INTELSAT'S DEVELOPMENT PROJECTS ON C-BAND VERY SMALL APERTURE ANTENNAS AND ASSOCIATED TECHNOLOGY

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1. INTRODUCTION

The design of satellite communications systems based on very small aperture terminals (VSAT) at C-band (4/6 GHz) poses a formidable challenge both in the antenna and in the modulation technique areas, due to the great potential for off-axis emission interference vis-a vis CCIR Recommendation 524-2. At C-band, for antennas with diameters smaller than 1.8 m, the potential for earth station antenna off-axis interference into adjacent satellites becomes particularly critical, since it is bound to occur not only through the antenna sidelobes, but also through the mainlobe, due to the very wide beamwidth of these antennas. Therefore, a very careful C-band earth station antenna design and selection of the modulation technique are required, in order to minimize interference to and from adjacent satellites.

INTELSAT's keen interest in the development of C-band VSAT technology is due to the fact that this is the band through which its satellites can offer true global coverage between any two points of the earth (INTELSAT satellites' Ku-band spot beams are narrow and normally pointed to the most heavily populated areas). INTELSAT has been offering the INTELNET services at C-band since 1984, which makes use of VSAT's with antennas as small as 0.6 m, and spread spectrum/code division multiple access (SS/CDMA) technology (Reference 1). However, the INTELNET service is primarily intended for low-speed data communications and not for voice. In order to provide voice communications through VSAT technology at C-band, different alternatives had to be explored, as this paper will describe. For this symposium, the antenna aspects are emphasized in the paper, but recognition is given to the fact that the modulation technique aspects are intimately related, since adjacent satellite interference is the major limiting factor for C-band VSAT designs.

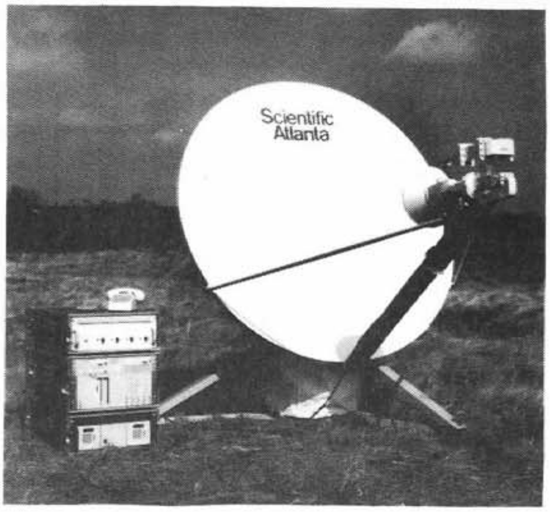


Figure 1. INTELSAT 1.8m C-Band Flyaway Terminal

2. THE INITIAL SOLUTION (1.8 m ANTENNA)

The initial solution consisted of selecting single channel per carrier/companded frequency modulation (SCPC/CFM), the modulation technique already used in the INTELSAT VISTA low-density services (see Reference 2), and determining the minimum C-band antenna size consistent with the use of Standard A earth stations (G/T = 40.7 dB/K) as a hub, and INTELSAT V global beam transponders. The major limiting factors in allowing the reduction in antenna diameter are:

(i) the off-axis emission criteria of CCIR Recommendation 524-2, and
(ii) the need to keep the earth station power amplifier within the limits of solid-state technology, which was on the order of 10 W at that time.

Based on link budget calculations and computer simulation of the antenna patterns, it was possible to anticipate that a 1.8 m dish could meet the two requirements identified above. Moreover, the selection of the 1.8 m dish was reinforced by the antenna transmit pattern simulation showing that the first null (between mainlobe and first sidelobe) would occur at about 2.5° from beam center, making it easier to comply with CCIR Rec. 524-2.

The terminal acquired in 1986 was of the "flyaway" type, i.e. could be disassembled and checked-in as commercial airline baggage (each volume weighting less than 70 lbs, and length + width + height measuring less than 80 inches). The entire terminal (antenna and electronics) can be assembled or disassembled in less than two hours by two persons, and operated from a portable 550 W gasoline-powered generator. These features make it particularly suitable for disaster and emergency relief services. A photograph of the "flyaway" terminal is shown in Figure 1 and its main characteristics are summarized in Table 1.

The major design features of the 1.8 m C-band "flyaway" antenna are presented in Table 2, and the measured transmit and receive radiation patterns are reproduced in Figure 2. It can be observed that both transmit and receive sidelobe patterns meet with considerable margin the envelope described in CCIR recommendations for antennas with $D/\lambda \leqq 100$:

$$G = 52 - 10 \log D/\lambda - 25 \log \theta, \text{ for } 100\, \lambda/D \leqq \theta < 48°$$

which in this case, where transmit $D/\lambda = 37.1$ and receive $D/\lambda = 23.7$, can be written as:

Transmit : $G_T = 36.3 - 25 \log \theta$, for $2.7° \leqq \theta < 48°$
Receive : $G_R = 38.3 - 25 \log \theta$, for $4.2° \leqq \theta < 48°$

With regard to the 3 dB beamwidth, it was found that the 2° and 3° values respectively measured for the transmit and the receive frequency bands are in good conformance with the expression normally associated with larger antennas:

$$\theta_{3dB} = 21/fD$$

where: θ_{3dB} is the antenna mainlobe 3 dB beamwidth, in degrees
f is the frequency, in GHz
D is the antenna diameter, in meters

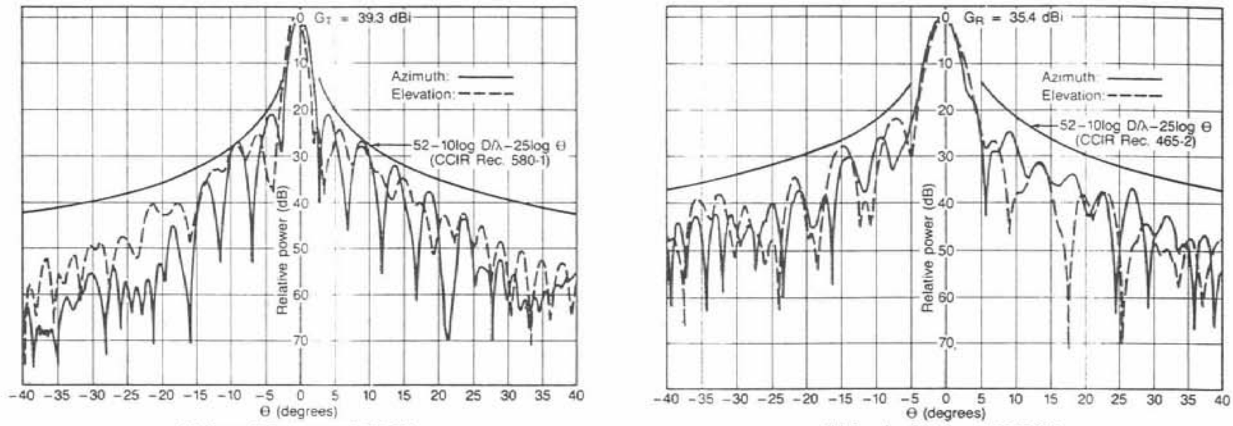
The elevation travel range of 5° to 90° is encompassed in two segments: one covering angles from 5° - 20° (lower-angle) and the other from 20° - 90° (upper-angle). Change between the two segments is simply achieved by reversing the entire antenna reflector and feed assembly in the pedestal mount. Therefore, the feed is positioned on top of the dish for low elevation angles, and on the bottom of the dish for high elevation angles. The solid state power amplifier, the GaAs FET low noise amplifier and the transmit reject filter are mounted in a weatherproof box just behind the feed.

Table 1
INTELSAT Flyaway Terminal
Main Characteristics

Antenna Diameter	1.8 m
Operating Band	C-Band
Transmit Frequency	5.925 to 6.425 GHz
Receive Frequency	3.700 to 4.200 GHz
Low Noise Amplifier	70 K uncooled GaAs FET
G/T @ 20° Elevation	15.0 + 20 log f/4, dB/K
Power Amplifier	10 W solid state
Max Uplink e.i.r.p.	48 dBW
Up/Down Converters	Dual conversion, 36 MHz BW
Modulation Technique	SCPC/CFM
Traffic Capability	One bi-directional voice or up to 9.6 kbit/s data
Nominal C/No	54.2 dB-Hz
Subjective Voice S/N	50.0 dB (10,000 pWOp)
Data Performance	BER = 10^{-6} @ 4.8 Kbit/s BER = 2×10^{-5} @ 9.6 Kbit/s
Temperature	−17°C to +50°C
Humidity	0 to 100%
Altitude	0 to 2000 m

Table 2
Major Design Features of the 1.8 m C-Band Flyaway Antenna

Reflector	1.8 m diameter formed by 6 segmented panels
Operating Band	C-Band (4/6 GHz)
Geometry	Offset fed
Pedestal	Elevation-over-Azimuth
Polarization	Orthogonal circular, reversible by rotation of the polarizer
Axial Ratio	1.25 : 1 (19 dB isolation)
Transmit Gain	39.3 dBi @ 6.175 GHz
Receive Gain	35.4 dBi @ 3.950 GHz
Efficiency	η = 63% for transmit and receive
Sidelobes	Less than 10% of the peaks exceed 32-25 log θ, $2.5° \leqslant \theta < 48°$
Beamwidth	Transmit : ≃ 2° (at 3 dB points) Receive : ≃ 3° (at 3 dB points)
Travel Ranges	Azimuth : ±180° Elevation (lower-angle) : 5°-20° (upper-angle) : 20°-90°
Initial Pointing	Within 1° (by tripod base leveling devices, inclinometer and compass)
Final Pointing	±0.2° (using pilot receiver AGC meter)



(a) Transmit Patterns at 6.175 GHz

(b) Receive Patterns at 3.950 GHz

Figure 2. 1.8m C-Band Flyaway Antenna Radiation Patterns

3. FURTHER STEPS TOWARDS A SMALLER C-BAND TERMINAL

The INTELSAT 1.8 m "flyaway" terminal became the world's smallest C-band earth station with the capability of transmitting and receiving a voice channel. However, when portability is a prime requirement, it is necessary to further reduce the antenna diameter to the 1.0 - 1.2 m range. Due to the tight off-axis emission constraints existing at C-band (CCIR Rec. 524-2), this reduction in the antenna size can best be achieved by resorting to more advanced modulation techniques, which require considerably less uplink power from the "flyaway" antenna.

Two emerging technologies (one analog, one digital) are capable of permitting a substantial reduction (≃ 10 dB) in the required C/No compared to CFM (References 3, 4 & 5):

(a) Amplitude companded single sideband/differential minimum shift keying (ACSSB/DMSK), and
(b) Vocoders using linear predictive coding (LPC) at 9.6 kbit/s associated with binary phase shift keying (BPSK) modems and Viterbi codecs.

INTELSAT, through subjective voice quality evaluations in three different languages, as well as field trials, has determined that both modulation schemes can provide adequate communications quality (mean opinion score between 3 and 4) for C/No values on the order of 44 dB-Hz. This leads to a lower uplink e.i.r.p. requirement from the remote station compared to CFM, which in turn translates into a smaller antenna diameter being allowed. INTELSAT has recently acquired two ACSSB/DMSK channel units, and is also in the process of acquiring two 9.6 kbit/s LPC/BPSK channel units.

4. REQUIREMENTS FOR 1.0 - 1.2 m C-BAND ANTENNAS

Table 3 summarizes the antenna mainlobe transmit gain differential requirements for cases involving the two modulation techniques mentioned above, global and hemispheric transponders of INTELSAT V and VA satellites, and assuming a Standard A station with G/T = 40.7 dB/K is used as a hub. The antenna mainlobe transmit gain differential is defined as the difference between the beam center gain and the off-axis gain at 2.5° from beam center, which is the minimum angle where CCIR Recommendation 524-2 applies. Due to the very wide beamwidth of C-band antennas in the 1.0 - 1.2 m range, the off-axis angle of 2.5° is still located in the antenna mainlobe, turning the interference problem considerably more severe than when sidelobes only are involved.

Still with regard to Table 3, it is worth noting that although the C/No and consequently uplink e.i.r.p. requirements for both ACSSB/DMSK and 9.6 kbit/s LPC/BPSK are of the same order, the potential for interference is quite distinct between the two modulation schemes.

While the ACSSB/DMSK spectrum is concentrated over only 4 kHz, the 9.6 kbit/s LPC/BPSK with rate 1/2 FEC spectrum is spread over 23 kHz representing an improvement of 7.6 dB (10 log 23/4) in terms of e.i.r.p. density.

Table 3
Minimum Required Antenna Transmit Gain Differential (INTELSAT V/VA, Standard A with G/T=40.7 as a Hub)

Modulation	ΔG_T (dB), Minimum	
	Global Transponder	Hemi/Zone Transponder
ACSSB/DMSK	14.4	11.2
9.6 kbit/s LPC/BPSK	6.8	3.3

Based on predicted and measured data from C-band spacecraft antennas of the diameters under consideration, it appears that the values of ΔG_T minimum shown in Table 3 are achievable for both modulation techniques. For ACSSB/DMSK the minimum antenna diameter achievable should be around 1.2 m; while for 9.6 kbit/s LPC/BPSK, the 1.0 m diameter dish should be able to meet the requirements of CCIR Recommendation 524-2. An additional margin of at least 1 dB needs to be included in the design to account for antenna pointing errors.

5. CONCLUSIONS

The paper has described the system elements involved in the design of C-band VSAT systems with the ability to provide voice services on a worldwide basis, an objective that has been pursued by INTELSAT since 1986. The major limiting factor in the design of these systems is the adjacent satellite interference vis-a-vis CCIR Recommendation 524-2.

For operation through INTELSAT satellites and with a Standard A earth station (G/T = 40.7 dB/K) as a hub, a 1.8 m dish can be used in conjunction with off-the-shelf SCPC/CFM equipment. In order to make possible the use of even smaller terminals, it is necessary to adopt more advanced modulation techniques such as ACSSB/DMSK or 9.6 kbit/s LPC/BPSK, in conjunction with carefully designed C-band antennas, so as to minimize the potential for interference. For C-band antennas in the 1.0 - 1.2 m range, adjacent satellite interference occurs not only through the sidelobes but also through the antenna mainlobe.

INTELSAT's major activities in this area include the design and acquisition of a 1.8 m flyaway C-band terminal, the acquisition of a pair of ACSSB/DMSK channel units and the ongoing efforts to procure a pair of 9.6 kbits/s vocoders using linear predictive coding (LPC) and associated BPSK modem with rate ½ Viterbi codec. The next step envisaged will be to procure and demonstrate a C-band antenna with a diameter in the 1.0 m to 1.2 m range.

6. REFERENCES

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7. ACKNOWLEDGEMENTS

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