EE648 (CC761-M) DSP II

Session 9 (hive: 2/9/99)

Outline

- 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 $t=T_0/2$

- Recall: for single antenna, multipath distorted waveform

$$g(t) = \sum_{l=1}^{P} g_l \, p_{rc}(t - \tau_l)$$

- received signal:

$$x(t) = \sum_{k=-\infty}^{\infty} a[k] \, g(t - kT_0)$$

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

$$x_0[n] = x(nT_0) = \sum_{k} a[k] \, g(nT_0 - kT_0)$$

- define:

$$\tilde{q}[n] = q\left(n\frac{T_0}{2}\right)$$

$$x_0[n] = x(nT_0) = \sum_k a[k]\, q\left[\frac{T_0}{2}\left(2(n-k)\right)\right]$$

$$= a[n] * q_0[n]$$

- where: $q_0[n] = \tilde{q}[2n]$

- consider symbol-rate sampling starting at $t = T_0/2$

$$x_1[n] = x\left(nT_0 + \frac{T_0}{2}\right)$$

$$= \sum_k a[k]\, g\left(nT_0 + \frac{T_0}{2} - kT_0\right)$$

$$= \sum_k a[k]\, g\left(\frac{T_0}{2}\left(\underbrace{2n+1-2k}_{2(n-k)+1}\right)\right)$$

$$= a[n] * g_1[n]$$

$$g_1[n] = \tilde{g}[2n+1]$$

$$= g\left(nT_0 + \frac{T_0}{2}\right)$$

• net effect:

$$\begin{tikzcd} & \boxed{g_0[n]=\tilde{g}[2n]} \arrow[r] & x_0[n] = x(nT_0) \\ a[n] \arrow[ur] \arrow[dr] & & \\ & \boxed{g_1[n]=\tilde{g}[2n+1]} \arrow[r] & x_1[n] = x\left(nT_0+\frac{T_0}{2}\right) \end{tikzcd}$$

• 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

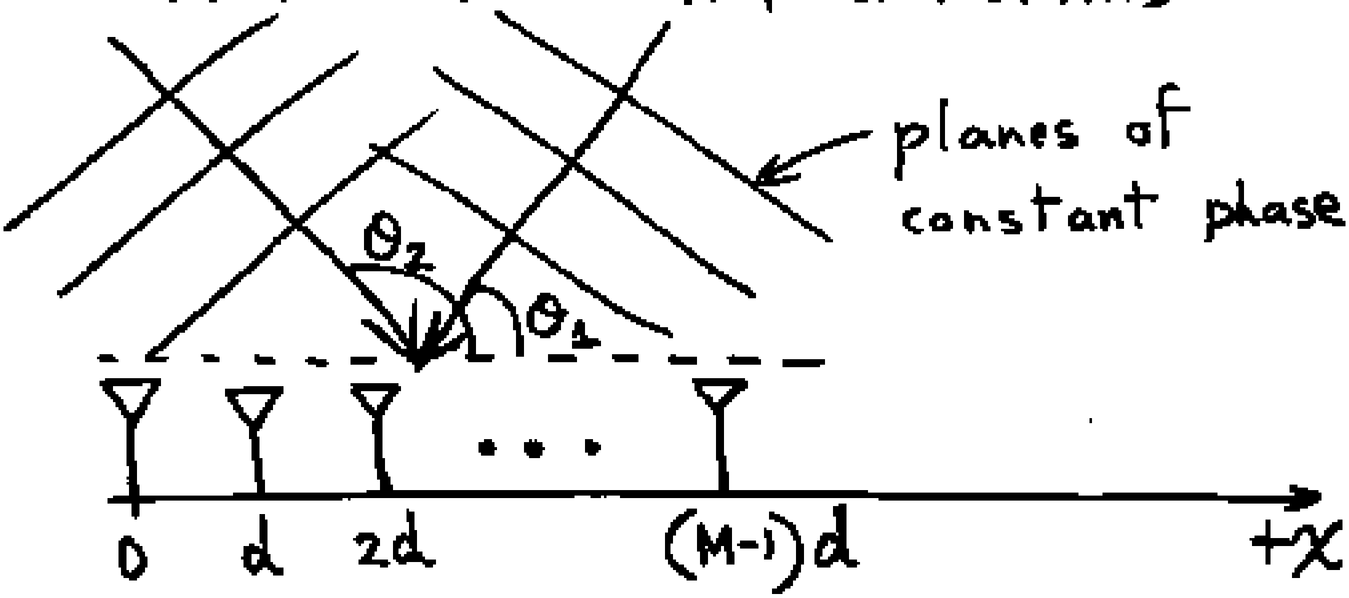
- thus: not as effective as having two spatially-separated antennas but less costly

- 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

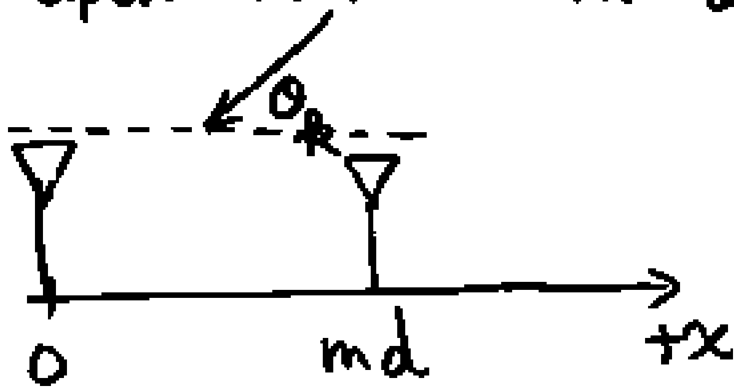


θ_k : angle-of-arrival (AOA) = angle between array axis and normal to k-th planewave

$k = 1, \ldots, P$

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:

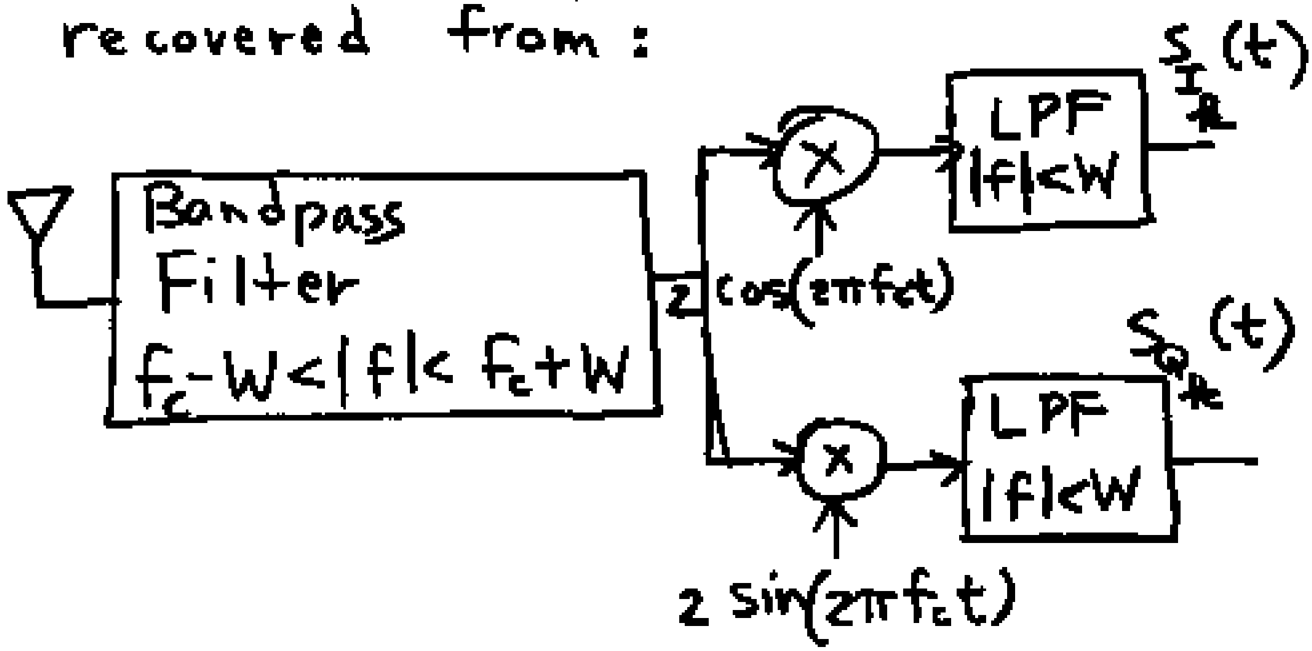
$$s_k(t) = s_{I_k}(t)\cos(2\pi f_c t) - s_{Q_k}(t)\sin(2\pi f_c t)$$

$$\left.\begin{array}{l} \cdot\, s_{I_k}(t) \\ \cdot\, s_{Q_k}(t) \end{array}\right\}$$ lowpass information bearing message signals

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

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

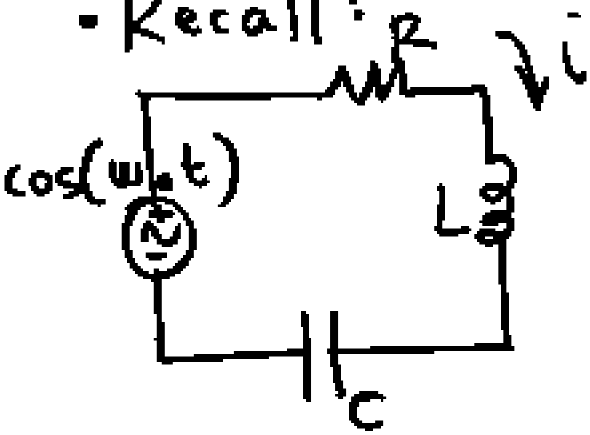
- $s_{I_R}(t)$ and $s_{Q_R}(t)$ can be recovered from:

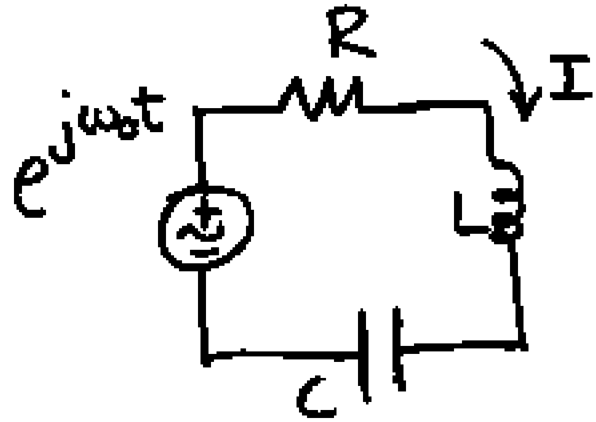


- LPF: lowpass filter

- 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:

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