Linear Time Varying Precoder Applied to an ISI Channel

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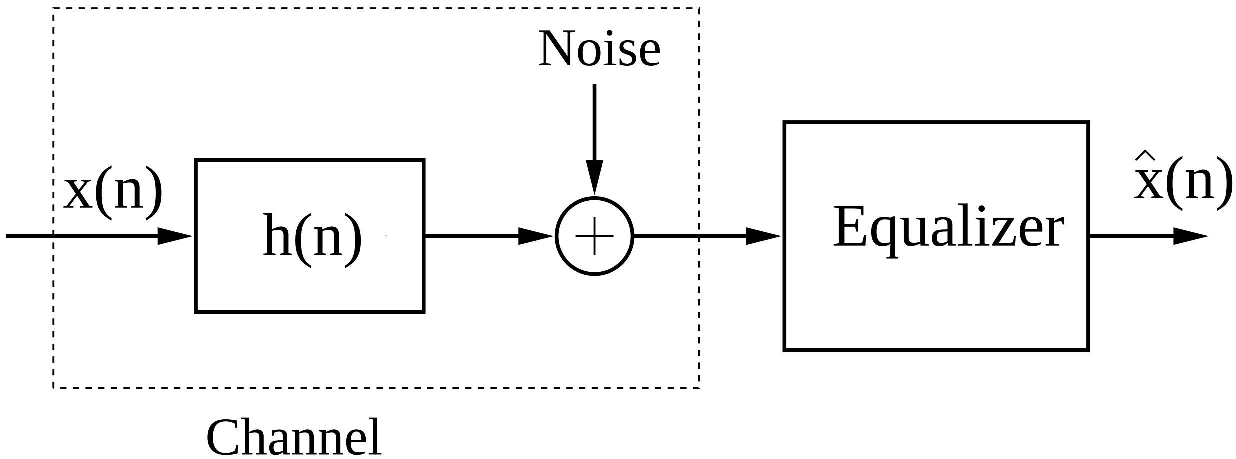
Outline

- ISI Channel Equalization and Precoding
- Modulo Arithmetic Precoding
- High Rate Data Transmission over PCM Voiceband Channels
- Linear Time Varying Precoding and Spectral Shaping
- Implementations
- Simulation Results
- Conclusions

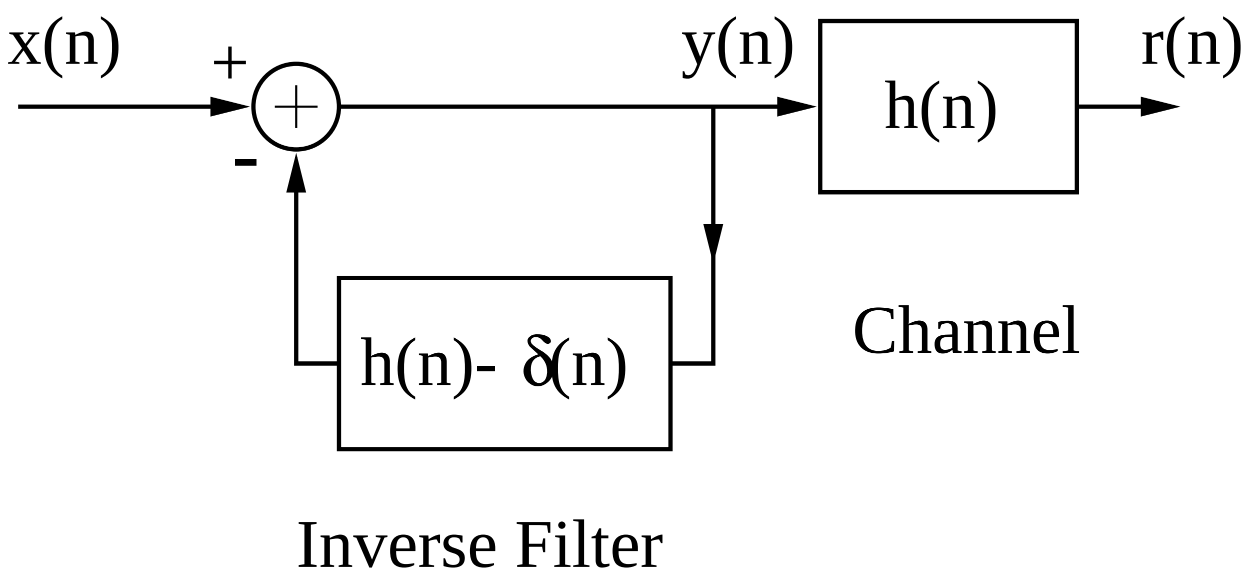
Introduction

- Intersymbol Interference (ISI) caused by the channel or transceiver filters limits the maximum transmission rate.
- Equalizers compensate for the channel distortion but linear equalizers can cause noise enhancement.
- Decision Feedback equalizers suffer from error propagation. There is no direct way to apply error correcting coding combined with decision feedback equalizer.



Equalization and Prefiltering

- If the channel is known at transmitter, prefiltering can theoretically eliminate ISI.
- A simple prefiltering can boost the peak and average transmit signal power.
- For channels with spectral nulls the inverse filter is not stable.



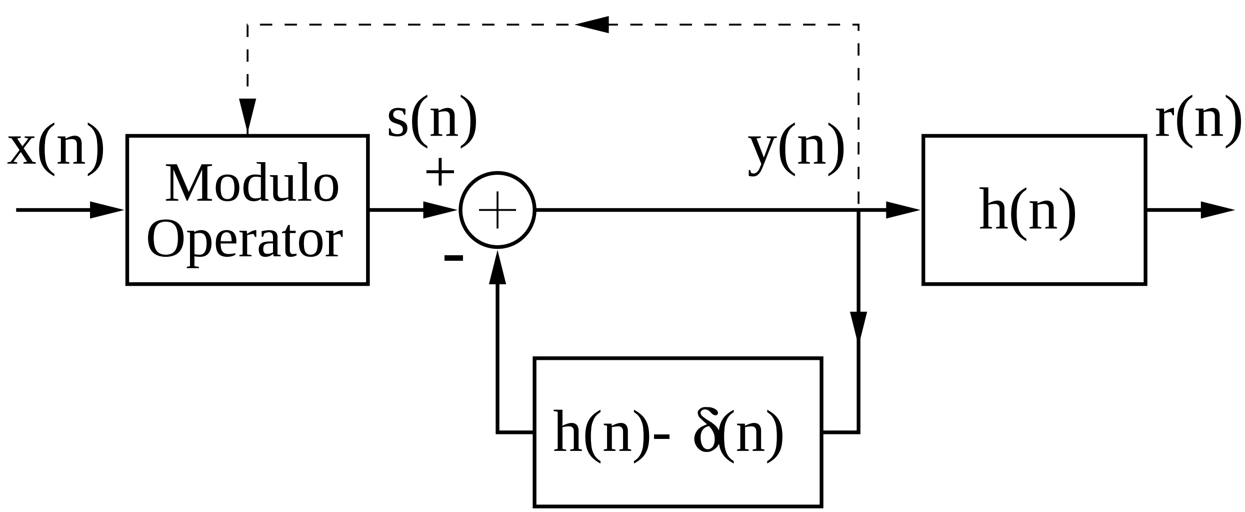
Modulo Arithmetic Precoding

The modulo Operator is a nonlinear, memoryless function which extends the input signal $x(n)$:

$$s(n) = x(n) + V_{max} \cdot k(n)$$

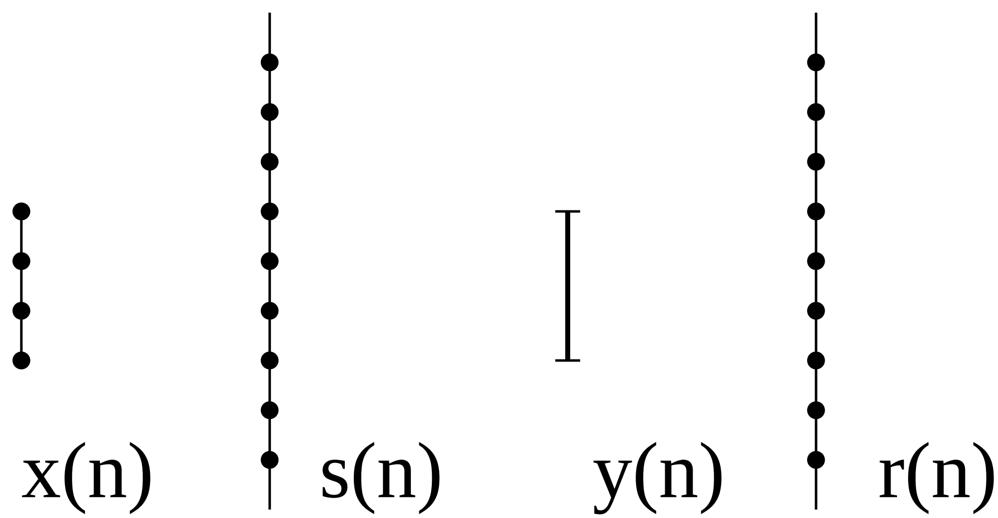
Choose $k(n)$ so that:

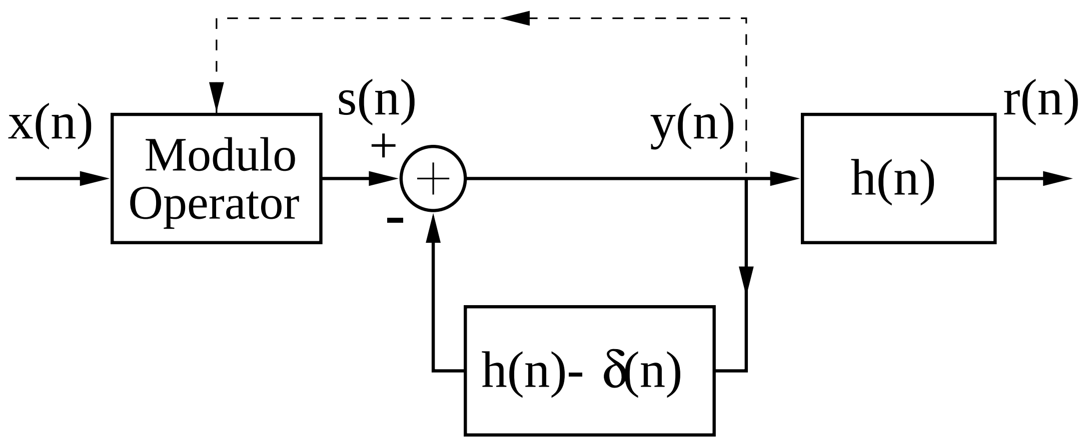
$$y(n) \in (-V_{max}/2, +V_{max}/2]$$

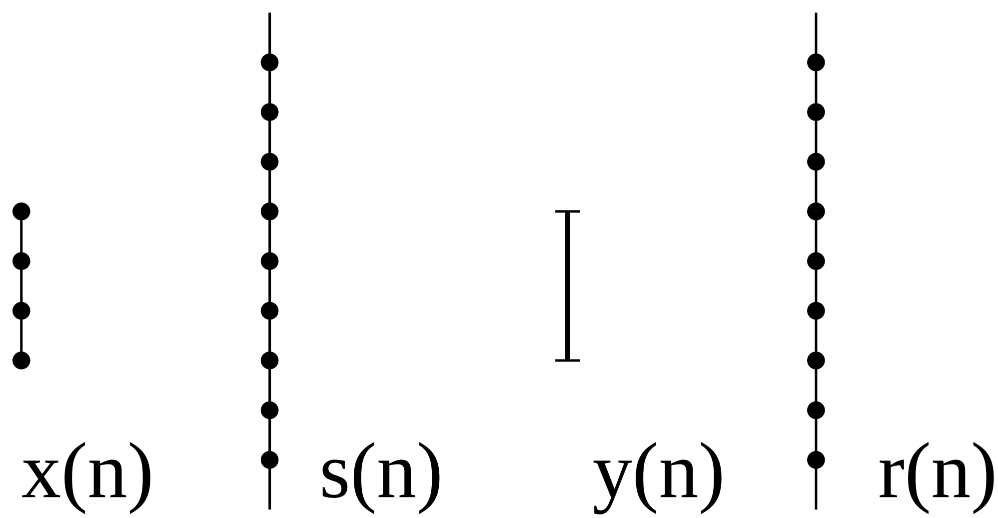


Tomlinson Harashima Precoder

- TH precoder limits the peak and average transmit signal power.
- There is a serious drawback associated with TH Precoder, it increases the dynamic range of the received signal.
- The increase in dynamic range can be particularly severe if the spectrum of the channel contains spectral nulls.



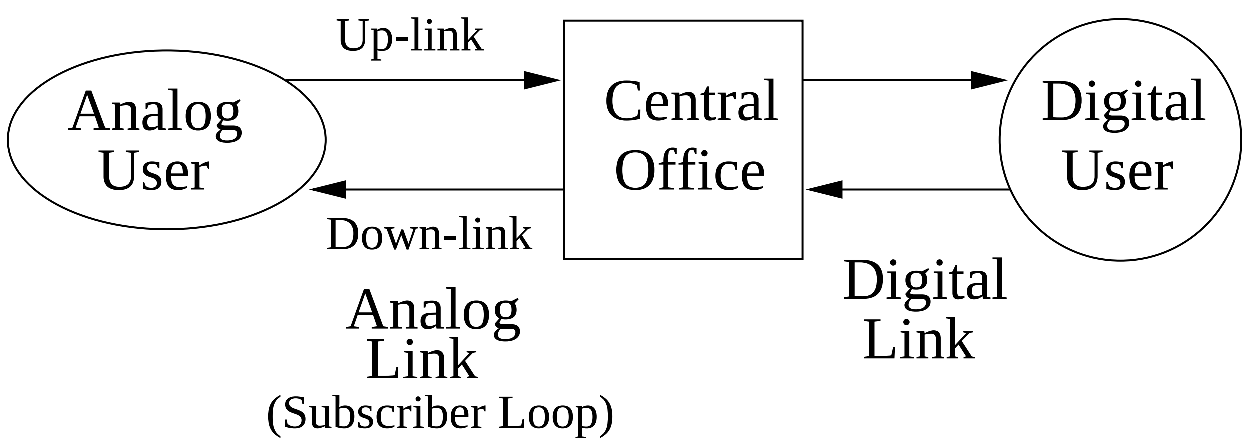

x(n)
Modulo
Operator
s(n)
+
-
y(n)
h(n)
r(n)
h(n)- δ(n)


x(n)
s(n)
y(n)
r(n)

Data Transmission over PCM Voiceband Channels

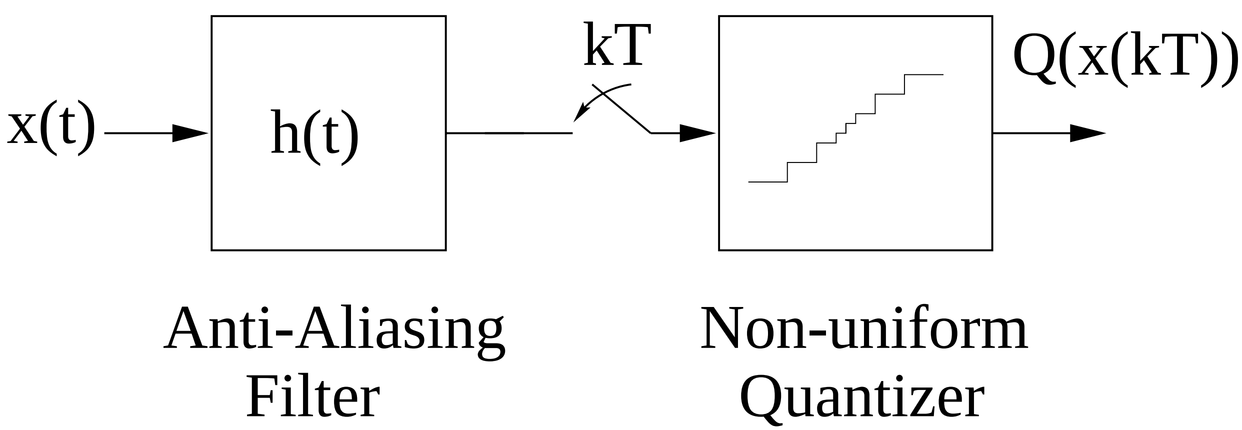
- In the PCM voiceband channel, the subscriber loop connecting an end user to the central office is analog.

- The predominant source of noise (Up-link) is quantization error due to Analog-to-Digital (A/D) conversion.



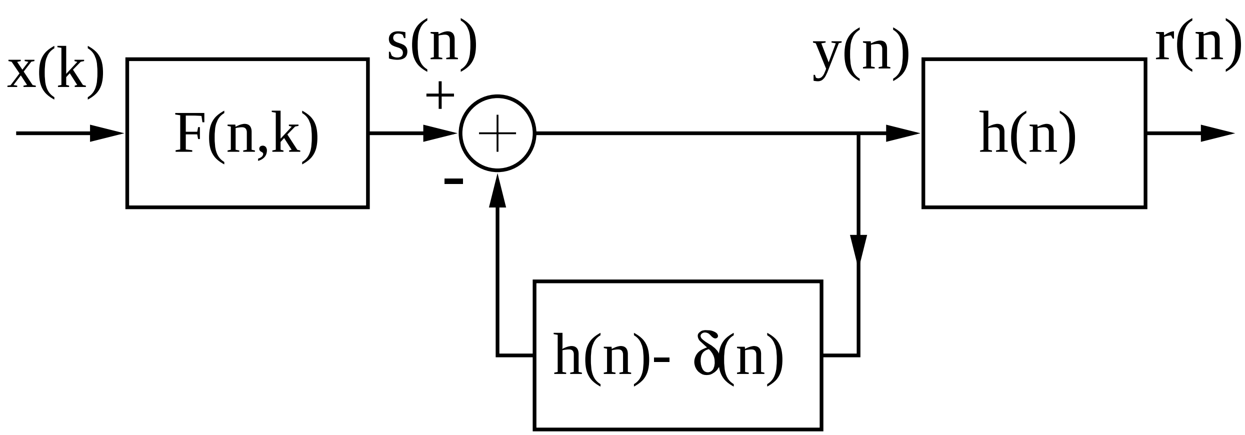
The Up-link Channel

- To eliminate the quantization error, the signal at the A/D at each sampling instance should take values near to one of the quantizer levels.
- We assume perfect synchronization between transmitter and A/D.
- The anti-aliasing filter prior to A/D reduces the bandwidth of the channel.



Linear Time Varying Precoder

- In order to stabilize the inverse filter $1/H(z)$, we add redundancy to the input signal to cancel poles of the inverse filter.
- $F(n,k)$ is a linear time varying filter which adds redundancy to the input signal.
- The added symbols are a linear combination of the previous input values. $F(n,k)$ operates on a block of inputs.



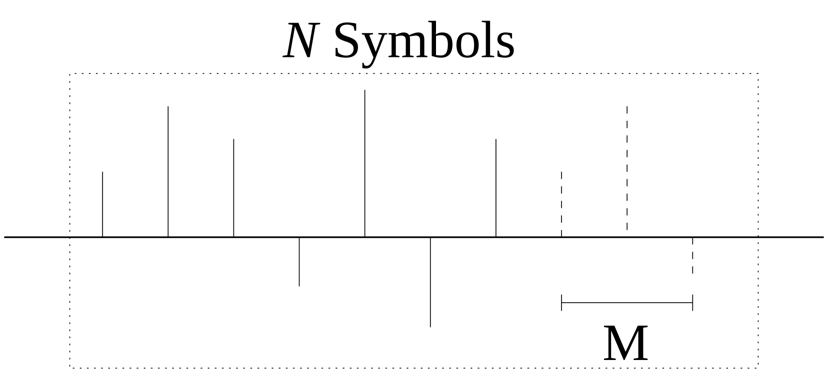
Spectral Shaping and Pole-Zero Cancellation

$S(z)$ can be decomposed into non-overlapping blocks of length N:

$$S(z) = \sum_{m=-\infty}^{\infty} \left(\sum_{l=0}^{N-1} s(mN+l) z^{-l} \right) z^{-mN}$$
$$= \sum_{m=-\infty}^{\infty} S_m(z) z^{-mN}$$

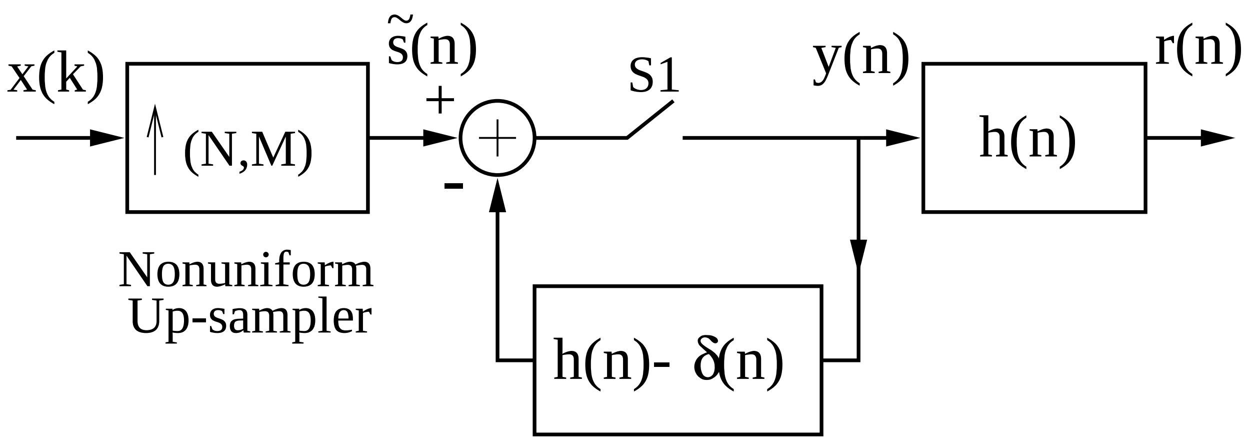
M redundant symbols in each block are selected so that:

$$S_m(z) = H(z) \cdot Y_m(z)$$



Implementations

- S1 performs as an on-off switch with a pattern of $(N - M)$ ones followed by M zeros.
- By turning off S1 for M consequent symbols, we clear the memory of the inverse filter.
- For each new block of input symbols the inverse filter starts from zero initial state.



Implementations

$$y(mN+l) = \begin{cases} \sum_{k=0}^{l} \tilde{s}(mN+l-k) \cdot h_{inv}(k) & 0 \le l < N-M \\ 0 & N-M \le l < N \end{cases}$$

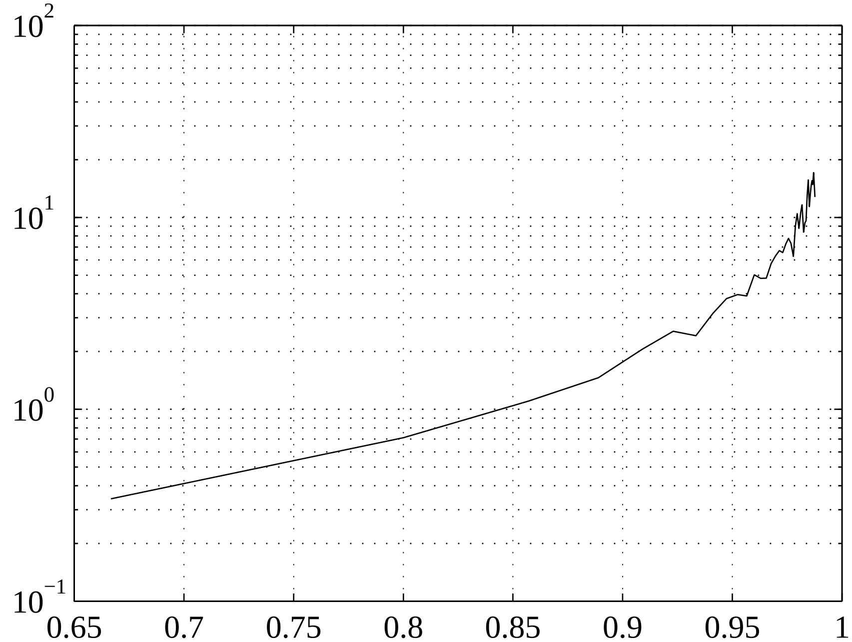
- $h_{inv}(n)$ may tend to infinity for large values of n but S1 truncates the impulse response.
- For a block length N much larger than the channel memory, the information rate reduction is tolerable.
- In the case of channel with a long memory, $h(n)$ can be decomposed into two parts.

$$h(n) = h_1(n) * h_2(n)$$

Example

$$H(z) = (1 - z^{-1})(1 + z^{-1})$$

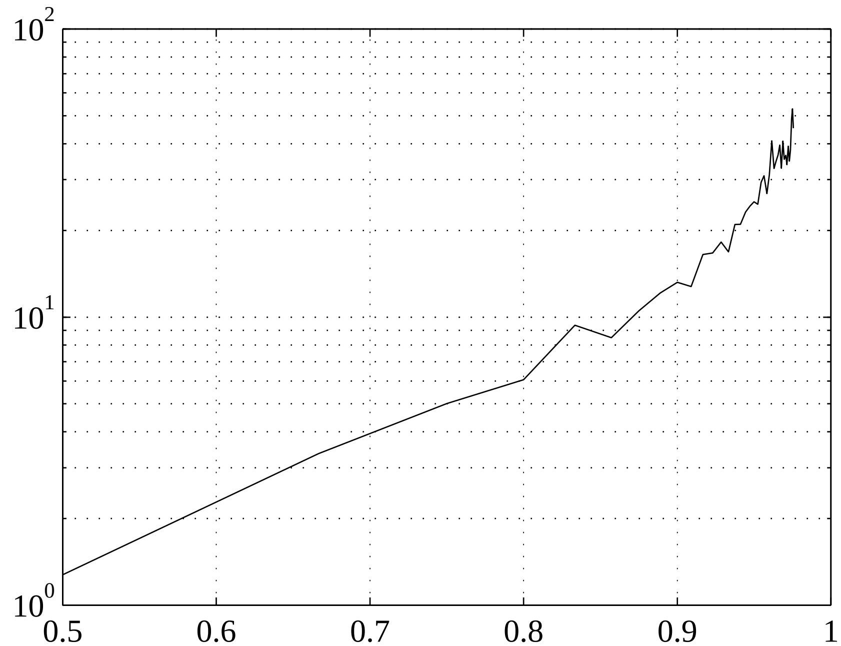
Average transmit power versus normalized rate



Example

$$H(z) = (1 - z^{-1})(1 + z^{-1})(1 - e^{j0.8\pi} z^{-1})(1 - e^{-j0.8\pi} z^{-1})$$

Average transmit power versus normalized rate



Conclusions

- Modulo arithmetic precoder increases the dynamic range of the received signal
- Linear time varying precoder stabilizes the inverse filter using signal shaping.
- A simple implementation of the time varying precoder employs a single switch in the feedforward path of the prefilter
- Increase in transmission rate would increase the average transmitted power.