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A Multipath Simulator for use in Evaluation of Spacecraft Ranging and Communication Systems

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Summary

Tests solely designed to test performance of spacecraft communication and ranging equipment under conditions of severe fading are usually impossible to perform, and when possible they are of too short duration to allow system modification to improve performance.

This paper describes a fading channel simulator which is readily constructed and flexible in operation. By use of this simulator communication and ranging equipment can be tested and optimized for operation during periods of severe fading.

The fading channel simulator described in this paper gives fading rates varying from about 2 to 30 cps.

Frequency and time scaling of the problem can be used if the fading rates of the channel to be simulated are outside this range.

Introduction

Communication and ranging are two of the most vital support operations in connection with spacecraft systems. In spite of this, equipment designed to measure the characteristics of the RF channel can only rarely be placed on board a spacecraft because of the great competition for the available payload by all interested parties. Channel measurements can thus usually only be obtained by analysis of incidental data from the operating communication and ranging links. Fading and multipath conditions occur most frequently during powered flight and when the spacecraft is close to the horizon. The duration of this condition is therefore usually very short, typically a minute or less. This time does not allow the system designer much time during which he can modify the system to improve its performance during these critical periods.

A convenient approach that allows the system designer to try different approaches in order to optimize the system performance in the laboratory is to use a multipath simulator.

This paper describes a multipath simulator that has been constructed in the Communication Laboratory of the University of Florida, GENESYS, at Port Canaveral.
demodulated in the receiver. The receiver performs both envelope and product demodulation. The output from the envelope demodulation provides information about the fading of the envelope of the received signal. The output from the product demodulator is used to extract information about the phase of the received signal. Reference signals for the product demodulator and for the subcarrier phase comparison are obtained directly from the transmitter by means of cables. This results in one great additional advantage accrued by use of the multipath simulator rather than the real thing. Since the reference signals used at the receiver can be obtained directly from the transmitter they do not have to be generated locally at the receiver. This eliminates a great source of uncertainty present in all actual system experiments, namely if the effects observed are due to the behavior of the channel or if they are due to inaccurate time, frequency and phase references used at the receiver.

Applications

The multipath simulator described in this paper is well suited to be used in experimental work whose goal is to improve the performance of existing spacecraft communication and ranging systems under multipath conditions. It is also well suited for experimental verifications of theoretical results that may be used in future spacecraft systems.

As an example of the former category is some work currently under way at University of Florida, GENESYS. The goal of this work is improvement of the stability of a phase locked loop (PLL) under conditions of severe multipath. It is a common experience that PLL's tend to lose lock under this condition. Most PLL's currently in use are optimized for use in an additive Gaussian noise environment. By use of the multipath simulator experimental optimization of the PLL under multipath conditions can be achieved; theoretical results can thus be verified and modified as required. In the second category falls various other more sophisticated methods of estimating the phase of the transmitted carrier.

The rate of deep fades obtainable with this multipath simulator is typically 5 to 10 fades per sec. Frequently the fading rate of the channel to simulated is outside this range. If this is the case, frequency and time scaling can be used to bring the problem within the range of the simulator.

This scaling is accomplished in the following manner. Let the ratio between the simulator and actual fading rates be K. In order to bring the problem within the range of the simulator all subcarrier frequencies must be multiplied by K. The value of all capacitors and inductors used in the signal circuits must be divided by K. The resulting system will yield similar performance when used on the simulator as the original circuit will give on the actual channel. The only difference is that the time scale must be stretched by \( \frac{1}{K} \). Nearly any type of multipath channels can thus be simulated by suitable reflectors, air bubbles and use of time and frequency scaling.

Tests

Investigation of various simulated channels have been carried out during the time since in Fig. 4. The two most interesting channel conditions are the one where the transmitted signal is reflected by a large number of incoherent scatters and the case where there is a strong specular component besides the incoherent scatters. The two types of channels are representative of conditions encountered during powered flight.

When all the received signal is reflected by incoherent scattering one experiences, as one would expect, the most serious fading conditions. Fig. 5 shows a typical spectrum of the amplitude of the received signal. We see that the amplitude spectrum has a width of about 30 Hz at the -25 DB level. At the -6 DB level it has a width of about 10 Hz. From Fig. 6 we see that this agrees well with the time records of the amplitude variations which show about 10 deep and 30 minor fades per sec.

Statistical analysis of the envelope and phase of the received signal has been carried out. This analysis shows that when the received signal is due to a large number of random scatters the probability density of the received carrier amplitude is approximately Rayleigh while the phase is uniformly distributed over the range \( \pm \frac{\pi}{2} \). When the phase variations are measured over the range \( \pm \frac{\pi}{4} \) the resulting measured probability distribution is approximately triangular as seen from Fig. 8.

When the received signal has a strong specular component beside the random reflections the power spectrum shows a steady signal at the carrier frequency. The part of the spectrum due to incoherent scattering is essentially unchanged. The probability of amplitude of the received carrier follows approximately the Rice distribution as can be seen from Fig. 9.

The probability density function for the phase shows the most interesting difference between the two simulated channels. It is now triangular but with a range \( \pm \frac{\pi}{2} \) rather than \( \pm \frac{\pi}{4} \). This result can be seen from Fig. 10.

Conclusions

A multipath simulator has been described that is readily constructed and flexible in operation. The multipath characteristics of the channel can be varied over a wide range of conditions allowing simulation of nearly all desired types of multipath channels.

Since the transmitter and receiver are located
close together, reference and synchronization signals required at the receiver can, if desired, be obtained by cables directly from the transmitter. Difficulties with the local reference signals can thus be avoided, allowing a more exact investigation of the effects of multipath condition on the transmitted signal and on the operation of the receiver.

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Fig. 1 Multipath channel simulator

Fig. 2 Multipath channel where the received signal is due to a large number of incoherent scatterers.
Fig. 3 Multipath channel with a strong specular signal component in addition to the randomly scattered signal.

Fig. 4. Block diagram of the GENESYS multipath channel simulator system.
Fig. 5  Spectrum of the envelope of the fading carrier. Incoherently scattered signals.

Fig. 6  Amplitude record of the fading carrier. Incoherent scatter. 20 mm/sec.
Fig. 7 Probability density of the envelope of the fading signal. Incoherent scattering.

Fig. 8 Probability density of the phase of the fading carrier. Incoherent Scattering.
Fig. 9 Probability density of the envelope of the fading carrier. Specular and incoherent reflections.

Fig. 10 Probability density of the phase of the fading carrier. Specular and incoherent reflections.