Signals in Nonlinear Bandpass Systems

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A thesis submitted for the degree of Doctor of Philosophy in:

May 1991

Abstract

Nonlinear distortion is a factor limiting performance in many bandpass systems such as are found in communications and radar. This thesis addresses a number of theoretical and practical issues relevant to the modelling and correction of distortion in High Frequency Radar Receivers. The theoretical results and the experiment methods are applicable to other bandpass systems.

Techniques for modelling nonlinear communication systems, using power series, amplitude and phase describing functions and Volterra series are reviewed. Some effort is expended in determining the class of nonlinear systems described by each model. In many systems, it often the case that only the class of systems with bandpass input and output is of interest. The usefulness of these models in predicting the performance of communications systems is evaluated.

It is shown that, for all three models considered, distortion in a bandpass context can be considered equivalent to distortion of the complex envelope of signal. It is also shown that the power series model and the amplitude and phase describing function model are special cases of the Volterra series model.

Many bandpass systems perform a frequency translation function. Radio receivers invariably use mixers to achieve frequency translation. Mixers are two input devices and in general the output is a nonlinear functional of both the input signal and the local oscillator signal. In classical communications receivers the local oscillator is a sinusoidal function of time, but in applications such as frequency hopping communications and in radar, the local oscillator may be a more complex signal.

The number of terms required to model a general, nonlinear functional of n signals goes up as $O(k^n)$ so it is undesirable to model a mixer as a general two input nonlinearity if it is avoidable. Further, modelling a real receiver containing mixers as a general, multi-input nonlinearity would require extra instrumentation to monitor the local oscillators.

The Wiener model of nonlinear systems is extended to the case of two input nonlinear systems. This representation is then used to examine the conditions under which a real mixer can be modelled by a combination of one input nonlinearities and ideal mixers. The extended Wiener model is also be used to show that, in a bandpass context, a phase shift in one local oscillator results in the same phase shift in all the output components.

The discrete time version of the Volterra series is chosen as a suitable means of modelling and correcting nonlinear distortion, since it is capable of approximating arbitrarily closely a very large class of nonlinear systems. An adaptive nonlinear filter based on the discrete time Volterra series is discussed and extended to the two input case. A number of different adaption algorithms are discussed and two nonlinear recursive least squares (RLS) algorithms (lattice and fast Kalman) are derived.

An experiment to estimate nonlinear distortion in an HFR receiver is described. There are a number of characteristics which make this experiment different from others described in the literature. Specifically:

- The receiver must be modelled as a two input device. The relative phase of the inputs can not be measured or controlled[1].
- The receiver has slight, but important, nonlinear distortion in the presence of large linear distortion. These two factors place severe constraints on the adaption algorithms, and prompted the development of the nonlinear RLS algorithms mentioned above.
- The receiver's inputs and outputs are at different frequencies. This was

[1]All the signals are phase locked, but there is no way to set the initial phase.

dealt with by estimating the distortion in the complex envelope instead of estimating the distortion of the original signals.

- The band width of the signals applied to the receiver's inputs should be very much greater than the band width of the receiver output to adequately probe the front end circuitry. Consequently, it is difficult to provide enough input samples so that enough information is available in the output for the estimation to be done. The problem can be alleviated by sampling the input data at slightly different rates. Different sampling rates complicates the processing of the data considerably, but the problem is tractable.

Sufficient experimental results are presented to verify that the methodology is capable of estimating the receiver's Volterra kernels. The results also verify some of the theoretical results in the thesis.

It is concluded that more efficient algorithms and/or more powerful computing hardware are necessary before the nonlinear filter approach is a practical way of estimating or correcting nonlinear distortion in systems similar to the HFR radar receiver.

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