'04

Stuff we missed ...

Gilbert cell (4D-8)

Math -- errors in the BFO (4B-3,4)

New: "Quadrature AM"

HW:
4.8-1,2
4.4-1
4.3-7

Quadrature AM --

What it does:

Allows 2 signals to share a channel, allowing twice as many channels to fit in the same spectrum.

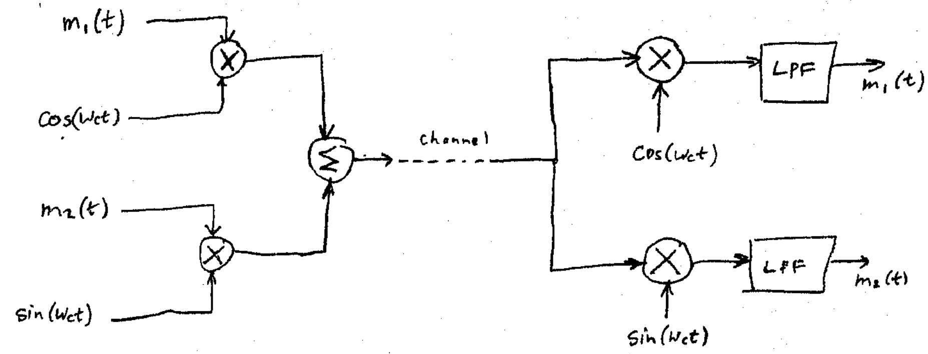
How?

Use 2 carriers at the same frequency, 90° apart.

To transmit --
Combine them, and feed both to the power amplifier and antenna.

To receive ...
Use 2 detectors, with their BFO's 90° apart. One is in phase-lock with each transmitted signal.

$$\varphi_{QAM}(t) = \underbrace{m_1(t)\cos(\omega_c t)}_{\text{one signal "I" (in-phase)}} + \underbrace{m_2(t)\sin(\omega_c t)}_{\text{The other signal "Q" (quadrature)}}$$



Analysis - see 4B-4
Book does it in time domain.

Analysis - when it doesn't work well..

θ = phase = 0 for I, $\frac{\pi}{2}$ for Q
(error)

From book --

$$x_1(t) = [m_1(t)\cos(\omega_c t) + m_2(t)\sin(\omega_c t)]\,(2\cos(\omega_c t + \theta))$$

by trig identity $\cos^2(x) = \frac{1}{2}(1+\cos(2x))$

$$= m_1(t)\cos\theta + m_1(t)\cos(2\omega_c t+\theta) \quad \leftarrow \text{desired signal}$$

$$- m_2(t)\sin\theta + m_2(t)\sin(2\omega_c t + \theta) \quad \leftarrow \text{error "Crosstalk"}$$

base band — harmonic - filtered out.

After LPF:

$$m_{12}(t) = m_1(t)\cos\theta - m_2(t)\sin\theta$$

θ is the carrier phase error.

$$\text{Crosstalk} = \frac{\sin\theta}{\cos\theta} = \tan\theta$$

θ	$\tan\theta$	$20\log(\tan\theta)$
1°	.0175	-35
2°	.0349	-29
5°	.0875	-21
.1°	.0017	-55

This error is manageable with phase locked loop.

Bigger problem with QAM ---

Selective fading —
non-symmetry in pre-detection filter
or anything that changes
one sideband relative to the other

all cause crosstalk.

Analysis is difficult,
but consider a similar system

Suppose we want to send $m_1(t)$ and $m_2(t)$
using sum and difference..

$$s(t) = m_1(t) + m_2(t)$$
$$d(t) = m_1(t) - m_2(t)$$

on receive ---
hopefully

$$m_1(t) = \frac{s(t) + d(t)}{2}$$
$$m_2(t) = \frac{s(t) - d(t)}{2}$$

Suppose $d(t)$ has a gain error of $-.01$ (.08 dB) --
(Gain = 1.01 or .99)

To measure crosstalk, set $m_1(t) = 0$, $m_2(t) = 1$
so $s(t) = 1$, $d(t) = -1$

$$m_1(t) = \frac{s(t) + .99\,d(t)}{2} = \frac{1 - .99}{2} = \frac{.01}{2} \leftarrow \text{crosstalk}$$

$$20 \log\left(\frac{.01}{2}\right) = -46 \text{ dB}$$

— Corresponds to setting gain with 1% resistors.

Suppose error is $-.1$ (Gain = .9) ($-.9$ dB)

(corresponds to setting gain with 10% resistors)

$$m_1(t) = \frac{s(t) + .9\,d(t)}{2} = \frac{.1}{2} = .05$$

$$20 \log(.05) = -26 \text{ dB}$$

This error can occur easily in the channel —

We can manage the circuit by using precision components and good design.

but both have this error so it's -20 dB.

We cannot improve the channel.

Another problem —

Both signals must be generated together —
in quadrature.

OK when signals are related (AM stereo, color TV)

but useless when signals are completely separate, as in two different radio transmitters.