EE648 (CC761-M) DSP II

Session 9 (hive: 2/9/99)

<u>Outline</u>

- Final word on adaptive equalization for digi. comm.
- Intro. to Space-Time Signal Processing

- ZF equalization's performance is greatly enhanced when there are at least two channels

- In digital communications with linear modulation, two channels may be realized by two different means:
- 1. Two spatially separated antennas
- 2. Symbol-rate sampling at both $t=0$ and $t=T_o/2$

- Recall: for single antenna, multipath distorted waveform

$$g(t) = \sum_{\ell=1}^{P} g_\ell \, p_{rc}(t-\tau_\ell)$$

- received signal:

$$x(t) = \sum_{k=-\infty}^{\infty} a[k]\, g(t-kT_o)$$

- symbol-rate sampling at $t=0$:

$$x_o[n] = x(nT_o) = \sum_k a[k]\, g(nT_o-kT_o)$$

- define:

$$\tilde{g}[n] = g\left(n\tfrac{T_o}{2}\right)$$

$$x_o[n] = x(nT_o) = \sum_k a[k]\, g\left[\tfrac{T_o}{2}\{2(n-k)\}\right]$$

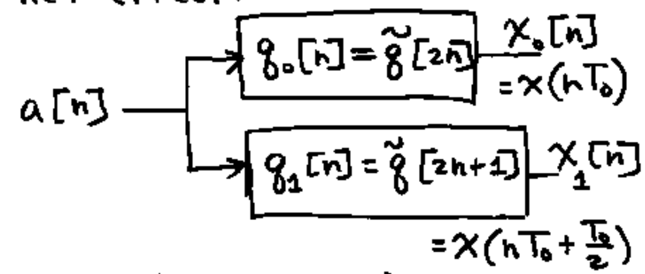
$$= a[n] * g_o[n]$$

- where: $g_o[n] = \tilde{g}[2n]$
- consider symbol-rate sampling starting at $t=T_o/2$

$$
\begin{aligned}
x_1[n] &= x\left(nT_0 + \tfrac{T_0}{2}\right) \\
&= \sum_k a[k]\, g\left(nT_0 + \tfrac{T_0}{2} - kT_0\right) \\
&= \sum_k a[k]\, g\left(\tfrac{T_0}{2}\left(\underbrace{2n+1-2k}_{2(n-k)+1}\right)\right) \\
&= a[n] * g_1[n]
\end{aligned}
$$

$$
\begin{aligned}
g_1[n] &= \tilde{g}[2n+1] \\
&= g\left(nT_0 + \tfrac{T_0}{2}\right)
\end{aligned}
$$

- net effect:



- where: $\tilde{g}[n] = g\left(n\frac{T_0}{2}\right)$
  - $g_0[n] = g(nT_0)$
- if the DTFT of $g_0[n]$ has a null

in the range $|\omega| < \omega_p = (1-\beta)\pi$, then it can be shown that the DTFT of $g_1[n]$ will have a null at the same frequency

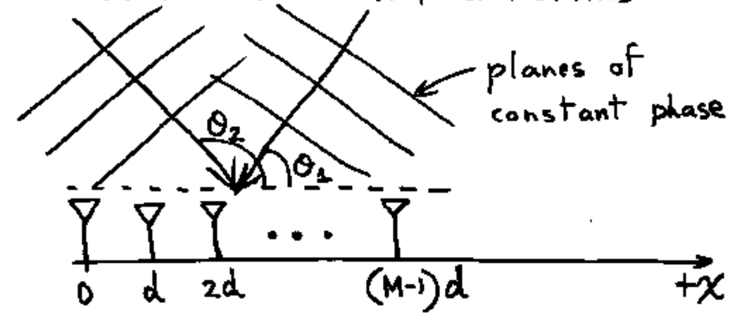
- thus: not as effective as having two spatially-separated antennas but less costly

- Intro. to Space-Time Signal Processing
- applications of adaptive filtering to adapting an array of antennas to receive a "desired" signal while cancelling co-channel interference
- array => "collection"

• Applications and sensor types

Application	Sensor
Wireless Communications	antenna
Radar Surveillance	antenna
Underwater Surveillance	hydrophone
Seismic Exploration	geophone
Sound Reinforcement	microphone

• Consider special case of linear array of equi-spaced omni-directional antennas

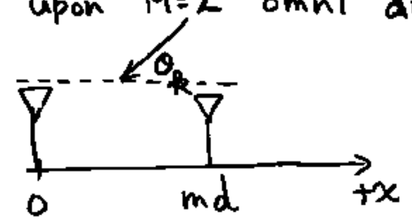


θ_k : angle-of-arrival (AOA) = angle between array axis and normal to k-th planewave

$k = 1, \ldots, P$

P = total no. of planewaves incident upon the array occupying same frequency band "passed" by front-end bandpass filter at each antenna

• First consider a single "narrowband" planewave incident upon $M=2$ omni antennas



$m = 0, 1, \ldots, M-1$

notation:
$x(m;t)$ = signal output from m-th antenna after mixing to baseband

- signal transmitted by k-th source:

$$s_k(t) = s_{I_k}(t)\cos(2\pi f_c t) - s_{Q_k}(t)\sin(2\pi f_c t)$$

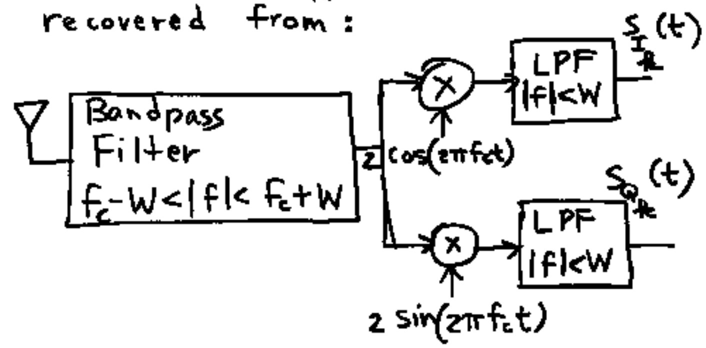
- $s_{I_k}(t)$
- $s_{Q_k}(t)$

$\Big\}$ lowpass information bearing message signals

$S_{I_k}(f) = 0$ for $|f| > W$

$S_{Q_k}(f) = 0$ for $|f| > W$

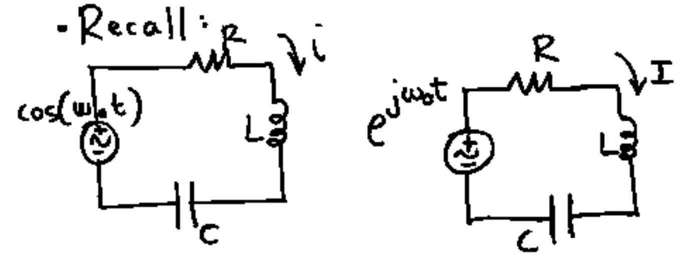
- $s_{I_k}(t)$ and $s_{Q_k}(t)$ can be recovered from:



- LPF: lowpass filter

- Complex envelope representation
- define: $\tilde{s}_k(t) = s_{I_k}(t) + j\, s_{Q_k}(t)$
- recall: $e^{j2\pi f_c t} = \cos(2\pi f_c t) + j\sin(2\pi f_c t)$
- can show: $s_k(t) = \mathrm{Re}\left\{\tilde{s}_k(t)\, e^{j2\pi f_c t}\right\}$

- Recall:



- Linearity dictates:

$$i(t) = \mathrm{Re}\{I(t)\}$$