A Sum-of-Products Model for Effective Coherent Modulation Filtering

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Background
Objective
To define a mathematically consistent signal model for filtering the envelopes of multi-component signals, allowing novel approaches to enhancement and/or separation of speech signals.

Narrowband Modulation (Sum of Products)
Low-frequency temporal envelopes (modulators) multiplying high-frequency carriers:

\[ x[n]=\sum x_i[n]=\sum m_{i}[n]c_{i}[n] \]

Multiple Solutions (Under-Determined)
Given \( x[n] \), there are at least two equally-valid solutions for finding a modulator \( m_{i}[n] \) and carrier \( c_{i}[n] \) such that \( x[n] = m_{i}[n]c_{i}[n] \).

Incoherent Demodulation (Conventional Hilbert Envelope)

\[ m_{i}[n]=|x_i[n]| \]
\[ c_{i}[n]=\exp\left(j\angle x_i[n]\right) \]

Coherent Demodulation (Complex-valued envelope)

Evaluation of Modulation Filtering
Define: Empirical Modulation Transfer Function,

\[ G_c(\omega) = \frac{1}{K} \sum_{k=1}^{K} M_k(\omega) - \frac{1}{K} \sum_{k=1}^{K} M_0(\omega) \]

Define: An “effective” modulation filtering operation when

\[ G_e(\omega) = \left|\tilde{\omega}(\omega)\right| \]

Explanation: Modulation Projection Test

Conclusions
Key Point: Modulation filtering modifies a signal relative to the carrier estimates.

Incoherent demodulation is an energetic envelope detector with no phase reference, i.e., no direct knowledge of the carriers.

Coherent demodulation explicitly detects well-behaved carriers for modulation filtering. It is audibly more effective at enhancement and separation than previous incoherent approaches.