On the Impulsive Nature of Interchannel Interference in Digital Communication Systems

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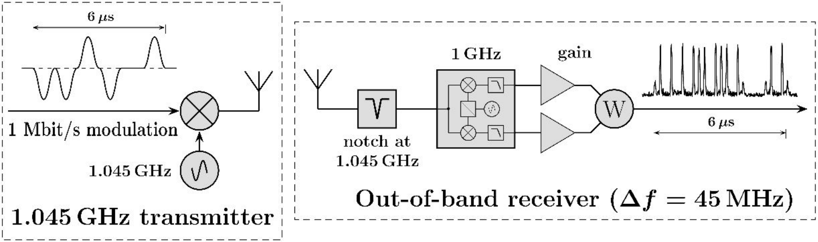
Illustrative measurement

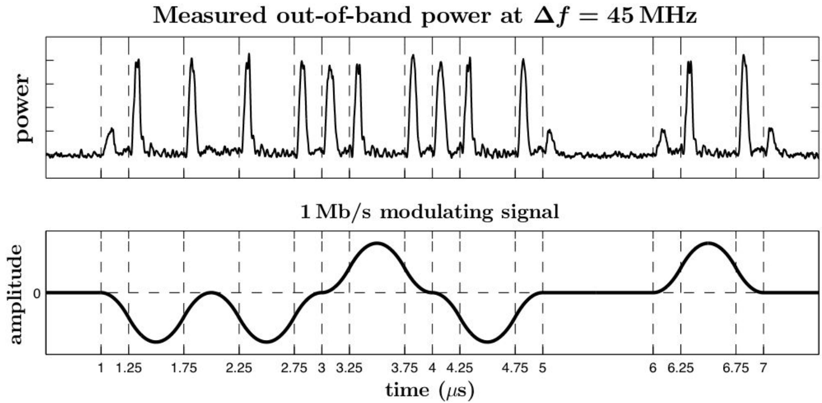
Courtesy of John B Lancaster



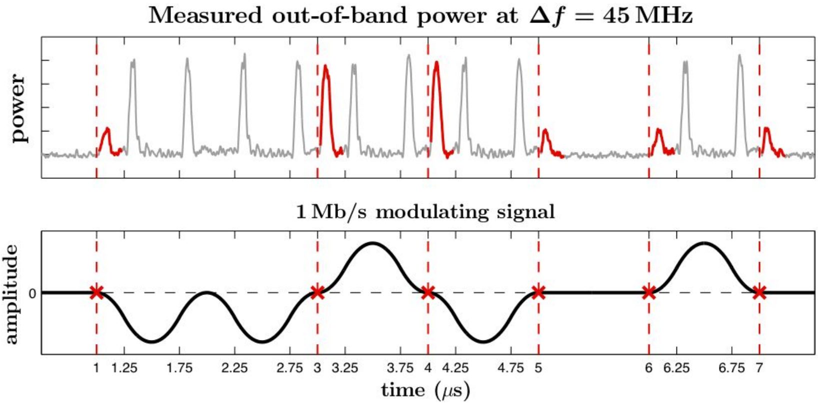
- Transmit a tone modulated by a 'smooth'-looking message
- Observe instantaneous power in an out-of-band receiver
  - impulsive pulse train

Illustrative measurement

Signal traces

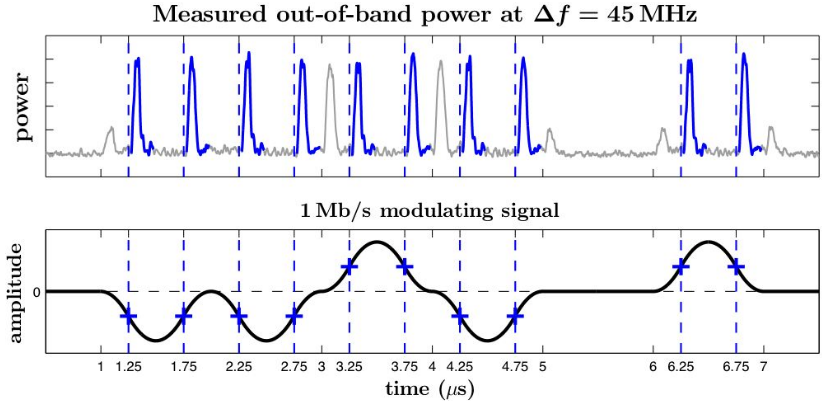


Illustrative measurement



- Some peaks originate at zero modulation amplitude
  - at onsets and ends of modulating pulses

Illustrative measurement



- Others originate at 'smoothest', most linear parts of modulating pulses

Elemental model

Setup

- Transmitter
  - linear combination of terms $x(t) = A_T\left(\bar{t}\right) \mathrm{e}^{\mathrm{i}\omega_\mathrm{c} t}$
  - $A_T(\bar{t})$ is complex-valued modulation, and $\bar{t} = \frac{2\pi}{T}\, t$
- Receiver
  - quadrature receiver at $f_c + \Delta f$ with baseband impulse response $w(t) = \frac{2\pi}{T}\, h\left(\bar{t}\right)$
- Signal in the receiver

$$I(t, \Delta f) + \mathrm{i} Q(t, \Delta f) =$$

$$\int_{-\infty}^{\infty} \mathrm{d}\tau\; A_T(\bar{\tau})\, w(t-\tau)\, \mathrm{e}^{\mathrm{i}\Delta\omega\tau}$$

  - windowed Fourier transform of $x(t)$

Elemental model

Analysis

- Use consecutive integration by parts:

$$I(t, \Delta f) + \mathrm{i}Q(t, \Delta f) =$$

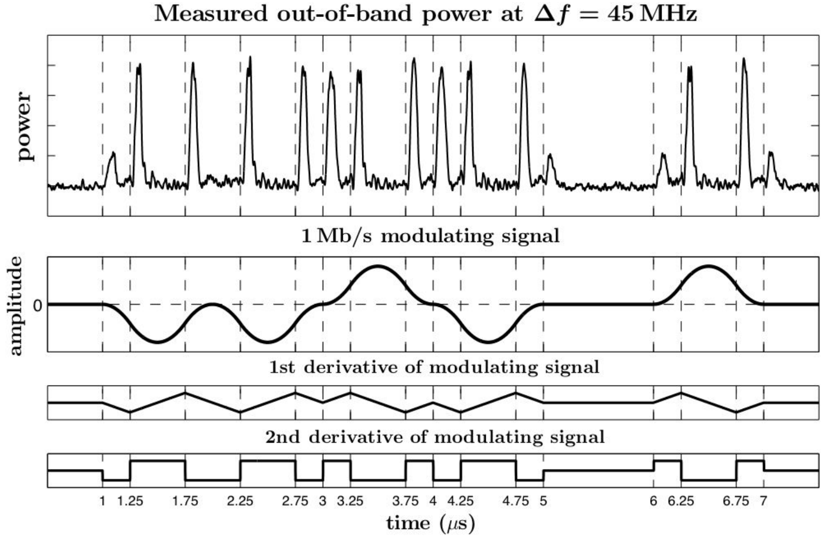
$$\frac{\mathrm{i}^n}{(T\,\Delta f)^n} \int_{-\infty}^{\infty} \mathrm{d}\bar{\tau}\, \mathrm{e}^{\mathrm{i}\,(T\,\Delta f)\,\bar{\tau}} \times \frac{\mathrm{d}^n}{\mathrm{d}\bar{\tau}^n} \left[A_T(\bar{\tau})\, h\,(\bar{t} - \bar{\tau})\right]$$

- Note that $A_T(\bar{t})$ is convolution of discrete signal and causal impulse response
  - differentiate until ‘singular’ component(s) appear

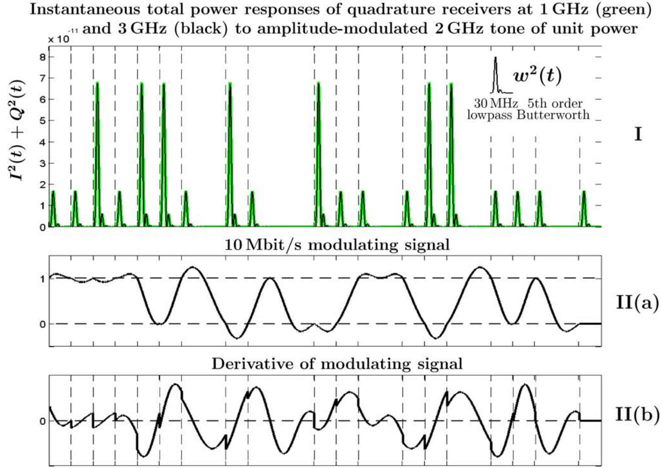
Then, for example:

$$P_x(t, \Delta f) = \frac{1}{(T\,\Delta f)^{2n}} \sum_i |\alpha_i|^2\, h^2\,(\bar{t} - \bar{t}_i)$$

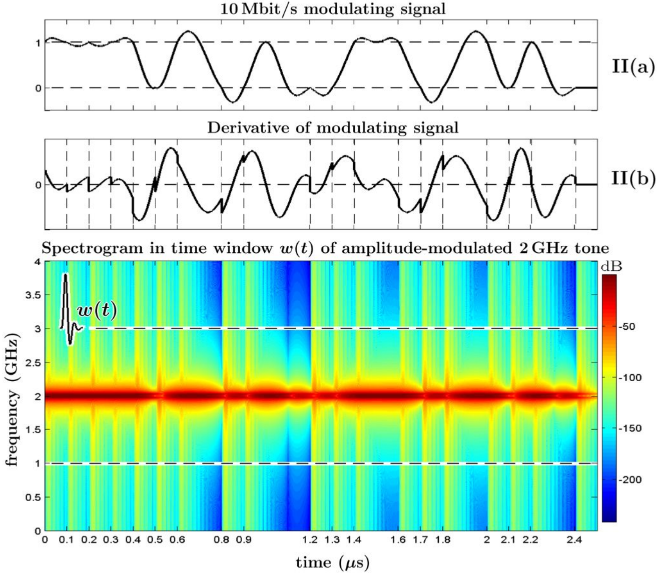
- for sufficiently large T and Δf
- impulsive pulse train
- $|\alpha_i|$ is magnitude of discontinuity of $A_T^{(n-1)}(\bar{t})$ at $\bar{t}_i$


Measured out-of-band power at $\Delta f = 45$ MHz
power
1 Mb/s modulating signal
amplitude
0
1st derivative of modulating signal
2nd derivative of modulating signal
1 1.25 1.75 2.25 2.75 3 3.25 3.75 4 4.25 4.75 5 6 6.25 6.75 7
time (μs)

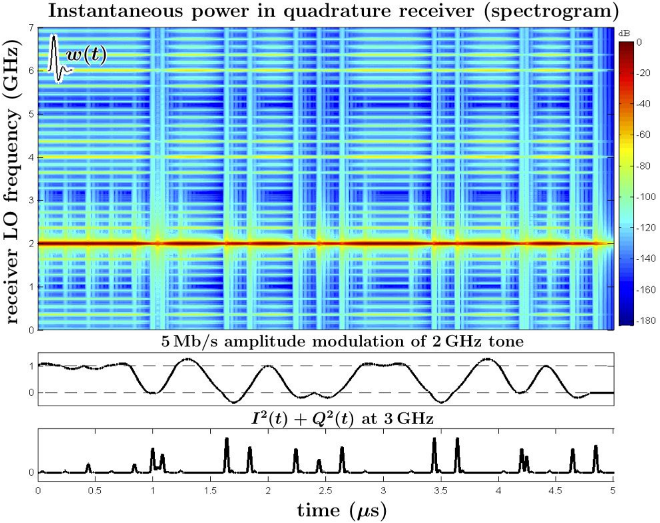
Raised cosine pulse shaping: Simulated idealized example



Raised cosine pulse shaping: Simulated spectrogram



Interference pattern with non-idealities



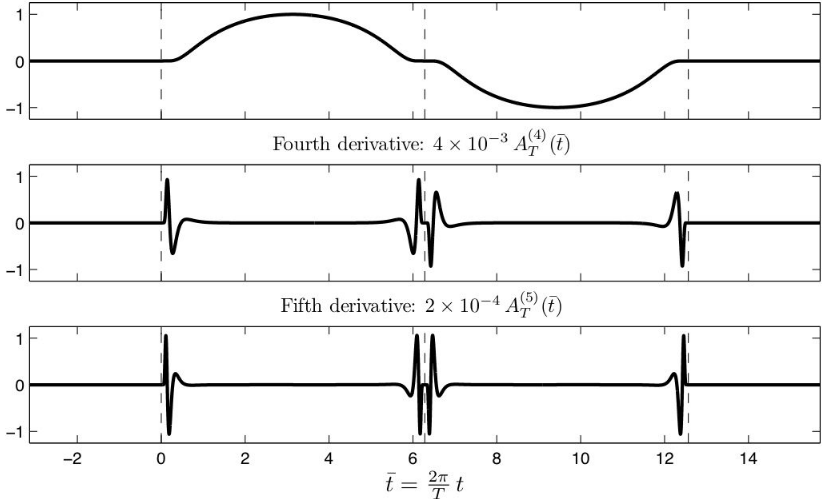
It follows:

- Impulsive nature of out-of-band interference results from causal nature of communications
- Effect can always be measured, may or may not be negligible
  - made stronger and more complicated by non-idealities in transmitter
  - enhanced by external EMI distortions from digital circuitry
- May motivate usage of nonlinear filtering techniques in the receiver
  - non-Gaussian interference makes nonlinear techniques effective

Appendix I

'Singular' derivatives of truly smooth modulation

$$A_T(\bar{t}) = \Psi(\bar{t}) + \Psi(\bar{t} - 2\pi), \quad \text{where } \Psi(\bar{t}) = \exp\left(1 + \frac{\pi^2}{\bar{t}^2 - 2\pi\bar{t}}\right) \mathbf{1}_{>0}\left(2\pi\bar{t} - \bar{t}^2\right)$$



Appendix II

Discontinuities in Continuous Phase Modulation

- Transmitted signal:

$$x(t) = A_T(\bar{t})\,\mathrm{e}^{\mathrm{i}\omega_\mathrm{c} t} = \left[A_0\,\mathrm{e}^{\mathrm{i}(T\,\Delta f_\mathrm{c})\int_{-\infty}^{\bar{t}}\mathrm{d}\tau\, a_T(\tau)}\right]\,\mathrm{e}^{\mathrm{i}\omega_\mathrm{c} t}\,,$$

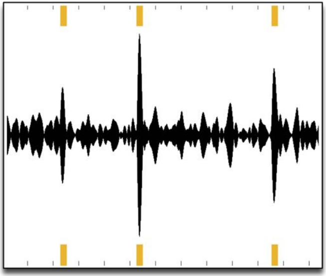
  where Δf_c is the frequency deviation
- Derivative of $A_T(\bar{t})$:

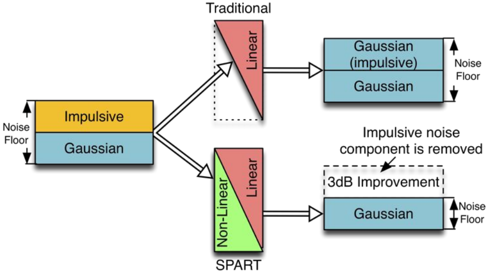
$$A'_T(\bar{t}) = \mathrm{i}(T\,\Delta f_\mathrm{c})A_T(\bar{t})\,a_T(\bar{t})$$

- Then, if $a_T^{(n-2)}(\bar{t})$ contains discontinuities, so does $A_T^{(n-1)}(\bar{t})$

Appendix III

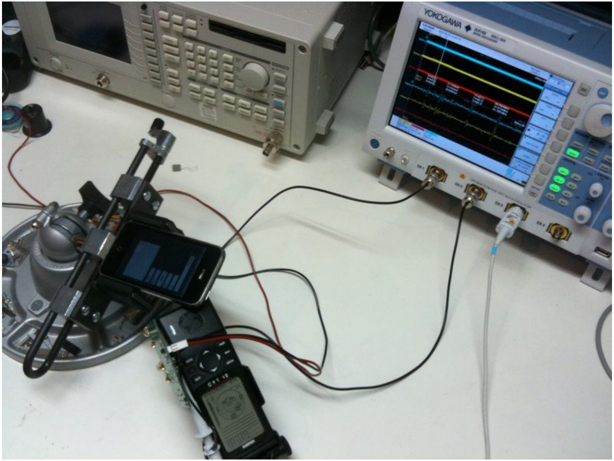
Impulsive noise and SPART filters: Linear vs nonlinear





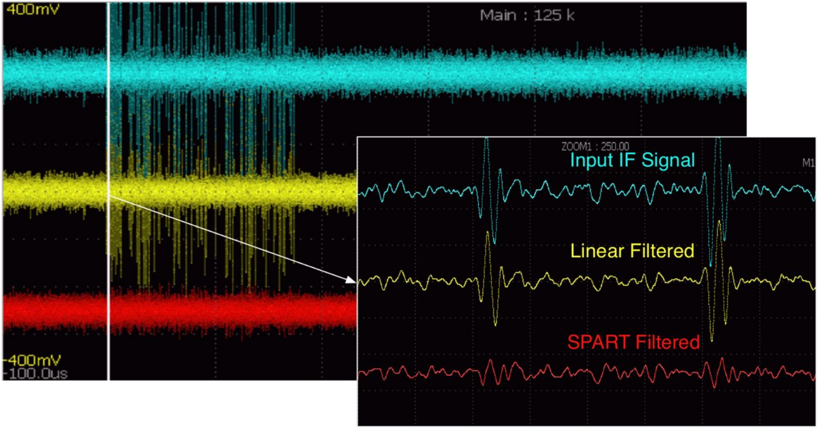
Appendix IV

EMI from WiFi/Bluetooth in GPS: Bench setup



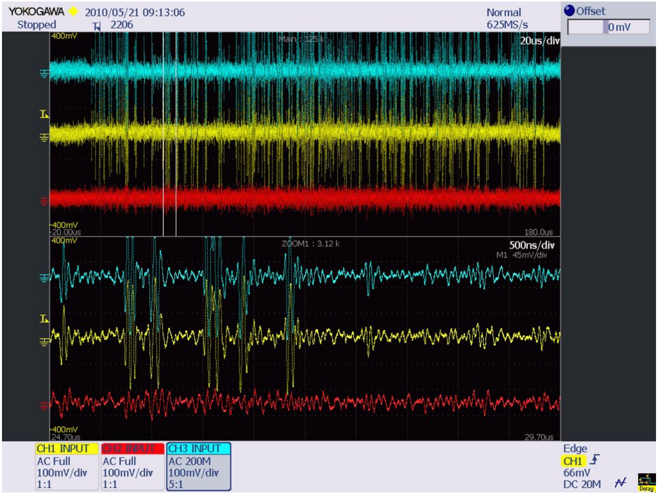
Appendix V

EMI from WiFi/Bluetooth in GPS: Scope traces



Appendix VI

Peakedness (impulsiveness) of EMI: EMI from WiFi in GPS



Appendix VII

Mitigating impulsive EMI in GPS: Test at GPS company