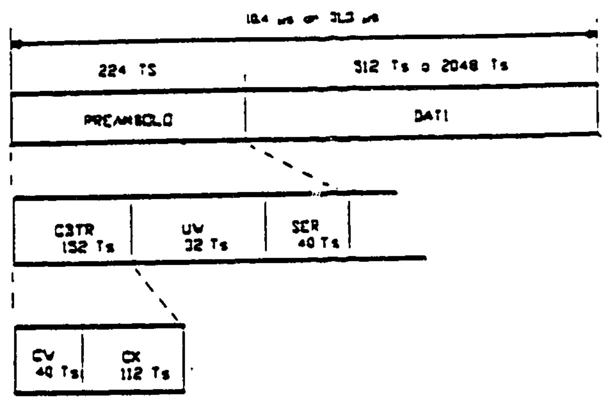

Fig. 5 - ITALSAT Burst Format

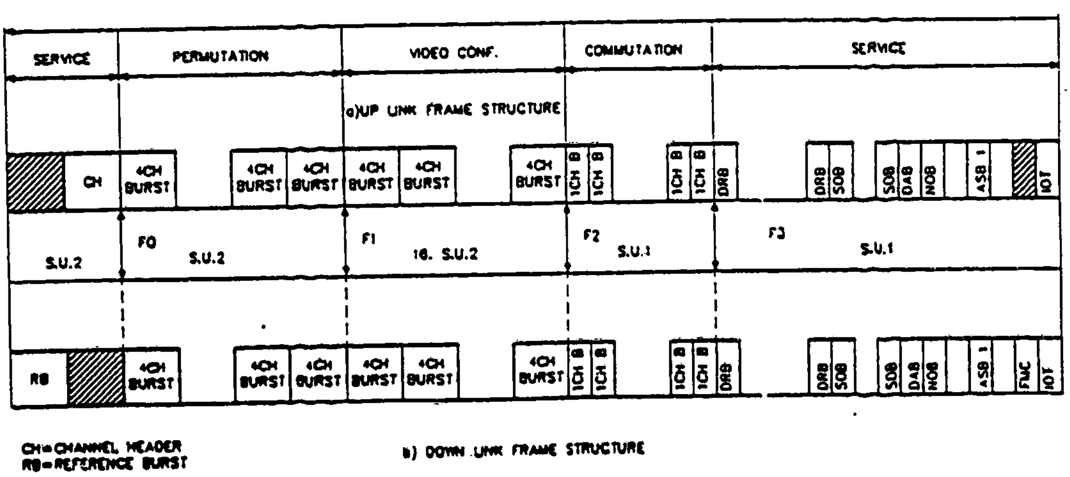

Fig. 4 - ITALSAT Multibeam Payload Frame Organization