SYSTEM ARCHITECTURE
ADVANCED SYSTEM ARCHITECTURE
BATEMAN
Chapter4: Sources and examples channel degradation

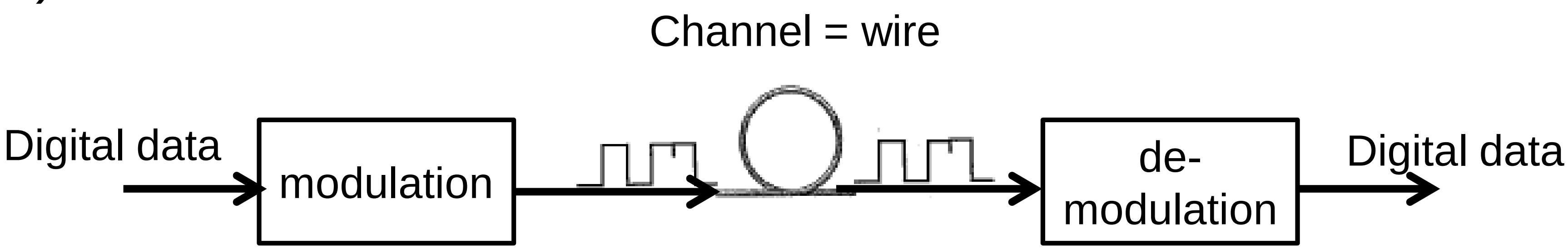
2013/Fall-Winter Term
Monday 12:50

Room# 1-322 or 5F Meeting Room

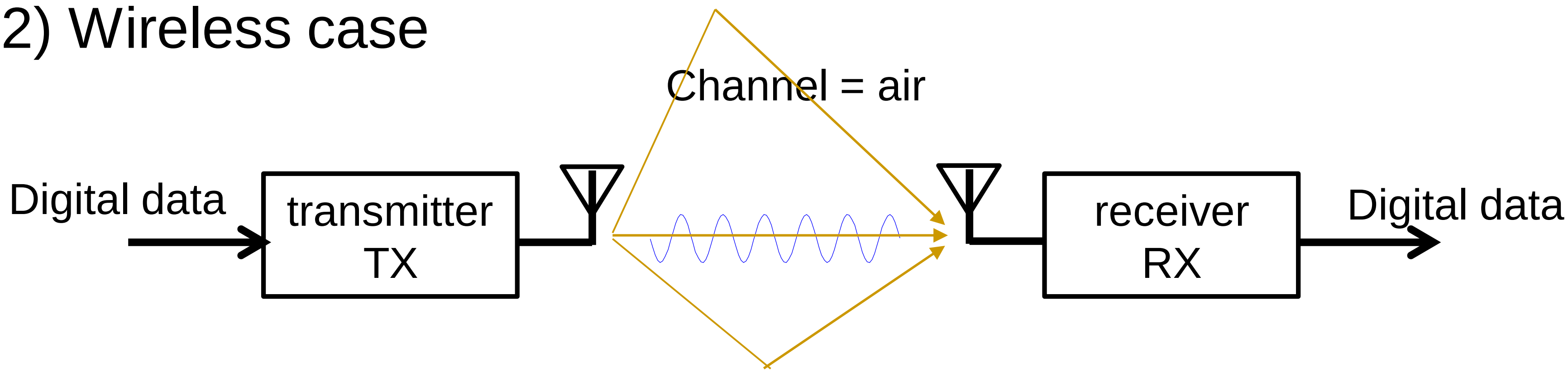
Instructor: Fire Tom Wada, Professor

Digital communication system

1) Wired case



2) Wireless case



Chapter4: Sources and examples channel degradation

4.1 Gain, phase and group delay distortion

4.2 Interference and noise

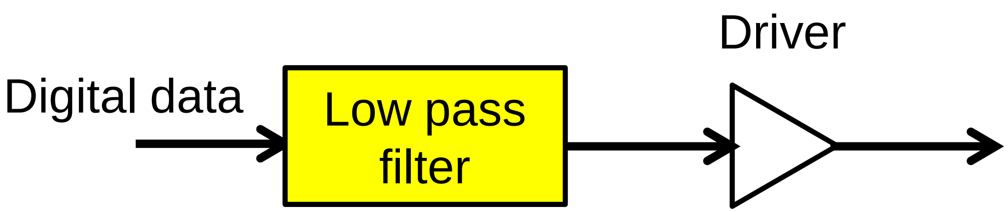
4.3 The telephone channel

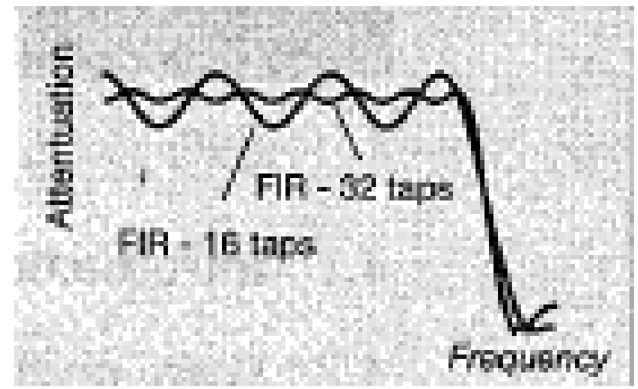
4.4 The wireless channel

Gain distortion

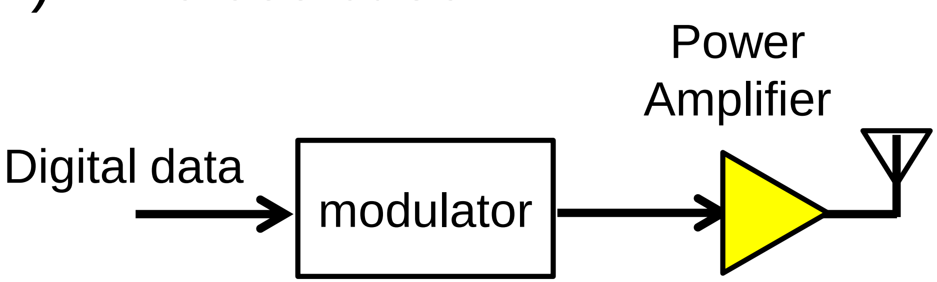
At transmitter or modulator

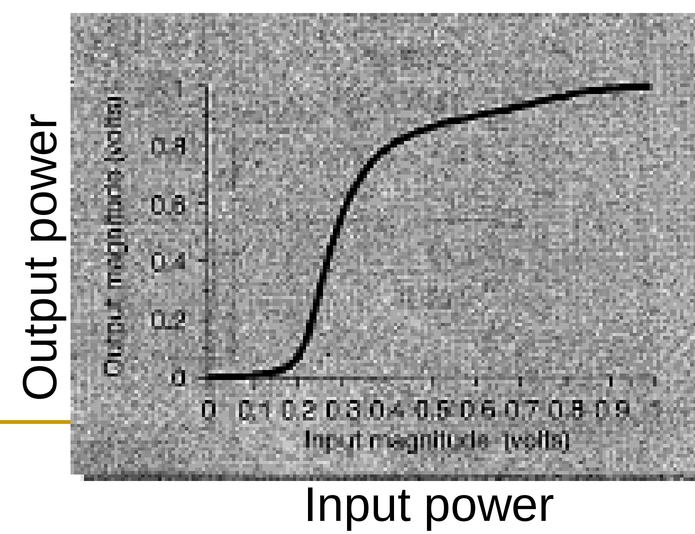
1) Wired case





2) Wireless case





Group Delay

'Group delay' is defined as 'the rate of change of phase shift with frequency'.

QUESTIONS

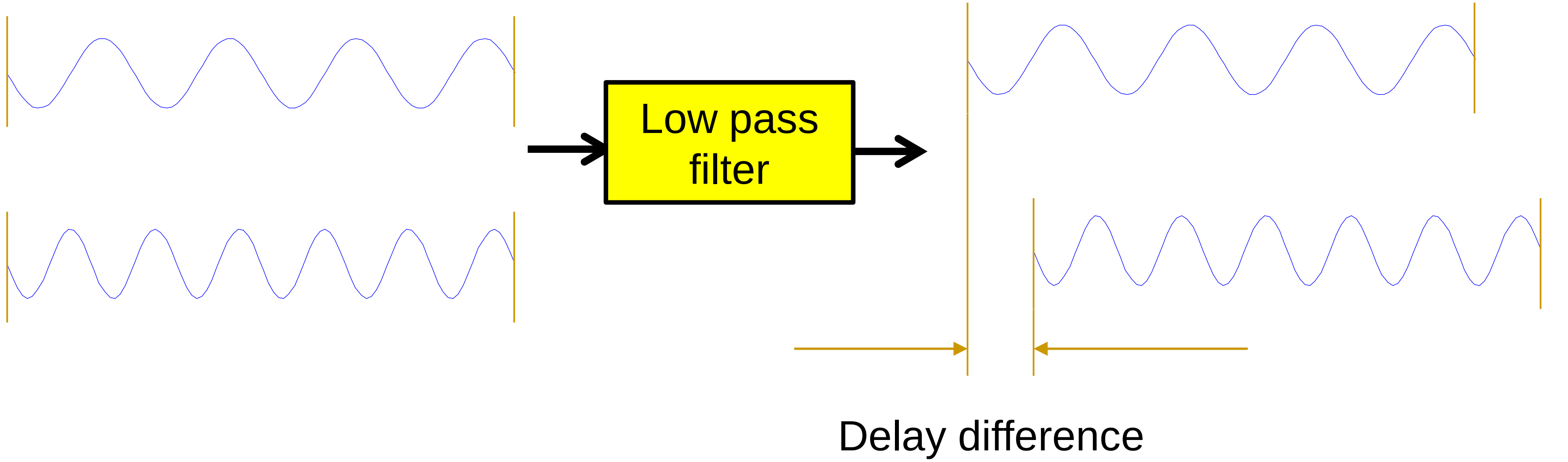
4.1 A cable is measured to have a flat gain response with frequency over the band of interest, but is found to have a phase response that changes proportionally with frequency, with a measured phase increase of 5° for every 1 MHz of bandwidth. What is the group delay response for the cable?

$$GroupDelay(\omega) = -\frac{d\theta(\omega)}{d\omega}$$

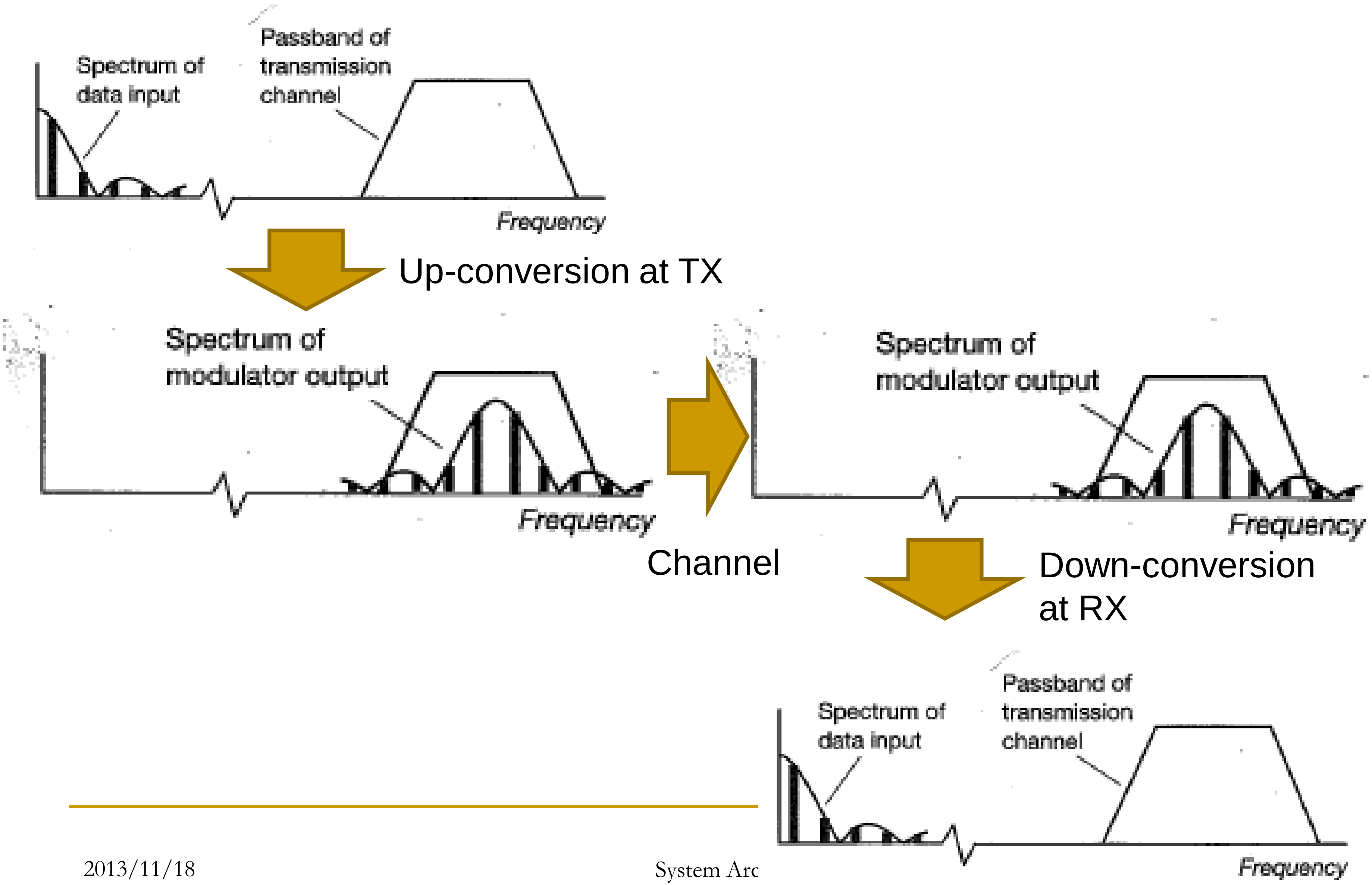
$$\omega = 2\pi f$$

FIR filter delay

FIR filter delay might be dependent with frequency range

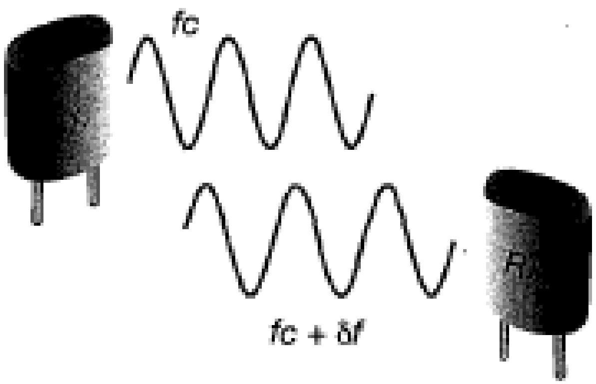


Up-conversion and down-conversion



Local oscillator error cause frequency error

For any bandpass modulation process it is necessary to generate sinewaves in both transmitter and receiver systems, ideally with precisely the same frequency and phase. This begs the question: 'Is it possible to implement two or more sinewave generators with perfect frequency and phase accuracy under realistic operating conditions (temperature variation, supply variation, ageing and so on)?'

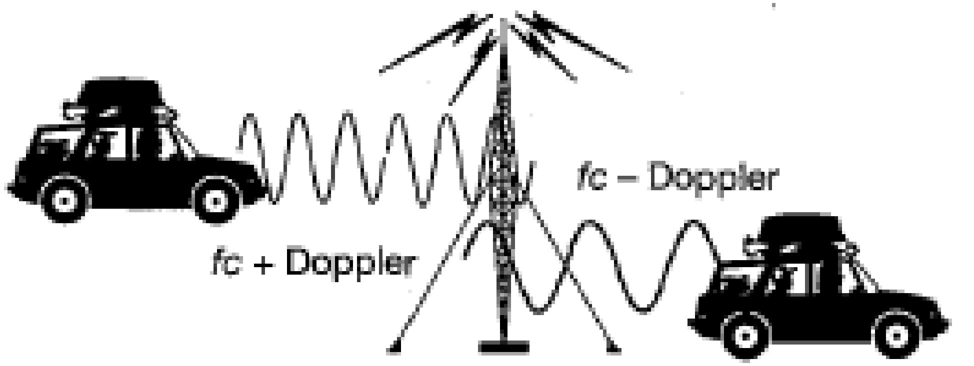


A reasonably cost-effective crystal oscillator (<$10) may have a stability of 1 ppm (part per million) over a given temperature range. This means that for a telephone modem with a carrier of say 2 kHz, the oscillators at each end of the link could have an error of $\pm 1 \times 10^{-6} \times 2 \times 10^{3} = 0.002$ Hz. If we could ensure that both transmit and receiver carrier oscillators begin with the same phase, then we can expect the phase error between them to reach 360° after 1/0.004 = 250 seconds, and 90°, giving zero output, after 75 seconds. These figures suggest that, providing an initial phase correction can be achieved, near phase-coherent detection can be ensured for a few seconds without further phase correction being required.

If we now consider the case of a cellular radio modem operating with a carrier of 1 GHz, then the oscillator frequency error for a 1 ppm source is ±1000 Hz. Here, it is clear that simply achieving a correct starting phase will not allow us to ensure adequate coherency for more than a few microseconds. In this application, it is necessary to find a method of correcting the receiver carrier oscillator frequency and phase to match that of the transmitter. This process is termed *carrier recovery*.

Doppler shift

Whenever a signal source moves towards or away from a receiver, the frequency of the signal as observed at the receiver increases or decreases respectively. This is known as the *Doppler effect*. The degree of frequency shift is a linear function of the speed of motion and the carrier signal frequency. For example, a source moving at 70 mph using a carrier frequency of 900 MHz will experience a Doppler shift of up to ±100 Hz at the receiver.



Correcting for Doppler shift can be very difficult, particularly in a multipath environment (see Section 4.5), where signals arriving from different angles experience different Doppler shifts.

Doppler shift

IN DEPTH

Doppler shift

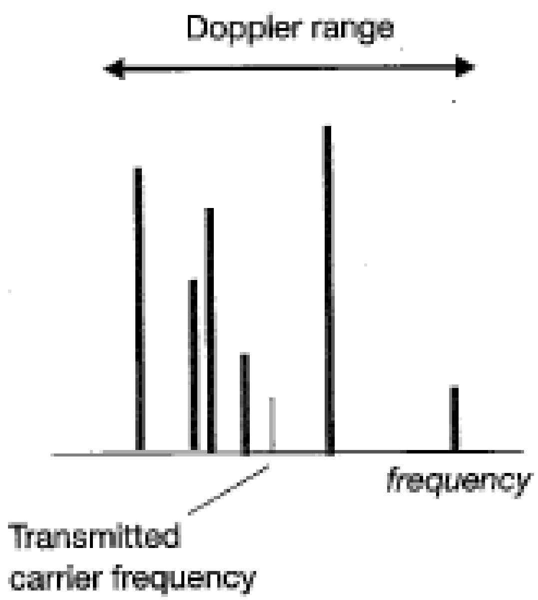
The Doppler shift introduced into a signal between transmitter and receiver units, or moving reflectors, is a function of their relative motion, the angle of arrival of the signal, and the operating frequency or wavelength. These parameters are related as follows:

$$\text{Doppler shift (Hz)} = v \cdot f \cdot \cos(x)/c$$

where v is the relative speed of TX and RX units in m/s, f is the carrier frequency in Hz, $c = 3 \times 10^8$ m/s and x is the relative angle of arrival in degrees.

For example, the Doppler shift experienced by a cellular phone within a car travelling at 70 mph directly away from a base-station transmitter, operating on the DCS1800 system (operating frequency 1.8 GHz) is 189 Hz. The Doppler shift for a person walking along the street at 4 mph is, however, much smaller at only 11 Hz.

A typical spectrum of a signal received at a mobile terminal when moving within a multipath environment with several reflectors each giving different angles of arrival and hence different Doppler shift is shown in the figure. The source was a single tone at the carrier frequency.



Chapter4: Sources and examples channel degradation

4.1 Gain, phase and group delay distortion

4.2 Interference and noise

4.3 The telephone channel

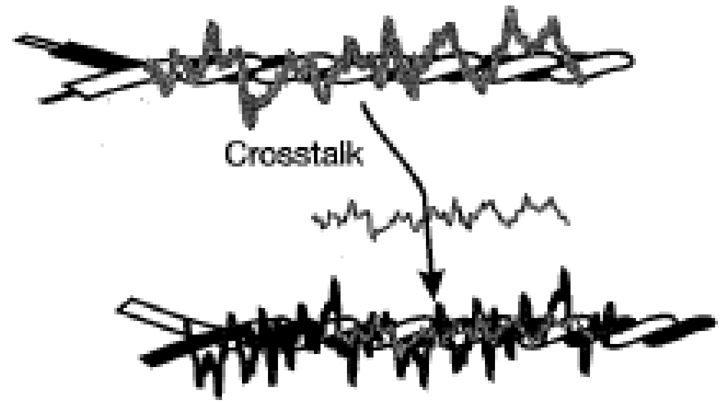
4.4 The wireless channel

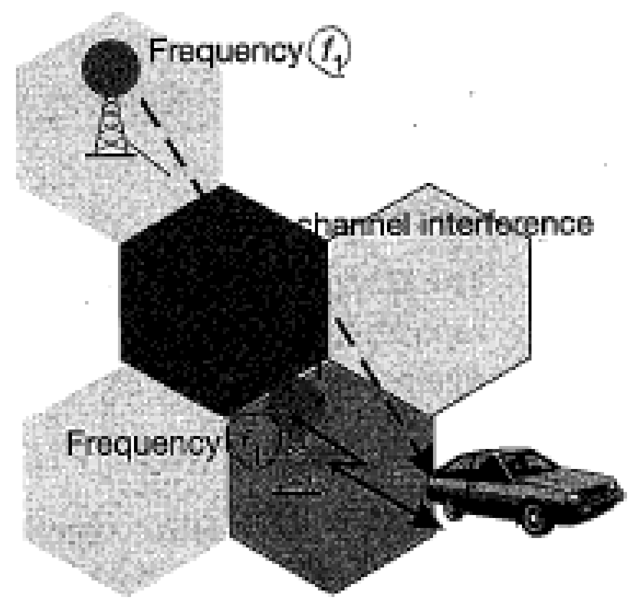
Source of interference

Most interference encountered in digital communications systems (except for deep space missions!) arises from either other communications systems or machinery. For example, crosstalk in telecommunications lines is classed as interference, as is the 'ignition noise' generated by a car engine.

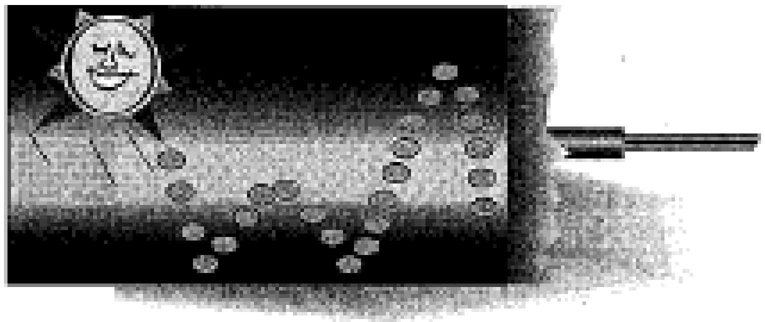
In radio systems in particular, a major source of interference is from other users of the radio spectrum. For example, equipment radiating on frequencies close to the wanted channel can pass through the receiver selection filtering, causing what is termed *adjacent channel* interference. In cellular applications, mobile users in different geographical locations are assigned the same frequency for their calls, and if they are not separated by sufficient distance, *co-channel interference* occurs.

In both radio and television, multipath interference is common, manifest as ghosting on the television screen, caused by signals travelling by many different paths between transmitter and receiver each with slightly different time delay.





Source of noise



Unlike interference, noise originates predominantly from within the communications link itself and is usually totally random in nature, making it very difficult to deal with. There is a variety of mechanisms by which noise is generated, the most commonly referenced forms being thermal noise, shot noise, flicker noise and atmospheric noise.

Thermal noise often dominates in communications systems and originates from the free movement of electrons within a conductor. The name arises because the energy and hence degree of movement of electrons increases proportionally with the temperature of the conductor. The current and hence voltage generated by this movement has a waveform that is entirely random in nature and which will, over time, have an average power spectrum that is flat over all frequencies. This property of thermal noise to contain all frequencies has resulted in it being called 'white noise' to mirror the property of white light to contain all colours.

A good text on the subject of noise in digital communications systems is by Schwartz (1990).

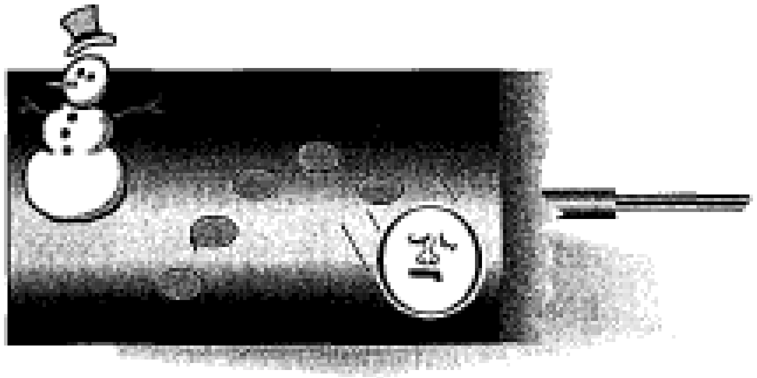
Thermal noise

Thermal noise

The *average power attributable to thermal noise* is:

Thermal noise $N_{av} = kTB$

where k is Boltzmann's constant $= 1.38 \times 10^{-23}$ Watts/Hz/°K, T is the absolute temperature in degrees Kelvin, and B is the bandwidth in which the measurement is made.



Thermal noise can clearly be reduced by cooling the noise source and this very principle is being applied in some radio receivers using cryogenic coolers, to improve the receiver sensitivity.

EXAMPLE 4.1

A radio receiver is limited in performance by thermal noise in the receiver 'front-end'. It is designed to provide an S/N ratio of better than 10 dB to the demodulator input. The channel bandwidth for the receiver is 25 kHz. What is the minimum received signal level that can be used to achieve this performance target, assuming the receiver is operating at a temperature of 280°K?

Solution

The average power of thermal noise for this case is given by:

$$N_{av} = KTB = 1.38 \times 10^{-23} \times 280 \times 25\,000 = 9.66 \times 10^{-17}\ \text{W}$$

or −130 dBm (dB relative to 1 mW).

To achieve an S/N ratio of 10 dB, the received signal power must therefore be in excess of $(-130 + 10) = -120$ dBm.

Chapter4: Sources and examples channel degradation

4.1 Gain, phase and group delay distortion

4.2 Interference and noise

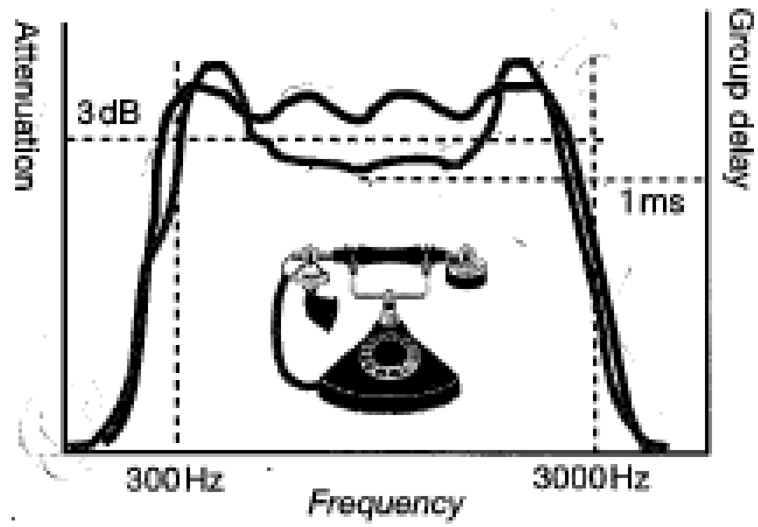
4.3 The telephone channel

4.4 The wireless channel

Telephone channel characteristics

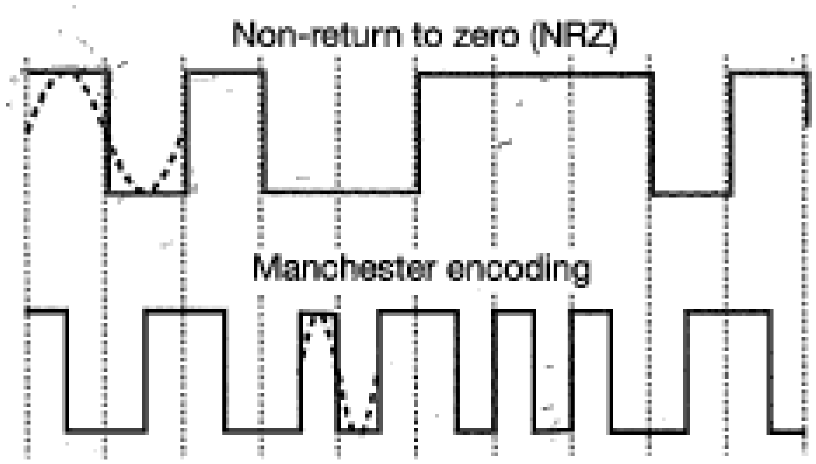
The domestic telephone channel is a classic example of a channel which is *bandpass* in nature, that is, it has a low frequency and high frequency cut-off in its gain response. The low frequency cut-off (ac-coupling) results from capacitive and/or inductive coupling of the telephone line at both the exchange and subscriber ends allowing dc power for the telephone to be passed over the same cable as the speech or data signal. The high frequency cut-off is a combination of deliberate filtering at the exchange to minimize noise on the channel and also the transmission line filtering effect of long lengths of cable.

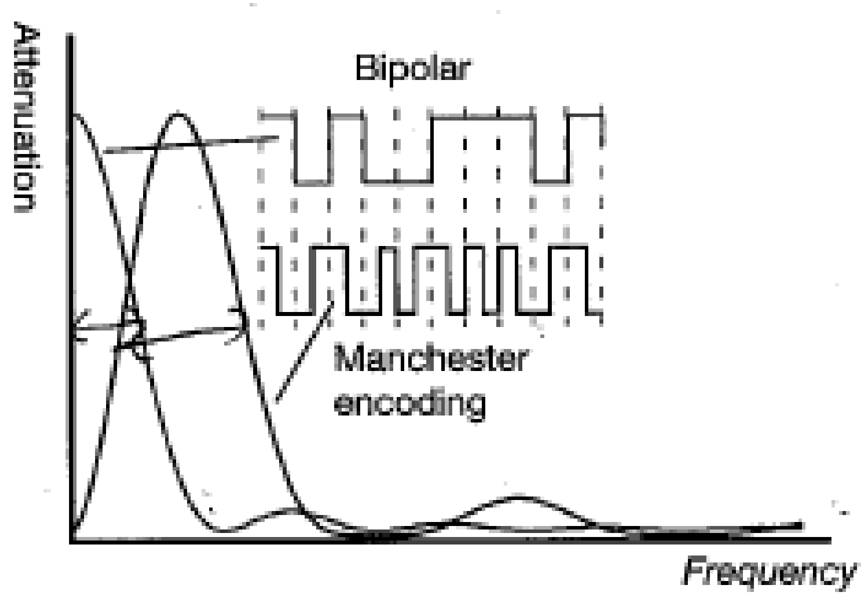
A typical telephone channel response is shown here. Notice that even within the channel, the gain response may not be flat and this in itself will introduce further symbol degradation.



Typical telephone channel response

NRZ vs. Manchester encoding





EXAMPLE 4.2

A cabled binary baseband data system that supports a maximum information transfer rate of 1200 bps using bipolar signalling has to be modified to allow ac coupling of the receiver unit owing to dc offset problems in the circuit design. How might the system be altered to fulfil this task, and what would be the impact on the information transfer rate?

Solution

An effective ac coupling method is Manchester encoding of the data which eliminates long strings of 1s or 0s. Manchester encoding, however, doubles the occupied bandwidth of the data signal and hence the usable data rate would drop from 1200 bps for bipolar signalling to 600 bps for Manchester encoded data transfer.

Chapter4: Sources and examples channel degradation

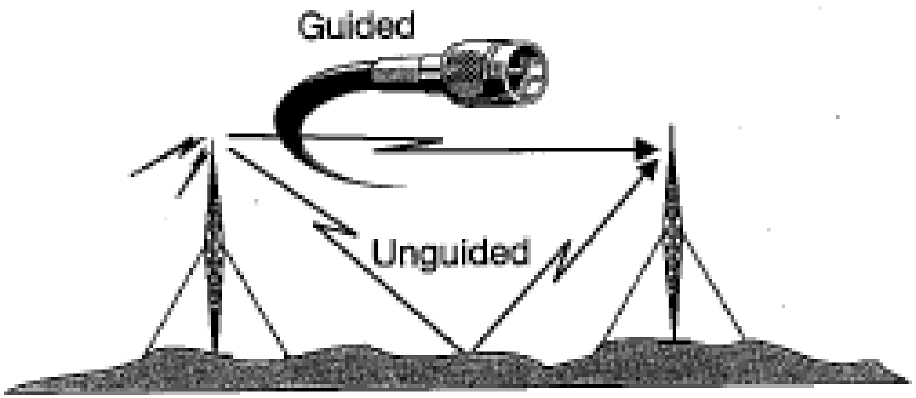
4.1 Gain, phase and group delay distortion

4.2 Interference and noise

4.3 The telephone channel

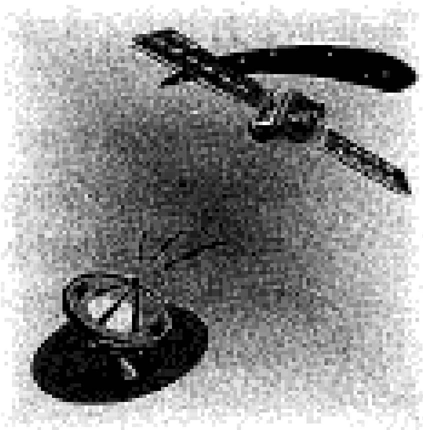
4.4 The wireless channel

Unguided propagation



The wireless channel is unique in that it is an *unguided medium* (unlike cable or fibre), and it is the means by which signals propagate from transmitter to receiver that dominates the data communications performance on a wireless link.

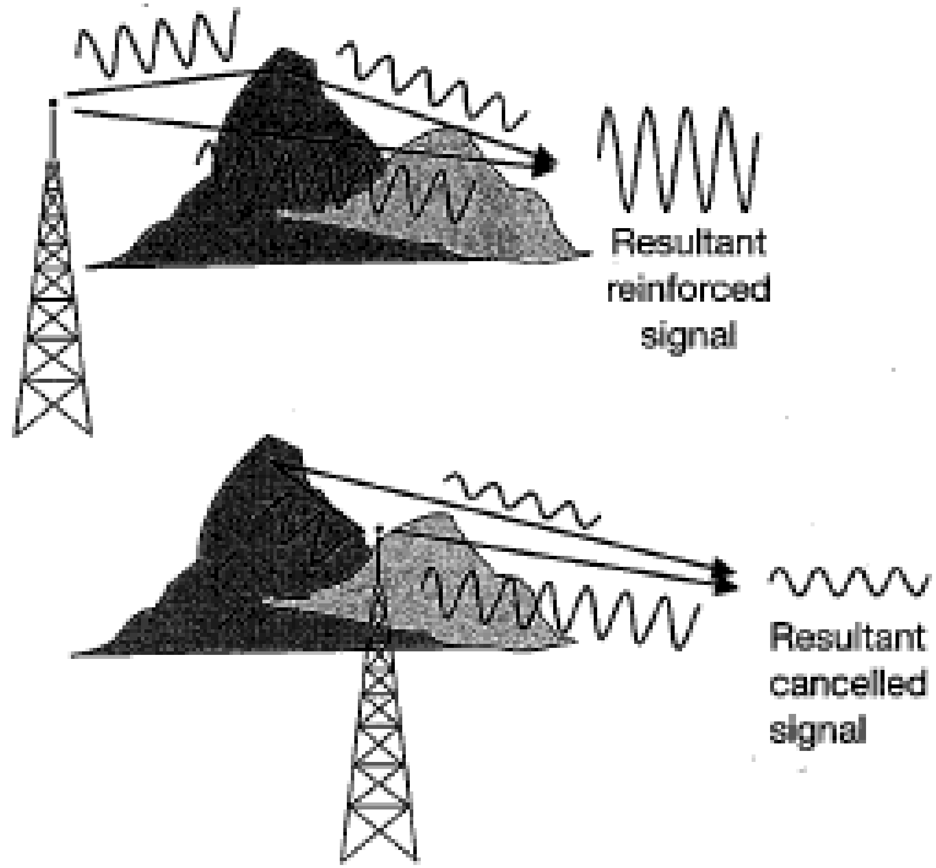
In essence there is little inherent filtering or distortion in a wireless link (other than frequency-dependent absorption in the atmosphere), provided that there is only one propagation path between TX and RX units. This can only be achieved by ensuring that there are *no reflections* of the transmitted signal arriving within the 'aperture' of the receiver. One of the few examples where this holds true is for satellite to ground communications where the receiving antenna is a very focused parabolic reflector pointing directly towards the satellite and there are no objects (other than distant planets!) from which a reflection can arise.



Multipath distortion

In applications where more than one propagation path will exist, the interaction of the signals from these multiple paths at the receiver (multipath propagation) gives rise to significant distortion of the received data symbols.

The same source signal, arriving by a different route, will experience a different path length and hence a different propagation delay. This difference in delay will result in different phases between the two received signals. If the phase difference approaches 180° then the signals will in fact partially cancel each other, while if the phase difference approaches 0° they will reinforce.

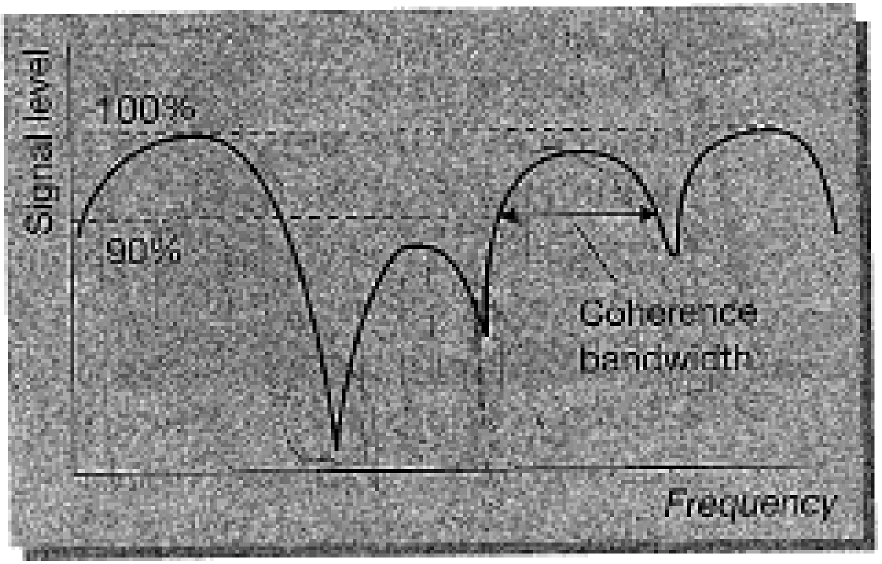


Multipath fading
- Ricean and Rayleight -

The depth of the resulting fading of the signal is very dependent on whether a strong 'line-of-sight' path exists between transmitter and receiver, in which case the fading signal envelope usually conforms to a *Ricean statistical distribution*, whereas if the line-of-sight path is obscured, and energy arrives at the receiver by a large number of reflections, then a *Rayleigh distribution* of the envelope level is more likely to occur. The characteristics of the fading signal envelope make a significant impact on the bit error rate performance for a digital communications link. An excellent book on multipath fading is Jakes (1993), and a very thorough text on the performance of data modems in fading is given in Proakis (1989).

Frequency selective fading

A challenging phenomenon of multipath propagation is that the degree of cancellation or reinforcement of signals changes for the different frequencies within a data signal. This is because the relative phase shift between two frequency components undergoing identical path delays will be different as the wavelength of the two components is altered. The effect is known as *frequency selective fading* and gives rise to notches in the frequency response of the channel.



Need one presenter

- Each presenter shall chose two problems from 4.2 and 4.3.
- Show your answer at the beginning of next lecture. Each has 5 minutes.
- Next lecture will be 11/25 (mon)