

Guest Editor's Prologue

Special Section on

Communications Over Nonlinear Channels

IF power is abundant and components are ideal, communication using all linear components may be achievable. However, in most practical communication systems, power is severely limited and the inefficiencies associated with actual linear power amplifier stages are intolerable. For these reasons, most communication systems employ highly nonlinear power amplifiers. Whether the resulting channel is linear or nonlinear depends on one's definition of the channel. If the *channel* is defined as being from the input of the transmitter to the output of the demodulator at the receiver, the channel is clearly nonlinear, even through the *electromagnetic channel* may be completely linear.

When multiple transmission (relay) links are employed, the resulting channel is nonlinear under essentially all definitions of the *channel*. (We exclude here regenerative repeaters.) This is particularly true in satellite communications where large distances and severe power constraints on the satellite repeater are characteristic and where most of the present day effort is being expended. It is, therefore, not surprising that all of the papers in this Special Section are concerned with satellite communication situations.

Another dimension to the nonlinear channel problem is that of bandwidth limitation. Many of the systems being built today must operate under severe bandwidth constraints imposed either by regulatory bodies or by the desire to transmit more bits per second per hertz of channel bandwidth. (More on this topic can be found in the Special Section on Bandwidth Efficient Modulation and Coding which appeared in the March 1981 issue of this TRANSACTIONS.) The result is a complex interplay between the characteristics of filtering (noise rejection, ISI, reduced sidelobes, reduced interference susceptibility) and those of the nonlinearity (AM/AM, AM/PM, sidelobe regeneration, IM distortion). Although many aspects of this problem have been considered in the past, few have been adequately analyzed and most require simulation to obtain performance characteristics. Finally, extensions of results, which are so easily accomplished in linear systems, are no longer valid in the nonlinear world and often minor parameter value changes can require new analyses or simulations to predict performance.

Contained in this Special Section are seven papers covering current research in many of the above areas. The first paper by Ekanayake and Taylor derives a structure for a ground receiver intended for use on a satellite repeater link. The receiver has a decision feedback structure and takes into account the channel uplink and downlink noises, ISI, and the nonlinear transfer characteristic of the satellite repeater.

Their structure, although suboptimal, is believed by the authors to be near optimal and their performance predictions are compared with simulation results for the hard limiter form of satellite nonlinearity.

The second paper by Eng and Stern considers the problem of estimating the frequencies of intermodulation products generated by passing multiple carriers through a nonlinearity. Of particular interest is the case where a sensitive receiver is located physically close to a high power transmitter, as is often encountered in a satellite transponder. Although the prediction of which intermodulation component is most likely to be the dominant one is conceptually quite simple, in practice it is often very difficult computationally. The authors describe a method of circumventing such difficulties.

The next two papers are primarily concerned with pushing hard on the bandwidth constraints. Both papers are from COMSAT Laboratories and both deal with broadband signals for TDMA use over the next generation INTELSAT or domestic satellite networks. The paper by Devieux and Jones examines the effects of transmitter and receiver filtering on a single QPSK signal. Their study is unique in that they first performed a hardware experiment to obtain some physical insight, then they used this intuition to guide their computer simulation activities. Finally, they closed the loop by performing a hardware verification of the most promising results from their simulation. The second paper describes an extensive series of computer simulations performed by Fang. The study treats QPSK, offset QPSK, and MSK modulation formats when used over a satellite link containing uplink and downlink nonlinearities, channel filtering, interference, and fading (as would be encountered on future 30/20 GHz links). His results favor the offset modulations such as OQPSK and MSK.

The last three papers deal primarily with the performance of nonlinear systems in the presence of interference. The first paper by Kennedy and Shimbo determines the effects of co-channel interference on both the uplink and downlink of a bandlimited satellite link. They conclude that uplink interference is less detrimental due to the small signal suppression effect of the nonlinearity. Huang, Omura, and Lindsey then evaluate the performance of a bandlimited satellite link with uplink and downlink noise and an unwanted uplink CW interference. Their results are analytical approximations to the actual performance made through a two-dimensional moment technique. In this technique a finite set of satellite transponder output moments are first calculated. Then, the smallest (two-dimensional in this case) point mass probability

density function which satisfies these moments is determined and used in place of the unknown actual density function to determine the average probability of error.

One of the most detrimental interference types is strong, pulsed CW. In the final paper, Weinberg determines the performance of a nonlinear satellite link when coding is used to combat such interference. His procedure consists of computing the computational cutoff rate R_o of the channel up to the soft decision demodulator output and then relating R_o to the bit error probability at the decoder output by an empirically determined relationship. The accuracy of his method is then verified via computer simulation.

The field of communications over nonlinear channels is a maturing field, as evidenced by the fact that most of these

papers are concerned with the composite effects of a number of detrimental factors rather than the isolated impact of each one separately. However, the analytical difficulties imposed by the nonlinear devices are substantial and the tools developed thus far to cope with them are, at best, weak. This Special Section has contributed to the strengthening of those tools, but much still remains to be done.

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From January 1967 through November 1969 he was employed by the Bell and Howell Company, Pasadena, CA, where he was involved in the design of high performance magnetic tape recorders. In November 1969 he joined the Leach Corporation, Azusa, CA, where he functioned as a systems design engineer and project engineer. Since June 1971 he has been at the Jet Propulsion Laboratory, Pasadena, CA, where he is currently Supervisor of Communications Concepts Research. He currently holds a joint appointment with the California Institute of Technology, Pasadena, where he has been and is involved with teaching courses in Signal Processing, Communications Theory, Information Theory, and Coding. His research interests are in the areas of information theory and statistical communications where he holds one patent.

Dr. Lesh has been an Associate Editor for Communication Theory for the IEEE TRANSACTIONS ON COMMUNICATIONS since 1975 and he is a member of the Communication Theory Technical Committee of the Communications Society. He recently served as the Communication Theory representative to the Technical Program Committee of NTC '80 and he is presently Local Arrangements Chairman for the 1981 Information Theory Symposium.