

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

* 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 (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 $y_r(t-t_0-r)$ 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 r 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.

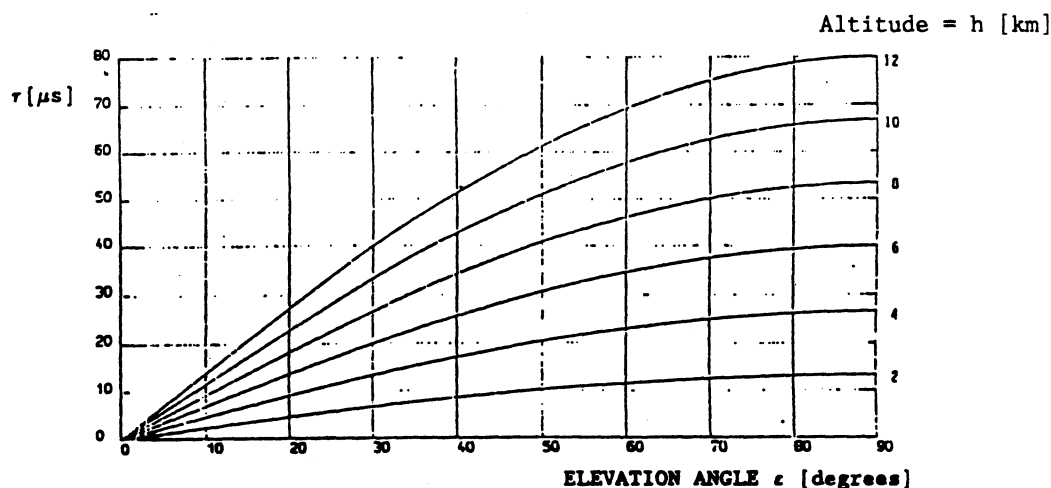


FIGURE 1

Differential delay τ between direct and reflected signal
as a function of elevation angle and altitude

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:

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

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.