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Measurement of Multipath Delay Profile in Land Mobile Satellite Channels

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ABSTRACT

Mobile satellite communication channel has been evaluated mainly with fading statistics of signal. When bandwidth of transmitting signal becomes wider, frequency selectivity of fading becomes significant factor of the channel. Channel characteristics, not only signal variation but multipath delay spread should be evaluated. A multipath measurement system is proposed and developed for mobile satellite applications. With this system and ETS-V satellite, multipath delay profiles are measured in various environments including Tokyo metropolis and Sapporo city at 1.5 GHz. Results show that the maximum excess delay is within 1μs and the maximum delay spread is 0.2μs at elevation angles of 40 to 47 degrees. In wideband signal transmission of about 1MHz and more, designers should consider the effect of selective fading due to the multipath of land mobile satellite channel.

INTRODUCTION

The evaluation of mobile satellite communication channels has focused on the fading statistics of level fluctuation. In the near future, the wideband signal will be used in CDMA, TDMA or mobile sound broadcasting systems. In the evaluation of wideband transmission, delay profile of channel should be measured, because multipath due to reflection off the structure around mobile earth station induces a frequency selectivity of the link, which results in wave form distortion or inter-symbol interference on the transmitting signal. In order to measure the multipath, we propose measuring system for mobile satellite channel and develop a prototype. This paper shows the proposed system and reports a preliminary results of measurement in Tokyo metropolis and Sapporo city.

BACKGROUND

There are some methods of multipath measurement in radio communication links(1)(2): the reception of a response to a transmitted narrow pulse signal, referred to as pulse method, the correlation of the transmitted PN-PSK-SS signal to reference PN sequence, which results in a similar response as in the pulse method, referred to as PN method.

In the pulse method, transmitting peak power must be high enough to obtain sufficient signal to noise ratio, however transponders are generally operating at power-limited mode and link margin is usually not enough to use the pulse method. The PN method is popular in terrestrial land mobile channels, however high precision local oscillator must be used at both transmitter and receiver as a reference carrier to achieve quasi-coherent detection, because carrier recovery function does not work well in a typical Rayleigh fading condition.

As the satellite communication link has a frequency conversion function in an onboard transponder, the use of high precision local oscillator in earth station cannot compensate frequency difference between the transmitting and receiving earth stations. Therefore another method should be used in mobile satellite channels.

In mobile satellite communications, line-of-sight links are mainly used and a receiver can easily track the phase of a direct wave. Therefore it is sufficient to measure the level of multipath delay profile and phase fluctuations of the delayed multipath components relative to the direct wave. The proposed measuring system receives the transmitted PN-SS signal through a satellite, achieves quadrature coherent detection while synchronizing to the direct wave and gives the delay profile as complex correlation outputs.

SYSTEM DESCRIPTION

In this system the earth station transmits a PN-SS signal to a satellite, then a coherent matched filter (CMF) receiver(3) of a receiving earth station detects quadrature multipath delay profiles as complex correlation outputs while a carrier recovery loop tracks the direct wave from the satellite. The CMF is a kind of Costas loop coherent detector for the PN-SS signal and contains two correlators for PN code as arm filters of the Costas loop.

Figure 1 shows the principle of the measurement system. The received PN-SS signal is converted to complex baseband signals with the recovered carrier. Digital correlators correlate the baseband signals with the reference PN code and give a complex delay profile for one frame of PN code. The carrier recovery loop tracks the largest correlation peak which comes from the direct wave. Therefore correlators produce delay profiles having information of the phase relative to the direct wave even if there are frequency conversions in satellite links. Signal to noise ratio at the correlator output can be improved by recursive integrators which consist of adders, frame memories and weighting circuits.

The measurement system is developed based on a communication equipment(4)(5). The system description and block diagram are shown in Table 1 and Figure 2, respectively. Digital correlators in both I and Q arms operate asynchronous with PN clock at twice the PN clock to avoid the use of clock recovery circuit. The bandwidth of the transmitting signal is limited to 3 MHz which corresponds to the bandwidth of a transponder.

RESULTS

Measurements are performed at urban, suburban and mountainous areas using ETS-V(Engineering Test Satellite five) located at 150 degrees East(6). The elevation angles to the satellite are relatively high and range from 40 to 47 degrees. This report shows the preliminary data of Shinjuku Tokyo where many tall buildings of up to 250 m in heights are risen, and Sapporo which is a typical large city in northern part of Japan.

a-5

As in Figure 3, Kashima base earth station transmits a PN-SS signal and the mobile earth station onboard a measuring van receive the left-handed circular polarized signal from the ETS-V at 1.5GHz. A receiving antenna used in the measurement is a quadrifilar helix antenna which has a gain 3 dBi and an omnidirectional beam. The received data are recorded on a digital data recorder.

Figure 4 and 5 show some examples of measured delay profiles at Shinjuku. In each figure, a broken line shows the reference profile where only direct wave exists. There are no output in Q-channel in principle if the received signal contains a direct wave only, whereas there are some level in Q-channels in Figure 4 and 5. This fact explains that the received signal consists of some delayed multipath components.

The mean excess delay *d* and the delay spread *S* which are the measure of multipath, are expressed in the following equations[2],

$$d = \int_0^\infty \tau E(\tau) d\tau \qquad (1)$$

$$S^2 = \int_0^\infty \tau^2 E(\tau) d\tau - d^2 \qquad (2)$$

where $E(\tau)$ is normalized power delay profile.

The delay spread is calculated in Equation (2) with the measured delay profiles, in these calculations the effect of band limitation to correlation function is considered. Table 2 and 3 summarize the measurements of the received signal level relative to the line-of-sight level and the delay spread in Shinjuku and Sapporo. Figure 6 and 7 are maps of the measuring points. So far, an excess delay of more than 1 μs is not observed and maximum delay spread is on the order of 0.2 μs.

The coherent bandwidth, which is a measure of frequency selectivity, is defined as the frequency separation at which correlation of two signals is 0.5. If the distribution of multipath delay follows exponential distribution, the coherence bandwidth Bc can be expressed with delay spread S as[2]

$$B_c = \frac{1}{2\pi S} \qquad (3).$$

For reference, the coherent bandwidths Bc are calculated with Eq. (3), which may not express the exact value of Bc of the channels. Calculated Bc are from 0.8 MHz to 4.0 MHz. More detailed analyses must be done on this point, however, design of wide band transmission link of approximately 1 MHz and more should consider the effect of multipath delay carefully.

CONCLUSION

A multipath measuring system for mobile satellite links is proposed and a prototype is developed. Field test measurements are performed using ETS-V satellite at 1.5 GHz. In land mobile satellite links at moderate elevation angles of around 45 degrees, there are no multipath components with an excess delay of more than 1 μs which is typical in terrestrial land mobile links. However, owing to the fact that the delay spread of around 0.2 μs is observed, it can be concluded that frequency selectivity should be considered in wide band system on the order of more than 1 MHz. Detailed analyses such as statistical properties of delay spread or coherence bandwidth are left as further study.

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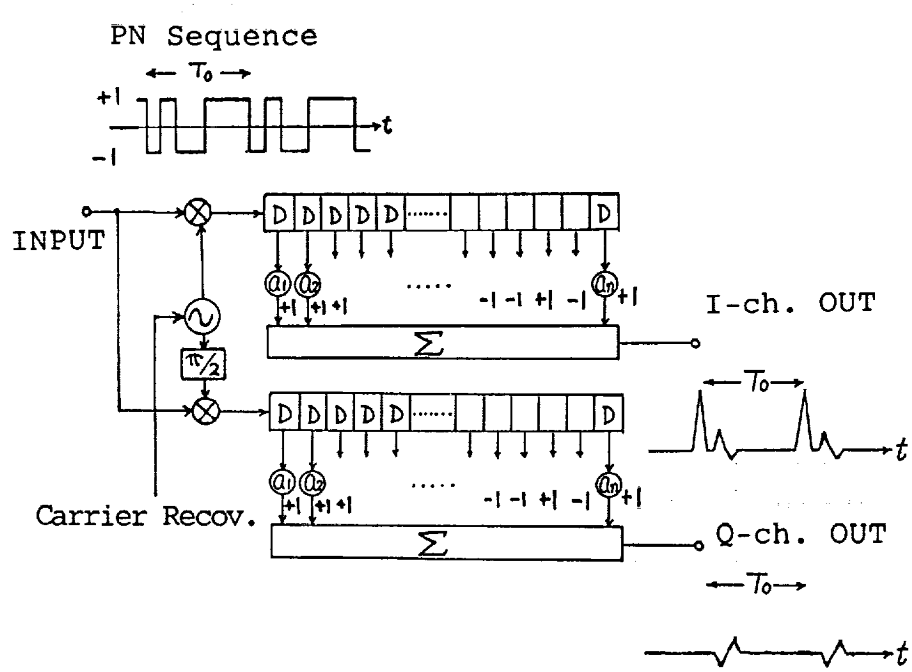

Fig. 1 Principle of multipath measurement

Table 1 Major specification of equipment

PN Code	M-sequence, Length 1023
PN Chip Rate	2.4552MHz
Modulation	BPSK
Demodulation	CMF, Coherent Detection
Matched Filter	8bits Digital Correlator, 2046stages
AFC Range	±10kHz

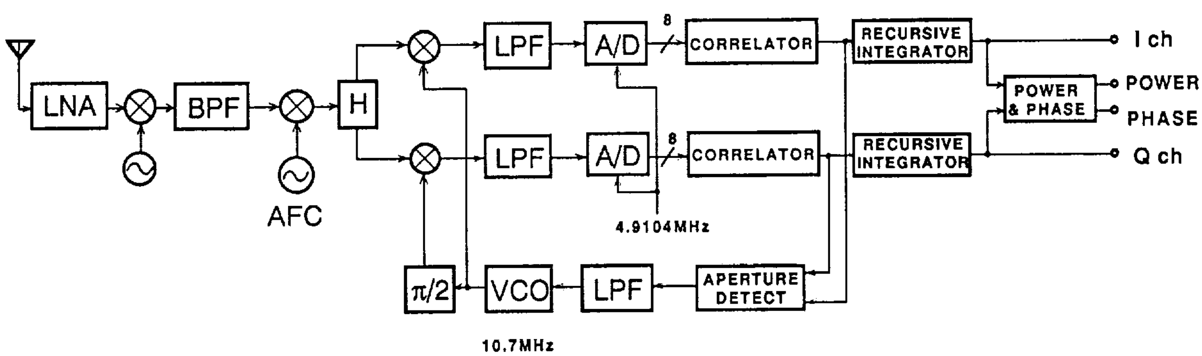

Fig. 2 Block diagram of receiver

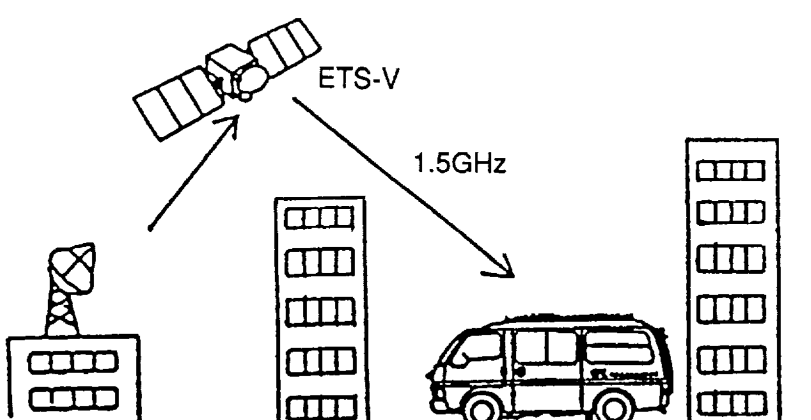

Fig.3 Configuration of experimental system

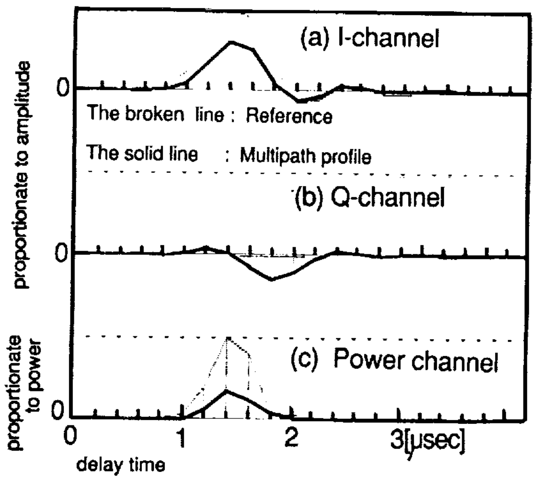

Fig.4 Multipath profile
Shinjuku data #12
(a) I-ch (b) Q-ch (c) Power-ch

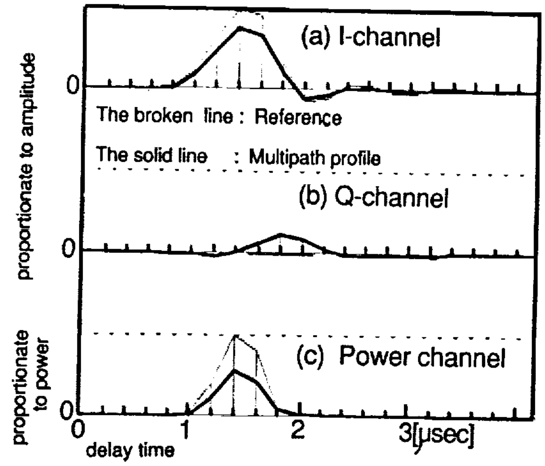

Fig.5 Multipath profile
Shinjuku data #19
(a) I-ch (b) Q-ch (c) Power-ch

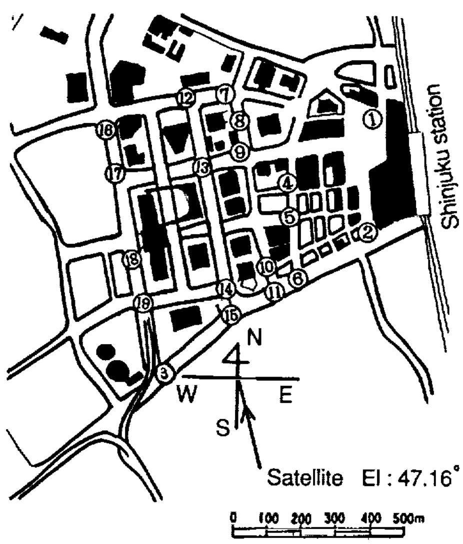

Fig.6 Point of measurement
(Shinjuku Tokyo) E 139.77° N 35.68°

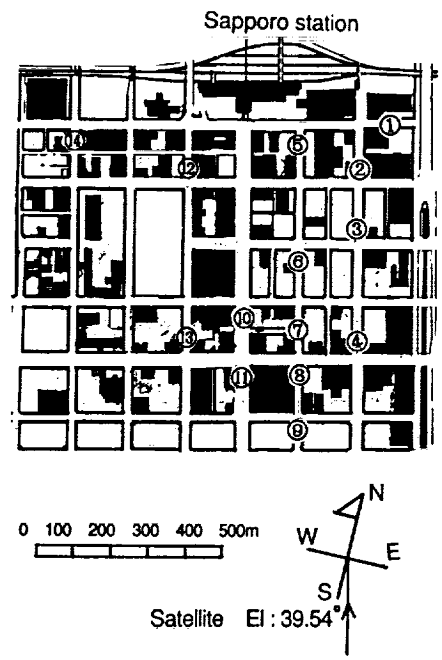

Fig.7 Point of measurement
(Sapporo Hokkaido) E 141.35° N 43.07°

Table.2 Shinjuku multipath data

Point	Received level [dB]	Delay spread [μ sec]
#1	−2.6	0.06
#2	−3.2	0.04
#3	−1.9	0.07
#4	−0.4	0.08
#5	−1.6	0.04
#6	−2.3	0.05
#7	0	0.05
#8	−2.1	0.04
#9	−2.0	0.05
#10	−8.3	0.18
#11	−1.9	0.05
#12	−4.9	0.16
#13	−1.7	0.10
#14	−1.4	0.06
#15	−2.0	0.06
#16	−0.7	0.07
#17	−1 7	0.04
#18	−0.7	0.05
#19	−2.7	0.11

Table.3 Sapporo multipath data

Point	Received level [dB]	Delay spread [μ sec]
#1	−0.6	0.07
#2	−1.3	0.08
#3	−1.9	0.08
#4	−2.3	0.19
#5	−4.6	0.15
#6	−3.2	0.15
#7	−5.8	0.11
#8	−3.9	0.19
#9	−4.3	0.09
#10	−11.0	0.12
#11	−7.3	0.13
#12	+0.3	0.07
#13	−3.6	0.16
#14	−4.9	0.05