THE USE OF NON-LINEAR AMPLIFIER MODELS IN BANDLIMITED CHANNELS

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ABSTRACT

The non-linear operating characteristics of efficient, high-powered amplifiers has motivated the development of constant envelope signaling schemes for satellite, mobile, and range communications. As such applications face demands for greater spectral efficiency, it has become useful to re-examine non-linear amplifiers with respect to spectral regrowth of filtered signals, and the performance of non-constant envelope signaling. This paper examines the use of amplifier models, empirical measurements, and software tools in the development of spectrally efficient QAM signal schemes.

INTRODUCTION

Reductions in bandwidth allocations for telemetry and range applications have prompted a need for greater spectral efficiencies in these systems. Towards this end, non-constant envelope modulation methods, previously avoided due to non-linear amplification, must now be considered. Multilevel QAM systems are needed to increase the number of user information bits per symbol, and pulse-shaping will be needed. This poses new challenges to the design of spectrally efficient systems, and requires that models of non-linear amplifiers be incorporated in design studies of such systems.

A typical quadrature amplitude modulation (QAM) system as shown in figure 1, uses filtering to minimize the transmission bandwidth, however, a tradeoff is involved between pre-amplification (baseband) filtering, and post-amplification (RF) filtering. It is preferable to minimize the need for post amplification filtering, since this must be accomplished at both higher energy and higher frequency, however, the nonlinear amplifier will cause spectral regrowth in a signal that has been filtered prior to the amplifier.

The typical high powered amplifier introduces two kinds of distortion into the QPSK signal: 1) non-linear amplitude response and 2) output phase shift as a function of input amplitude. The amplitude response of the amplifier is referred to as AM-AM conversion, while the phase characteristic is referred to as AM-PM conversion. If it were not necessary to limit the bandwidth of the QPSK signal, neither of these would be a problem, since the constant envelope input would produce a constant envelope output, while the constant phase offset would be picked up by the synchronizing circuitry in the receiver. When the input is bandlimited, the input amplitude is not constant and the AM-AM and AM-PM effects come into play.

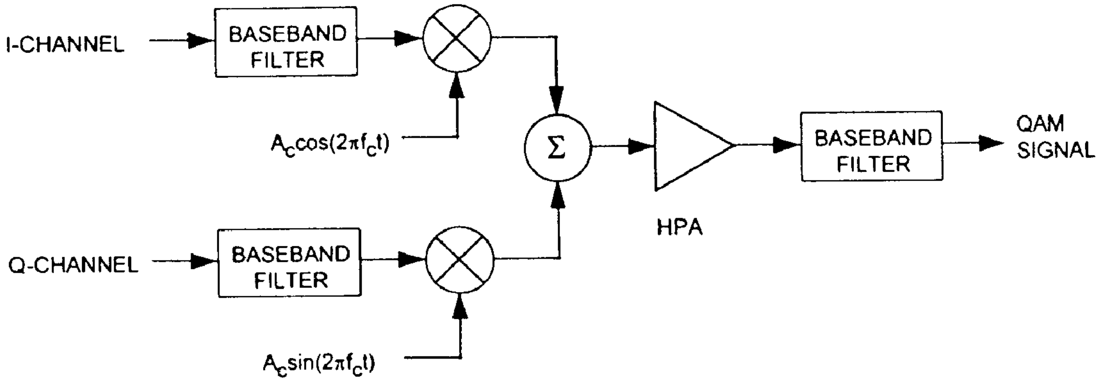

Figure 1. Typical QPSK modulation system.

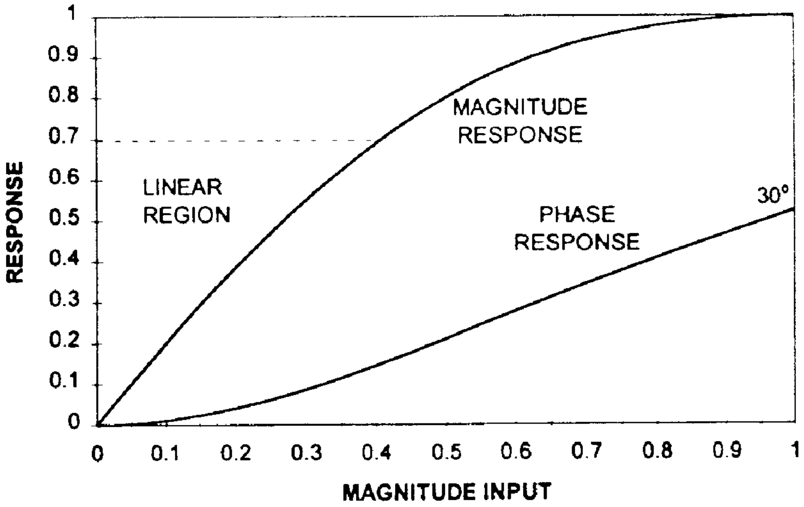

Figure 2. Typical Non-linear Amplifier Response.

The response of the amplifier to an input of the form:

$$s(t) = A(t)\cos[2Bf_c t+\theta(t)]$$

is of the form:

$$x(t) = g[A(t)]\cos(2Bf_c t+\theta(t)+\phi[A(t)])$$

where g and ϕ are respectively the amplitude and phase response characteristics of the amplifier [1,2]. The amplitude response will significantly effect the spectrum of the output signal, whereas the phase response will affect the spectrum of the signal to a lesser degree. Figure 3 shows the amplitude and phase response of a typical high-powered amplifier (HPA), or traveling wave tube amplifier (TWTA). Although TWT's are being replaced by modem solid state amplifiers, nonlinearities are still present, although to a lesser degree, and the mathematical models of the new amplifiers are of similar form. The magnitude response is of the form

$$g(x) = \mathit{maximum\ output} \cdot \frac{2x}{1+x^2}$$

and the phase response is of the form

$$\phi(x) = \mathit{maximum\ phase\ distortion} \cdot \frac{2x^2}{1+x^2}$$

where x is the input relative to the maximum.

Spectral regrowth depends on how close the amplifier is driven to saturation. If the amplifier is operated at low input levels, the response is essentially linear and the effect on the spectrum is negligible but this uses less than the full power of the amplifier, and therefore reduces the link margin. Hence a tradeoff between output power and spectral spreading is involved.

To illustrate this, sequences of random QPSK symbols were generated using 8-samples per channel (I and Q) per symbol. The Fourier Transform of the sequence was taken and filtered to a bandwidth (on-sided) of Rs. The inverse Fourier Transform was generated to recover the I and Q components of the filtered signal. A non-linearity of the kind discussed previously was applied to the signal. Finally, the power spectrum of the non-linearized signal was taken. This was done with the amplifier operated at various backoffs from saturation, and the result is shown in figure 3. Here, the narrower spectrums are associated with the greater backoffs.

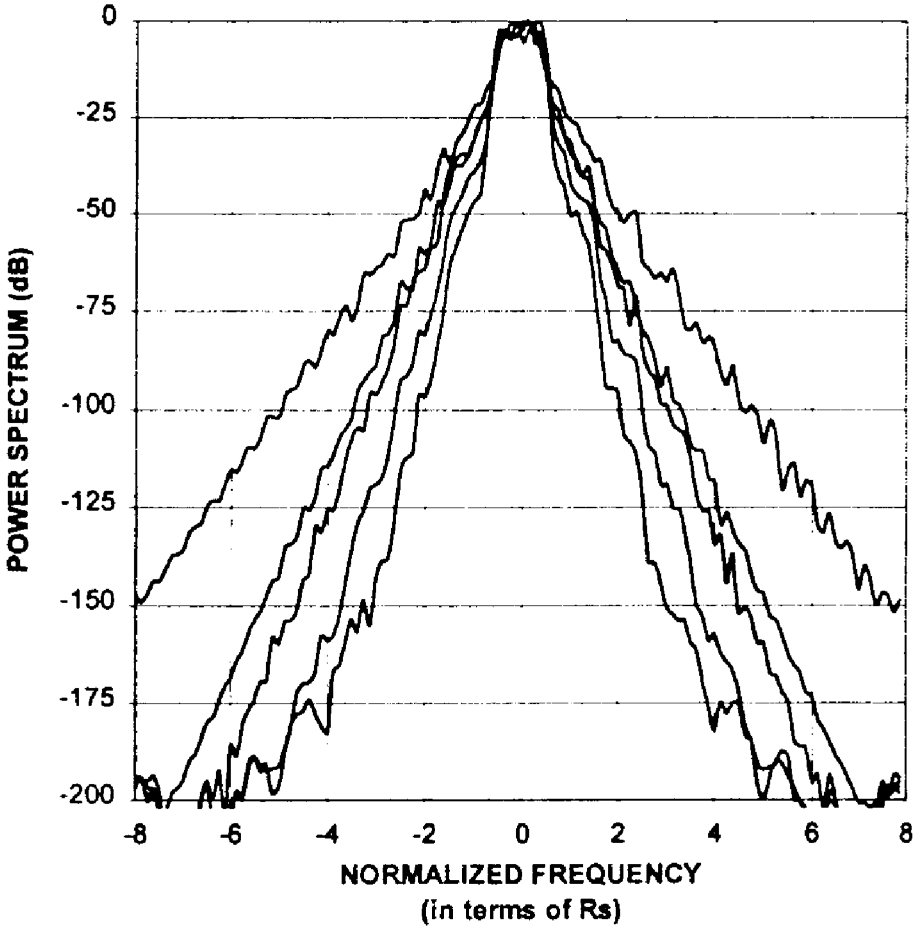

Figure 3. Spectrum of QPSK at output of a non-linear amplifier operating at output backoffs of 0, 1, 3, 5, and 10 dB, using a premodulation 6th order Butterworth filter with a bandwidth of 0.5 Rs.

NON-LINEAR AMPLIFIERS AND SPECTRALLY EFFICIENT SYSTEMS

In addition to the effects described in the previous section, a non-linear amplifier poses additional challenges to the implementation of spectrally efficient systems: 1) Amplitude and phase distortion must be compensated to support multi-level signal constellations, and 2) the distortion impairs the performance of pulse shaping systems. This will be illustrated using a rate 4/5 trellis-coded [3,4,5] 32-QAM system currently in computer simulation at NMSU. The system has the signal constellation of figure 4, and uses matched square root raised cosine filters at the transmitter and receiver.

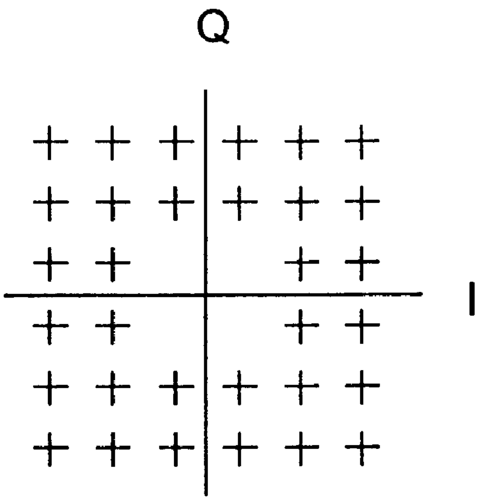

Figure 4. 32-QAM constellation for the system discussed in this paper.

The non-linear amplitude and phase characteristics of the high-powered amplifier were corrected by adding a non-linear equalizer to the system as shown in figure 5. The equalizer is of the form:

$$Ieq = \sum_{ij} u_{ij} I^i Q^j \qquad Qeq = \sum_{ij} v_{ij} I^i Q^j \qquad \text{where } i,j \geq 0 \text{ and } i+j \leq 3.$$

In other words, the non-linearity of the equalizer can be corrected by a Volterra equalizer of order 3. The coefficients for the equalizer were found by minimum mean squared error and are given in table A-l. Because the 3rd order correction is not perfect, it introduces distortion in the response of the raised cosine filter, the effect of which is more significant when a lower rolloff factor is used. The bit error rate performance of the system is shown in figure 6. Without any non-linearities, the system will function, with no significant performance loss, with a rolloff factor as low as 0.2. With the high powered amplifier corrected by the equalizer, the system functions with negligible loss at a rolloff factor of 0.4, however, a loss of approximately 0.5 dB occurs at a rolloff factor of 0.2.

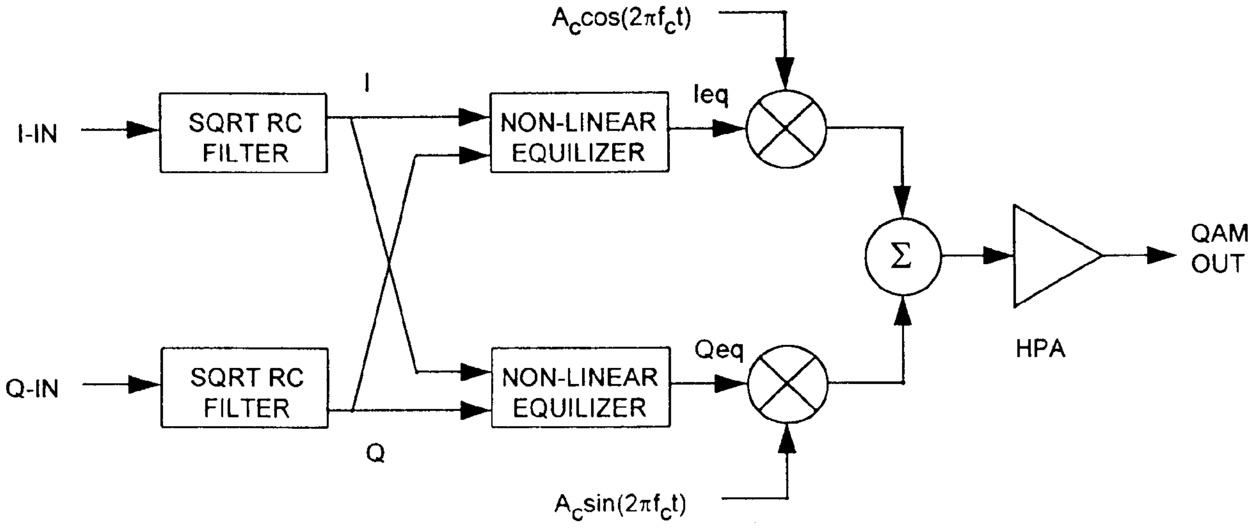

Figure 5. QAM Modulator with pulse shaping and non-linear equalizers.

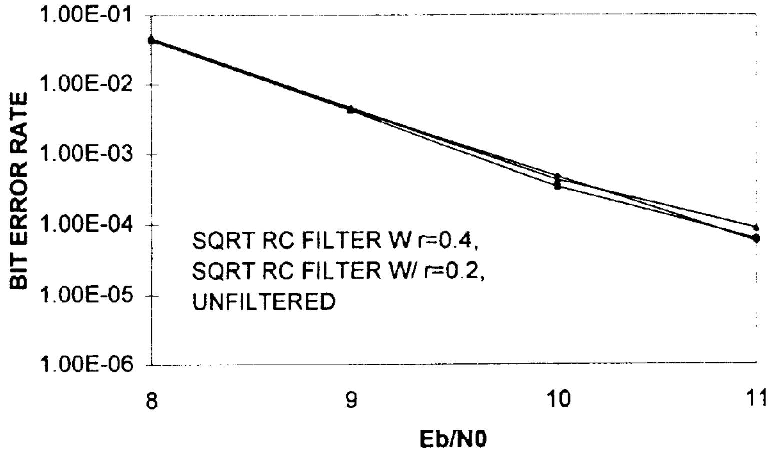

Figure 6. Bit Error rate of rate 4/5 trellis coded 32-QAM with sqrt raised cosine filtering and non-linear amplifier corrected by 3rd order equalizer.

CONCLUSION

As bandwidth allocations for telemetry and range applications decline, non-constant amplitude modulation formats, previously avoided in systems with non-linear amplification must now be considered. In this paper, we have used a traditional non-linear amplifier to illustrate spectral regrowth as a function of backoff in a QAM system, and to show that non-linearities can be corrected by a 3rd order equalizer. Other possibilities exist using digital technology

ACKNOWLEDGMENT

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APPENDIX

u30	6.954E-02	v30	-8.752E-02
u21	9.976E-02	v21	6.962E-02
u12	6.972E-02	v12	-1.002E-01
u03	8.773E-02	v03	7.089E-02
u20	-7.439E-07	v20	8.260E-07
u11	2.837E-09	v11	-1.024E-06
u02	7.919E-07	v02	3.684E-07
u10	3.440E-01	v10	2.115E-02
u01	-2.112E-02	v01	3.433E-01

Table A-l. Coefficients for non-linear equilizer.