Principles of Communications
ECS 332

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4.6 QAM

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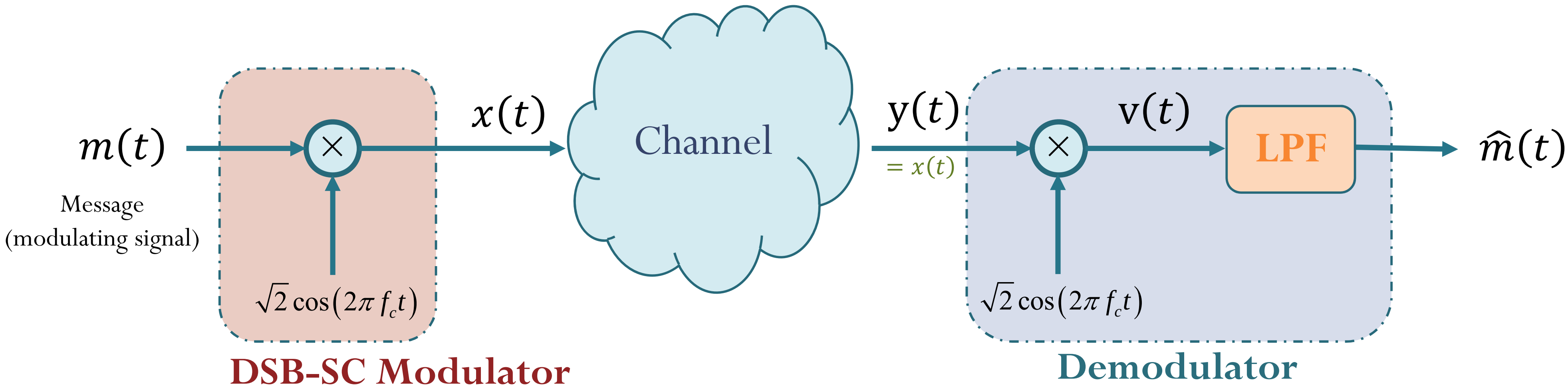
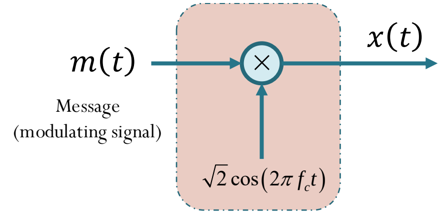
DSB-SC Modem

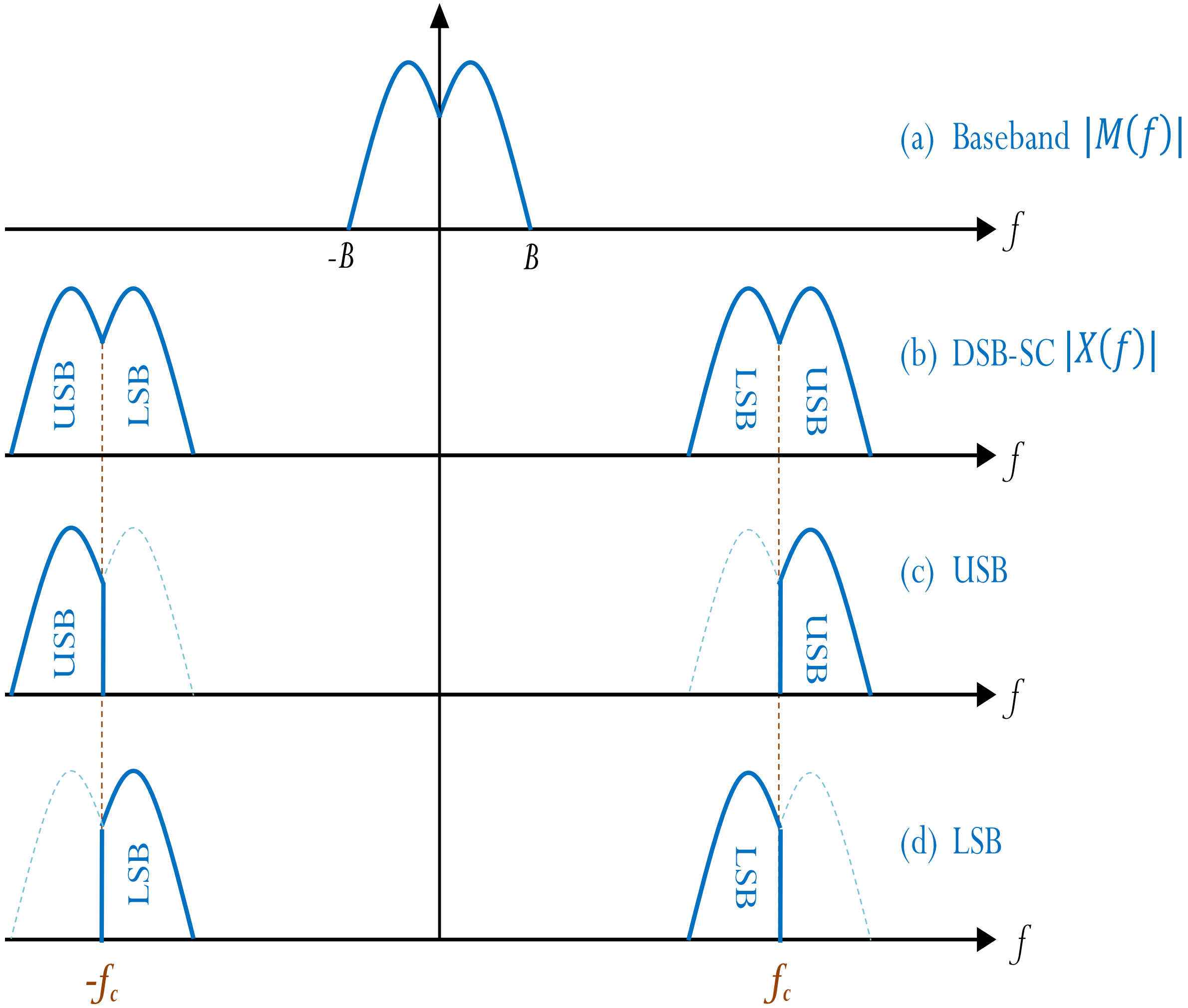


[4.8] Implementation issues:

Problem	Solutions
Modulator construction	Square mod [4.56]; SW mod [4.58],
Demodulator construction; Synchronization between the two (local) carriers/oscillators	AM (Additional carrier component is transmitted) + Rectifier/Envelope Detector [4.71-4.72]
Spectral inefficiency	[Sec. 4.6] Bandwidth-Efficient Mod.

DSB = double sidebands





[Figure 31 in Example 4.80]

- [2.30] When $m(t)$ is real-valued, its spectrum $M(f)$ has **conjugate symmetry**.
- [4.9] With such message, the corresponding modulated signal's spectrum $X(f)$ will also inherit the symmetry but now centered at f_c (instead of at 0).
- The portion that lies above f_c is known as the **upper sideband (USB)** and the portion that lies below f_c is known as the **lower sideband (LSB)**.
- Similarly, the spectrum centered at $-f_c$ has upper and lower sidebands.

HW 5 — Due: Not Due Solution

Lecturer: Prapun Suksompong, Ph.D.

Problem 4. This question starts with a ***square-modulator*** for DSB-SC . Then, the use of the square-operation block is further explored on the receiver side of the system. [Doerschuk, 2008, Cornell ECE 320]

(a) Let $x(t) = A_c m(t)$ where $m(t) \underset{\mathcal{F}^{-1}}{\overset{\mathcal{F}}{\rightleftharpoons}} M(f)$ is bandlimited to B, i.e., $|M(f)| = 0$ for $|f| > B$. Consider the block diagram shown in Figure 5.3.

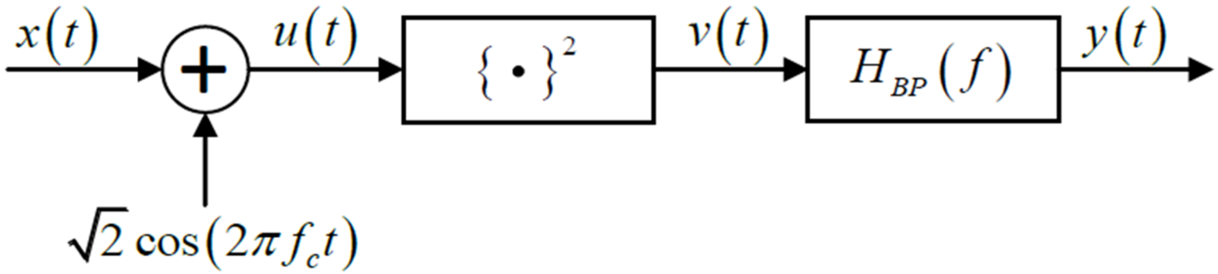


Figure 5.3: Block diagram for Problem 4a

Assume $f_c \gg B$ and

$$H_{BP}(f) = \begin{cases} 1, & |f - f_c| \le B \\ 1, & |f + f_c| \le B \\ 0, & \text{otherwise.} \end{cases}$$

ECS 332: Principles of Communications **2019/1**

HW 5 — Due: Not Due **Solution**

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Problem 6. Consider a signal $g(t)$. Recall that $|G(f)|^2$ is called the **energy spectral density** of $g(t)$. Integrating the energy spectral density over all frequency gives the signal's total energy. Furthermore, the energy contained in the frequency band I can be found from the integral $\int_I |G(f)|^2 df$ where the integration is over the frequencies in band I. In particular, if the band is simply an interval of frequency from f_1 to f_2, then the energy contained in this band is given by

$$\int_{f_1}^{f_2} |G(f)|^2 df. \tag{5.1}$$

In this problem, assume

$$g(t) = 1[-1 \le t \le 1].$$

(a) Find the (total) energy of $g(t)$.

$$E_g = \int_{-\infty}^{\infty} |g(t)|^2 dt = \int_{-\infty}^{\infty} (1[-1 \le t \le 1])^2 dt = \int_{-1}^{1} 1\, dt = 2.$$

HW 5 — Due: Not Due **Solution**

Lecturer: Prapun Suksompong, Ph.D.

(b) Figure 5.7 define the main lobe of a sinc pulse. It is well-known that the main lobe of the sinc function contains about 90% of its total energy. Check this fact by first computing the energy contained in the frequency band occupied by the main lobe and then compare with your answer from part (a).

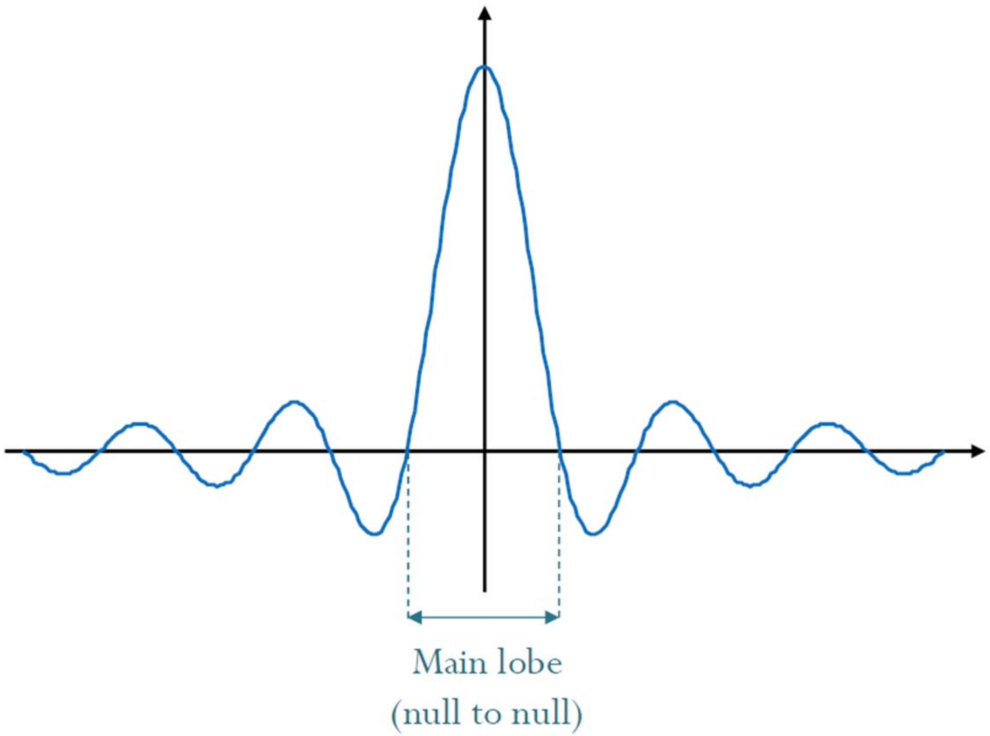


Figure 5.7: Main lobe of a sinc pulse

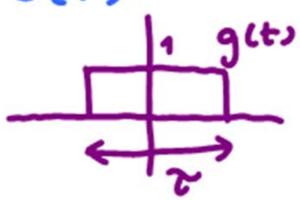
HW 5 — Due: Not Due **Solution**

Lecturer: Prapun Suksompong, Ph.D.

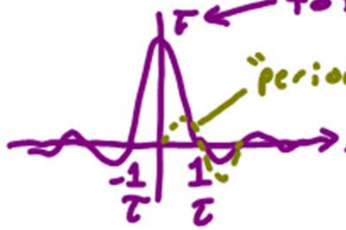
(b) Figure 5.7 define the main lobe of a sinc pulse. It is well-known that the main lobe of the sinc function contains about 90% of its total energy. Check this fact by first computing the energy contained in the frequency band occupied by the main lobe and then compare with your answer from part (a).

First, we need $G(f)$.

Recall that



$\xrightarrow{\mathcal{F}}$



τ ← total area in time-domain

"period" $= \frac{2}{\tau}$ ⇒ "freq" $= \frac{\tau}{2}$ ⇒ $\sin\left(2\pi \frac{\tau}{2} f\right)$

$G(f) = \tau \operatorname{sinc}(\pi f \tau)$

Here, $\tau = 2$. So, $G(f) = 2\operatorname{sinc}(2\pi f)$

The main lobe occupies an interval of frequency from $f_1 = -\frac{1}{\tau} = -\frac{1}{2}$ to $f_2 = +\frac{1}{\tau} = +\frac{1}{2}$.

So, the energy contained in the band $B = [f_1, f_2]$ is given by $\int_{-1/2}^{1/2} \left(2\operatorname{sinc}(2\pi f)\right)^2 df \approx 1.8056$ ← MATLAB

Compared with the answer from part (a), this is $\approx 90\%$ of the total energy.

HW 5 — Due: Not Due **Solution**

Lecturer: Prapun Suksompong, Ph.D.

(c) Suppose we want to include more energy by considering wider frequency band. Let this band be the interval $I = [-f_0, f_0]$. Find the minimum value of f_0 that allows the band to capture at least 99% of the total energy in $g(t)$.

Using MATLAB, we can look at the fraction of energy as a function of f_0. We found that at around $f_0 \approx 5.1$, the fraction begins to exceed 99%.

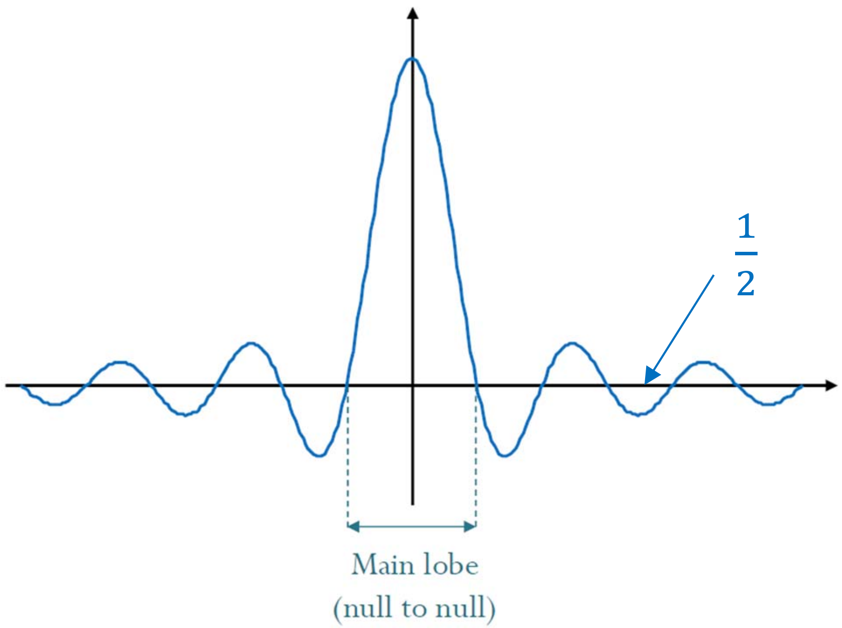
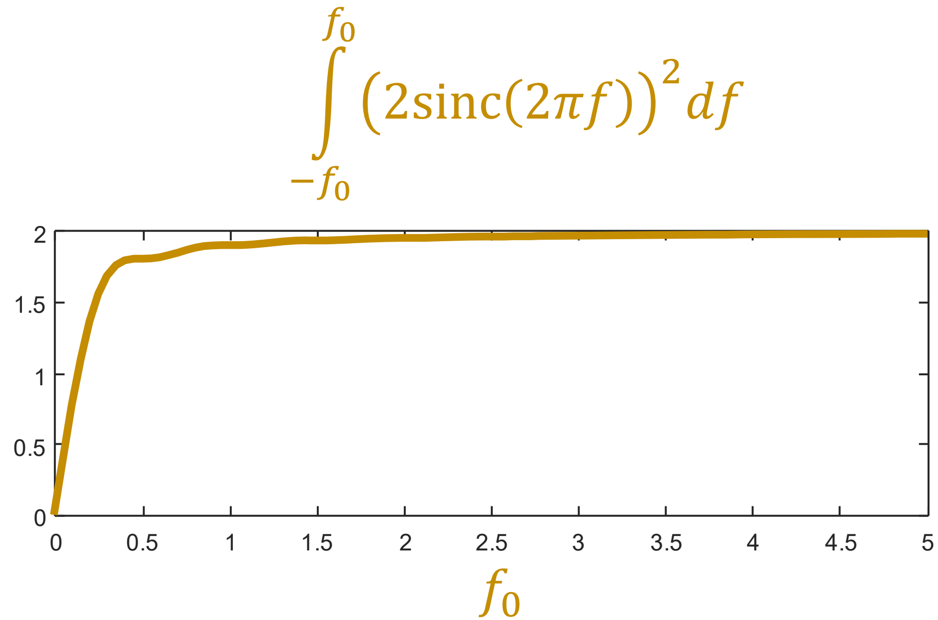
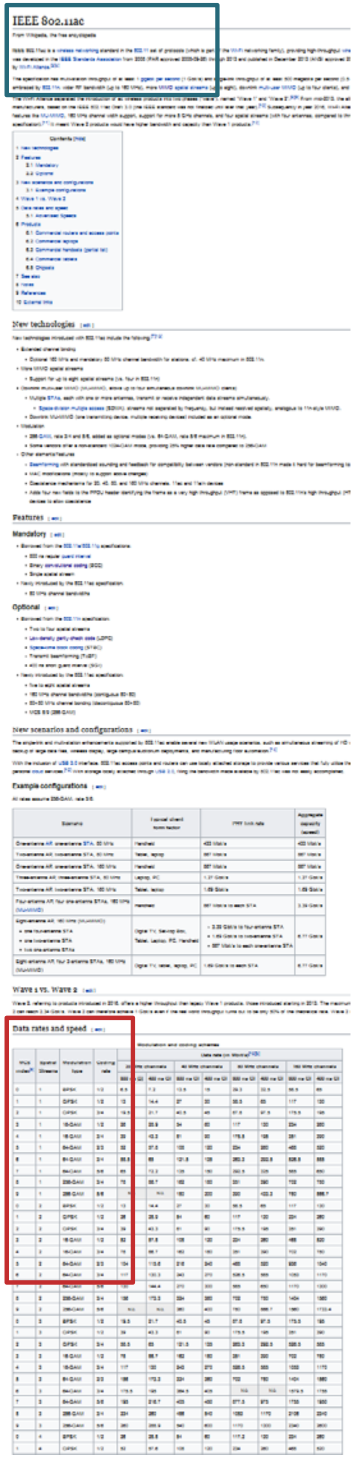


Figure 5.7: Main lobe of a sinc pulse





IEEE 802.11ac

From Wikipedia, the free encyclopedia

IEEE 802.11ac is a wireless networking standard in the 80
The standard was developed in the IEEE Standards Assoc
retroactively labelled as **Wi-Fi 5** by Wi-Fi Alliance.[3][4]

Data rates and speed [edit]

MCS index[a]	Spatial Streams	Modulation type	Coding rate
0	1	BPSK	1/2
1	1	QPSK	1/2
2	1	QPSK	3/4
3	1	16-QAM	1/2
4	1	16-QAM	3/4
5	1	64-QAM	2/3
6	1	64-QAM	3/4
7	1	64-QAM	5/6
8	1	256-QAM	3/4
9	1	256-QAM	5/6
0	2	BPSK	1/2
1	2	QPSK	1/2
2	2	QPSK	3/4
3	2	16-QAM	1/2
4	2	16-QAM	3/4
5	2	64-QAM	2/3
6	2	64-QAM	3/4
7	2	64-QAM	5/6
8	2	256-QAM	3/4
9	2	256-QAM	5/6

LTE

Lte
Lte ADVANCED
Lte Advanced Pro
5G
1x20MHz CA
2x2 MIMO
64 QAM DL
2x20MHz CA
2x2 MIMO
64 QAM DL
3x20MHz CA
2x2 MIMO
64 QAM DL
>5×20 MHz CA
4×4 MIMO
256 QAM DL
LAA
CBRS
Public Safety
Massive MIMO
1024 QAM DL
mmWave
URLL
100Mbps↓
150Mbps↓
300Mbps↓
600Mbps↓
1.2Gbps↓
20Gbps↓
CAT3
CAT4
CAT6
CAT11/12
CAT16/18
CAT "X"
2008/9: Rel. 8/9
2011/12: Rel. 10/11
2014/15: Rel. 13/14
2018/19: Rel. 15/16

Three Forms of QAM

Emphasize that there are two messages

1. $$x_{\text{QAM}}(t) = 3\sqrt{2}\cos(2\pi f_c t) + 4\sqrt{2}\sin(2\pi f_c t)$$

$$\Leftrightarrow 3\sqrt{2}\angle 0° + 4\sqrt{2}\angle - 90° \approx 5\sqrt{2}\angle - 53°$$

2. $$\Leftrightarrow 5\sqrt{2}\cos\left(2\pi f_c t + (-53°)\right)$$

Emphasize that the messages are embedded in both amplitude and phase of the carrier

$$e^{jx} = \cos(x) + j\sin(x) \qquad -je^{jx} = -j\cos(x) + \sin(x)$$

$$\cos(x) = \{e^{jx}\} \qquad \sin(x) = \{-je^{jx}\}$$

3. $$x_{\text{QAM}}(t) = 3\sqrt{2}\text{Re}\{e^{j2\pi f_c t}\} + 4\sqrt{2}\text{Re}\{-je^{j2\pi f_c t}\}$$

$$= \sqrt{2}\text{Re}\{(3 - 4j)e^{j2\pi f_c t}\}$$

Emphasize the use of the combined complex-valued representation of the two messages.

Three Forms of QAM

Emphasize that there are two messages

1 $$x_{\text{QAM}}(t) = m_1(t)\sqrt{2}\cos(2\pi f_c t) + m_2(t)\sqrt{2}\sin(2\pi f_c t)$$

$$\Leftrightarrow m_1(t)\sqrt{2}\angle 0^\circ + m_1(t)\sqrt{2}\angle - 90^\circ$$

$$= E(t)\sqrt{2}\angle\phi(t)$$

2 $$\Leftrightarrow \sqrt{2}E(t)\cos\left(2\pi f_c t + \phi(t)\right)$$

Emphasize that the messages are embedded in both amplitude and phase of the carrier

$$e^{jx} = \cos(x) + j\sin(x) \qquad -je^{jx} = -j\cos(x) + \sin(x)$$

$$\cos(x) = \left\{e^{jx}\right\} \qquad \sin(x) = \left\{-je^{jx}\right\}$$

3 $$x_{\text{QAM}}(t) = m_1(t)\sqrt{2}\text{Re}\left\{e^{j2\pi f_c t}\right\} + m_2(t)\sqrt{2}\text{Re}\left\{-je^{j2\pi f_c t}\right\}$$

$$= \sqrt{2}\text{Re}\left\{\left(m_1(t) - jm_2(t)\right)e^{j2\pi f_c t}\right\}$$

Emphasize the use of the combined complex-valued representation of the two messages.