ECE4634
Digital Communications
Fall 2007

Instructor: R. Michael Buehrer

Lecture #20: Non-coherent Reception

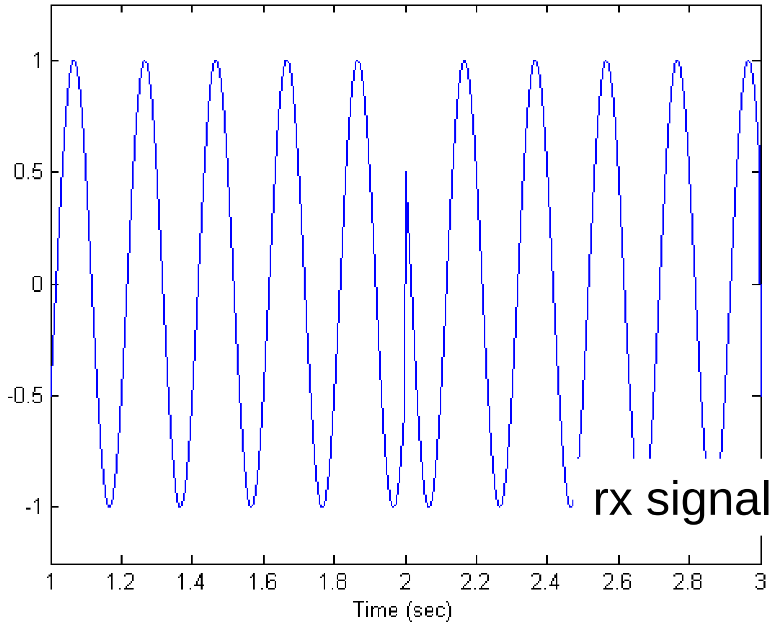
Analog and Digital Communications

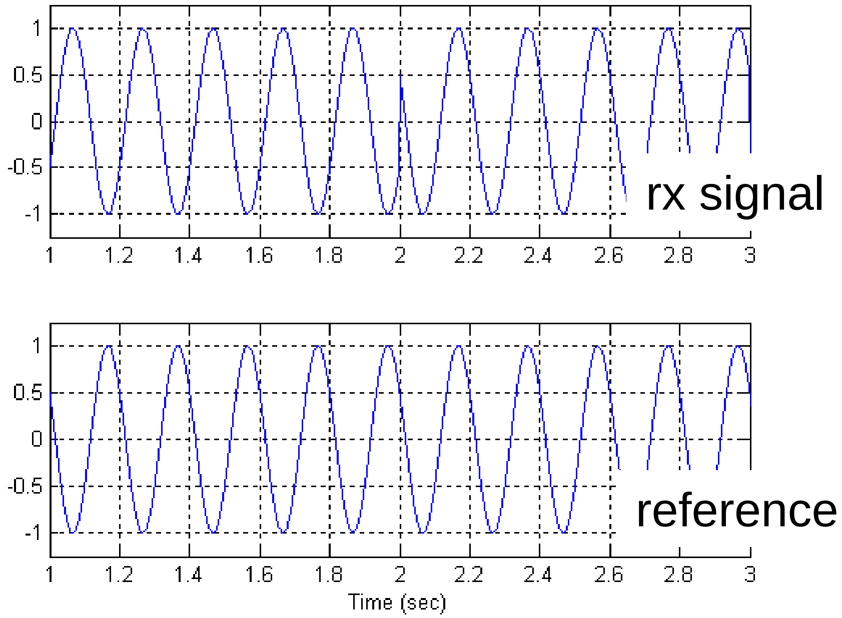
Introduction

- Many of the previous receiver models assume that a *coherent carrier reference* is available
    - We must know the absolute phase of the unmodulated carrier signal.
- Phase knowledge isn’t necessary for ASK or FSK
    - However, better performance is possible if this phase is known as we will see later
- With PSK, knowledge of the reference is crucial unless modulation is *differential*
- Today we will examine non-coherent receivers
- What to read – Section 7.6

Example

- Do we know which BPSK symbol is transmitted just from the received signal?
- How about if we know the reference?





Noncoherent Receivers

- Up to this point, we have usually assumed that receivers are coherent (i.e. they are able to detect and track the phase of the signal).
    - For telephone lines, fixed microwave links, and some fixed satellite links, coherent reception is frequently possible.
- While there are practical circuits (phase-locked loops) which accomplish this (or an unmodulated pilot signal can be sent), in many cases strict phase synchronization is not possible.
    - For many mobile and wireless systems, multipath components and movement of the receiver prevent phase synchronization.

Coherent vs. Non-coherent Receivers

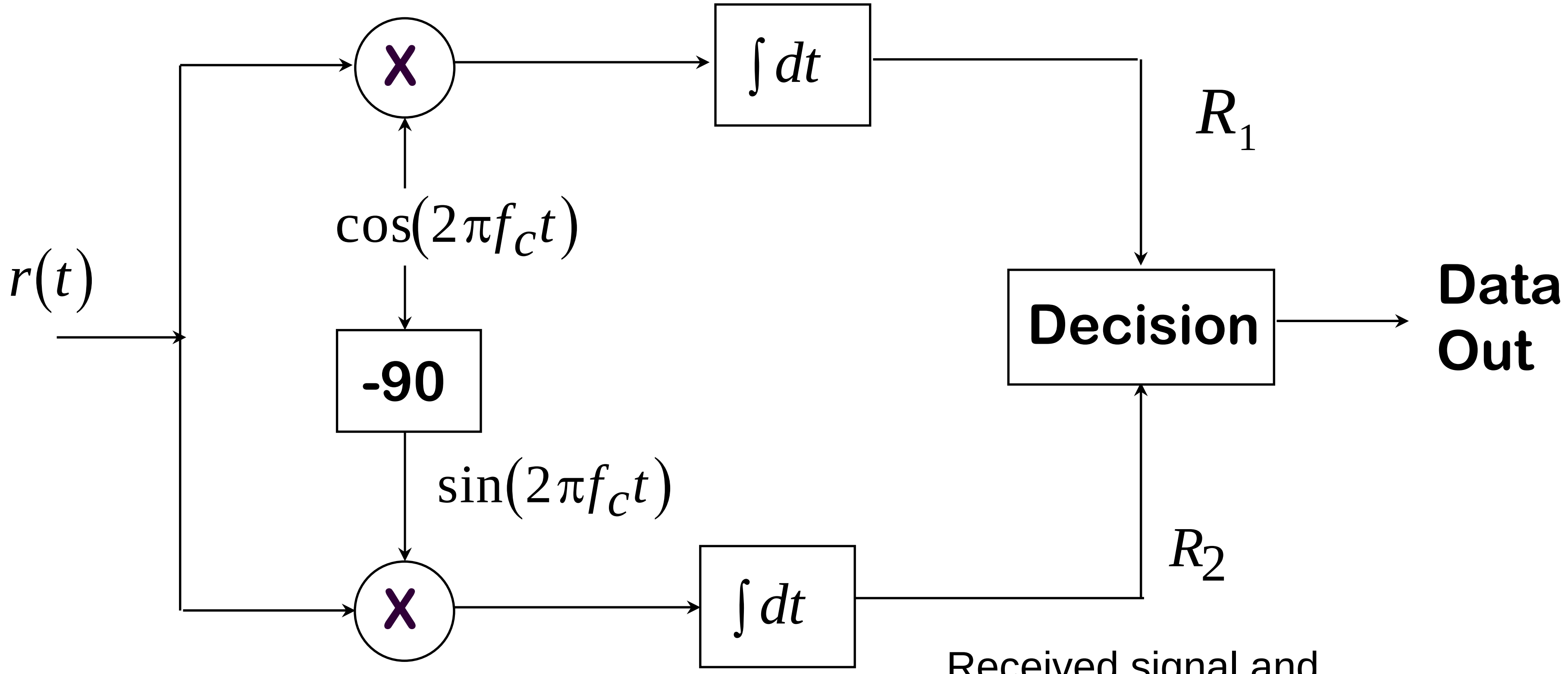
Analog and Digital Communications

- For coherent reception we need to know the absolute phase of the incoming signal to determine the information
- Non-coherent reception we do not need to know the absolute phase

Transmitted Signal $$s(t) = A_C \cos\left[\omega_C t + \frac{2\pi}{M} m(t)\right]$$

Received Signal $$r(t) = A_c \cos\left[\omega_c t + \frac{2\pi}{M} m(t) + \underbrace{\theta_o}_{\substack{phase\\offset}}\right] + \underbrace{n(t)}_{noise}$$

Coherent Receiver – PSK



$$r(t) = \cos\left(2\pi f_c t + m(t)\right) + n(t) \longrightarrow$$

Received signal and local reference differ only by the data *m(t)*. They are thus *coherent* with each other. (θ_o=0)

Impact of phase offset - PSK

θ_o = phase difference between incoming carrier and locally generated sinusoid

$$R_1 = \int_0^{T_b} A_c \cos\left[\omega_c t + \frac{2\pi}{M} m(t) + \theta_o\right] \cos(\omega_c t)\,dt$$

$$= \int_0^{T_b} \frac{A_c}{2}\left(\cos\left[2\omega_c t + \frac{2\pi}{M} m(t) + \theta_o\right] + \cos\left[\frac{2\pi}{M} m(t) + \theta_o\right]\right) dt$$

$$= \frac{A_c T_b}{2} \cos\left[\frac{2\pi}{M} m(t) + \theta_o\right]$$

$$R_2 = \int_0^{T_b} A_c \cos\left[\omega_c t + \frac{2\pi}{M} m(t) + \theta_o\right] \sin(\omega_c t)\,dt$$

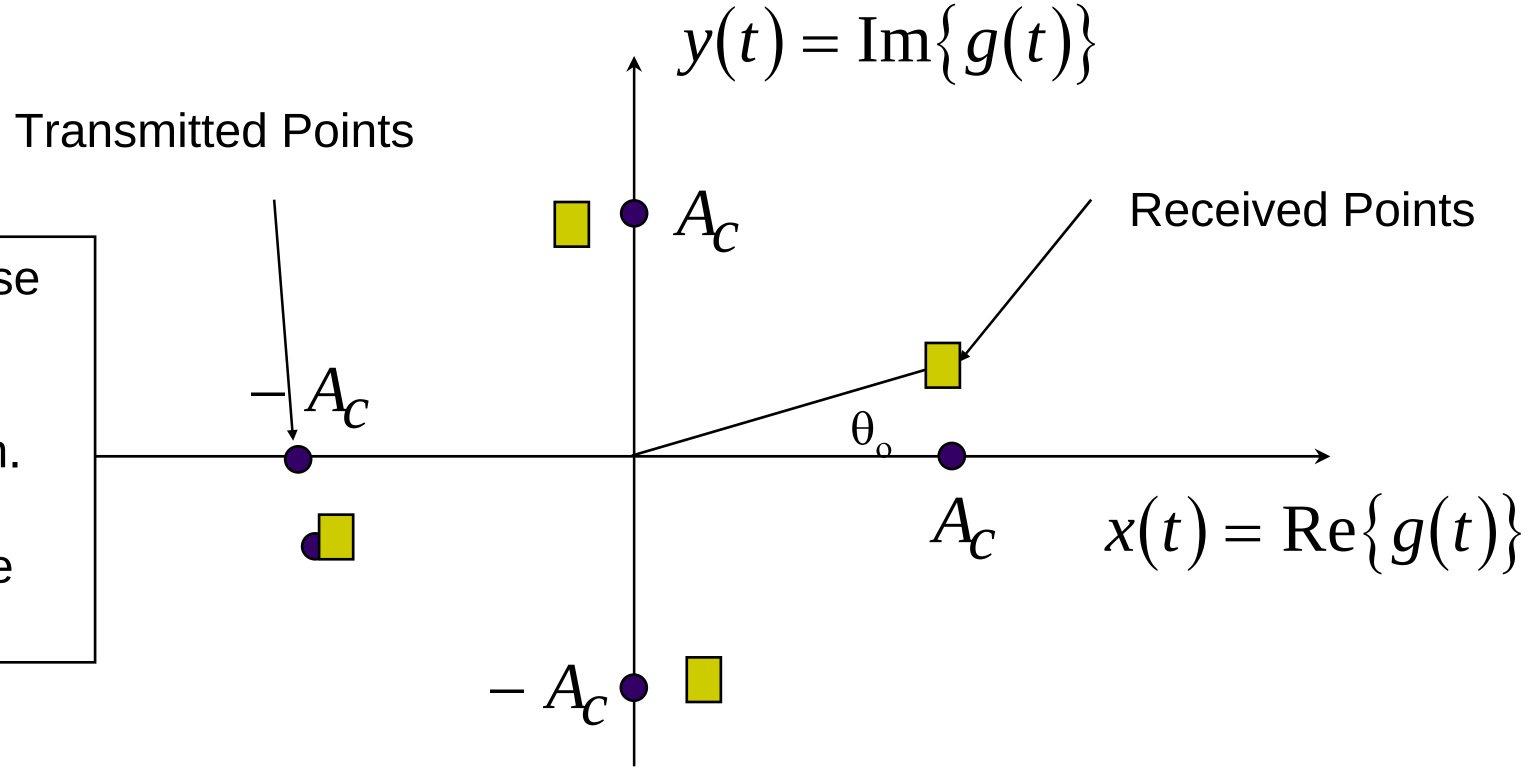
$$= \int_0^{T_b} \frac{A_c}{2}\left(\sin\left[2\omega_c t + \frac{2\pi}{M} m(t) + \theta_o\right] + \sin\left[\frac{2\pi}{M} m(t) + \theta_o\right]\right) dt$$

$$= \frac{A_c T_b}{2} \sin\left[\frac{2\pi}{M} m(t) + \theta_o\right]$$

In order to make proper decisions, θ_o must be zero!

Coherent vs. Non-coherent Receivers

- Example: QPSK



$y(t) = \mathrm{Im}\{g(t)\}$

Transmitted Points

Received Points

A_c

$-A_c$

θ_o

A_c

$x(t) = \mathrm{Re}\{g(t)\}$

$-A_c$

Inexact phase knowledge rotates the constellation. For proper reception we need θ_o=0

Types of Noncoherent Reception

- PSK and QAM signals represent information with the phase of the signal.
- In many cases, even though it is not possible to detect the absolute phase of a signal, it is possible to detect the difference in phase from one symbol to the next.
  - “Differentially” Coherent - compromise between fully coherent and noncoherent
- For FSK with sufficiently spaced tones, demodulation can be accomplished with no phase information using a noncoherent receiver.
- With ASK demodulation can be accomplished using a non-coherent receiver.

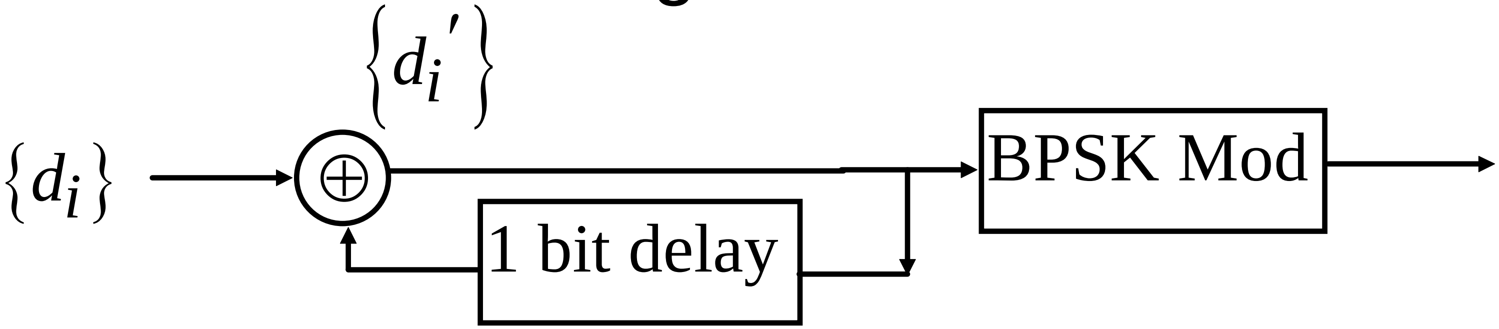
Differential Encoding of Data

- Consider BPSK modulation:

$$0 \Rightarrow s(t) = \sqrt{2P}\cos(2\pi f_c t)\Big|_0^T$$

$$1 \Rightarrow s(t) = \sqrt{2P}\cos(2\pi f_c t + \pi)\Big|_0^T = -\sqrt{2P}\cos(2\pi f_c t)\Big|_0^T$$

- Differential Encoding Transforms Raw Data:



$\{d_i'\}$

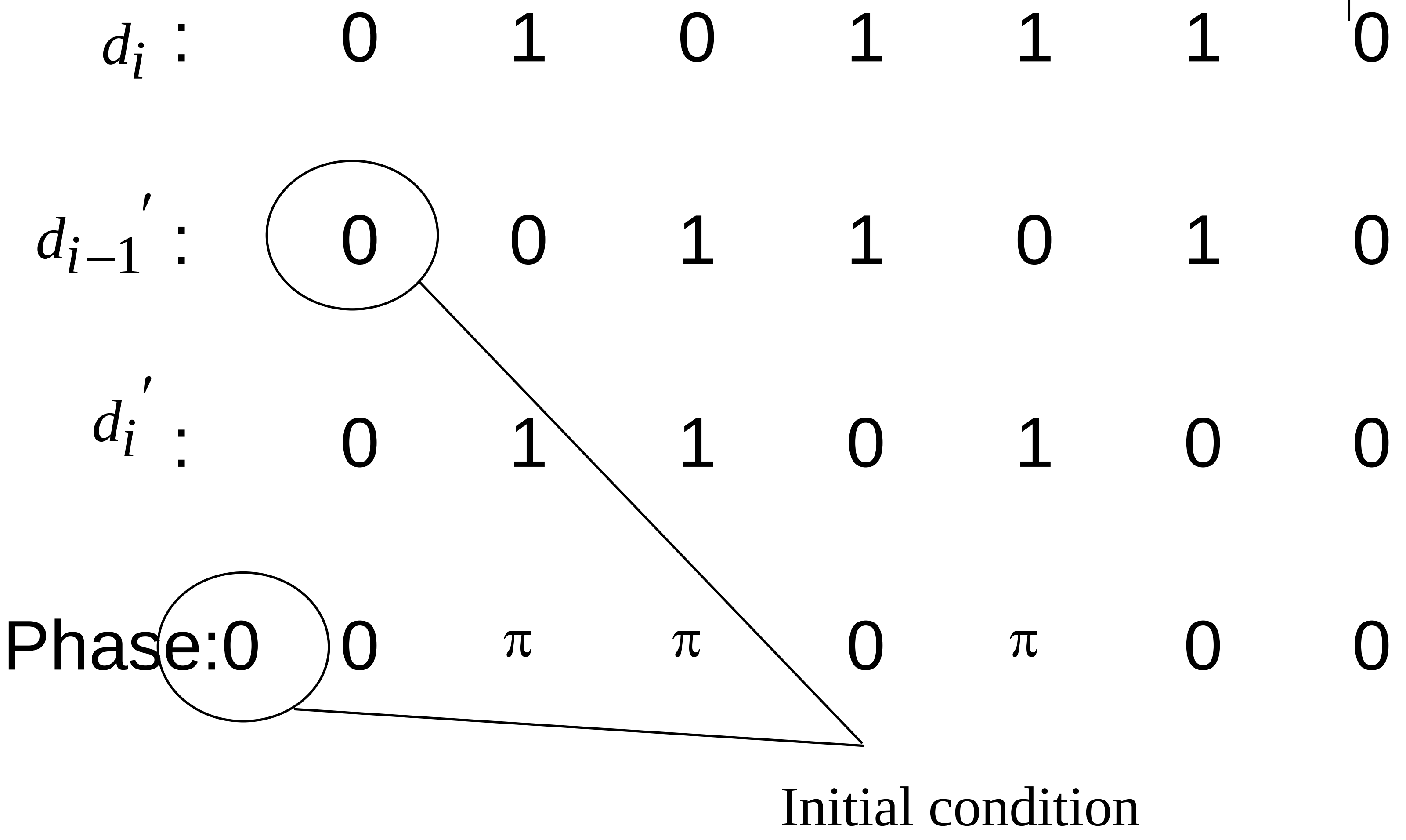
$\{d_i\}$ $\oplus$

BPSK Mod

1 bit delay

- Rule: “Change the phase if input data is a 1”

Example of Differential Encoding



d_i :	0	1	0	1	1	1	0
d_{i-1}' :	0	0	1	1	0	1	0
d_i' :	0	1	1	0	1	0	0
Phase:0	0	π	π	0	π	0	0

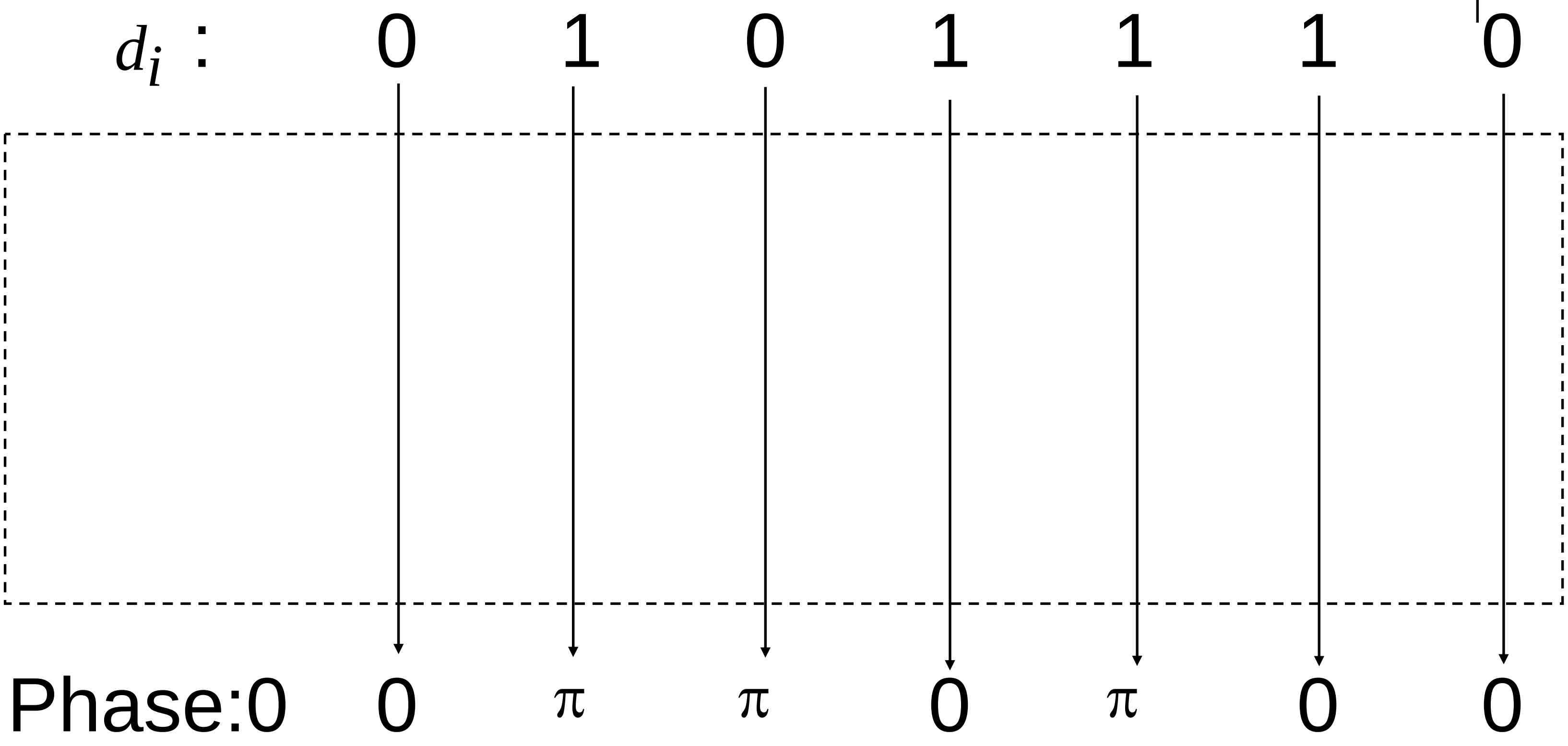
Initial condition

Example of Differential Encoding – View 1

d_i :	0	1	0	1	1	1	0
d_{i-1}' :	0	0	1	1	0	1	0
d_i' :	0	1	1	0	1	0	0
Phase:0	0	π	π	0	π	0	0

Use BPSK modulation on *differentially encoded data*

Example of Differential Encoding – View 2



d_i : 0 1 0 1 1 1 0

Phase:0 0 π π 0 π 0 0

Original data causes *changes in the phase*

Differential Encoding

- Differential Encoding can be used with either coherent detection or non-coherent detection
- Coherent detection still requires differential decoding
- Non-coherent detection requires *differential* detection which also inherently involves differential decoding

Differential Decoding Data

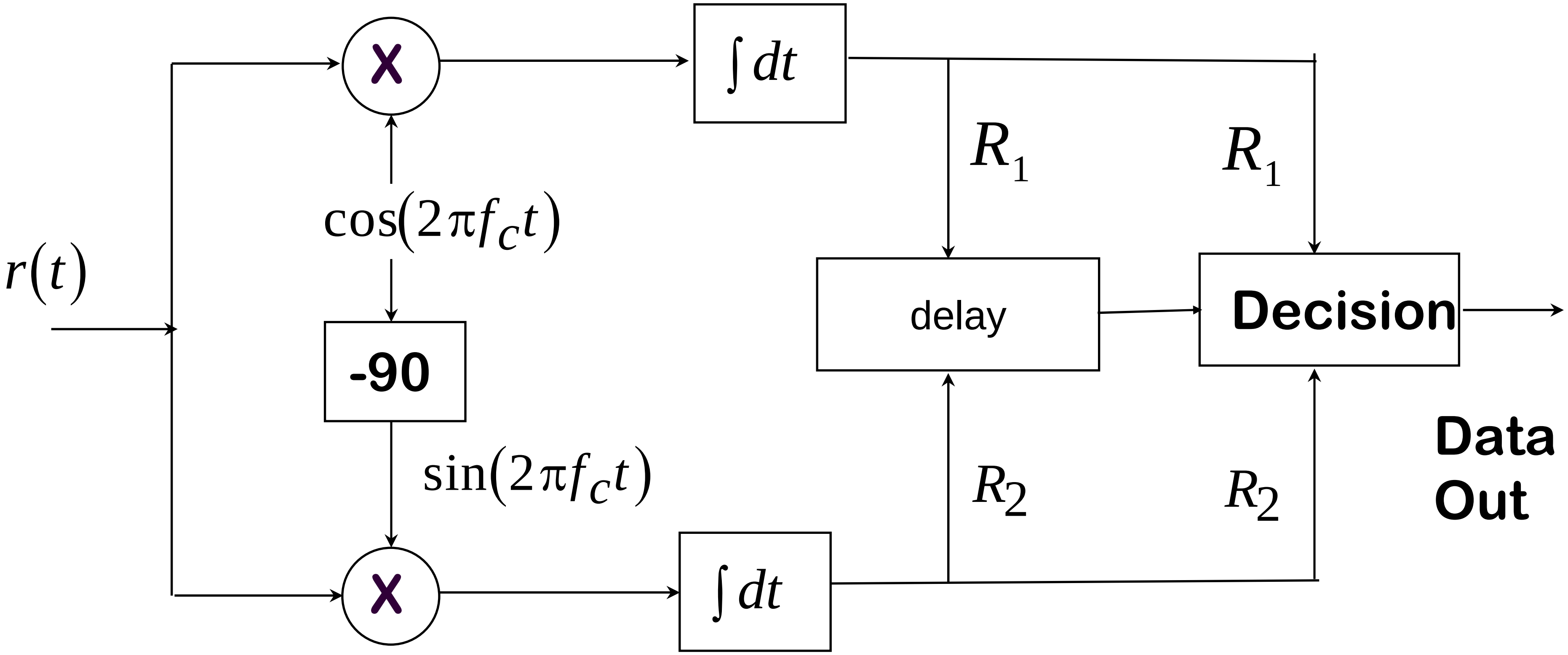
- If we *coherently* detect the signal we follow it with differential decoding
- Differential decoding is accomplished by multiplying the current bit estimate by the previous:

modulo 2 addition for bits

Rx Phase	0	π	π	0	π	0	0
$\hat{d}_{i-1}'$:	0	0	1	1	0	1	0
$\hat{d}_i'$:	0	1	1	0	1	0	0
$\hat{d}_i$:	0	1	0	1	1	1	0

Original Bits

Differential Reception



Differential Reception

$$R_1^i = \frac{A_c T_b}{2} \cos\left[\frac{2\pi}{M} m_i(t) + \theta_o\right]$$

$$R_2^i = \frac{A_c T_b}{2} \sin\left[\frac{2\pi}{M} m_i(t) + \theta_o\right]$$

$$R_1 = R_1^i R_1^{i-1} + R_2^i R_2^{i-1}$$

$$R_2 = R_2^i R_1^{i-1} - R_1^i R_2^{i-1}$$

$$R_1 = \cos\left(\frac{2\pi}{M}\left[m_i(t) - m_{i-1}(t)\right]\right)$$

$$R_2 = \sin\left(\frac{2\pi}{M}\left[m_i(t) - m_{i-1}(t)\right]\right)$$

- •Phase offset eliminated!
- •Difference between consecutive phases tells us the change in the phase which is the info

Example of Differential Detection

$\theta(i)$:	θ_o	$\theta_o+\pi$	$\theta_o+\pi$	θ_o	$\theta_o+\pi$	θ_o	θ_o
$\theta(i-1)$:	$\boxed{\theta_o}$	θ_o	$\theta_o+\pi$	$\theta_o+\pi$	θ_o	$\theta_o+\pi$	θ_o
$\Delta\theta(i)$:	0	π	0	π	π	π	0
$\hat{d}_i$:	0	1	0	1	1	1	0

Initial condition

Original Bits

Example of Differential Decoding - With Error

$\theta(i)$:	θ_o	$\theta_o+\pi+N$	$\theta_o+\pi$	θ_o	$\theta_o+\pi$	θ_o	θ_o
$\theta(i-1)$:	θ_o	θ_o	$\theta_o+\pi+N$	$\theta_o+\pi$	θ_o	$\theta_o+\pi$	θ_o
$\Delta\theta(i)$:	0	N	N	π	π	π	0
$\hat{d}_i$:	0	?	?	1	1	1	0

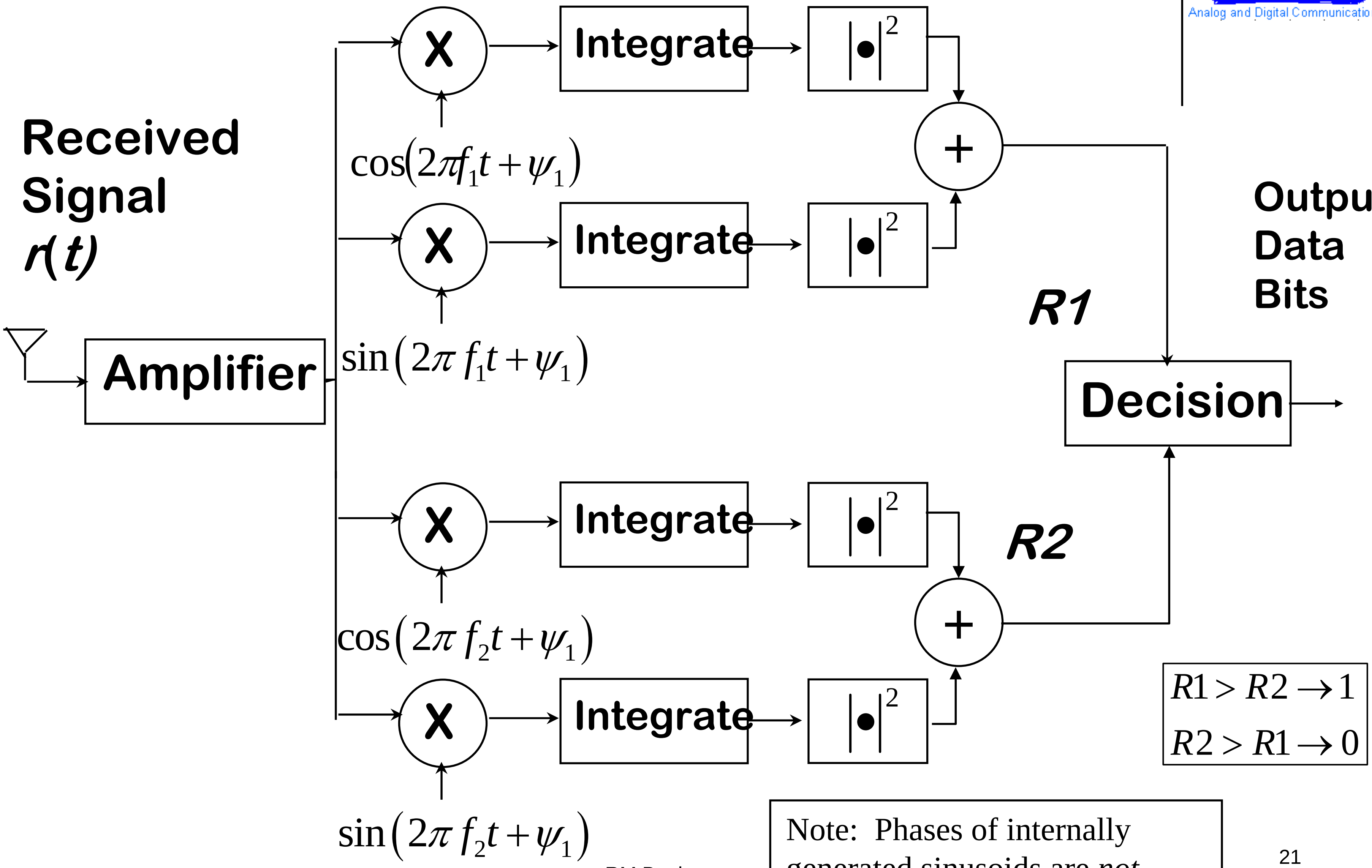
Noise causes 2 errors

Practical Application: π/4 DQPSK

- Used in North American Digital Cellular Standard
    - IS-54/IS-136 (SunCom phones in Southwest Va)
- Like regular QPSK except
    - *Differential* encoding is used so that information is represented by the difference in phase between symbols
    - Phase shifts by a factor π/4 each symbol period to help maintain synchronization
- Thus $\theta_i = \text{ phase during symbol period } i$

$$\begin{aligned}\theta_{i+1} &= \text{ phase during symbol period } i+1\\ &= \theta_i + \pi/4 + \pi m(t)/2\,, m(t) \in \{0,1,2,3\}\end{aligned}$$

Non-coherent Receiver for FSK



Received Signal ***r(t)***

Amplifier

$\cos(2\pi f_1 t + \psi_1)$

$\sin(2\pi f_1 t + \psi_1)$

$\cos(2\pi f_2 t + \psi_1)$

$\sin(2\pi f_2 t + \psi_1)$

X

Integrate

$|\bullet|^2$

+

R1

R2

Decision

Output Data Bits

$R1 > R2 \rightarrow 1$

$R2 > R1 \rightarrow 0$

Note: Phases of internally generated sinusoids are *not* matched to incoming sinusoids.

Receiver operations

- Assume that f_1 is sent:

$$\begin{aligned} V_1 &= \int_0^T \sqrt{P}\cos(2\pi f_1)\cos(2\pi f_1+\psi)dt \\ &= \frac{\sqrt{P}}{2}\int_0^T \cos(4\pi f_1+\psi)dt + \frac{\sqrt{P}}{2}\int_0^T \cos(\psi)dt \\ &\approx \frac{\sqrt{PT}}{2}\cos(\psi) \end{aligned}$$

$$\begin{aligned} V_2 &= \int_0^T \sqrt{P}\sin(2\pi f_1)\cos(2\pi f_1+\psi)dt \\ &= \frac{\sqrt{P}}{2}\int_0^T \sin(4\pi f_1+\psi)dt + \frac{\sqrt{P}}{2}\int_0^T \sin(\psi)dt \\ &\approx \frac{\sqrt{PT}}{2}\sin(\psi) \end{aligned}$$

$$\begin{aligned} V_3 &= \int_0^T \sqrt{P}\cos(2\pi f_2 t)\cos(2\pi f_1 t+\psi)dt \\ &= \frac{\sqrt{P}}{2}\int_0^T \cos(2\pi(f_2+f_1)t+\psi)dt + \frac{\sqrt{P}}{2}\int_0^T \cos(2\pi(f_1+f_2)+\psi)dt \\ &\approx 0 \end{aligned}$$

$$\begin{aligned} V_4 &= \int_0^T \sqrt{P}\sin(2\pi f_2 t)\cos(2\pi f_1 t+\psi)dt \\ &= \frac{\sqrt{P}}{2}\int_0^T \sin(2\pi(f_1+f_2)t+\psi)dt + \frac{\sqrt{P}}{2}\int_0^T \sin(2\pi(f_1-f_2)t+\psi)dt \\ &\approx 0 \end{aligned}$$

Decision Statistics

- First statistic

$$R_1 = \left(\frac{\sqrt{PT}}{2}\cos(\psi)\right)^2 + \left(\frac{\sqrt{PT}}{2}\sin(\psi)\right)^2$$

$$= \frac{PT^2}{2}$$

- Second statistic $R_2 = 0$

- Statistics are independent of the phase offset Ψ.
- Same can be shown for ASK

Summary

- Coherent reception requires knowledge of the absolute phase of the incoming unmodulated signal
  - Requires phase recovery circuitry
  - Can be challenging in mobile or other difficult environments
- Non-coherent reception is possible for ASK and FSK since no information is in the phase
- Differential modulation/reception possible for PSK