第三章 自适应滤波引言

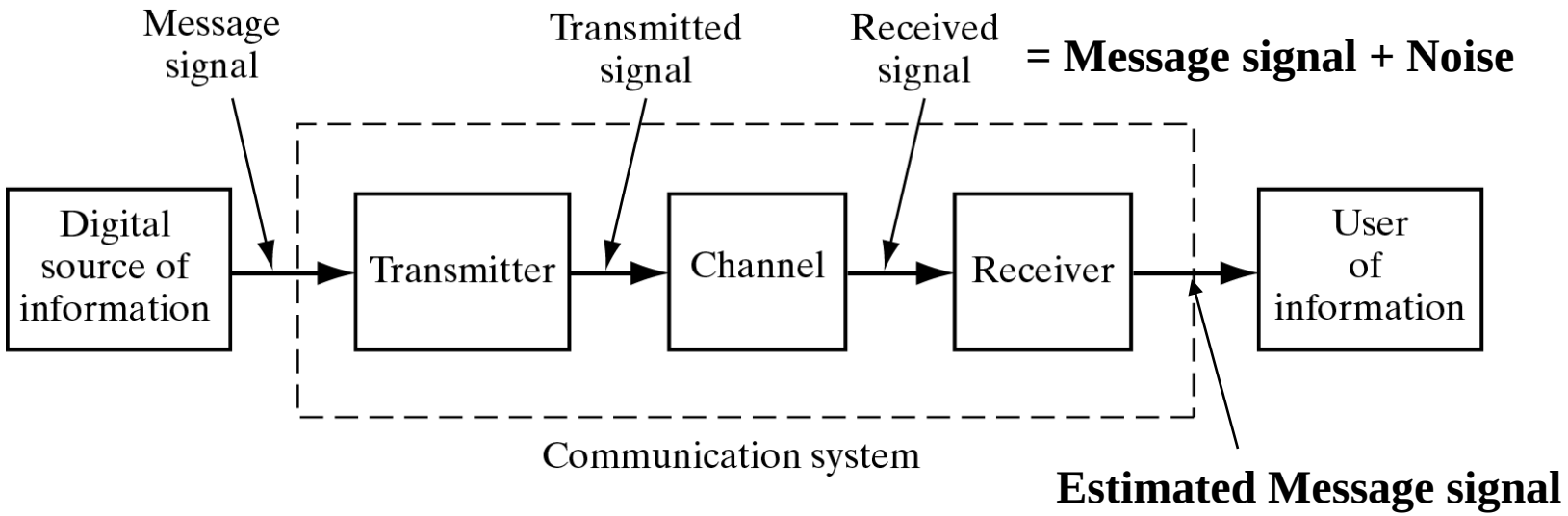
- 线性滤波
- 最优滤波
- 自适应滤波
- 自适应滤波应用举例
- 维纳滤波
- 卡尔曼滤波

3.1　线性滤波 最优滤波 自适应滤波及其应用

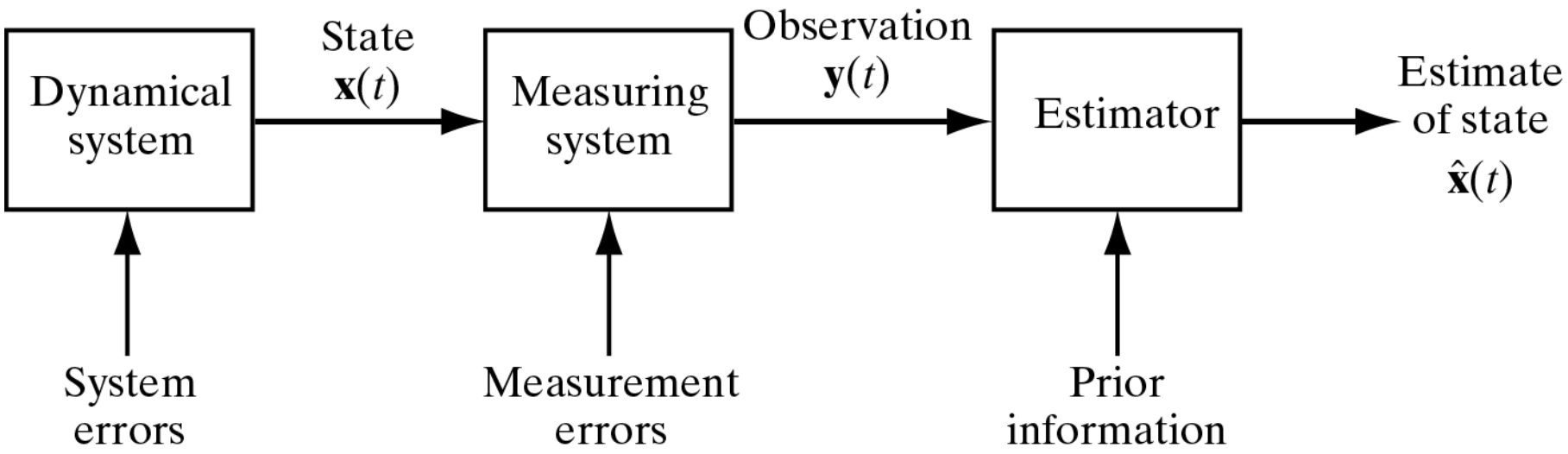
1. 滤波器(Filter)的概念

一个器件或系统(硬件系统或软件系统),它对混有噪音的数据序列过滤(Filtering)或估计(Estimating),达到提取(Extract)有用信息的目的.

------Estimator



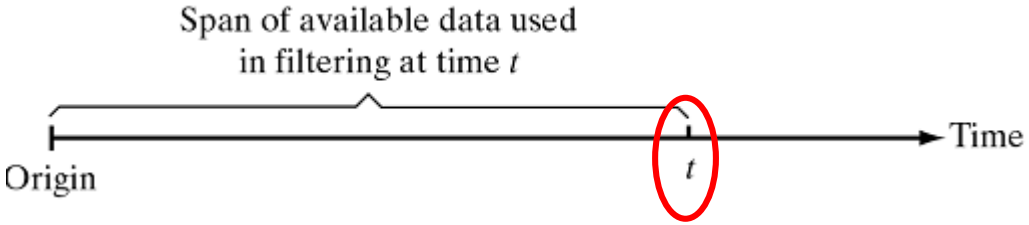
通信示例


Dynamical system
State
$\mathbf{x}(t)$
Measuring system
Observation
$\mathbf{y}(t)$
Estimator
Estimate of state
$\hat{\mathbf{x}}(t)$
System errors
Measurement errors
Prior information

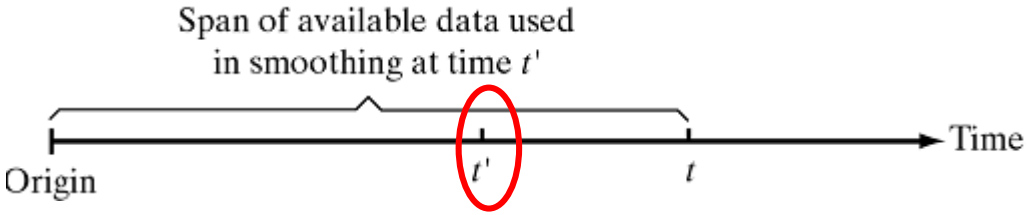
系统状态参数估计示例

滤波器的三种基本的信号处理模式

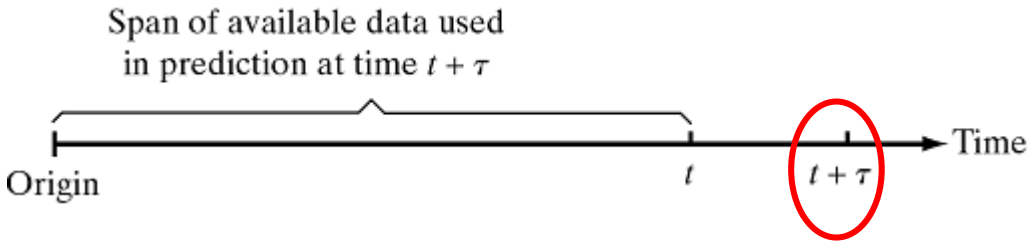
- 滤波 使用<=t 的数据 => t时刻有用信息(因果)



- 平滑 使用<=t'和> t'的数据 => t'时刻有用信息(非因果)



- 预测 使用< =t 的数据 => $t+\tau(\tau>0)$ 时刻有用信息(因果)



2. **线性滤波(Linear Filtering)**

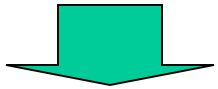
指滤波器的输出（被滤波, 平滑, 预测的输出量）是其输入数据的线性加权.

注意:与线性系统定义的区别

3. **最优线性滤波(Optimum Linear Filtering)**

指在已知输入信号的某些统计特性的条件下, 线性滤波的结果是有用信息(被估计量, 需提取的量)按某一准则的最优估计.

准则:最小均方误差(Minimum Mean Square Error,MMSE)



维纳滤波(Weiner Filtering), 卡尔曼滤波(Kalman Filtering)

信号平稳, 已知统计特性（先验知识）

信号非平稳, 已知状态和观察方程（先验知识）

4. 自适应滤波(自适应线性滤波 Adaptive Linear Filtering)

维纳滤波和卡尔曼滤波在实际应用中的困难:难以获得有关输入信号的先验知识;或者由于信号的统计特性是随时间变化的,而难以获得有关输入信号的先验知识.

一种解决途径:1)在获取大量输入数据后,估计统计特性;2)根据估计结果,设计最优滤波器,并进而进行最优滤波. ----资源消耗大，非实时，仅适合平稳

另一种实用的途径:**自适应滤波**.构造叠代算法,该叠代算法在每获取新的输入数据同时,按某一准则更新滤波器的参数.(具有某种学习的能力)

(1)自适应滤波定义

当滤波器的系数或参数可随新的数据获取而按某一预定准则而变化时,称之为自适应滤波.

自适应线性滤波

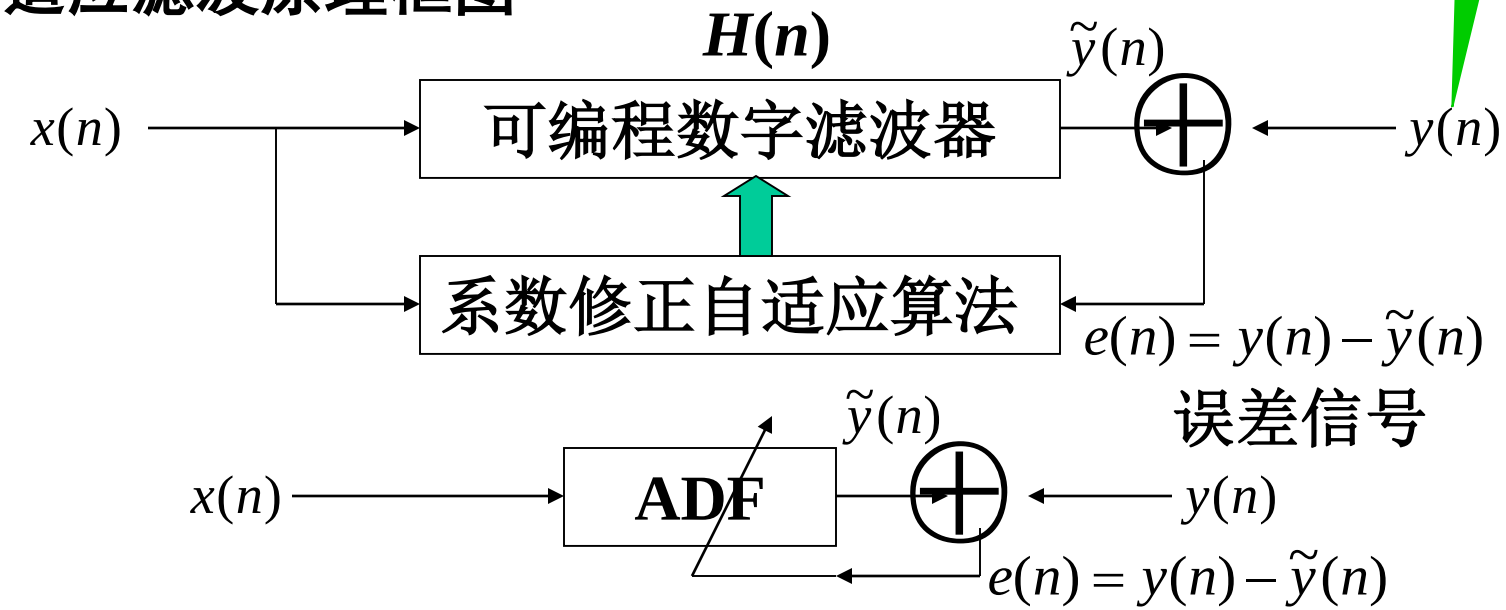
参考信号

真实信号

注意:

自适应线性滤波:在输出是输入的线性加权的意义上, 但滤波器的参数是依赖于输入数据的,所以不满足叠加原理.

(2)自适应滤波原理框图



自适应滤波器 = Filtering Process + Adaptive Process

参考信号在自适应滤波中具有重要地位→ill-posed problem

(3)自适应滤波分类

自适应滤波按所采用的分类方式而有不同的分类:

- 最优准则

如:

1. Least Mean Square(LMS),最小均方误差
2. Least Absolute Value(LAV),最小绝对值误差
3. Least Square(LS),最小二乘方(平方)误差

- 系数修正算法

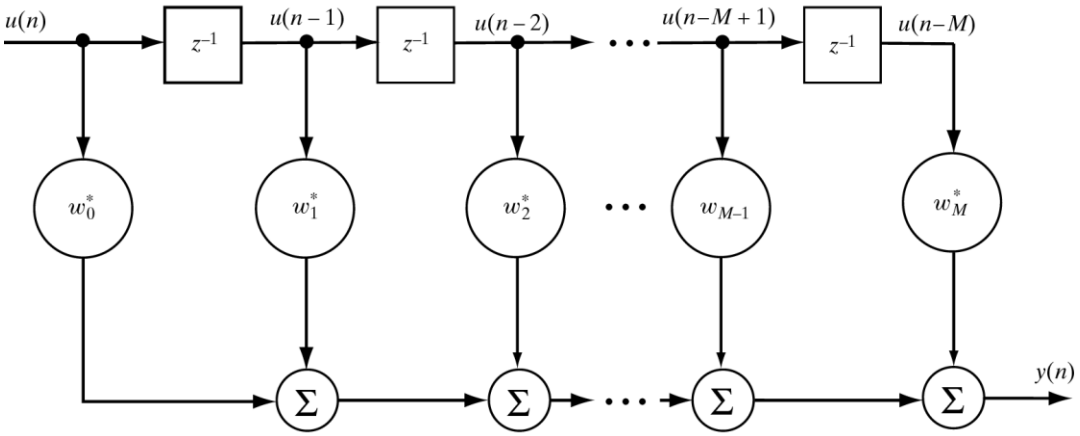
如:

1. 梯度算法
2. 符号算法
3. 递推算法

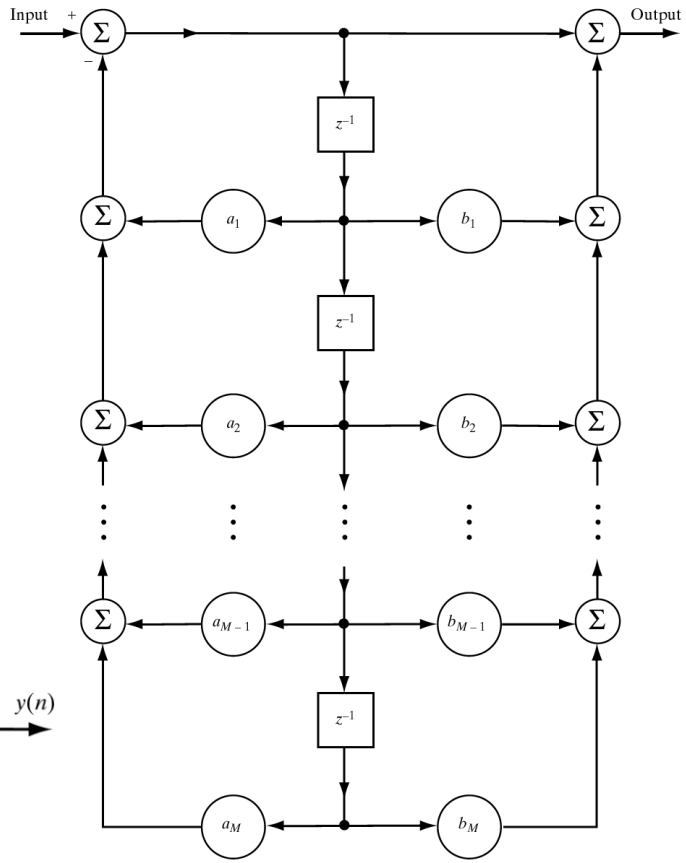
➢可编程滤波器结构

1.IIR:直接型,级联型,并联型

2.FIR:直接型,级联型,Lattice结构



FIR:直接型



IIR:直接型

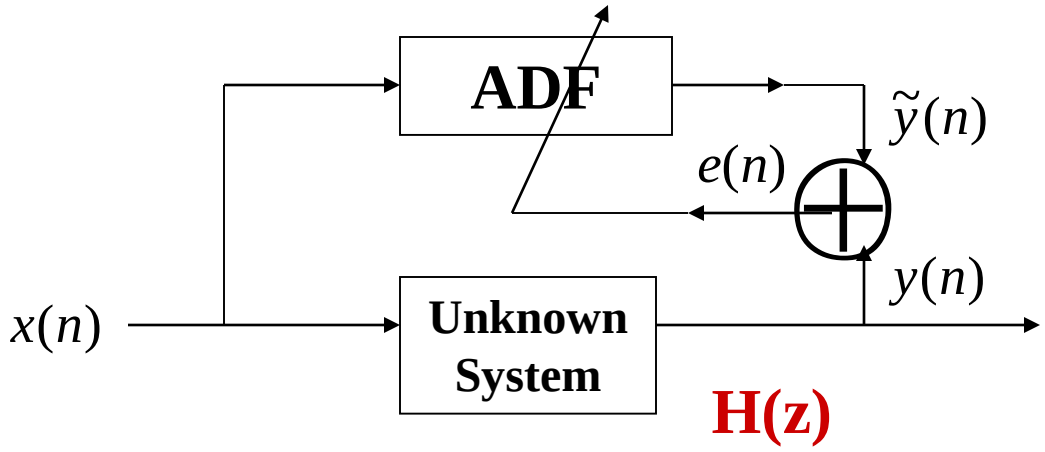
➢ 被处理信号类型

1. 一维或多维
2. 实信号或复信号

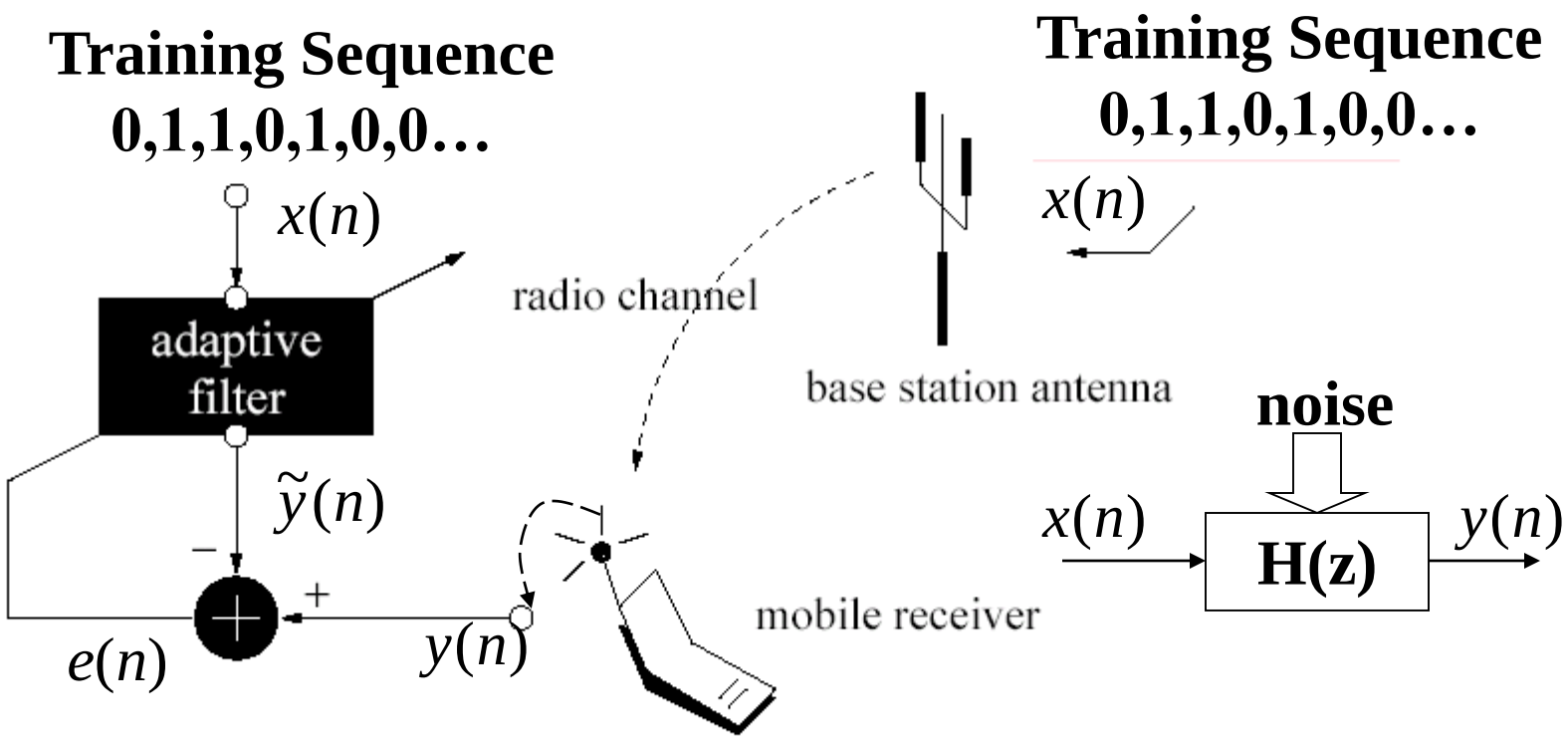
(4)自适应滤波应用分类及应用举例:系统辩识;自适应逆滤波;自适应预测;自适应干扰抵消

重点理解自适应滤波在实际应用中应用原理,特别是在不同应用中参考信号的获取与选取.

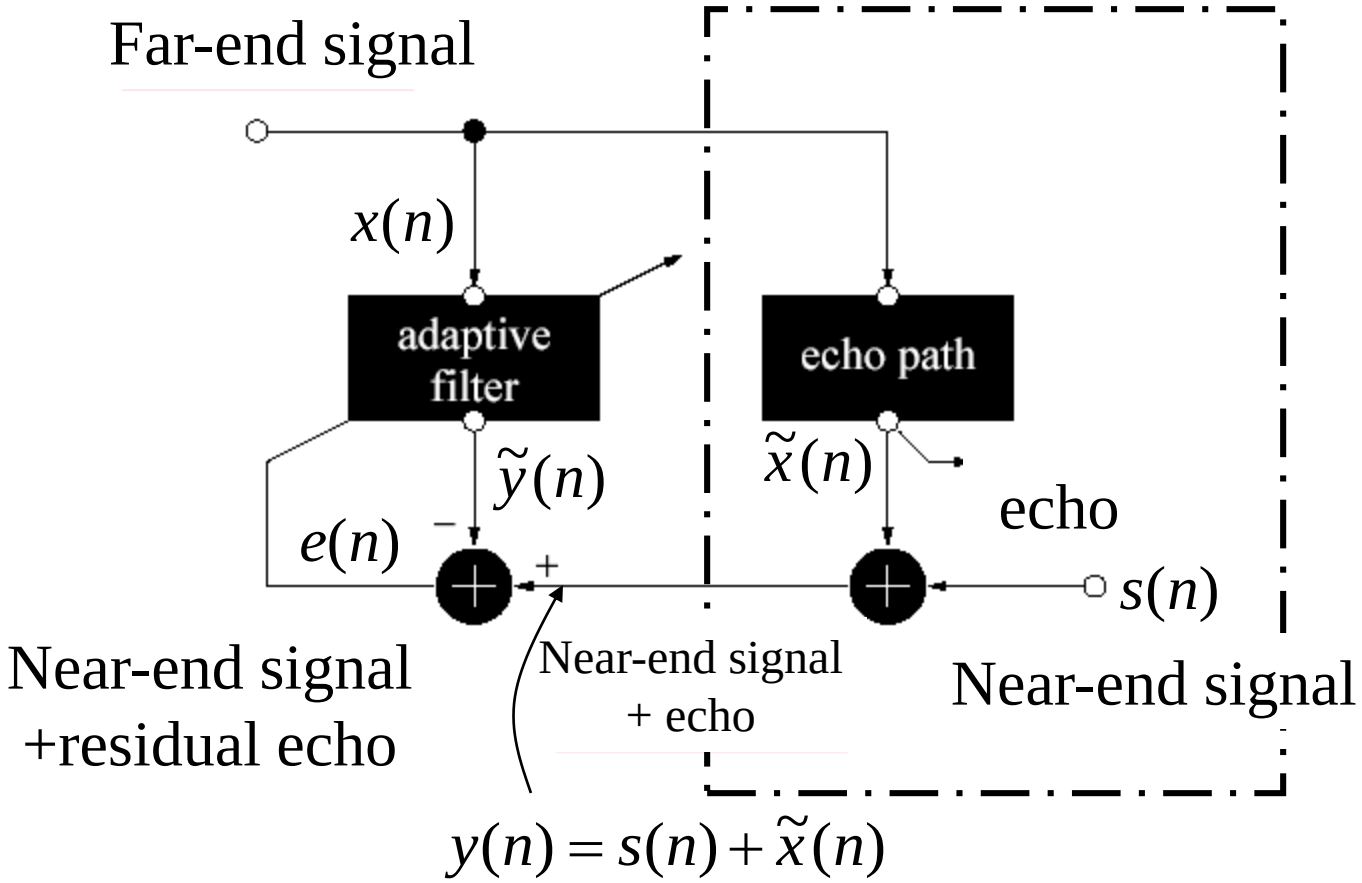
- **系统辩识,System Identification(Unknown dynamic system Identification)**
  - **Layered earth modeling;**
  - **Radio channel Modeling;**
  - **etc.**



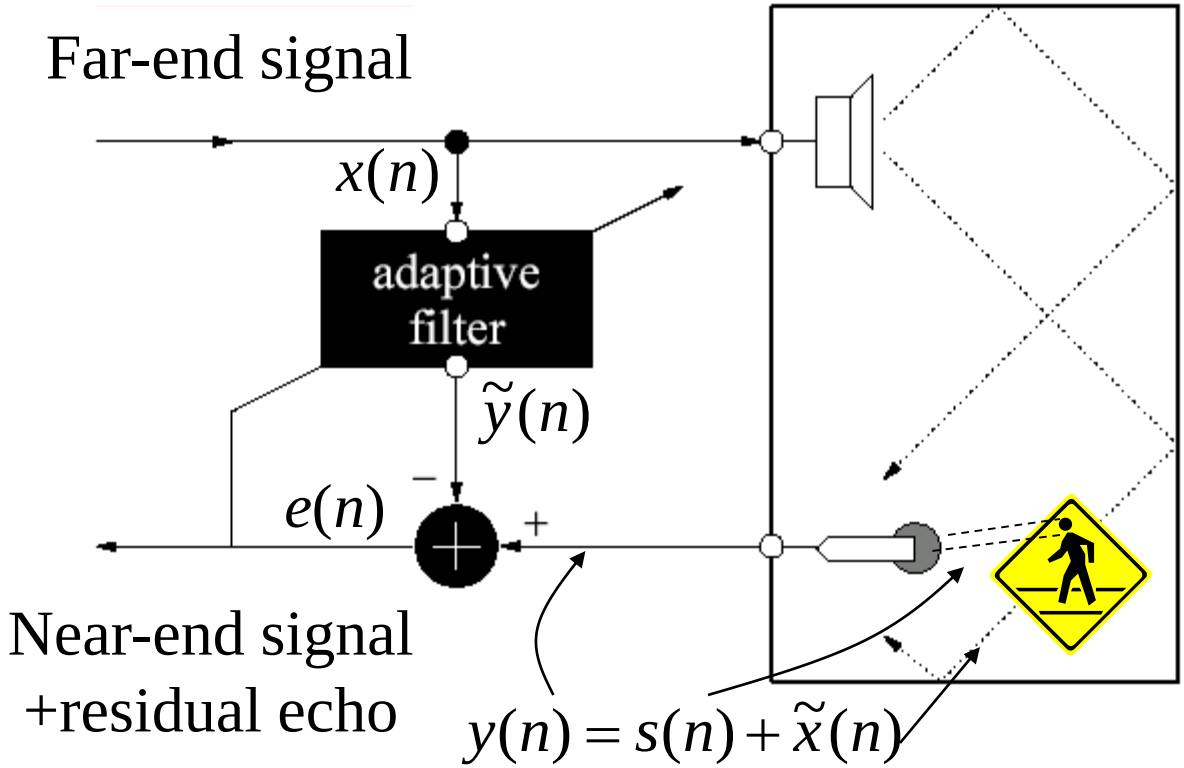
Example 1:Channel identification(信道辩识）



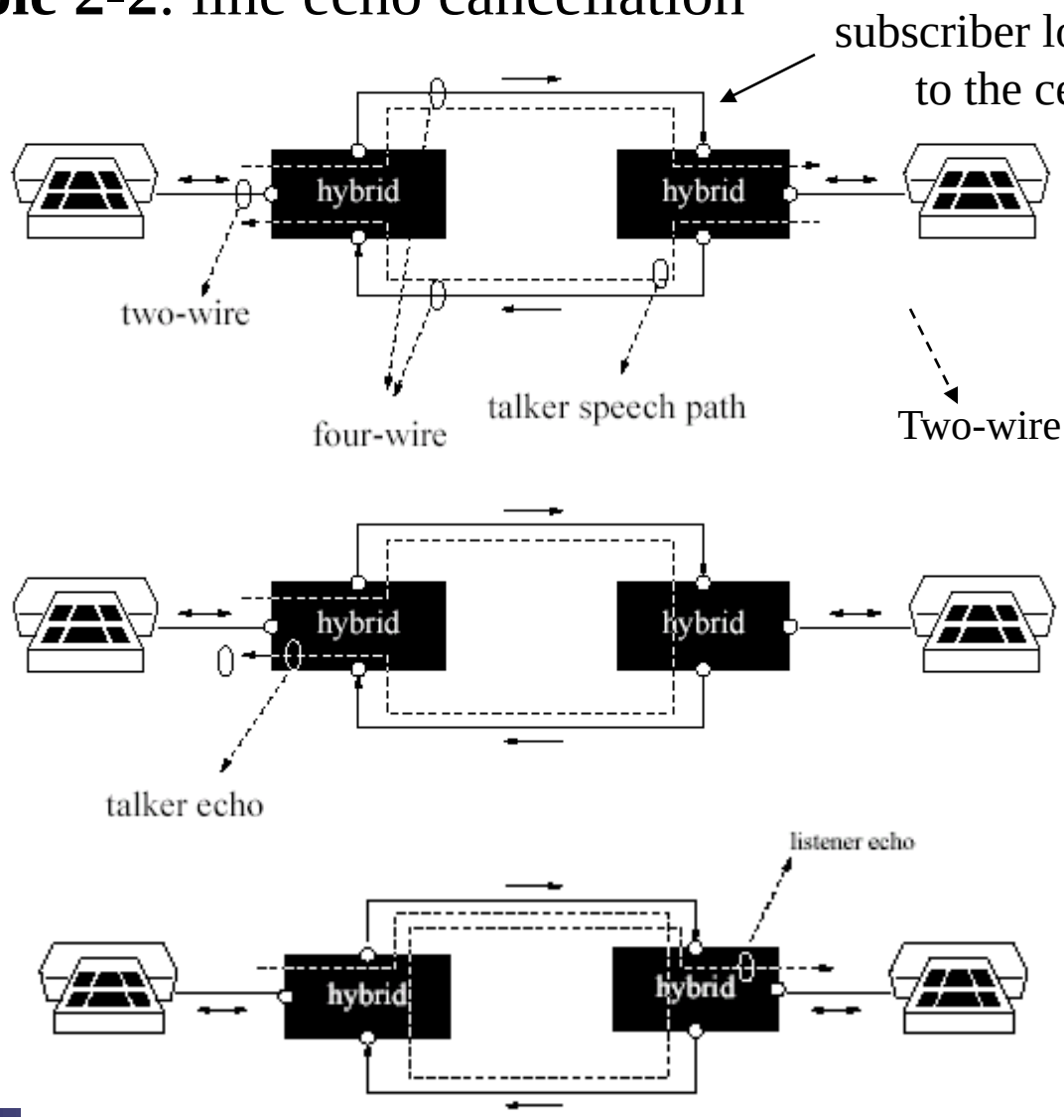
Example 2: echo cancellation



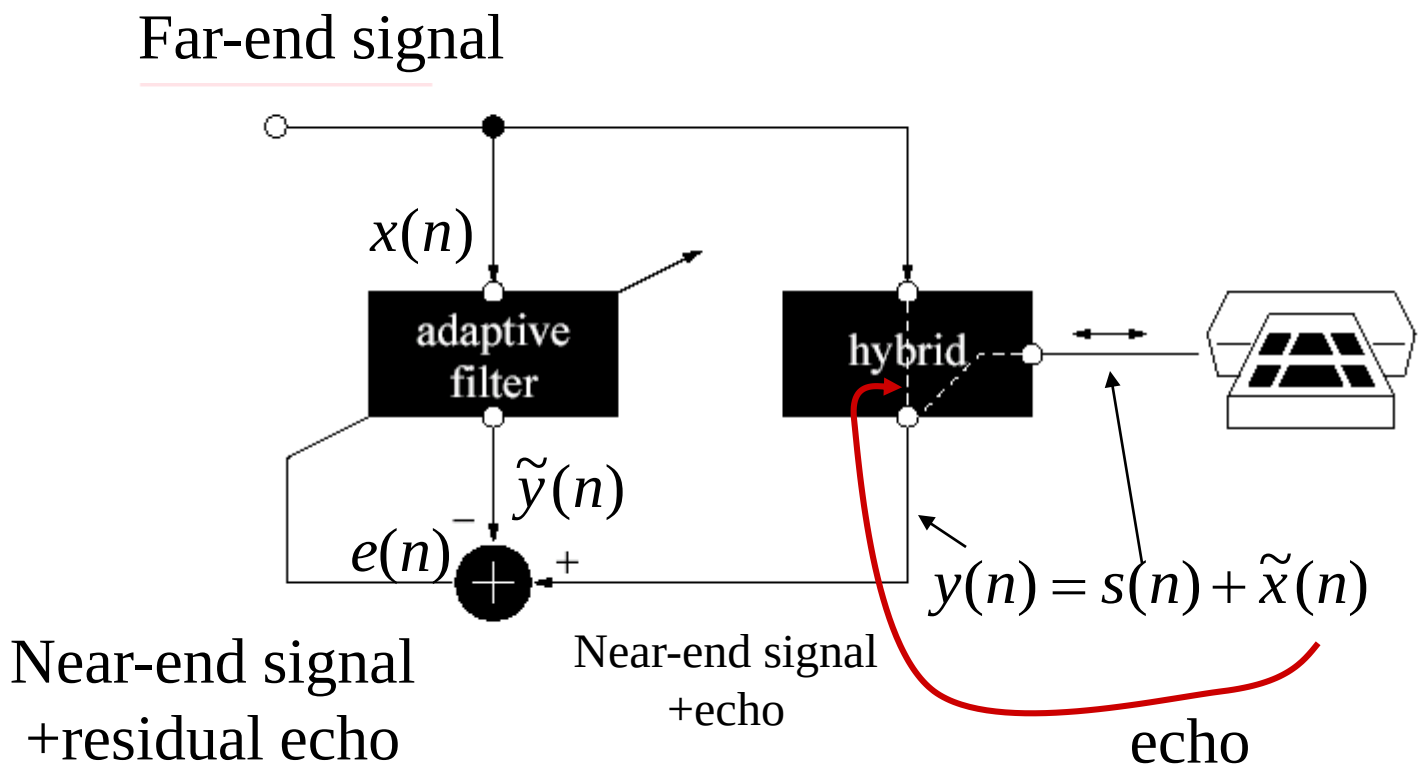
Example 2-1: acoustic echo cancellation



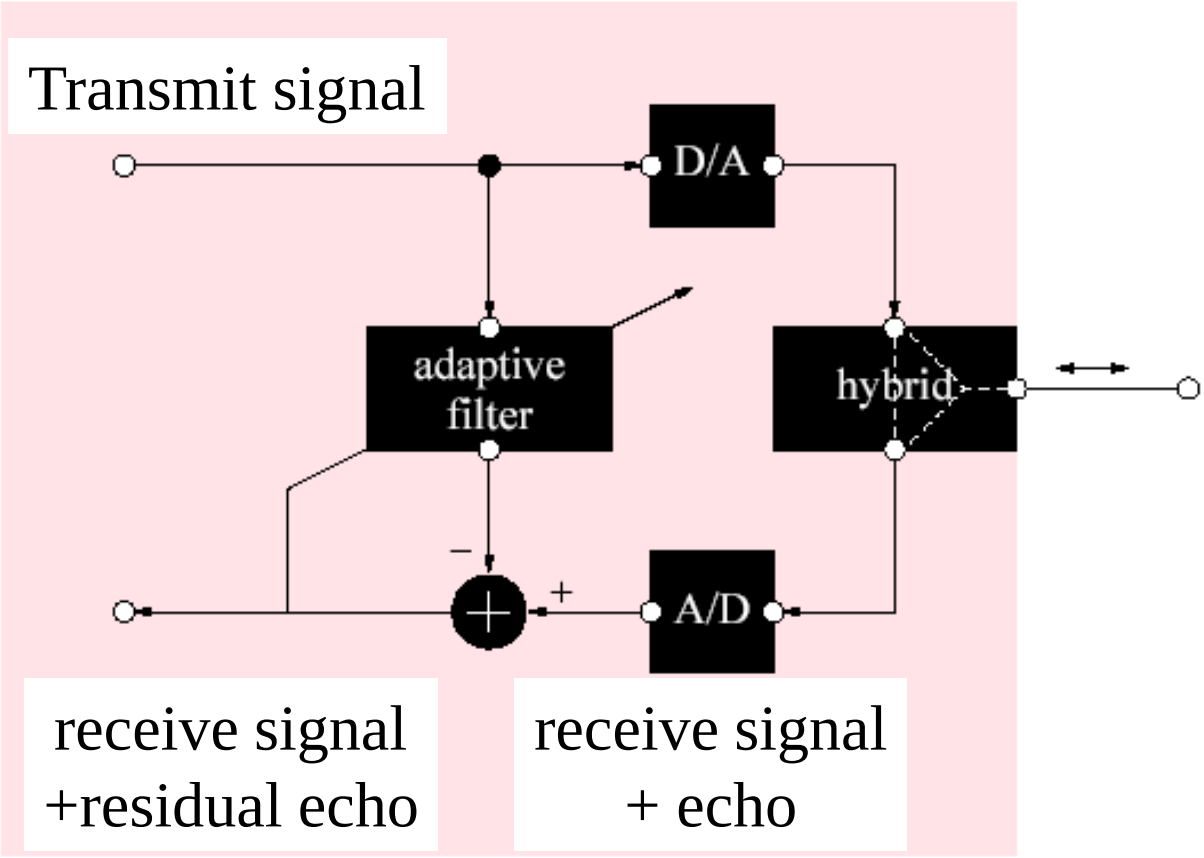
Example 2-2: line echo cancellation



Example 2-2: line echo cancellation(cont.)

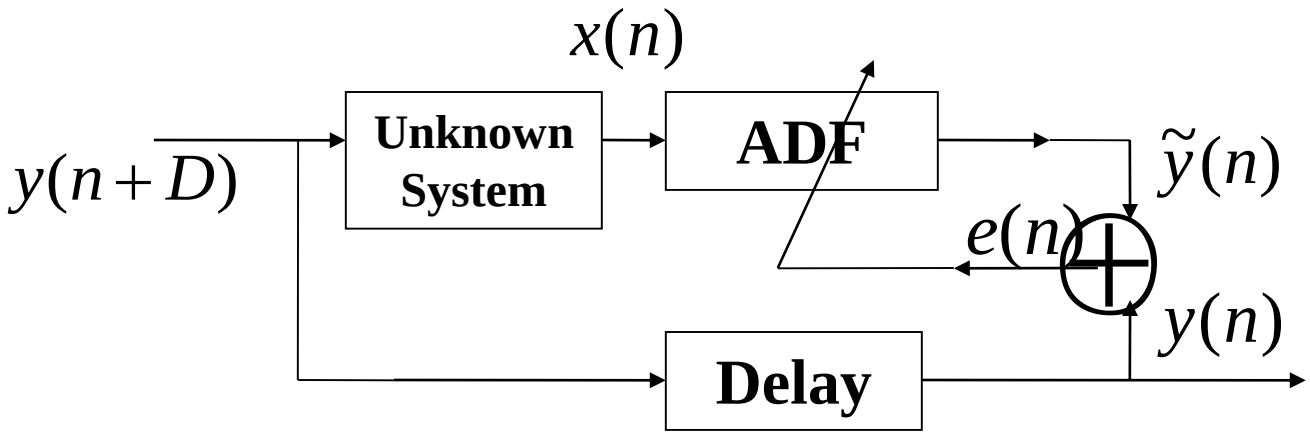


Example 2-3: echo cancellation in full-duplex modems

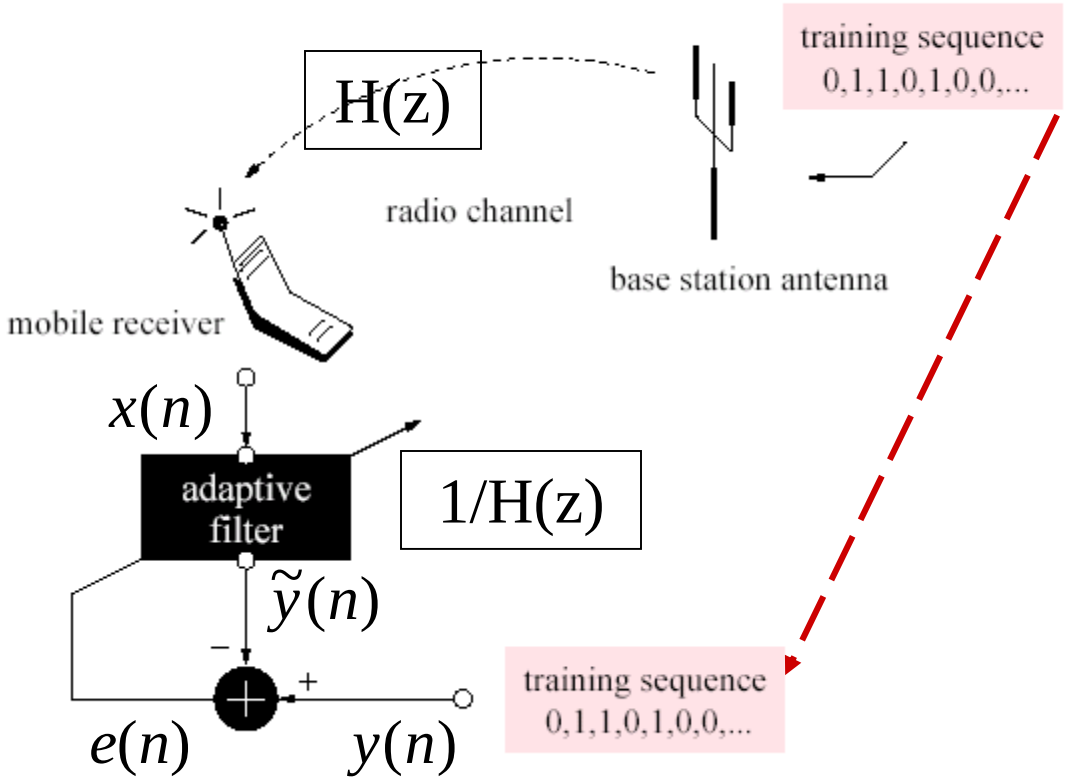


- **自适应逆滤波,Inverse Modeling**

  Channel Equalization(信道均衡）

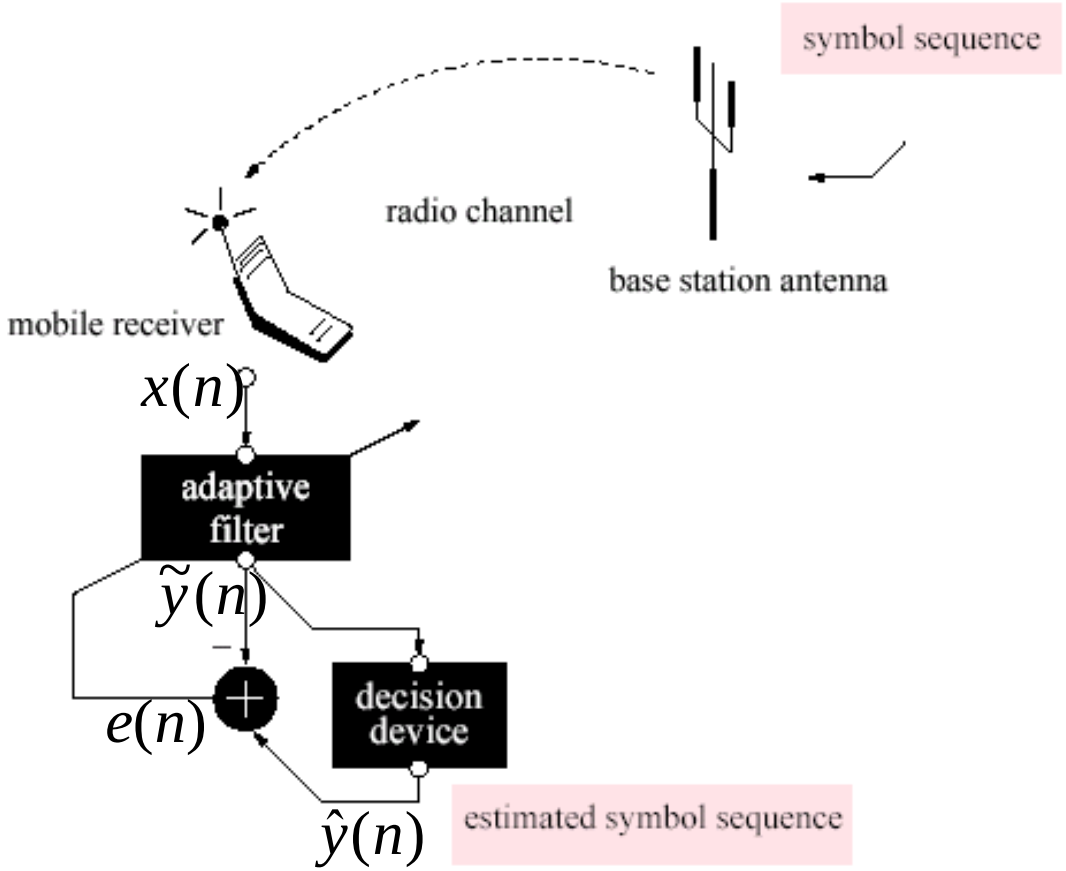


example : channel equalization (training mode)



消除码间串扰(symbol interference)

example : channel equalization (decision-directed mode)

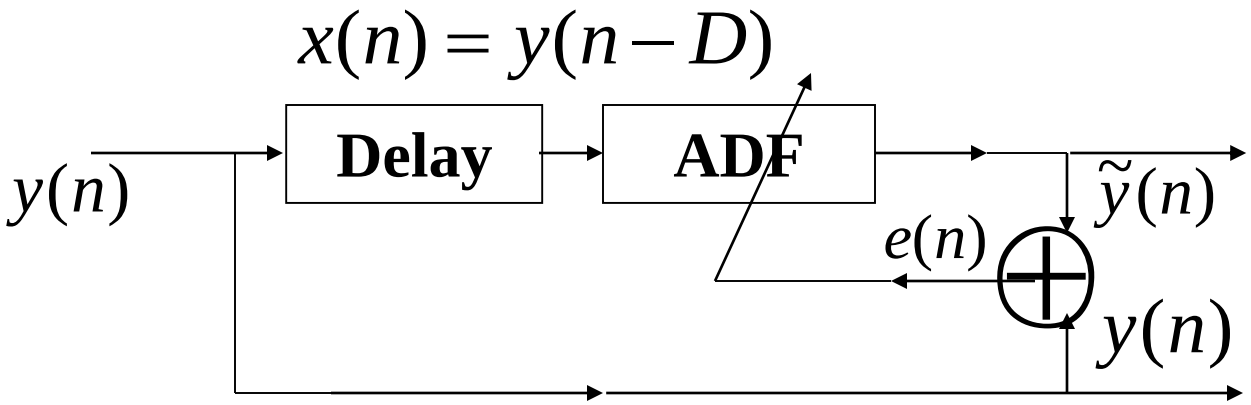


基于判决的方法

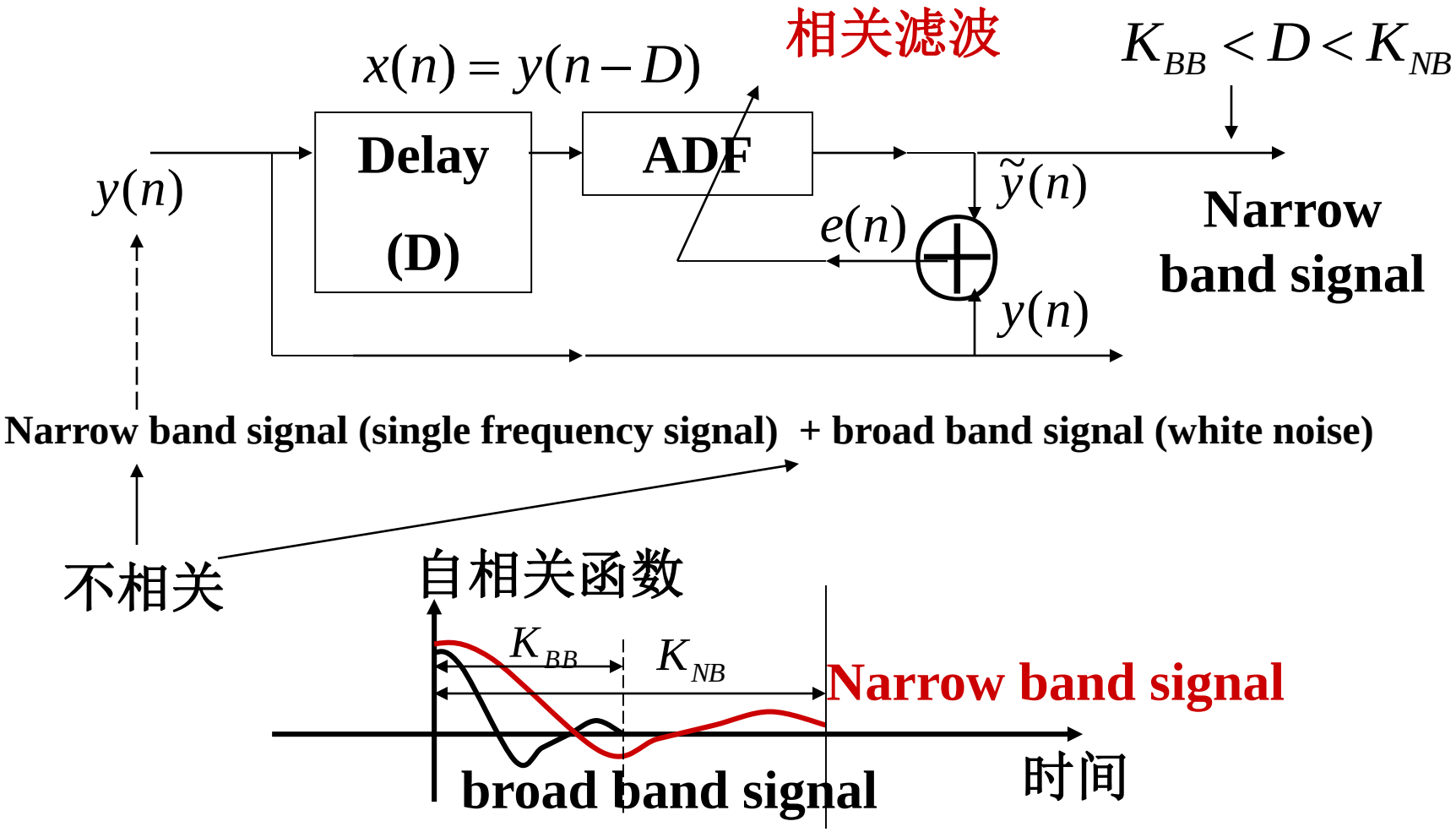
- **自适应预测,Adaptive Prediction**

  Speech Linear predictive coding;（语音线性预测编码）

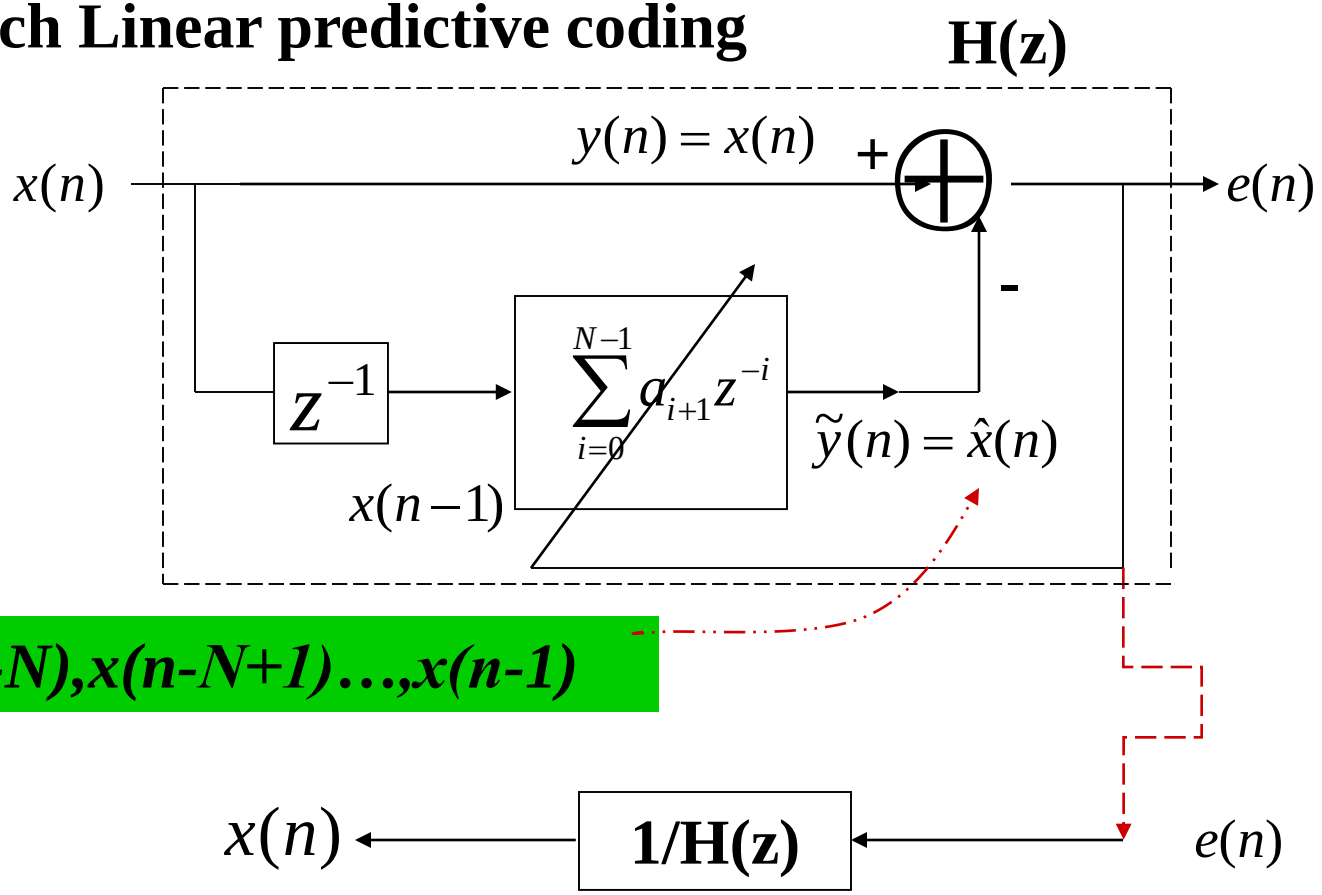
  Adaptive line Enhancer（自适应谱线增强）



自适应谱线增强(Adaptive line Enhancer)



Speech Linear predictive coding



$$H(z)=1-\sum_{i=1}^{N} a_i z^{-i}$$

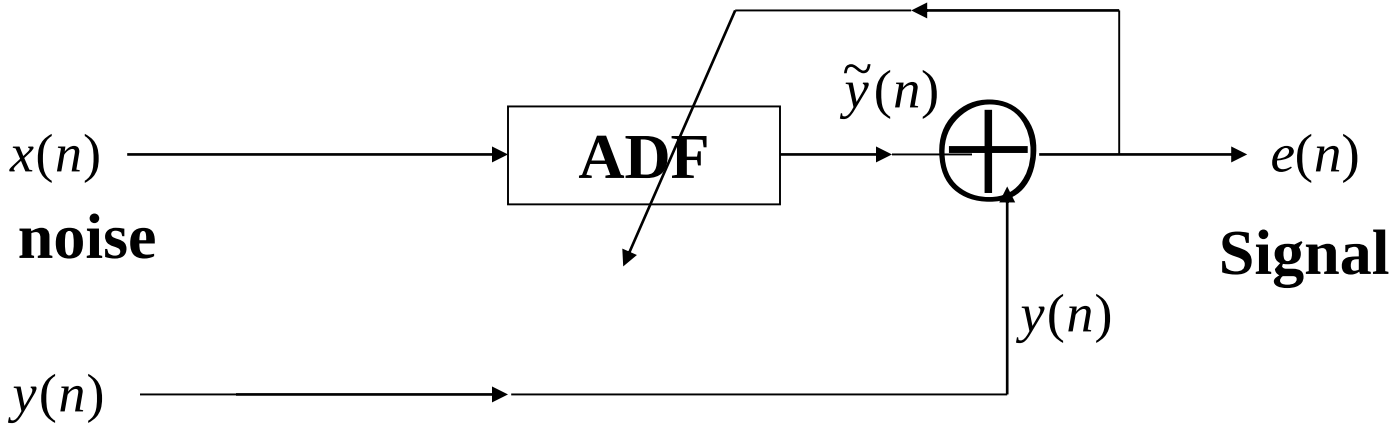
- **干扰抵消,Interference Cancellation(Noise cancellation)**

有源噪声抵消(Noise-robust Microphone)

心电图记录仪中50HZ陷波器

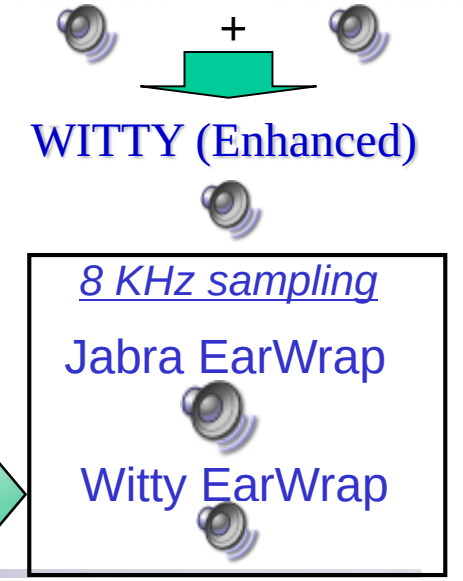
胎儿心电信号的测试

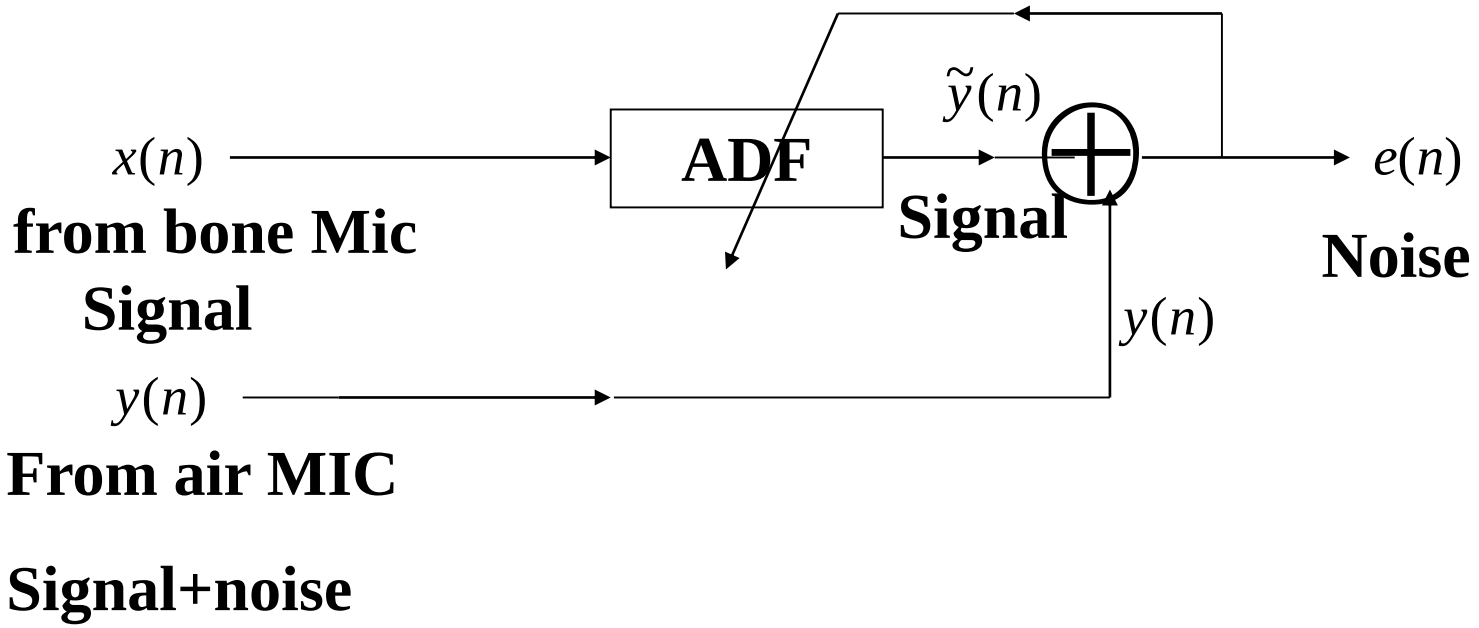
自适应空间滤波(自适应波束形成, Beamforming)



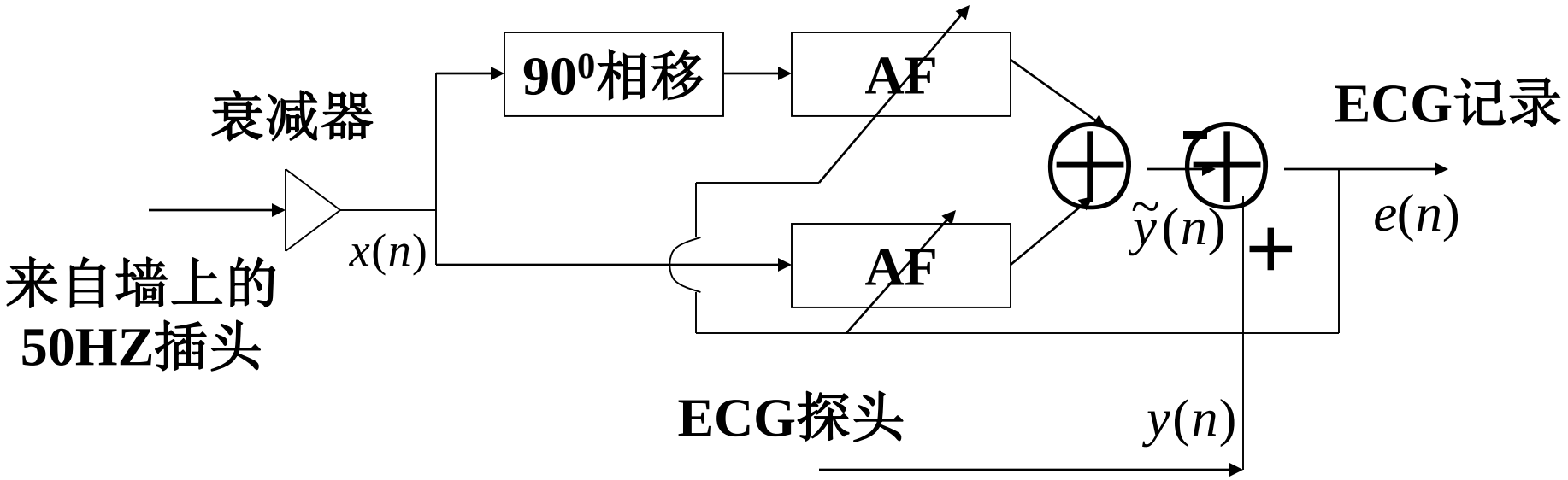
Noise-robust Microphone

- Conventional microphone
  - √ High-quality audio
  - x Sensitive to external noise or speech
- Bone microphone
  - √ Very resistant to external noise or speech
  - x Low-quality audio (less than 3KHz, distorted)
- "Witty" fusion technology is a breakthrough!
  - Cost-effectively eliminate the noise problem
  - Make speech recognition real
  - Enhance human communication quality as well




$x(n)$
from bone Mic
Signal
$y(n)$
From air MIC
Signal+noise
ADF
$\tilde{y}(n)$
Signal
$e(n)$
Noise
$y(n)$

心电图记录仪中50HZ陷波器:



胎儿心电信号的测试:胎儿心电信号受母体心电信号的干扰

自适应波束形成, Beamforming

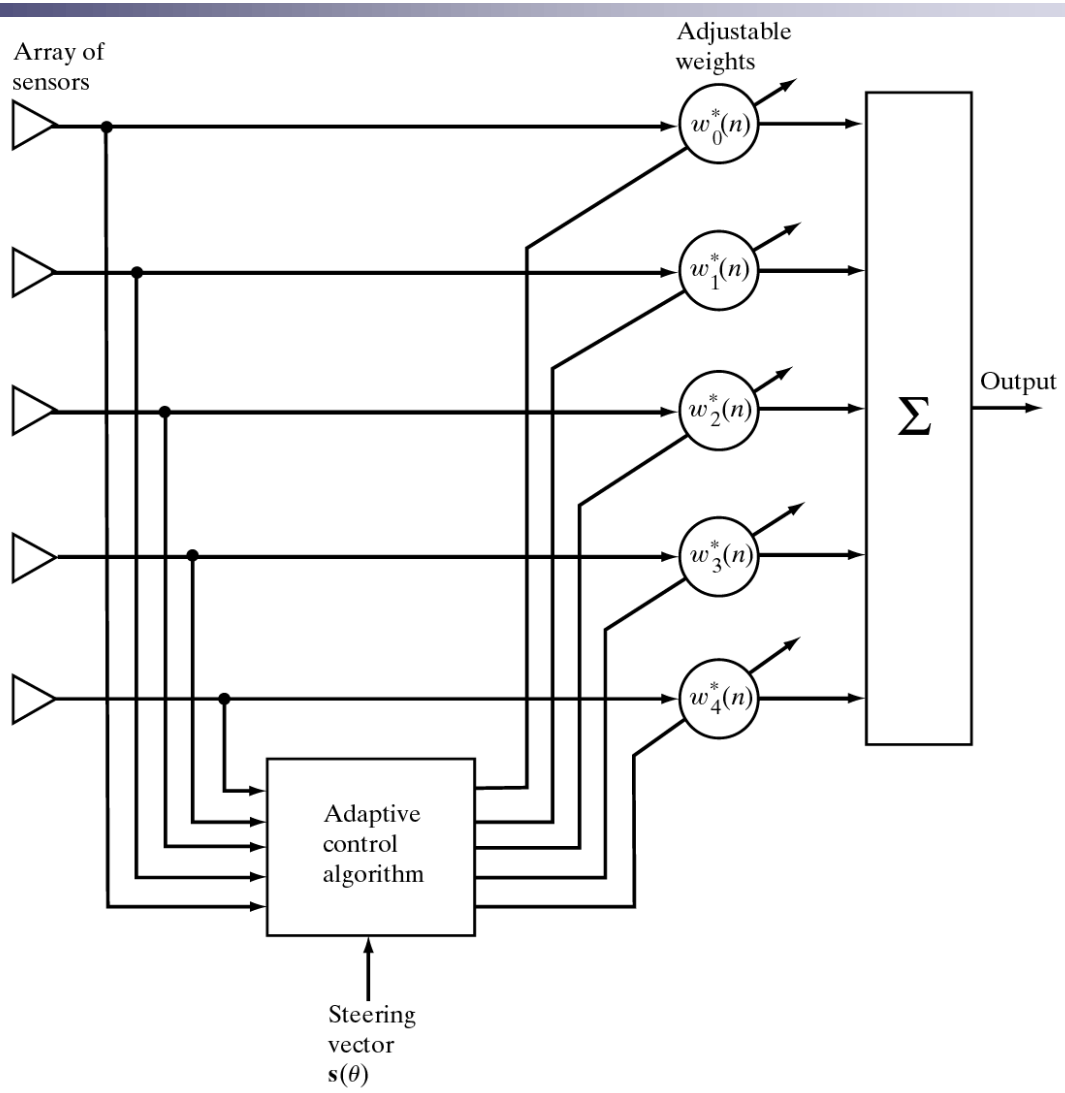


Figure 00.12

Adaptive beamformer for an array of five sensors. The sensor outputs (in baseband form) are complex valued; hence, the weights are complex valued.