

# ECE4634 Digital Communications Fall 2007

Instructor: R. Michael Buehrer  
Lecture #20: Non-coherent  
Reception



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## 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

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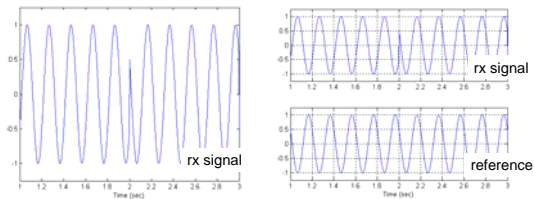
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## Example



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



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## 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.

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## Coherent vs. Non-coherent Receivers



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

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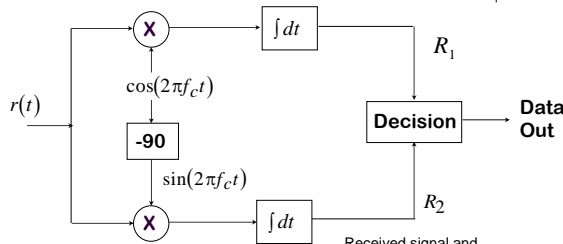
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## Coherent Receiver – PSK



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

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

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## Impact of phase offset - PSK



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

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

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

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

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

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

$\theta_o$  = phase difference between incoming carrier and locally generated sinusoid

In order to make proper decisions,  $\theta_o$  must be zero!

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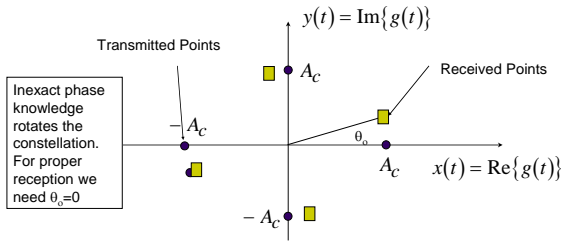
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## Coherent vs. Non-coherent Receivers



- Example: QPSK



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## 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.

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## Differential Encoding of Data

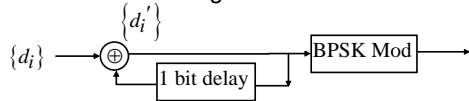


- Consider BPSK modulation:

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

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

- Differential Encoding Transforms Raw Data:



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

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## 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	$\pi$	$\pi$	0	$\pi$	0	0

Initial condition

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## 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	$\pi$	$\pi$	0	$\pi$	0	0

Use BPSK modulation on *differentially encoded data*

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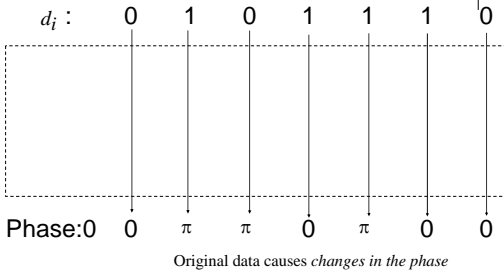
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## Example of Differential Encoding – View 2



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## 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

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## 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:

Rx Phase	0	$\pi$	$\pi$	0	$\pi$	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

modulo 2 addition for bits

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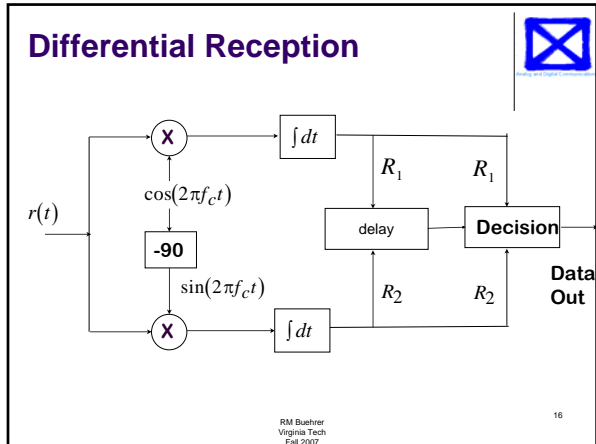
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### Differential Reception

$$R_1^i = \frac{A_c T_b}{2} \cos \left[ \frac{2\pi}{M} m_i(t) + \theta_o \right] \quad R_1 = R_1^i R_1^{i-1} + R_2^i R_2^{i-1}$$

$$R_2^i = \frac{A_c T_b}{2} \sin \left[ \frac{2\pi}{M} m_i(t) + \theta_o \right] \quad R_2 = R_2^i R_1^{i-1} - R_1^i R_2^{i-1}$$

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

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

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

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### Example of Differential Detection

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

Initial condition Original Bits

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### Example of Differential Decoding - With Error

$\theta(i)$	:	$\theta_0$	$\theta_0 + \pi + N$	$\theta_0 + \pi$	$\theta_0$	$\theta_0 + \pi$	$\theta_0$	$\theta_0$
$\theta(i-1)$	:	$\theta_0$	$\theta_0$	$\theta_0 + \pi + N$	$\theta_0 + \pi$	$\theta_0$	$\theta_0 + \pi$	$\theta_0$
$\Delta\theta(i)$	:	0	N	N	$\pi$	$\pi$	$\pi$	0
$\hat{d}_i$	:	0	?	?	1	1	1	0

Noise causes 2 errors

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### Practical Application: $\pi/4$ 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  $\pi/4$  each symbol period to help maintain synchronization
- Thus  $\theta_i =$  phase during symbol period  $i$   
 $\theta_{i+1} =$  phase during symbol period  $i + 1$   
 $= \theta_i + \pi/4 + \pi m(t)/2, m(t) \in \{0,1,2,3\}$

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### Non-coherent Receiver for FSK

Received Signal  $r(t)$

Amplifier

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

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

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

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

Integrate

Integrate

Integrate

Integrate

$R1$

$R2$

Decision

Output Data Bits

$R1 > R2 \rightarrow 1$   
 $R2 > R1 \rightarrow 0$

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

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## Receiver operations



- Assume that  $f_1$  is sent:

$$V_1 = \int_0^T \sqrt{P} \cos(2\pi f_1 t) \cos(2\pi f_1 t + \psi) dt$$

$$= \frac{\sqrt{P}}{2} \int_0^T \cos(4\pi f_1 t + \psi) dt + \frac{\sqrt{P}}{2} \int_0^T \cos(\psi) dt$$

$$\approx \frac{\sqrt{PT}}{2} \cos(\psi)$$

$$V_2 = \int_0^T \sqrt{P} \sin(2\pi f_1 t) \cos(2\pi f_1 t + \psi) dt$$

$$= \frac{\sqrt{P}}{2} \int_0^T \sin(4\pi f_1 t + \psi) dt + \frac{\sqrt{P}}{2} \int_0^T \sin(\psi) dt$$

$$\approx \frac{\sqrt{PT}}{2} \sin(\psi)$$

$$V_3 = \int_0^T \sqrt{P} \cos(2\pi f_2 t) \cos(2\pi f_1 t + \psi) dt$$

$$= \frac{\sqrt{P}}{2} \int_0^T \cos(2\pi(f_2 + f_1)t + \psi) dt + \frac{\sqrt{P}}{2} \int_0^T \cos(2\pi(f_2 - f_1)t + \psi) dt$$

$$\approx 0$$

$$V_4 = \int_0^T \sqrt{P} \sin(2\pi f_2 t) \cos(2\pi f_1 t + \psi) dt$$

$$= \frac{\sqrt{P}}{2} \int_0^T \sin(2\pi(f_2 + f_1)t + \psi) dt + \frac{\sqrt{P}}{2} \int_0^T \sin(2\pi(f_2 - f_1)t + \psi) dt$$

$$\approx 0$$

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## Decision Statistics



- First statistic

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

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

- Second statistic

$$R_2 = 0$$

- Statistics are independent of the phase offset  $\psi$ .
- Same can be shown for ASK

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## 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

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