REPORT 1169*

SEA SURFACE MULTIPATH EFFECTS IN THE AERONAUTICAL MOBILE-SATELLITE SERVICE

(Question 88/8)

(1990)

1. Introduction

Multipath, especially sea surface-reflected multipath, is a significant parameter to be considered in the design of an aeronautical mobile-satellite system in the 1.5/1.6 GHz bands. The new information contained in section 3 of this Report reconfirms the results of previous experiments and extends the multipath characterization investigations undertaken.

A number of factors related to the potential impact of sea-reflected multipath on aeronautical mobile-satellite communications made the characterization of this parameter a principal subject for early experimental investigation, which began in the early 1970s. The factors included:

1) the anticipated power level of the reflected signal relative to the direct path signal;

2) the characteristics of the multipath signal; and

3) the relative inability of aircraft antennas to discriminate the sea reflected signal (especially for low elevation angles and for broad beamwidth, relatively inexpensive low gain antennas).

Section 4 of this Report contains some early information on the operational performance of one phased array aircraft antenna installation with respect to the impact of sea surface multipath effects.

2. Field experiments via ATS satellites

The first extensive aeronautical mobile-satellite-based multipath experiments in the 1.5/1.6 GHz bands were sponsored by the United States Federal Aviation Administration (FAA) using the United States National Aeronautics and Space Administration (NASA) Applications Technology Satellite (ATS) Number 5 (ATS-5). Controlled continuous wave (CW) multipath and data link communication characterisation experiments were conducted over various sea states, elevation angles, and direct path to multipath signal ratios [FAA, 1973]. Canada also conducted multipath tests complementary to the FAA tests, using pseudo-random codes [Chinnick and Matt, 1971]. The United States FAA sponsored, in the mid-1970s, more

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* This ―――――― Report should be brought to the attention of Study Group 5 for information.

sophisticated broadband multipath characterisation experimentation to validate a channel simulator testbed, using the NASA ATS Number 6 (ATS-6) satellite [FAA, 1976]. The performance of various data link and voice modulation techniques was also evaluated with this ATS-6 satellite, which had significantly more power using a nine meter diameter antenna. The broad ATS-6 programme also included programmes carried out by Canada and the European Space Agency (then the European Space Research Organization).

These past programmes and results are summarized in the aforementioned references and in CCIR ~~documentation~~ documentation (see Reports 505 and 599, Vol. VIII, Kyoto, 1978). The principal sea reflected multipath characterization results included:

1) the power of the multipath signal versus elevation angle characteristics agreed substantially with predicted values;

2) the multipath signal was noise-like in nature (Rayleigh-distributed, not specular);

3) the total direct path plus multipath signal was Rician distributed in nature, and

4) the fading characteristics resultant from the total received signal reflected the need for appropriate signal structure design (e.g., coding and interleaving) to combat periodic burst errors in the radio frequency channel, and provided guidance for signal design.

3. Experiments in the Fed. Rep. of Germany

3.1 In measurements performed in 1985 and 1986 by the Federal Republic of Germany, with the aid of a stable continuous wave carrier transmitted from an INMARSAT MARECS-satellite, the direct signal and the reflected multipath signal were separately recorded on board aircraft. The recordings were used to control a laboratory channel simulator (the stored channel principle) and to determine the probability-distribution function of the reflected signal. Furthermore, the mean fade durations in a link with a preoperational 3 dB aircraft antenna were determined /_ Hagenauer et al., 1986_/. The remainder of this report addresses this measurement programme in more detail.

3.1.1 Channel modeling and probing

3.1.2 Theoretical channel model

If the satellite transmits a signal x(t) then the aircraft receives in general two components. The direct component $y_d(t-t_0)$ and the reflected (multipath) component $y_r(t-t_0-\tau)$ from the Earth's surface. The propagation delay t_0 has no influence on the channel model and is therefore neglected in further considerations. The differential delay τ depends basically on the geometry. It can be calculated as a function of the elevation angle to the satellite, ε, and aircraft altitude as shown in Figure 1.

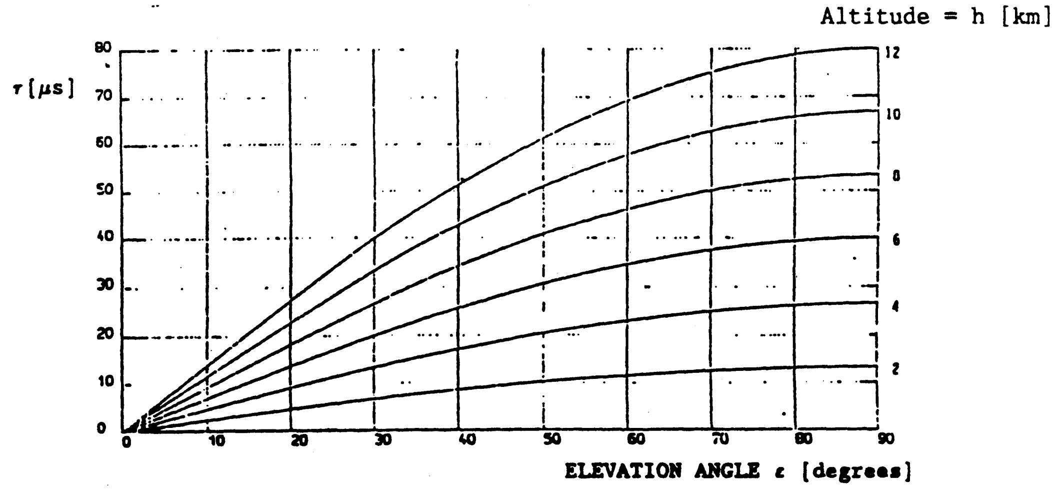

FIGURE 1

<u>Differential delay τ between direct and reflected signal as a function of elevation angle and altitude</u>

The signal y(t) at the receiver of the aircraft results from the addition of the direct and the reflected component at the antenna used. This multipath reception is the reason for signal fading. As the reflection coefficient of land is much smaller than that of salt-water, the following considerations concentrate on multipath reception from the sea.

Due to aircraft motion and the roughness of the earth surface, the aeronautical channel in principle has to be modelled as a randomly time-variant channel. The theory of randomly time-variant linear channels is described in a fundamental paper [Bello, 1963]. Applying this to the aeronautical circumstances, the reflected signal component can be seen as transmitted over a wide-sense stationary uncorrelated scatter (WSSUS) channel [Bello, 1973, FAA, 1976, Volume 5]. For all signal bandwidths B considered [Hagenauer, Papke, 1982], this channel is described by multiplicative (non-frequency selective) fading, i.e., the time variant transfer function T(f,t) is independent of frequency within these ranges:

$$T(f,t) \approx T(t) \quad \text{for } f_0 - \frac{B}{2} < f < f_0 + \frac{B}{2} \qquad (1)$$

f_0 = carrier frequency

3.1.3 Channel probing

The direct and reflected signal had been received by two separate receiver chains and finally recorded on analogue tape. These recordings of the direct and reflected signals can be used in the laboratory together with the stored channel simulator [Hagenauer, Papke, 1982], to simulate all desired antenna patterns. Furthermore, a precise statistical offline evaluation can be performed.

These two receiver chains were fitted with one antenna for reception of the direct signăl (a conformal, electronically steerable, phased array of 10 dB gain) [Splitt, Forster, 1986] and a pair of antennas for reception of the RHC and the LHC polarized reflected signals (mechanically steerable helix antennas (10 dB gain) installed near the tail, pointing towards the specular reflection point).

3.2 Results

3.2.1 Rice-factor C/M

The measured ratios "directly received power C" to "right-hand-circular multipath power M" for an ideal 0 dBi antenna and a 3 dBi antenna as a function of the elevation angle ε is shown in Figure 2.

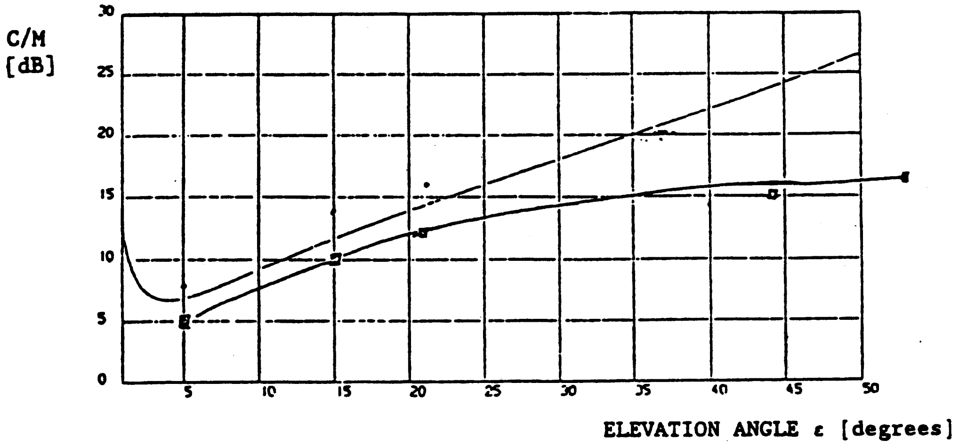

FIGURE 2

Measured directly received power to multipath power ratios versus elevation angle for indicated antennas and theoretical predictions

- 0 dBi antenna

□ pre-operational 3 dBi antenna

In a wide range, there is a good coincidence to the C/M derived from Fresnel's reflection coefficients for specular reflections and the divergence factor [Beckmann, Spizzichino, 1963].

3.2.2 Bandwith of Doppler power spectra

According to the theory in [Bello, 1973] the Doppler-power-spectrum of the reflected signal has a Gaussian shape:

$$P(\nu) = \frac{\sqrt{2}}{B_{rms}\sqrt{\pi}} \exp\left(-\frac{2\nu^2}{B^2_{rms}}\right) \qquad (2)$$

This Gaussian shape was verified in all measurements.

In (2) the rms Doppler spread is defined as twice the standard deviation of $P(\nu)$

$$B_{rms} = 4 \frac{\alpha}{\lambda_0} \cdot v \cdot \sin \varepsilon \qquad (3)$$

where α is the rms value of the surface slope, λ_0 the wavelength of the transmitted carrier and v the speed of the aircraft along the route with constant elevation angle. Figure 3 shows measured values for B_{rms}, compared to the above equation with α equals to 0.04, 0.12 and 0.2, λ_0 = 0.2 m and v = 380 knots.

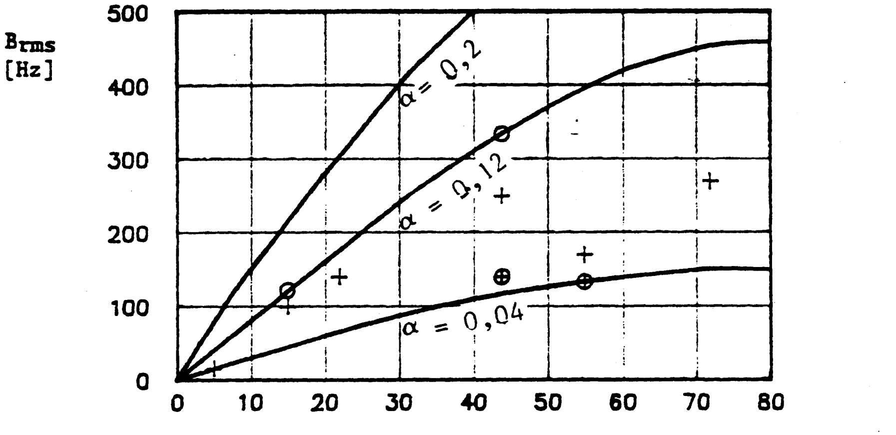

FIGURE 3

Measured Doppler-spread values versus elevation angle and rms surface slope values

x LHC at flight level 30,000 feet

0 RHC at flight level 30,000 feet

⊕ LHC at flight level 6,000 feet

3.2.3 Fade duration and connection interval

A fade is defined as the event that the received power level is below a certain threshold. In the following the thresholds "mean power (0 dB)" and "5 dB below mean power" are considered.

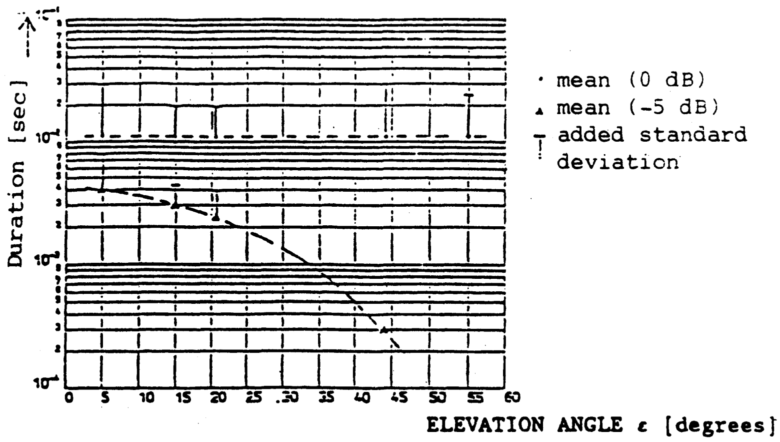

FIGURE 4

Mean fade duration versus elevation angle

Figure 4 shows the mean fade duration T_{fmean} versus satellite elevation obtained from processing the data of five measurement flights.

The mean fade duration for the 0 dB threshold is almost constant over the elevation angle, for the -5 dB threshold it decreases significantly. It should be noticed that the standard deviation is relatively high.

Furthermore, the maximum fade duration T_{fmax} and the duration value $T_{f99.9}$ which is with a probability of 99.9% not exceeded by a fade, are of interest. Both values are presented in Figure 5 for the low elevation flights.

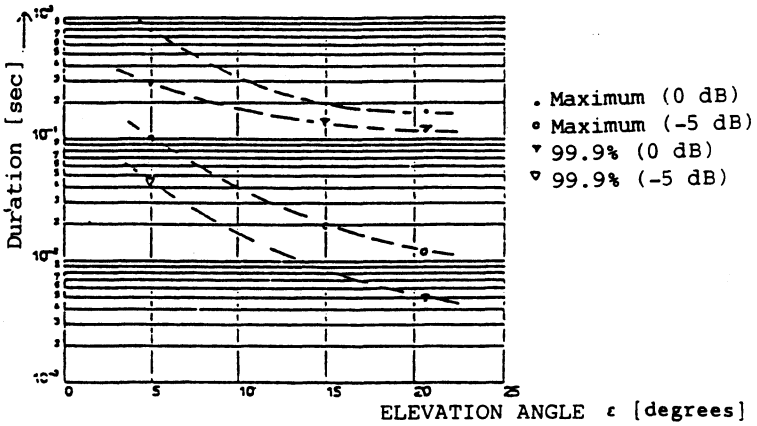

FIGURE 5

Maximum and 99.9% fade duration versus elevation angle

The complementary event to a fade is a connection. Connection intervals are important for the throughput of packetized data transmission. Figures 6 and 7 show the results for T_{cmean}, T_{cmax} and $T_{c99.9}$.

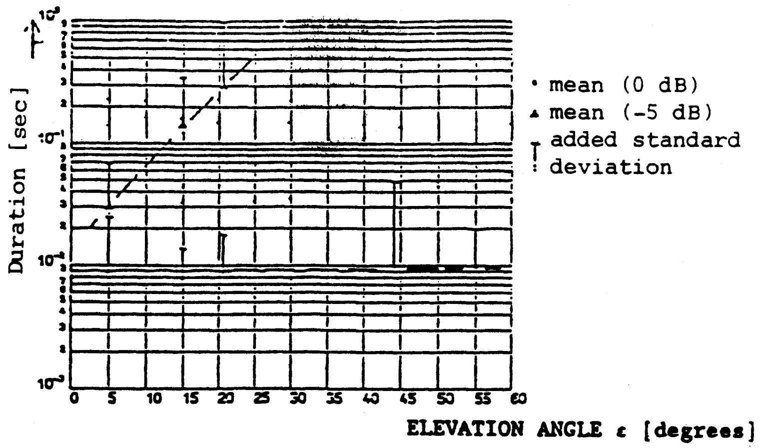

FIGURE 6

Mean connection duration versus elevation angle

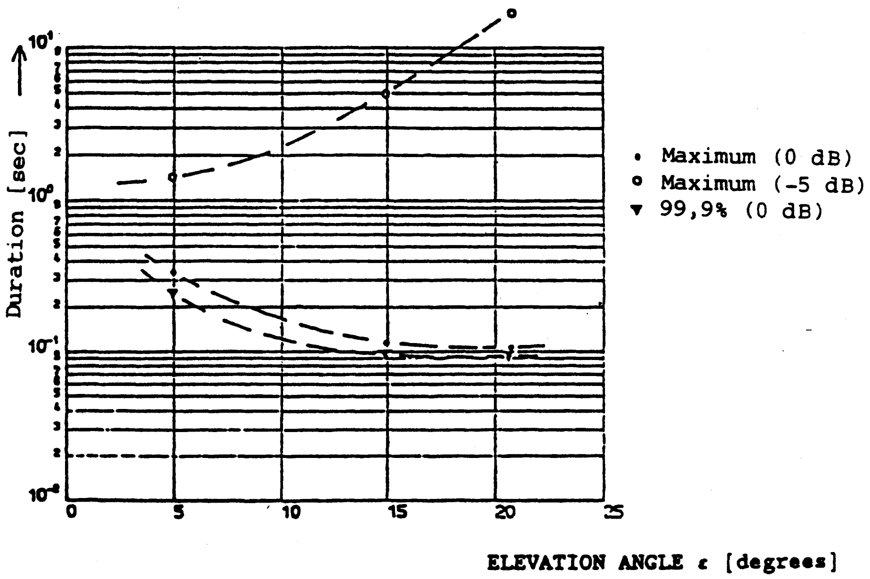

FIGURE 7

Maximum and 99.9% connection duration versus elevation angle

3.3 Conclusions

In measurements performed by the Federal Republic of Germany in 1985 and 1986 a continuous wave carrier transmitted from an INMARSAT MARECS-satellite was used to characterize the aeronautical satellite communication channel. The tests used the stored channel principle and included separate reception of the direct and reflected signal components, as well as measurements with a pre-operational 3 dB aircraft antenna. The data results from this measurements programme presented in this report support the following conclusions:

1) the reflected signal component was proven to be exactly Rayleigh-distributed. The rms Doppler spread was evaluated to be in the range from 10 Hz (5° elevation) to 330 Hz (44° elevation);

2) the statistical evaluation of the measurement data for the pre-operational antenna confirmed the Rice fading model with C/M ranging from 5 dB at 5° elevation to 15 dB at 55° elevation;

3) the mean fade duration related to a threshold 5 dB below mean power is 4 ms at 5° elevation and decreases to 0.3 msec at 44°. At 5° elevation a maximum fade duration of 100 msec was measured;

4) the mean duration of a connection interval (signal power above threshold) with respect to a threshold 5 dB below mean power is 30 ms at 5° elevation and increases to 300 msec at 21°.

4. Aeronautical Satellite Communication Experiments in Japan

In Japan, aeronautical satellite experiments via ETS-V and INMARSAT satellites in the 1.5/1.6 GHz bands have been carried out using commercial jet planes on transoceanic flight routes. Operational type two-tier 16-element phased array antennas using circular microstrip patches were installed on the top of the fuselage of B-747 type aircraft.

Multipath fading due to sea surface reflection was not observed even at low elevation angles. The reason is that signals reflected from the sea surface were blocked by the wings and fuselage before they could reach the antenna installed on the top of the fuselage.

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REPORT 920-2

MARITIME SATELLITE SYSTEM PERFORMANCE AT LOW ELEVATION ANGLES

(Question 88/8)

(1982-1986-1990)

1. Introduction

Maritime satellite system performance at low elevation angles is affected by, *inter alia*, a number of propagation factors. The results of tests performed by the USA and the U.S.S.R. are described in this Report, and a preliminary assessment of the system performance at low elevation angles is given.

2. USA tests

2.1 *Background*

In October 1978, an experiment to determine the extent of degradation of satellite-to-ship and ship-to-satellite signals at low elevation angles in the bands 1.5/1.6 GHz was performed by the USA using the Atlantic Marisat satellite. A MARISAT ship earth station having a G/T of -4 dB(K^{-1}) was used on-board the S.S. Mobile AERO, an 18 600-ton oil tanker, while on route from Norfolk, Virginia to Texas City, Texas, with elevation angles changing from 17° to 0°. Baseline measurements were made during the initial portion of the trip. On a straight line sailing from Tampa, Florida to Texas City, Texas on a heading of 274°, the elevation angle from the ship earth station to the satellite decreased steadily from 11° to 0.3° at an average rate of 0.3° per hour. During this 40 h period the experiment was conducted without interruption.

2.2 *Data collection*

The equipment block diagram of the measurement set-up at the ship earth station is shown in Fig. 1. An IDS-1310A data test set was used to generate either 2400 bit/s or the 1200 bit/s data for input to a DPSK modem (ICC-24LSI) or an FSK modem (GDS1200ES), respectively. The input/output point was at the data jack on the ship earth station console (VOICE/DATA). A 600 ohm variable attenuator, not shown in Fig. 1 was inserted at the data jack for the purpose of adjusting the interface level between the console and the modem. The block size for each transmit/receive test could be either 10^6 or 10^7 bit/s, taking either 7 or 70 min to complete for 2400 bit/s tests, and taking twice as long for 1200 bit/s tests. Besides direct readings from the data test set, a printer was also employed to record the bit error ratios [Fang *et al.*, 1981].