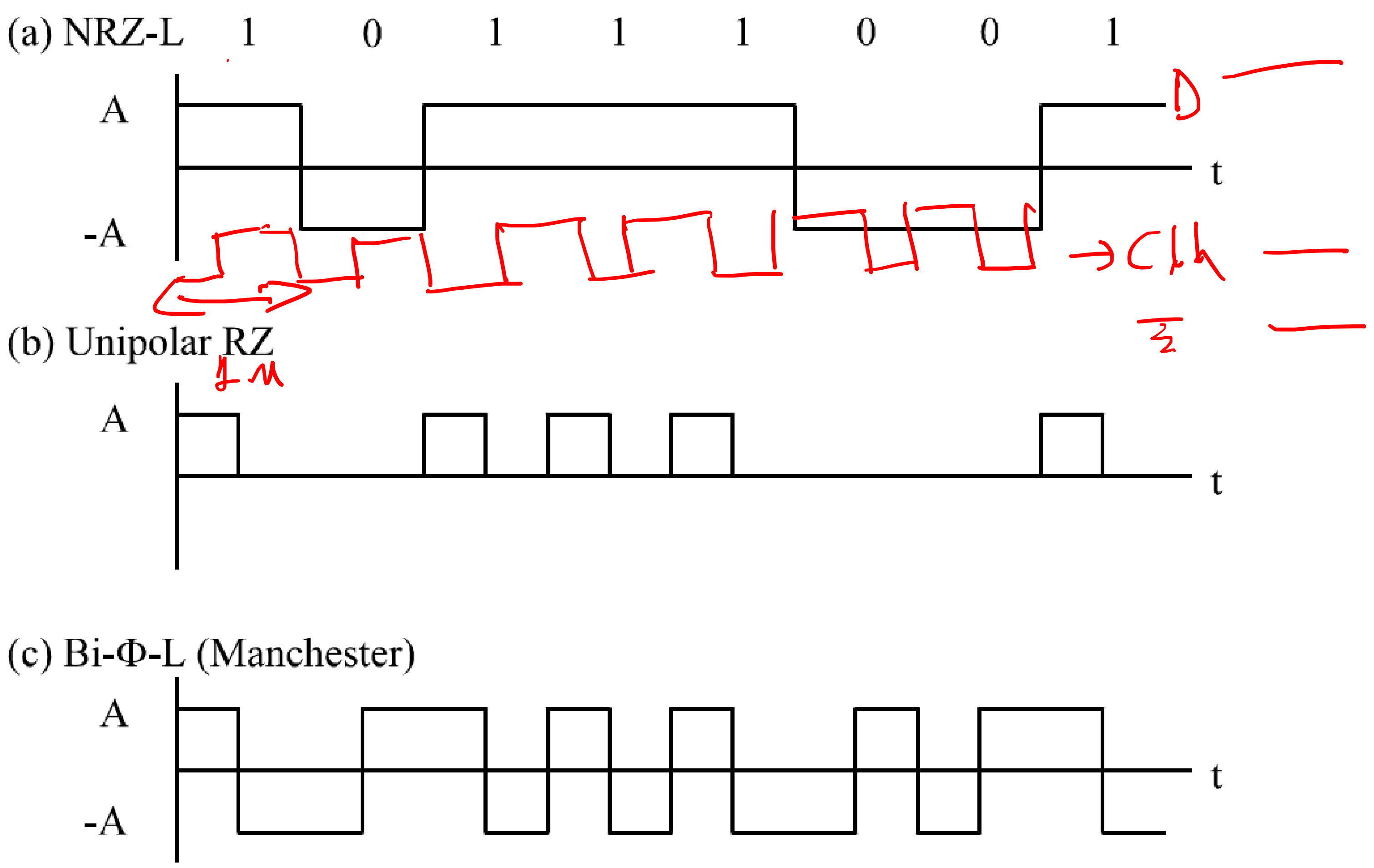
SI-2024 Introduction to CubeSat and Satellite Communication

Satellite Communication System

27th June 2024

SiliconTech

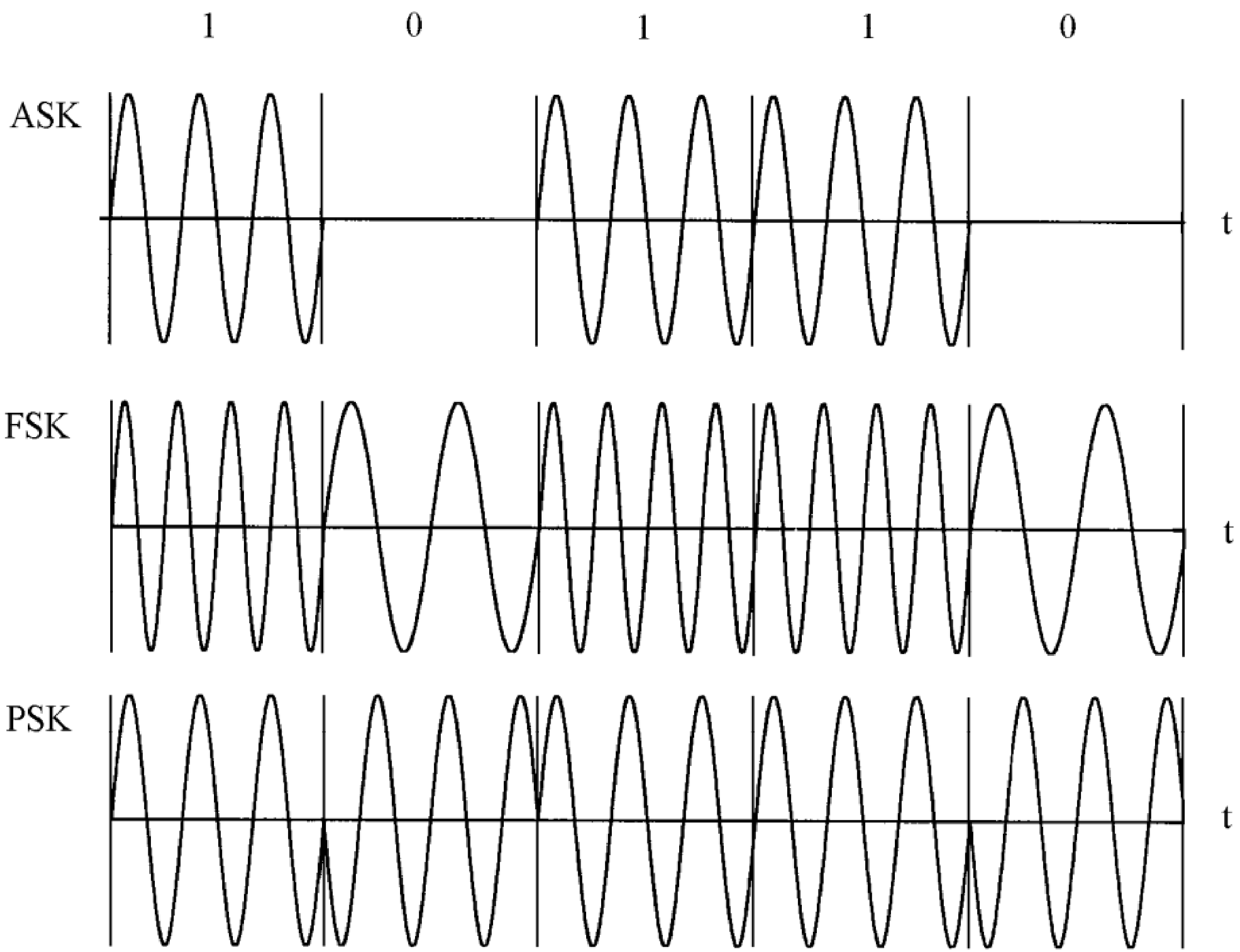
Basic Digital Modulation Methods



a) **Nonreturn to zero-level (NRZ-L)** modulation which represents a symbol 1 by a positive square pulse with length T and a symbol 0 by a negative square pulse with length T.
b) The second one is the **unipolar return to zero** modulation with a positive pulse of T/2 for symbol 1 and nothing for 0.
c) The third is **the biphase level or Manchester modulation** which uses a waveform consisting of a positive first-half T pulse and a negative second-half T pulse for 1 and a reversed waveform for 0.

Source: Xiong, "Digital Modulation Techniques"

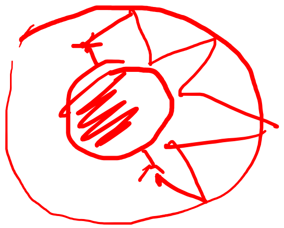
Basic Bandpass Modulation (Carrier Modulation)

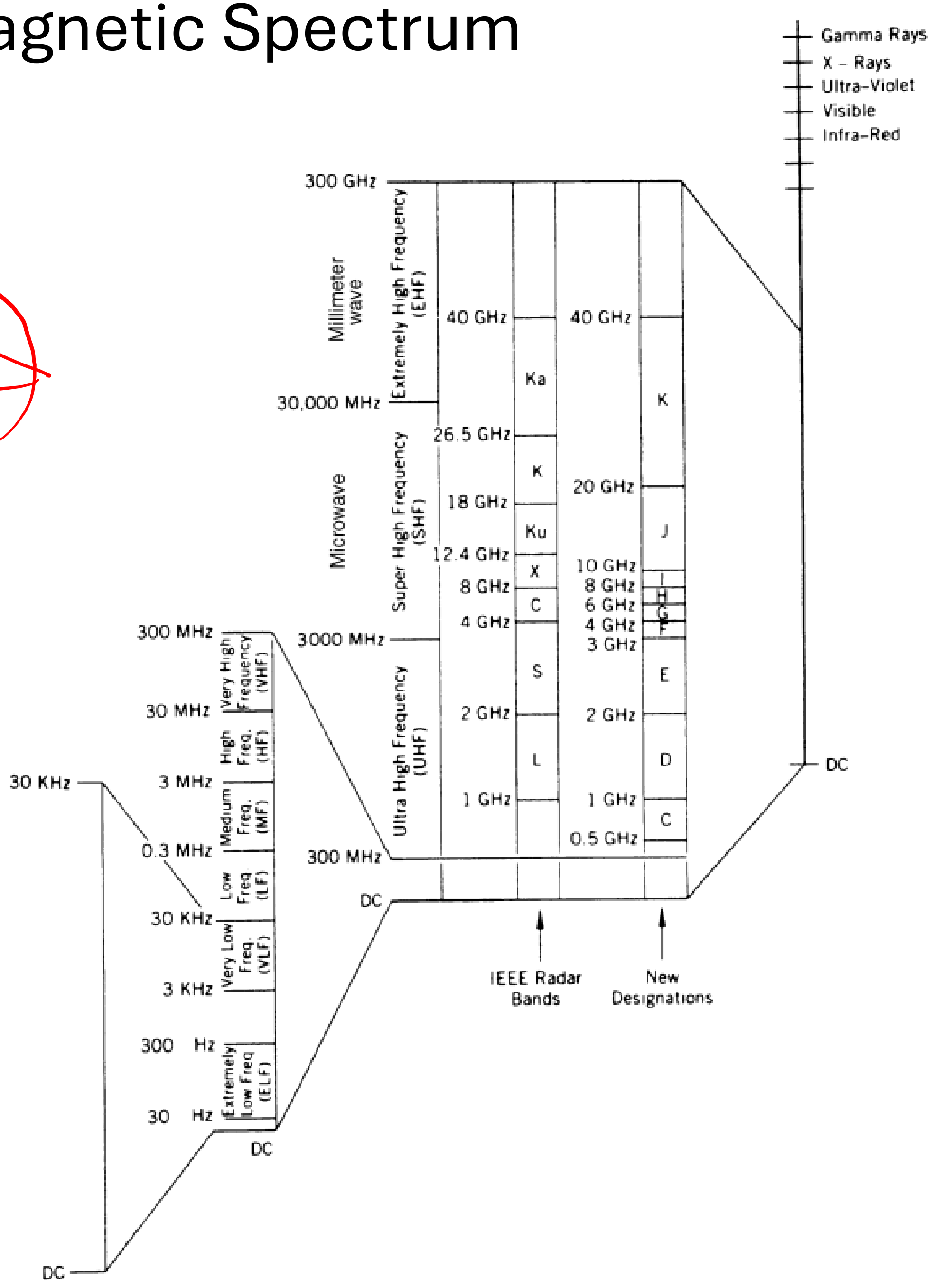


a) Amplitude Shift Keying (ASK), the modulator puts out a burst of carrier for every symbol 1, and no signal for every symbol 0.
b) FSK, for symbol1 a higher frequency burst is transmitted and for symbol 0 a lower frequency burst is transmitted.
c) In PSK, a symbol 1 is transmitted as a burst of carrier with 0 initial phase while a symbol 0 is transmitted as a burst of carrier with 180◦ initial phase

Source: Xiong, "Digital Modulation Techniques"

Electromagnetic Spectrum





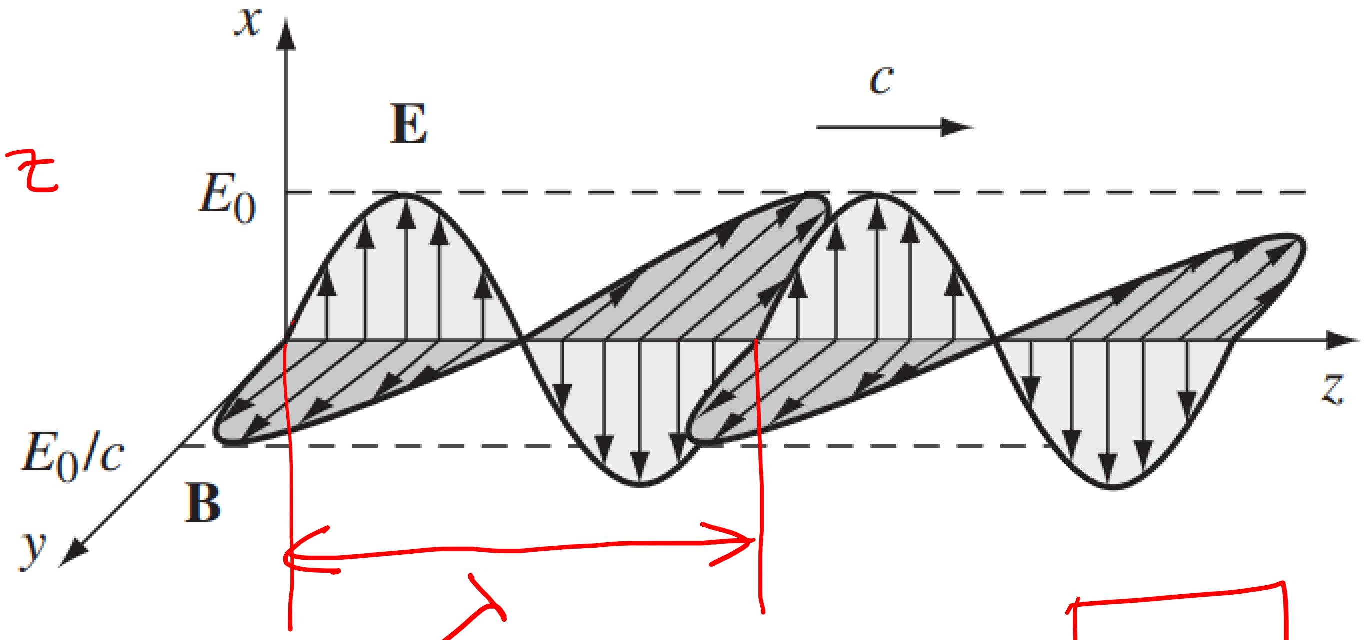
Source: Chang, “Ri

Frequencies	Band	Characteristics	Services
3 Hz–30 kHz	ELF, VLF	High atmospheric noise, Earth-ionosphere waveguide modes, very inefficient antennas	Submarine, navigation, sonar, long-range navigation
30–300 kHz	LF	High atmospheric noise, Earth-ionosphere waveguide modes, absorption in the ionosphere	Long-range navigational beacons
0.3–3 MHz	MF	High atmospheric noise, good ground wave propagation, Earth magnetic field cyclotron noise	Navigation, maritime communication, AM broadcasting
3–30 MHz	HF	Moderate atmospheric noise, ionosphere reflections that provide long-distance links, affected by solar flux density	International shortwave broadcasting, ship-to-shore, telephone, telegraphy, long-range aircraft communication, amateur radio
30–300 MHz	VHF	Some ionosphere reflections at the lower range, meteor scatter possible, normal propagation basically line of sight	Mobile, television, FM broadcasting, air-traffic control, radio navigation aids, land-mobile communications
0.3–3 GHz	UHF	Basically line-of-sight propagation, efficient portable antennas	Television, radar, land-mobile communications, satellite communications, Global Positioning Satellite (GPS), PCS, wireless local-area networking, mobile phones
3–30 GHz	SHF	Line-of-sight propagation, atmospheric absorption at upper frequencies	Radar, microwave links, land-mobile communication, satellite communication, UWB, wireless LANs and PANs, fixed broadband, 3G PCS
30–300 GHz	EHF	Line-of-sight propagation, very subject to atmospheric absorption	Radar, secure and military communication, satellite links, mm-wave personal-area networking
300–10^7 GHz	IR—optics	Line-of-sight propagation, very subject to atmospheric absorption	Optical communications, fiber optical links

Electromagnetic Wave

$f = \underline{300\ MHz}$

$c = 3\times10^8\ m/s$



$10 \rightarrow 100\ cm$

$3GHz \rightarrow \boxed{10cm}$

$\lambda = \frac{c}{f} \frac{3\times10^8 m/s}{3\times10^8 /s} = \boxed{1m} = 100cm.$

$433 MHz \rightarrow 80\ cm$

$40\ cm$

$20\ cm$

$30MHz \rightarrow \boxed{10m}$

$3\ MHz \rightarrow \underline{100\ m}$

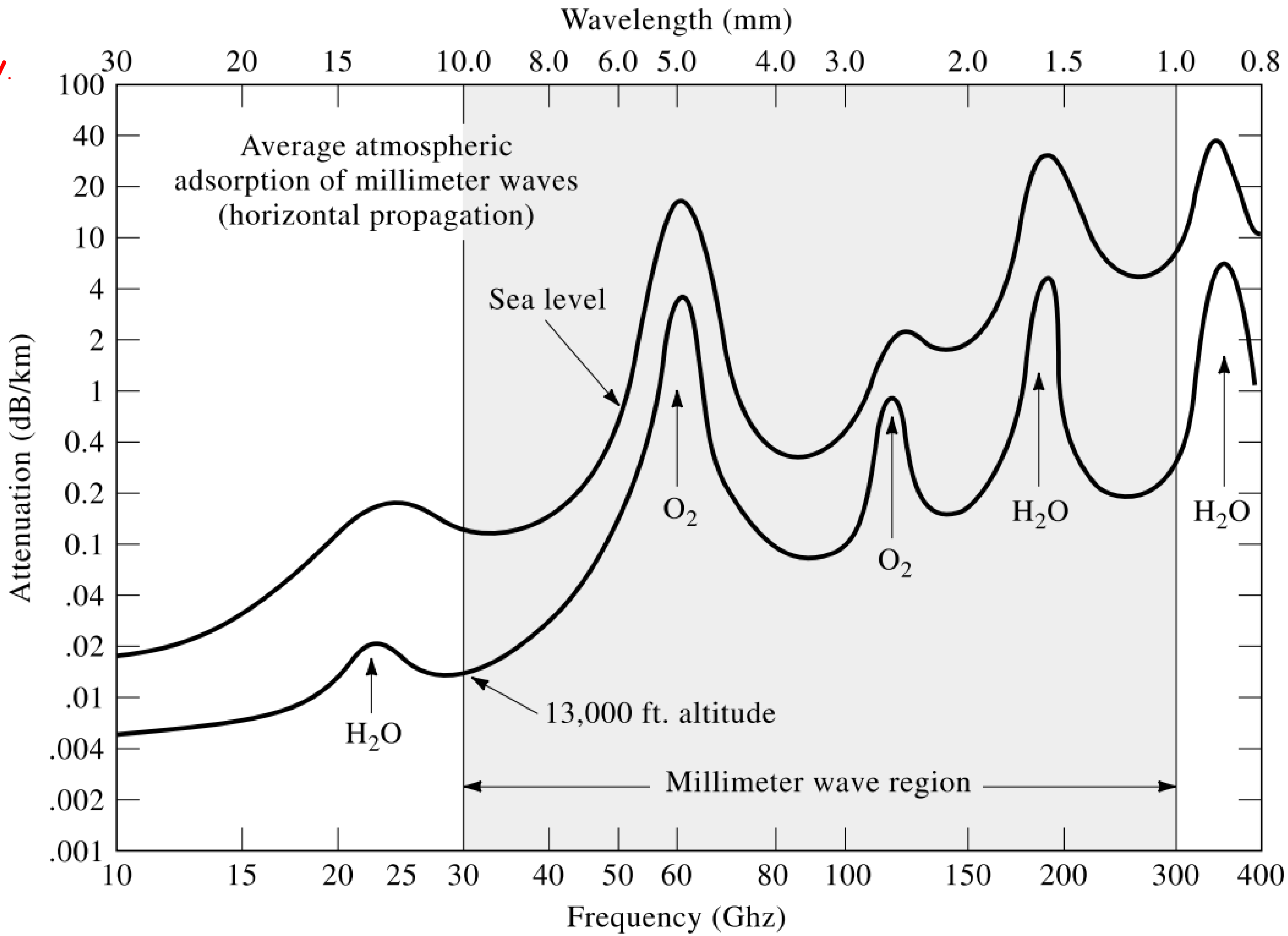
$\frac{\lambda}{2}, \frac{\lambda}{4}$

Atmospheric Attenuation for mmWave Signals

1V → 1mV

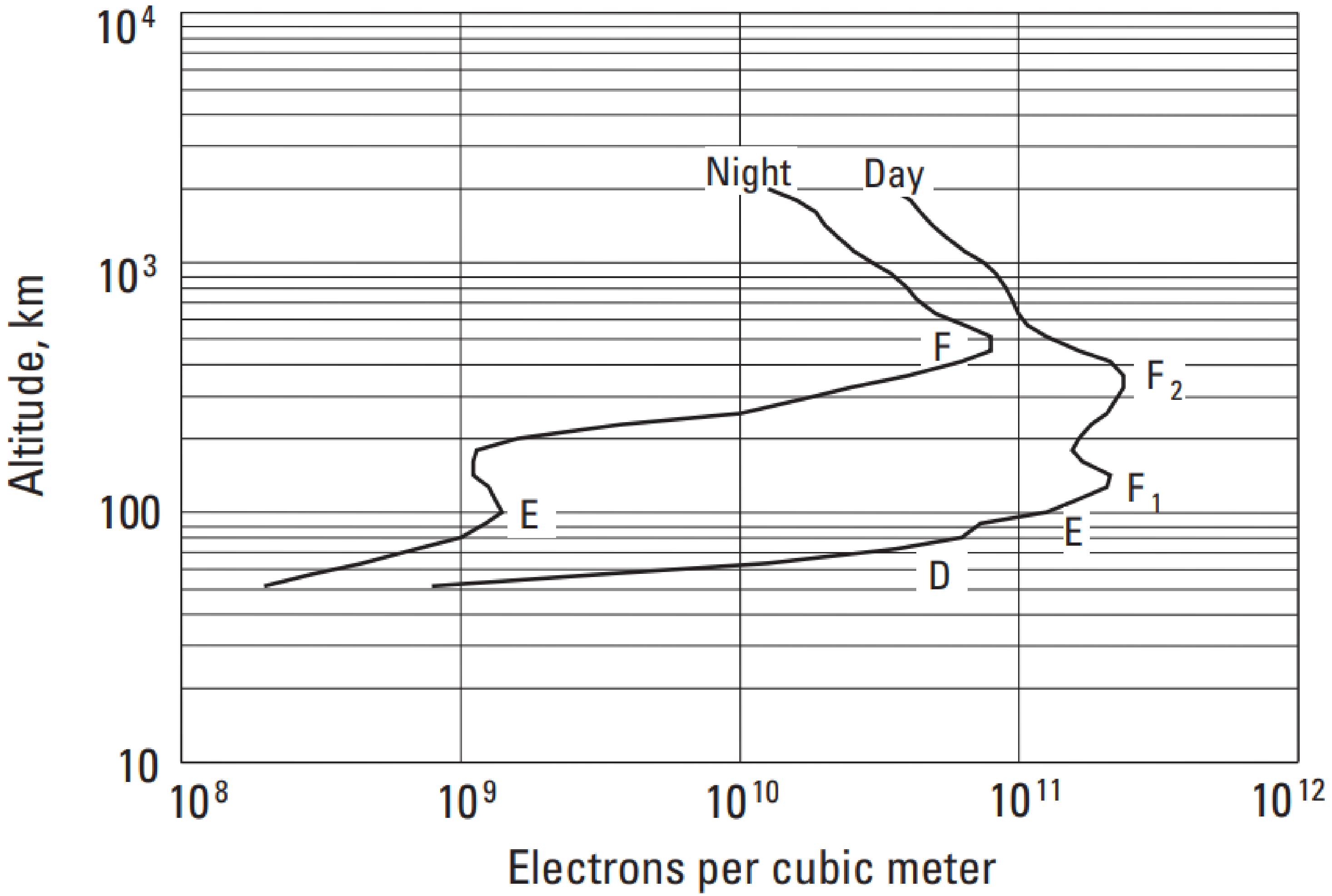
$20 \log \left(\frac{1mV}{1V} \right)$

$-60dB$



Source: Chang, "RF and Microwave Wireless Systems"

Electron Density Profile of Ionosphere



Source: Chang, "RF and Microwave Wireless Systems"

Carrier Frequency Selection Criteria

a) **Power Efficiency**: The bit error rate or bit error probability of a modulation scheme is inversely related to Eb/No, the bit energy to noise spectral density ratio.
b) **Bandwidth Efficiency**: The bandwidth efficiency is defined as the number of bits per second that can be transmitted in one Hertz of system bandwidth.
c) **System Complexity**: System complexity refers to the number of circuits involved and the technical difficulty of the system.
d) **Frequency allocation and regulation**.

Source: Xiong, "Digital Modulation Techniques"

Satellite Orbit Fundamentals

- Satellite Orbit follows Kepler Laws: $T = \dfrac{2\pi R_a^{1.5}}{\sqrt{\mu_{\oplus}(1 + m_a)}}$

T: *orbit time – period,*
R_a: *major elliptical distance from earth center,*
$\mu_{\oplus}$: *earth gravitation parameter,*
m_a: *ratio of weight earth and satellite*

- Velocity from a distance r from the center of Earth:

$\boxed{433 \text{ MHz} + 100 \text{ KHz}}$

v_a

$$v_a = \sqrt{\mu_{\oplus}\left[\frac{2}{r} - \frac{1}{R_a}\right]}$$

- Doppler effect

$\log(2 \times 10^5)$

$20 \log(2) + 20 \log 5$

$3 + 100 = 103$

$+32$

136

$\log(2) = 3$

- Path Loss (dB): $F = 32.4479 + 20\log(fD_s)$

5×4
20, $\times 10^4$
2×10^5

- Ds in km, f in MHz

$f = 400$ MHz

$D_s = 500$ km.

$= 32.44 + 106$

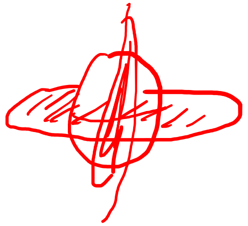
$= 138.448$

$\frac{138}{20} = 6.9$

10^7

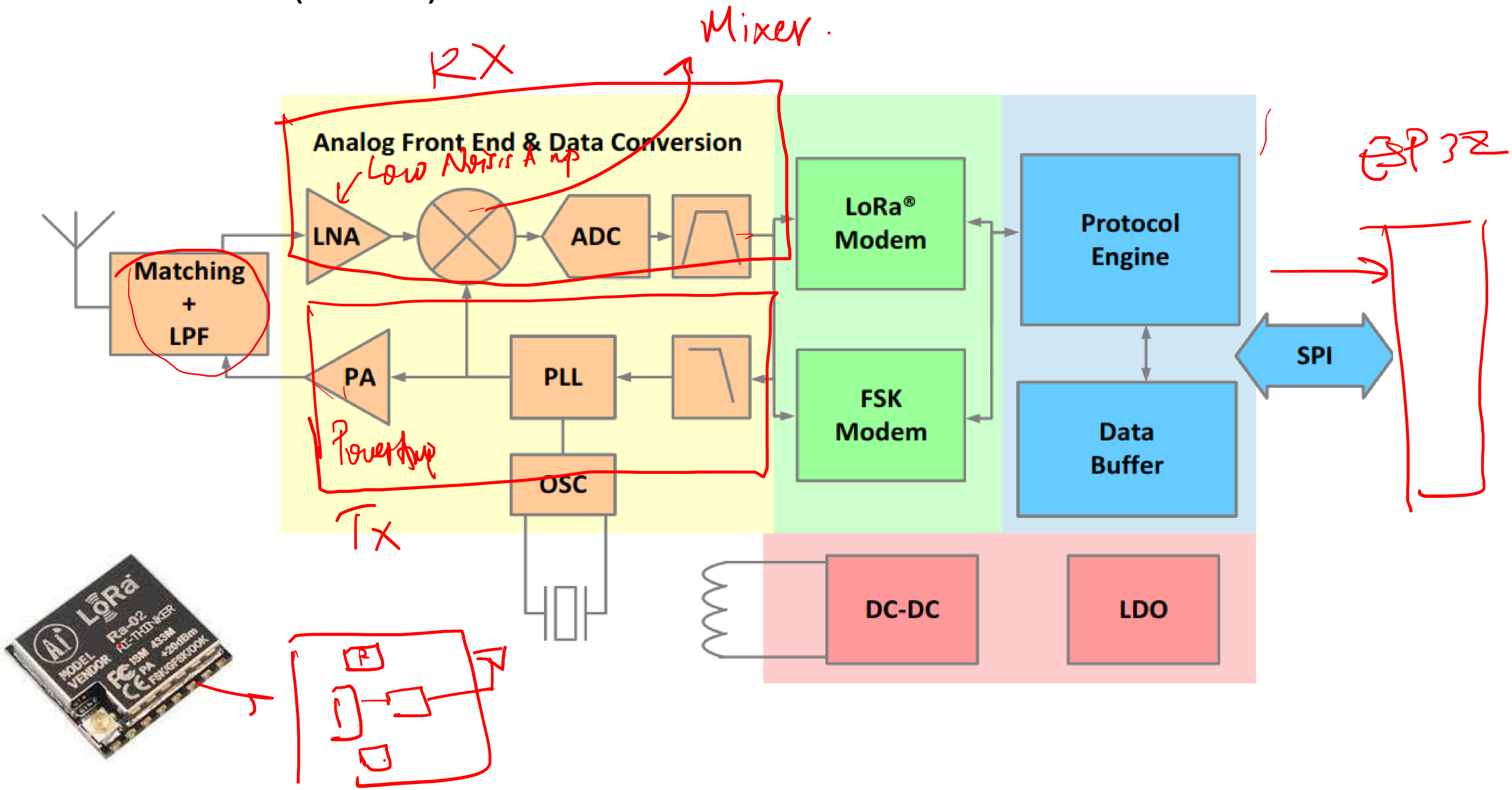
$=$

Four Types of Orbits

Orbital Element	LEO	MEO	GEO	EEO
Satellite	Iridium	GPS	INTELSAT	Molniya
Epoch  (revolution of epoch)	2006 231.40822226 (rev 48,635)	2006 230.32290049 (rev 11,658)	2006 230.72851175 (rev 74,158)	2006 230.72851175 (rev 412)
Orbital inclination	86.4009°	54.76780°	0.01080°	62.08880°
RAAN	171.4706°	263.9384°	1.62870°	214.5329°
Argument of perigee	77.8669°	155.0343°	148.7212°	266.2404°
Eccentricity	0.0002548	0.0097258	0.00026580	0.7242485
Mean anomaly	282.2821°	205.50360°	129.1125°	16.2853°
Mean motion	14.34216969	2.00563941	1.00274158	2.00707324
Drag	–0.00000e–000	–0.00000e–000	–0.00000e–000	0.00000e–000

Source: Xiong, "Digital Modulation Techniques"

LoRa Transceiver (Radio) Architecture



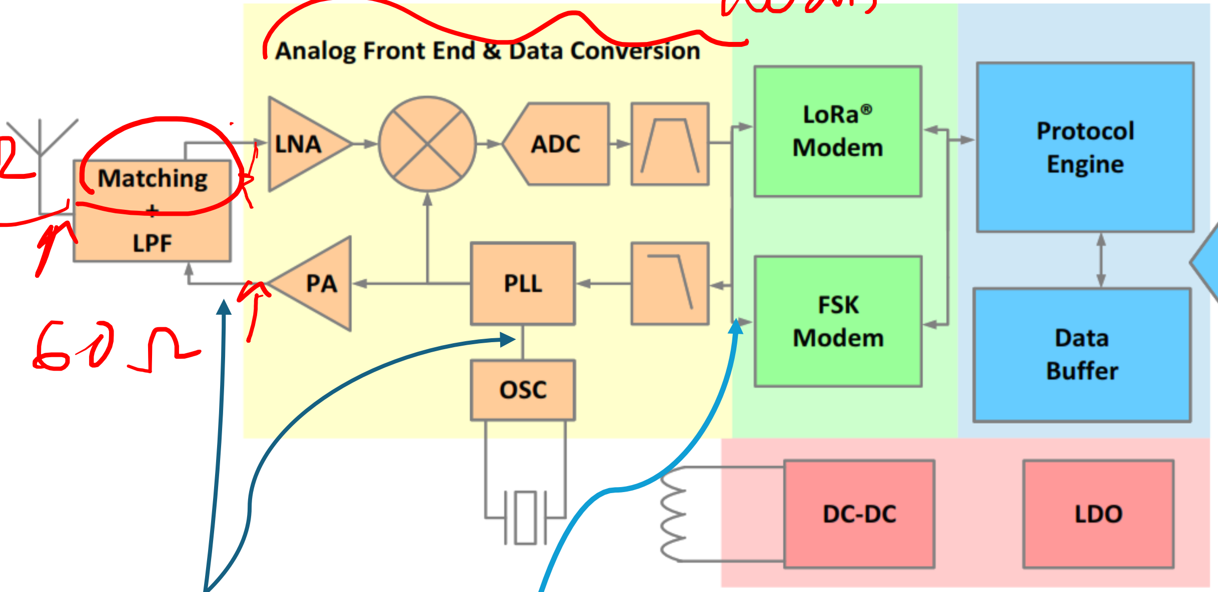
LoRa Transceiver (Radio) Architecture

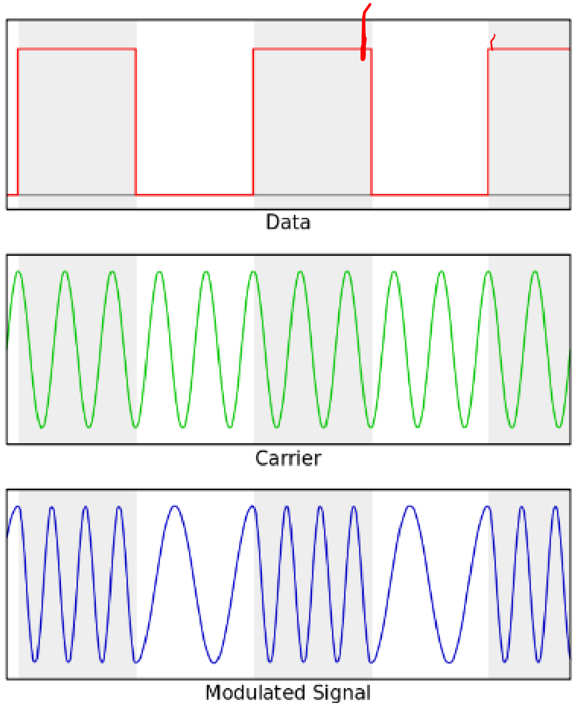
50Ω

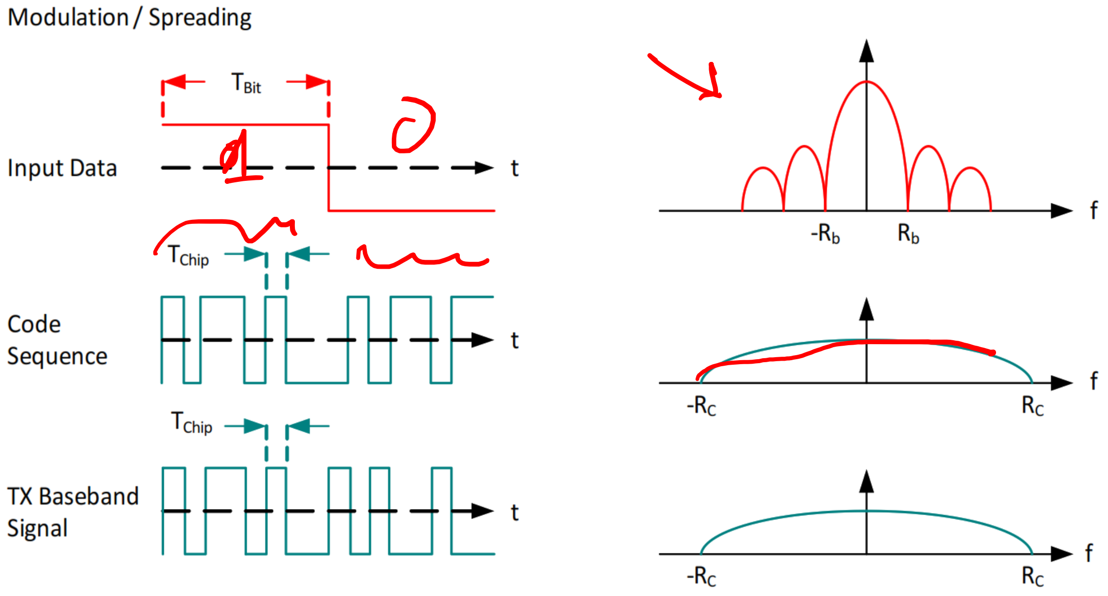
60 + j2Ω − j2Ω

60Ω

100 dB







$V_m = V_c \cdot \cos(\omega_c t) \times 1, 0$

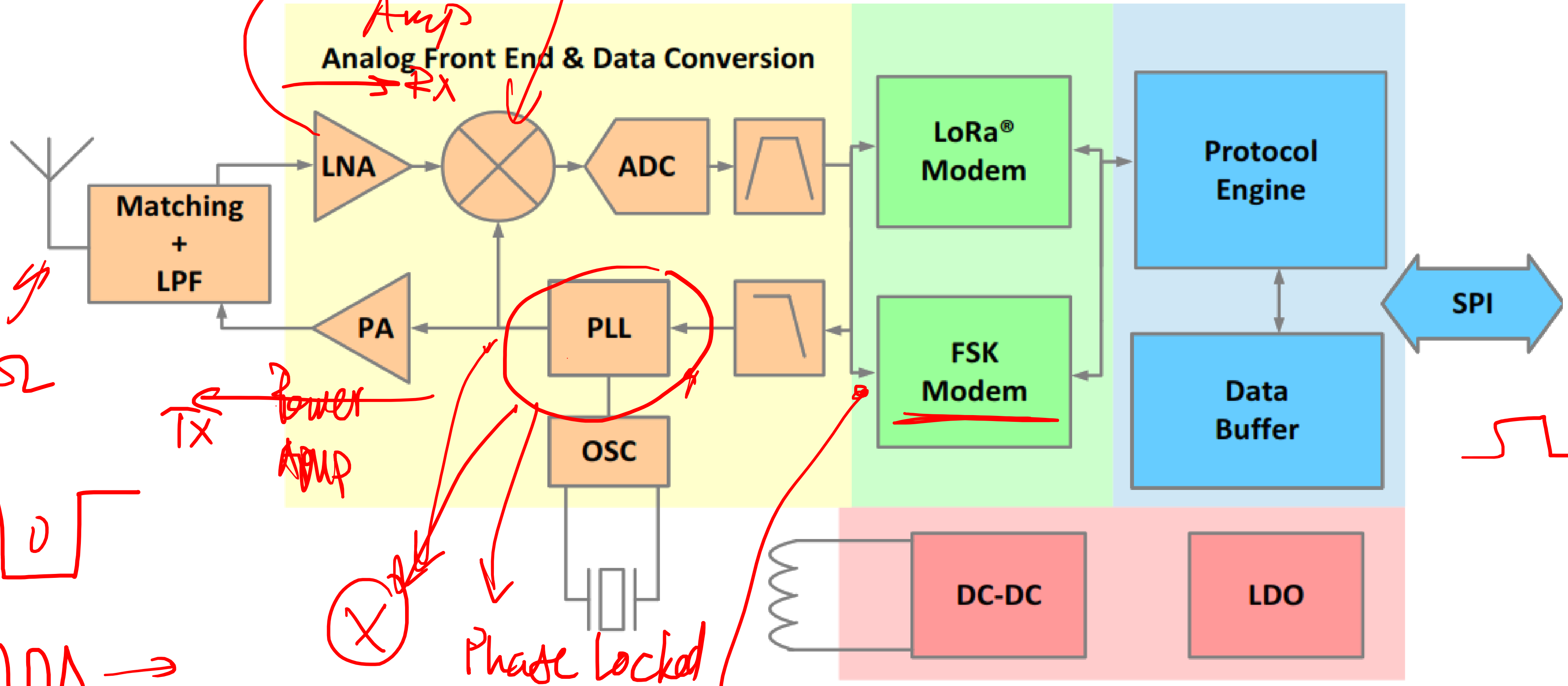
$V_{RX} \cos(\omega_c t) \times \cos(\omega_c' t) = \frac{V_{RX}}{2}(1+\cos 2\omega_c t)$

Mixer

$\cos^2 \omega t \to \frac{1 + \cos 2\omega t}{2}$

Low Noise Amp

RX



50 Ω

Tx

Power Amp

ESP32

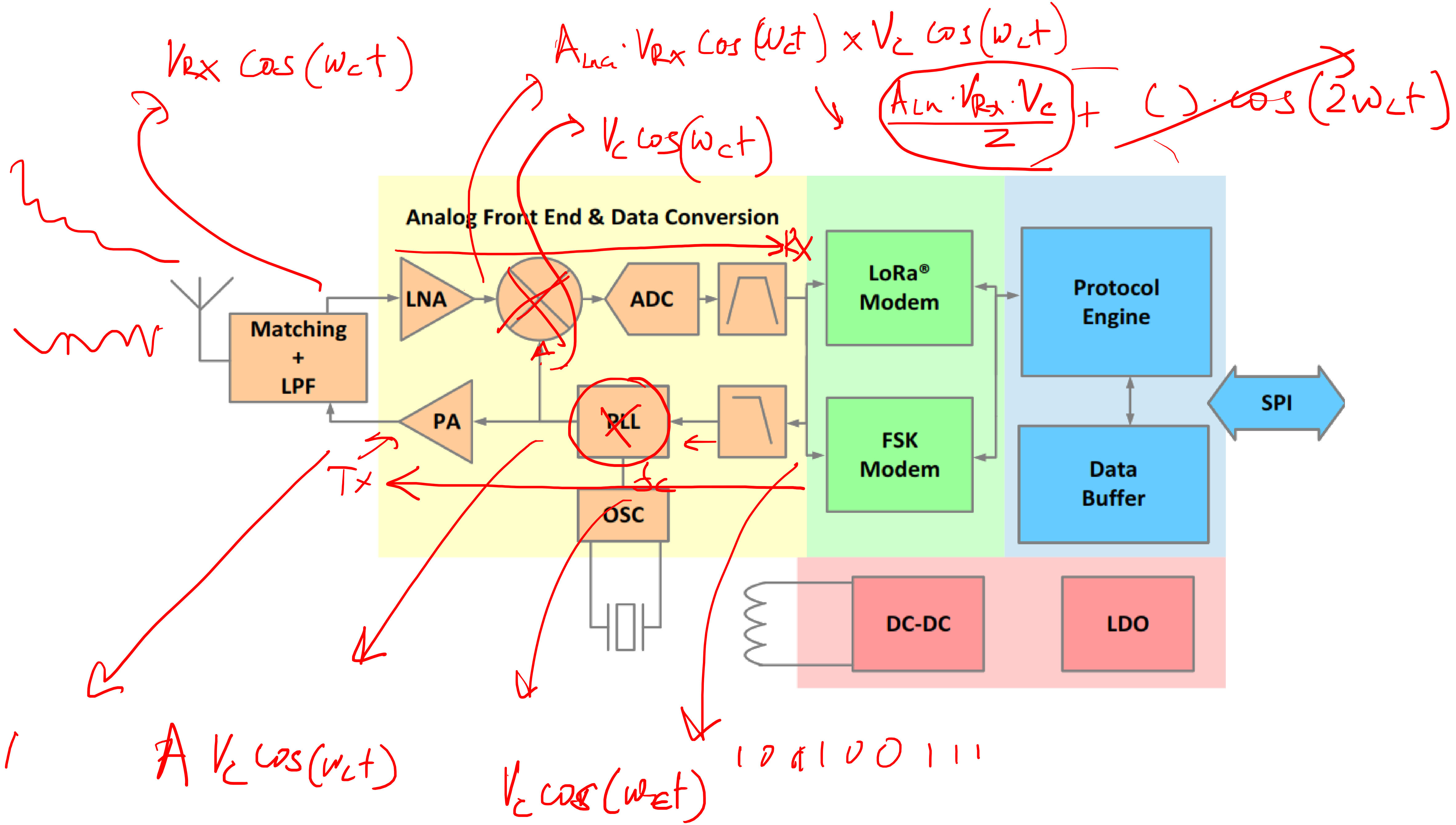
1

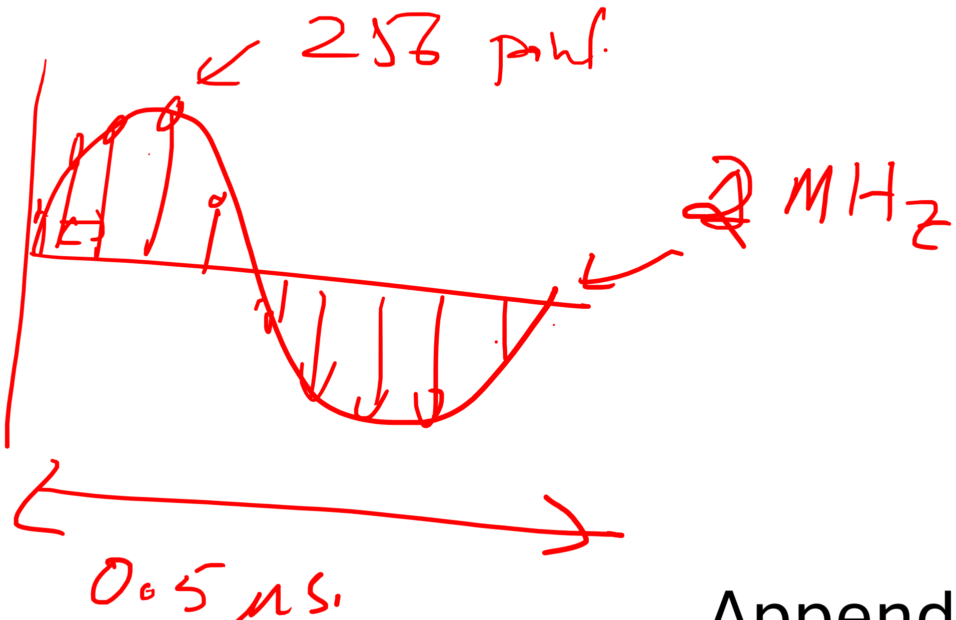
0

x

$V_c \cos(\omega_c t)$

Phase Locked Loop


V_Rx cos(w_c t)
A_LNA · V_Rx cos(w_c t) × V_c cos(w_c t)
V_c cos(w_c t)
A_Ln · V_Rx · V_c / 2 + ( ) · cos(2w_c t)
Analog Front End & Data Conversion
Rx
LNA
ADC
LoRa® Modem
Protocol Engine
Matching + LPF
PA
PLL
FSK Modem
Data Buffer
SPI
Tx
f_c
OSC
DC-DC
LDO
A V_c cos(w_c t)
V_c cos(w_c t)



$$t_s = \frac{0.5\mu s}{256} = \frac{500n}{256} = \underline{2ns}$$

$$t = [0, 2n, 4n, 6n, 8 \ldots \ldots 500ns].$$

$$\underline{f_c} = np.cos(w_c t)$$

Appendix

#!/usr/bin/env python3

$chmod +x <file>

$./<filename>