EE220 - RFIC DESIGN - I

Radio Frequency Integrated Circuits Design - I

Fall 2016, SJSU

Dr. Marshall Wang

- Ph.D. Rensselaer Polytechnic Institute
- 25+ years in RFIC industry
- 10 years RFIC start-up – the first wireless gamepad provider
- Over 40 millions devices sold in market

Aarthi Ramadhas - ISA

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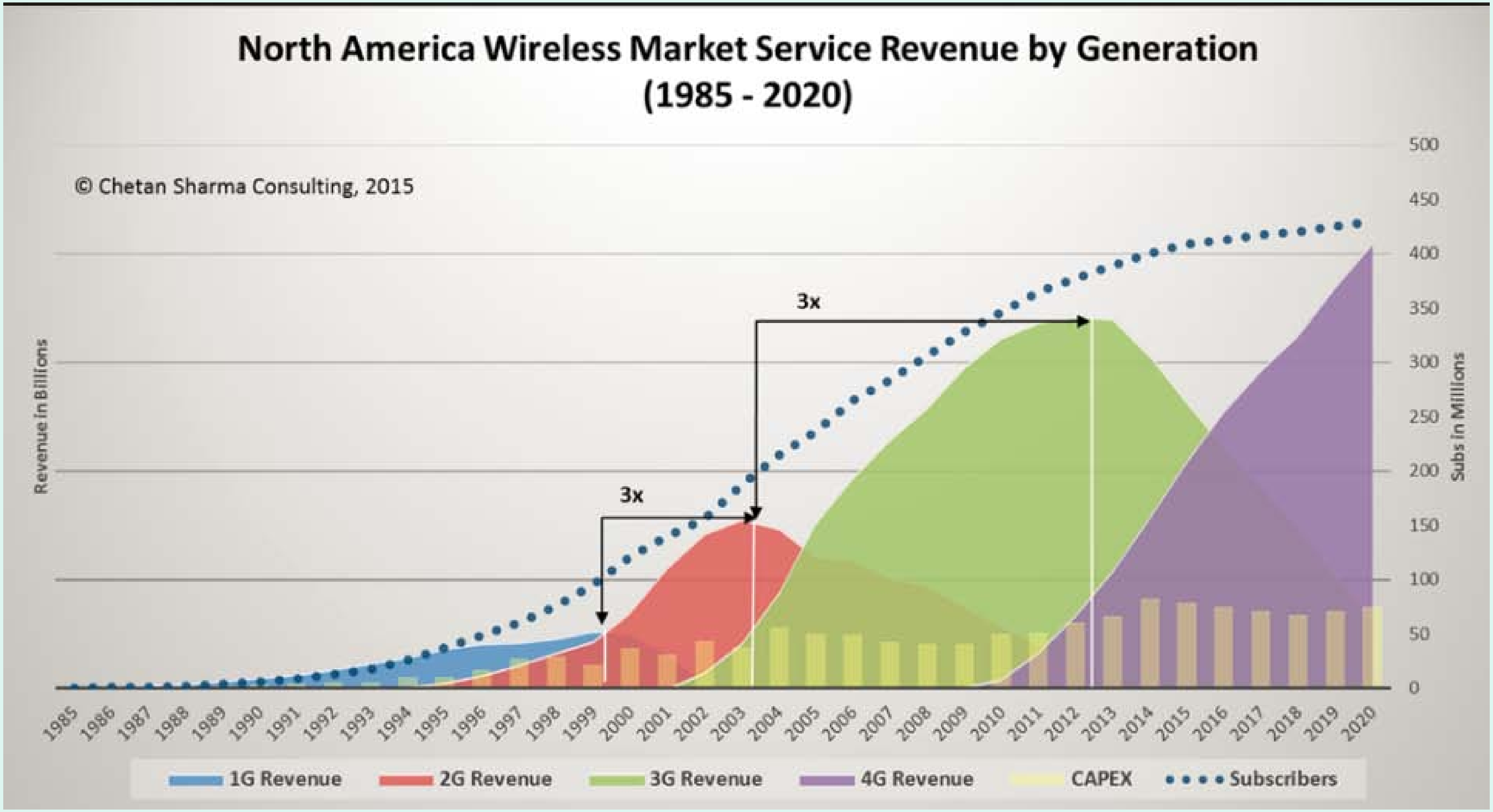
Can you name a wireless standard?

Ubiquitous Wireless Communication

- People own multiple wireless devices in modern society.
- Constant improvement on power, data-rate, standard, and application.
- Millennials take the wireless connection for granted.
- IOT (InterNet of Things) brings the information highway to the next level.

Wireless Market Growth



What is iBeacon ?

iBeacon

From Wikipedia, the free encyclopedia

iBeacon is a protocol developed by Apple and introduced at the Apple Worldwide Developers Conference in 2013.[1] Various vendors have since made iBeacon-compatible hardware transmitters - typically called beacons - a class of Bluetooth low energy (BLE) devices that broadcast their identifier to nearby portable electronic devices. The technology enables smartphones, tablets and other devices to perform actions when in close proximity to an iBeacon.[2][3]

iBeacon uses Bluetooth low energy proximity sensing to transmit a universally unique identifier[4] picked up by a compatible app or operating system. The identifier and several bytes sent with it can be used to determine the device's physical location,[5] track customers, or trigger a location-based action on the device such as a check-in on social media or a push notification.

One application is distributing messages at a specific Point of Interest, for example a store, a bus stop, a room or a more specific location like a piece of furniture or a vending machine. This is similar to previously used geopush technology based on GPS, but with a much

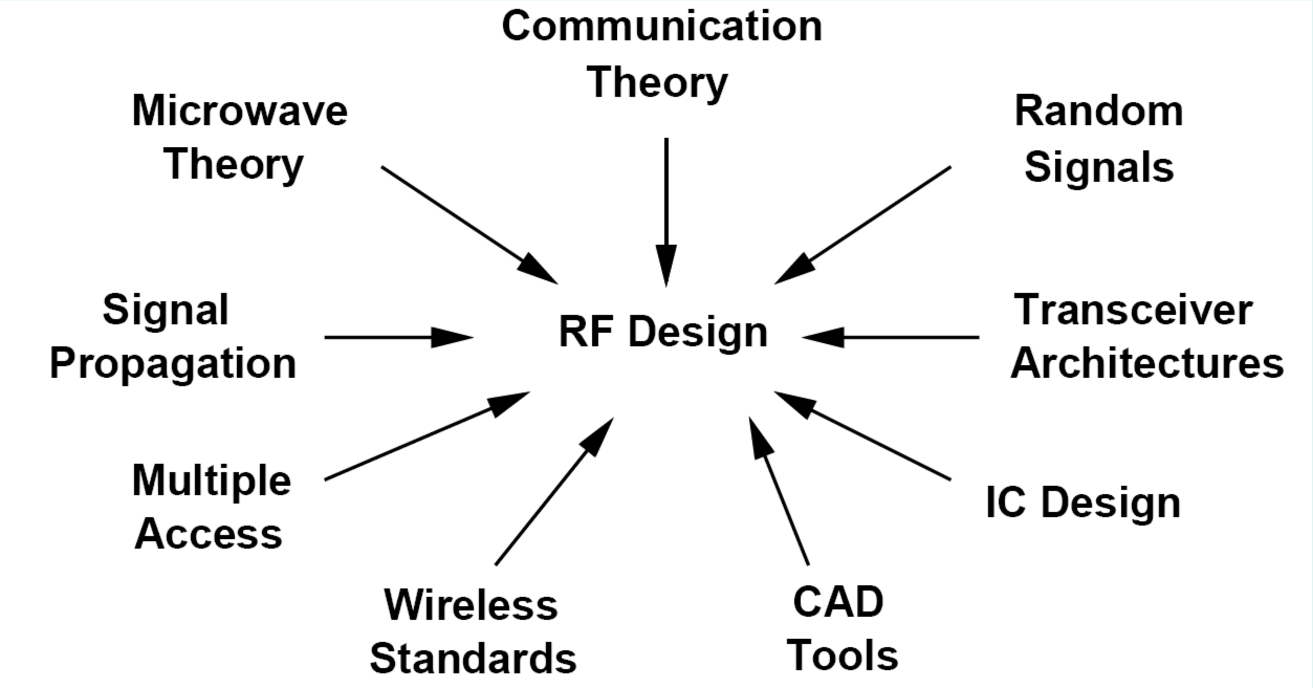
Smartphone detecting an iBeacon transmitter

https://www.youtube.com/watch?v=aIiHfIG_rMQ

What is iBeacon ?

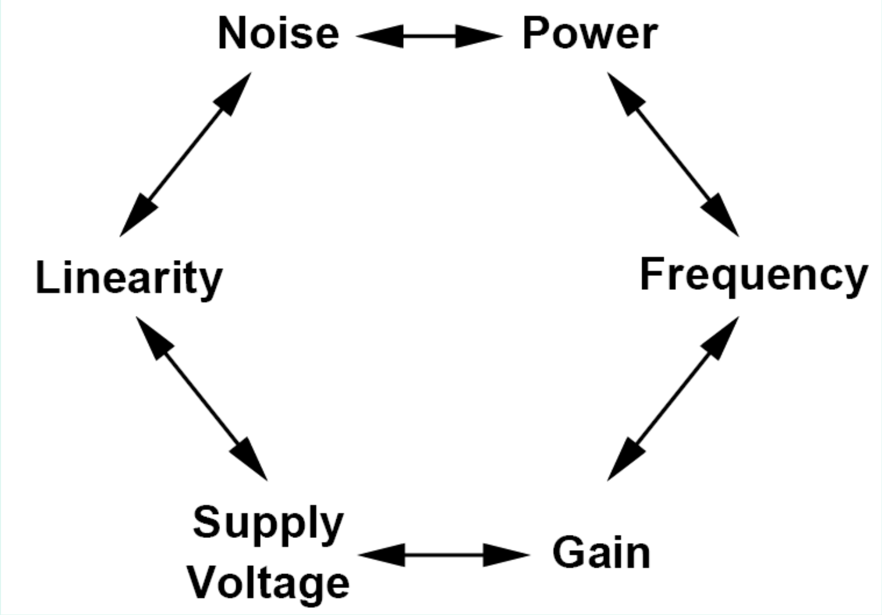
Range is 295 feet.
Battery life 18 months.
$29.00

RF Design is Challenging: Multi-discipline



- RF design draws upon a multitude of disciplines.

RF Design is Challenging: Trade-offs



- RF circuits and transceivers must deal with numerous trade-offs.
- Demand for higher performance, lower cost and greater functionality

What Wireless Companies Need:

Design:
Architecture design
Circuits design
Simulation & Layout
Silicon bring-up and test

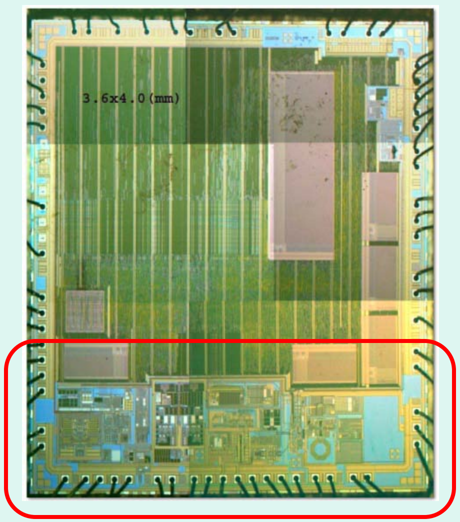
Application:
System validation
Reference design
Application Note
Customer support

Product:
Bench test HW/SW setup
Evaluation PCB design
Package design
Product qualification

Test:
ATE HW/SW setup
Production board design
Yield improvement
Test time reduction

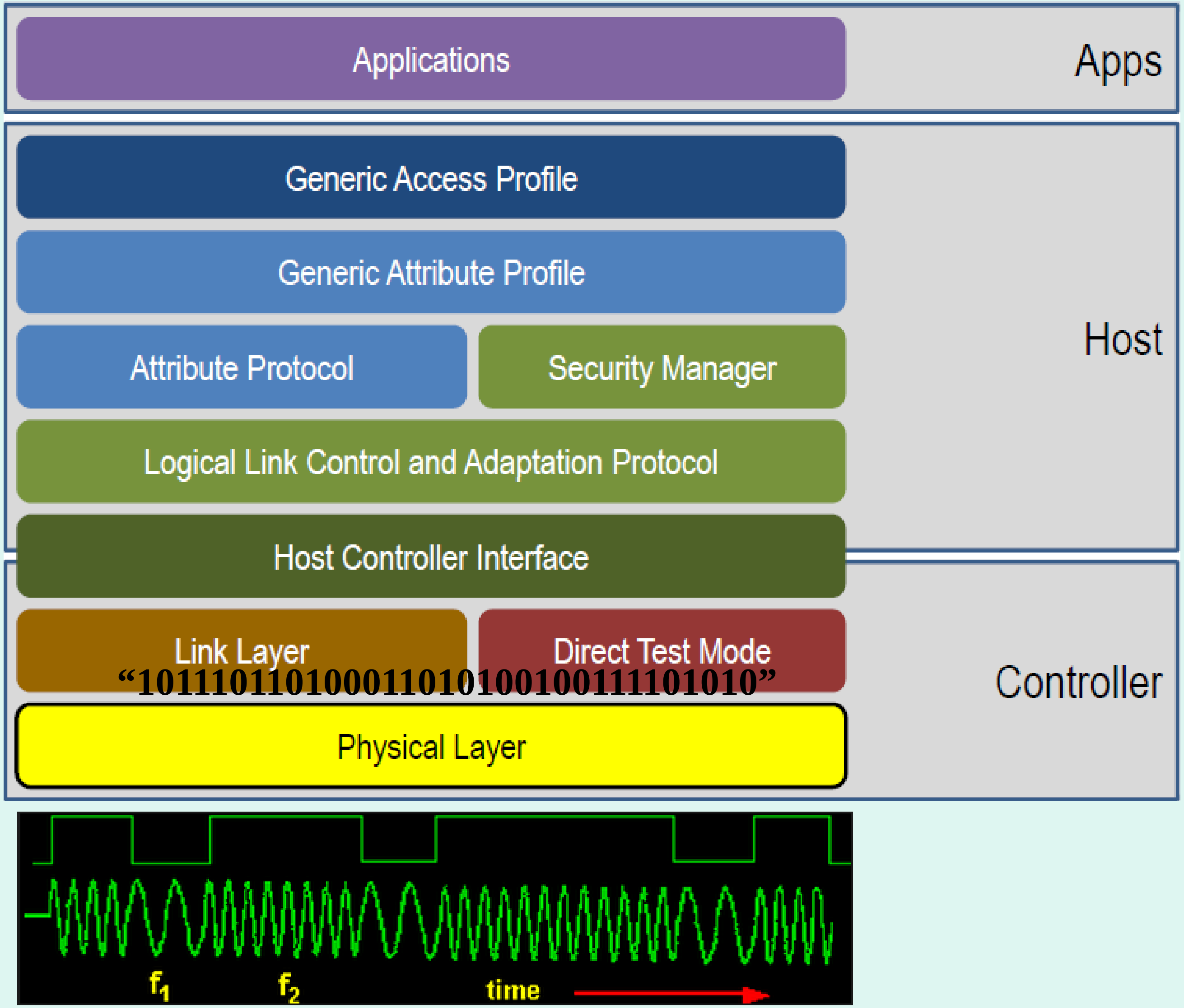
RFIC, SOC, Smartphone

System on Chip (SOC)



RFIC

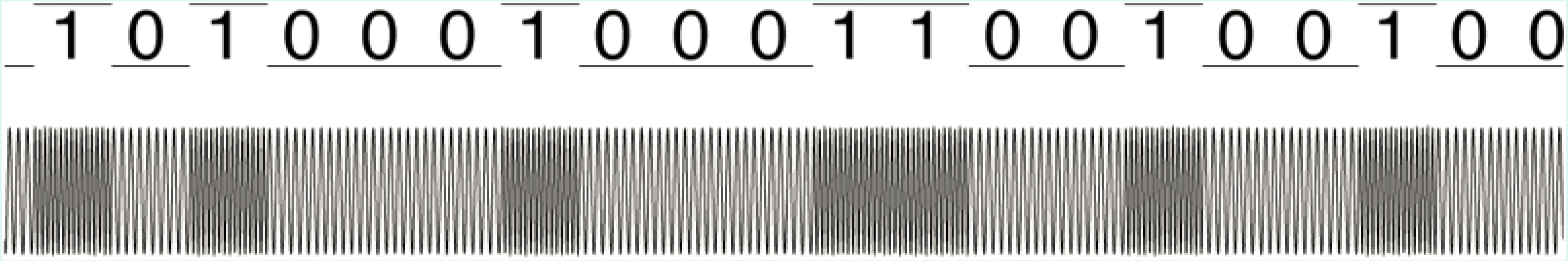
BLE (Bluetooth Low-Energy) System Architecture



Data Modulation

The electromagnetic wave (called **carrier**) is modulated to carry “1” and “0” data.

Amplitude-Shift-Keying (ASK)



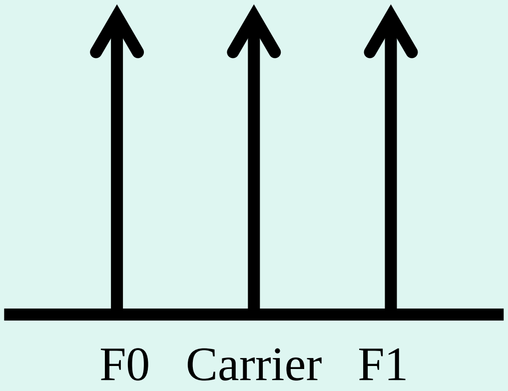
Frequency-Shift-Keying (FSK)

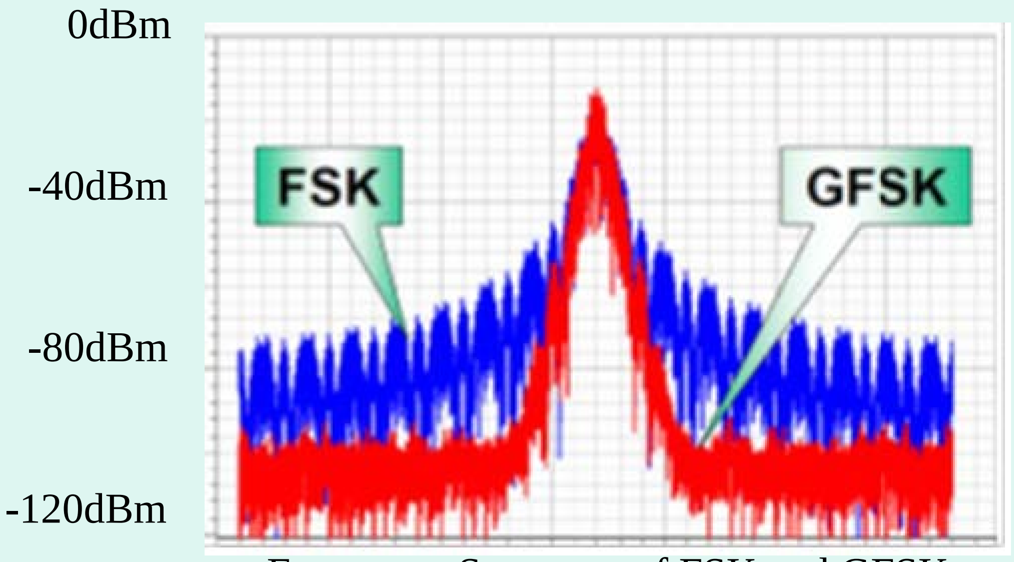
GFSK Modulation in Bluetooth Low-Energy (BLE)

- GFSK modulation is a FSK modulation with a ***Gaussian filter*** to make the transitions smoother to limit its spectral width.
- **Modulation Index**: the ratio of F1-F0 to data rate.

F0 = Carrier – 250KHz, F1 = Carrier + 250KHz, data rate = 1MHz

=> Modulation Index = 0.5 (BLE spec = 0.45 – 0.55)



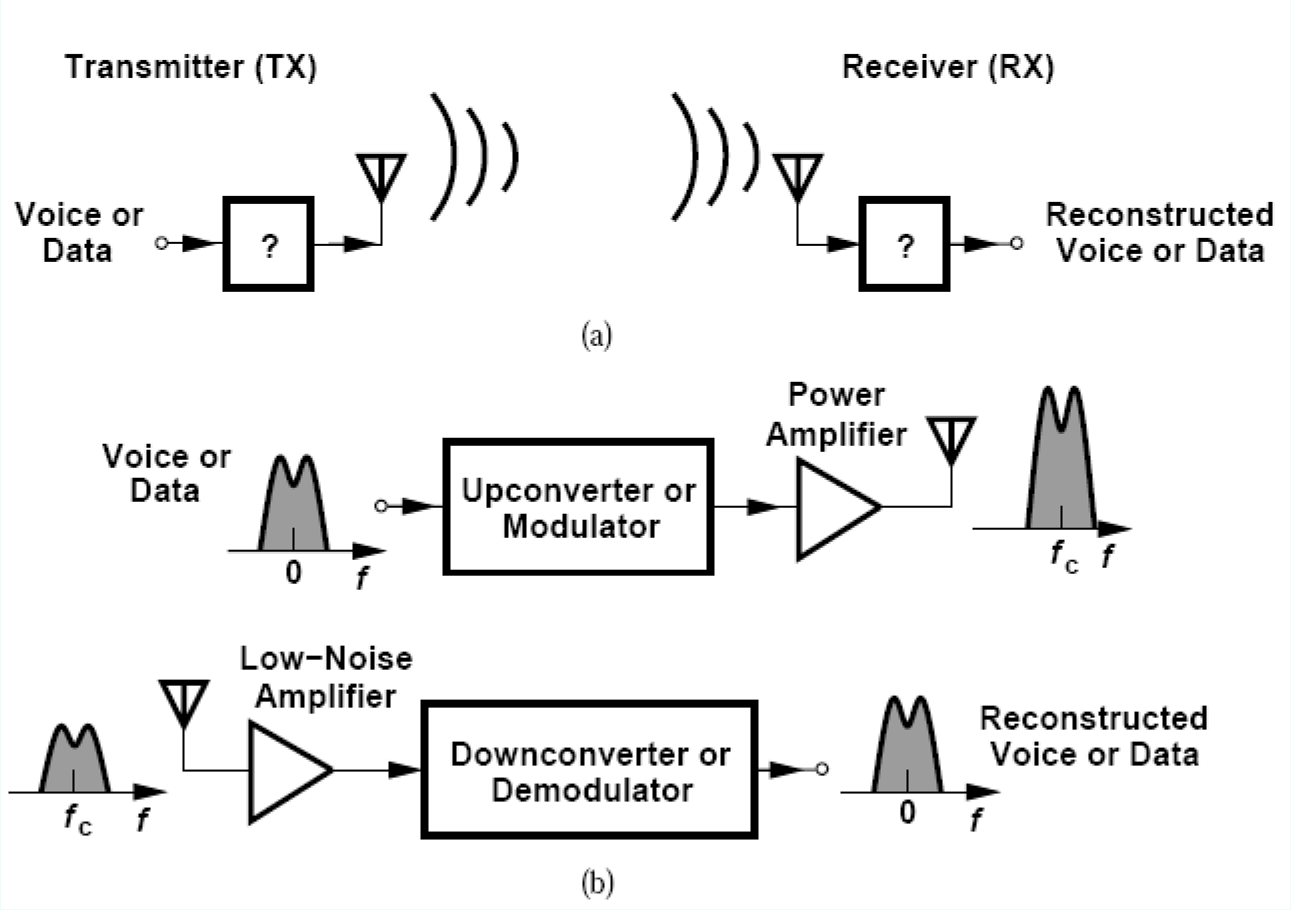


Frequency Spectrum of FSK and GFSK

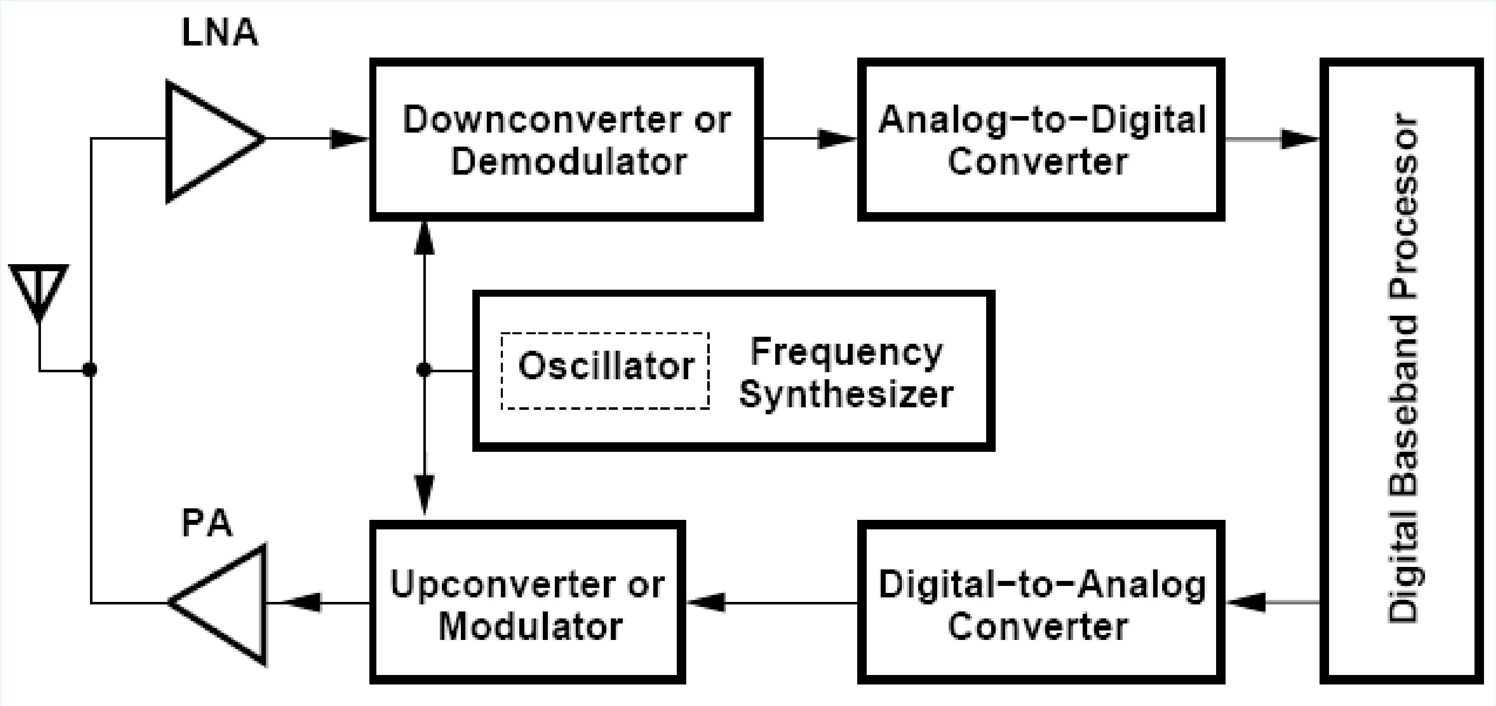
The Big Picture: RF Communication

TX: Drive antenna with high power level

RX: Sense small signal (amplify with low noise)

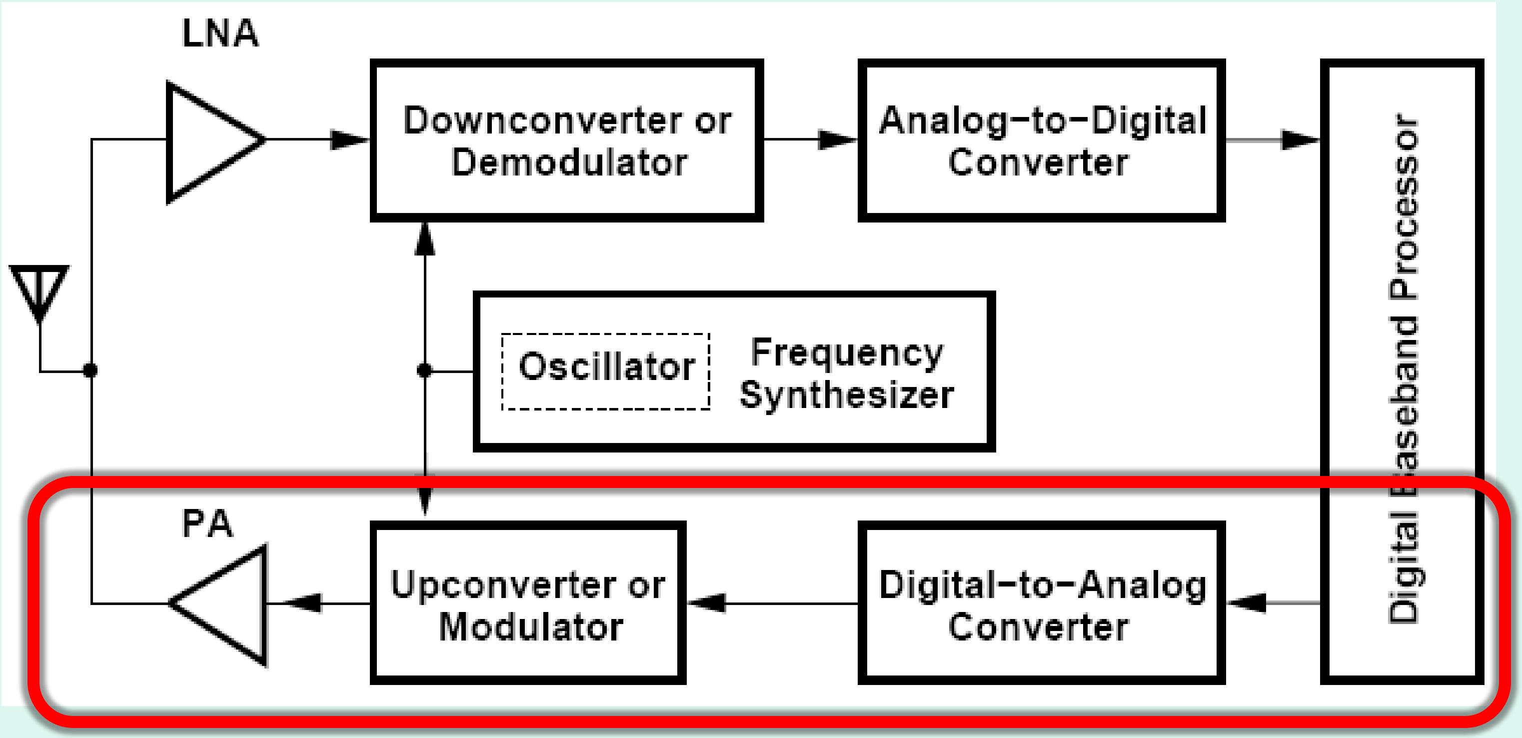


The Big Picture: Generic RF Transceiver

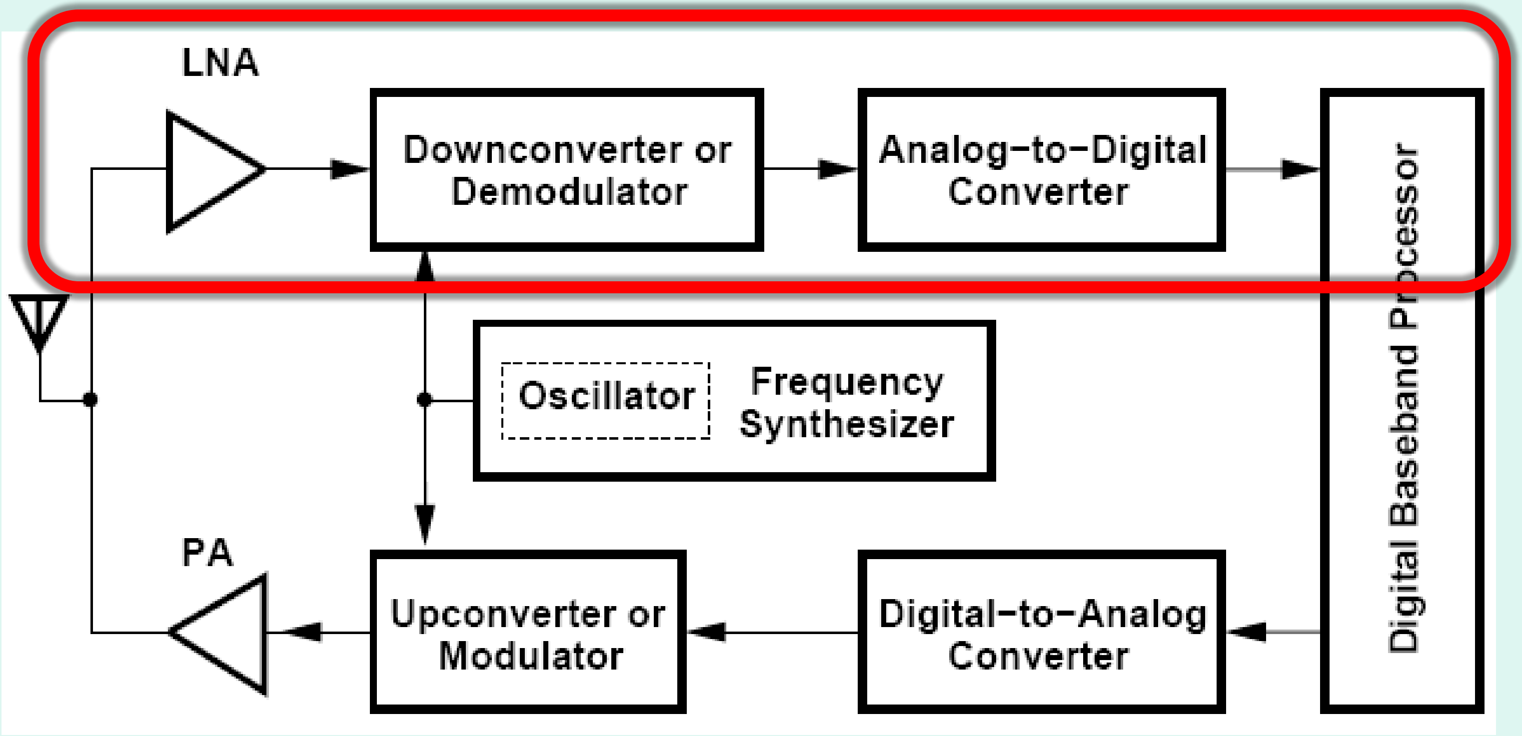


- Signals are upconverted/downconverted at TX/RX, by an oscillator controlled by a Frequency Synthesizer

Transmitter

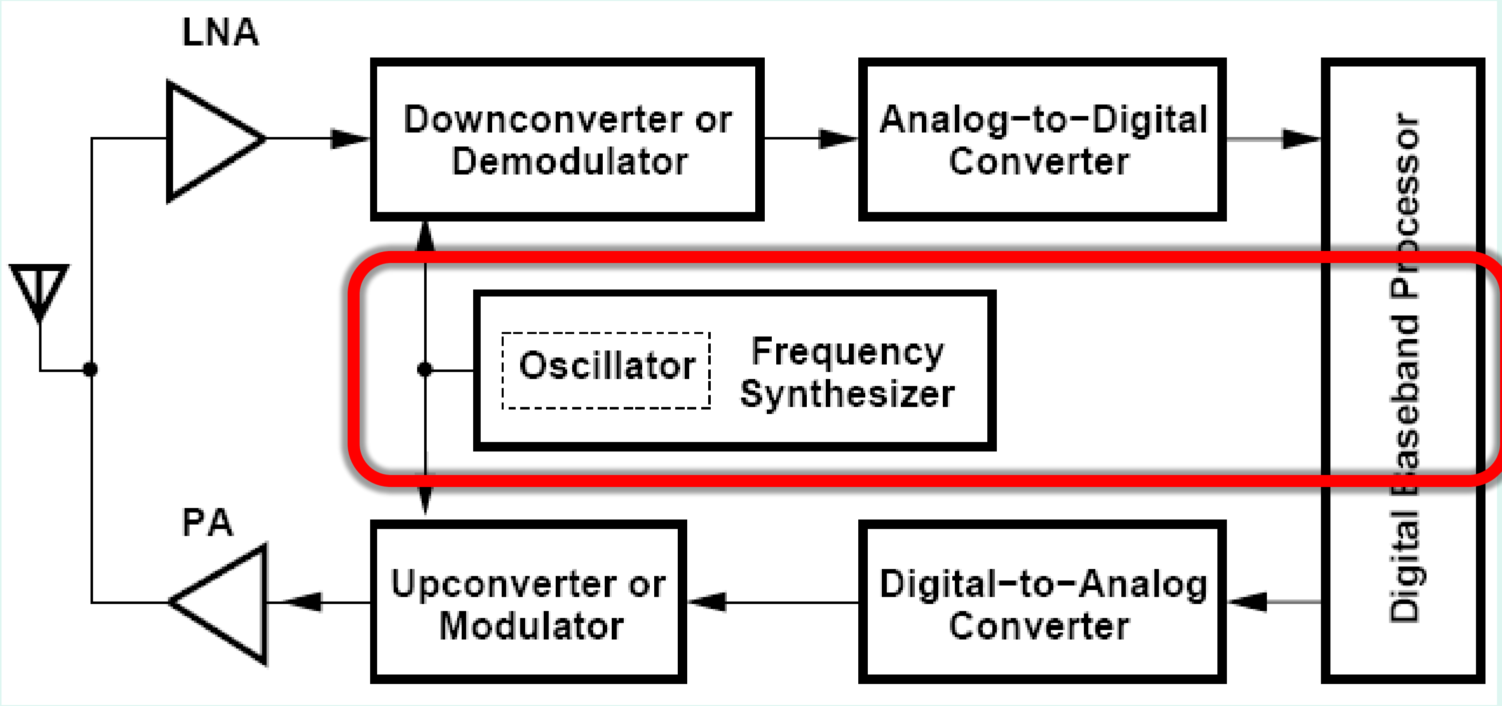


Receiver



LNA
Downconverter or Demodulator
Analog−to−Digital Converter
Digital Baseband Processor
Oscillator
Frequency Synthesizer
PA
Upconverter or Modulator
Digital−to−Analog Converter

Frequency Synthesizer



Real Product in the Market Today

CYPRESS
PERFORM

CYRF8935

WirelessUSB™ NL 2.4 GHz Low Power Radio

Features

- Fully integrated 2.4-GHz radio on a chip
- 1-Mbps over-the-air data rate
- Transmit power typical: 0 dBm
- Receive sensitivity typical: –87 dBm
- Below 1 µA typical current consumption in sleep state
- Closed-loop frequency synthesis
- Supports frequency-hopping spread spectrum
- On-chip packet framer with 64-byte first in first out (FIFO) data buffer
- Built-in auto-retry-acknowledge protocol simplifies usage
- Built-in cyclic redundancy check (CRC), forward error correction (FEC), data whitening
- Supports DC ~ 12-MHz SPI bus interface
- Additional outputs for interrupt request (IRQ) generation

Among the advantages of WirelessUSB NL are its fast lock times and channel switching, along with the ability to transmit larger payloads. Use of longer payload packets, compared to multiple short payload packets, can reduce overhead, improve overall power efficiency, and help alleviate spectrum crowding.

Combined with Cypress's enCoRe™ family of USB and wireless microcontrollers, WirelessUSB NL also provides the lowest bill of materials (BOM) cost solution for PC peripheral applications such as wireless keyboards and mice, as well as best-in-class wireless performance in other demanding applications such as toys, remote controls, fitness, automation, presenter tools, and gaming.

Applications

- Wireless keyboards and mice
- Handheld remote controls
- Wireless game controllers
- Hobby craft control links
- Home automation

What are the key features/specifications?

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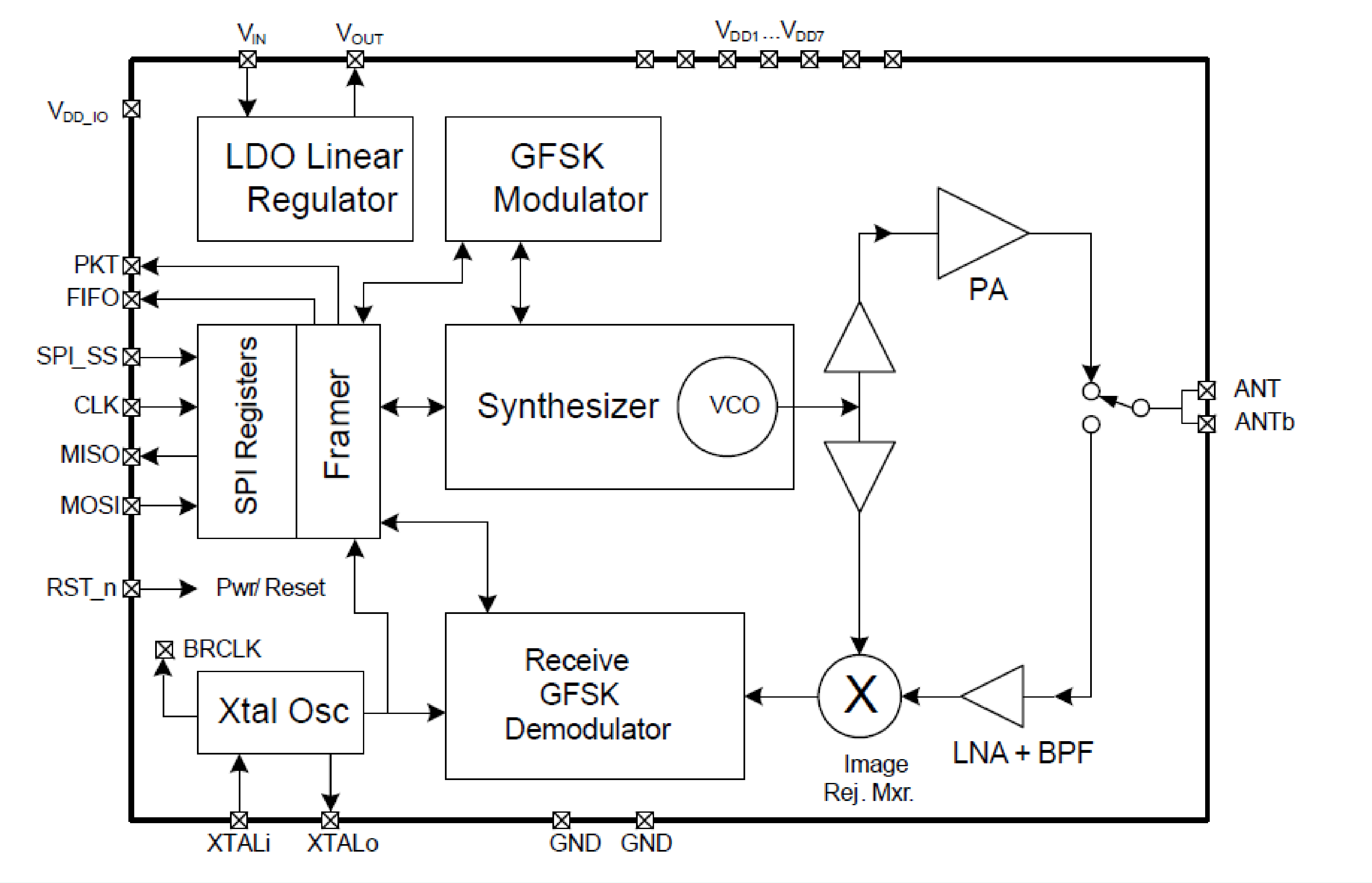
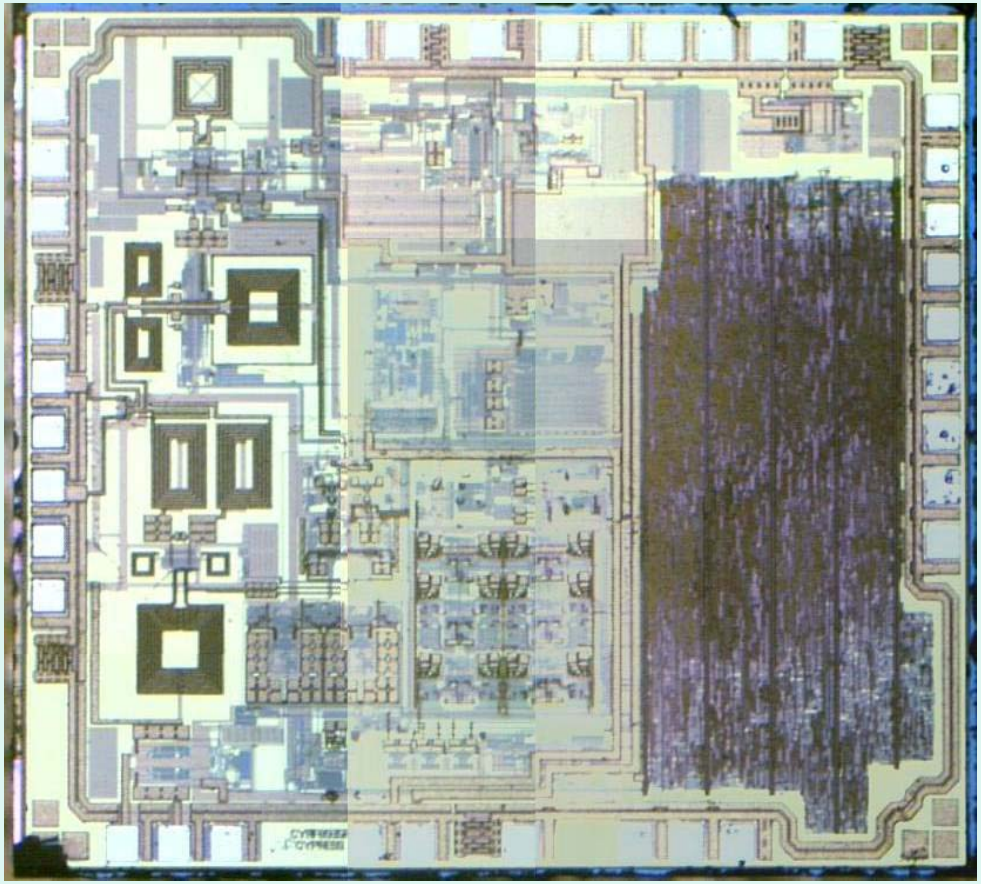
CYRF8935 Block Diagram



CYRF8935 Die Photo



Die Area = 2.2 mm x 1.9 mm = 4.2mm2

Transmitter Power (TXP) = 0dBm

$$A_V|_{\mathrm{dB}} = 20\log\frac{V_{out}}{V_{in}}$$
$$A_P|_{\mathrm{dB}} = 10\log\frac{P_{out}}{P_{in}}.$$

- This relationship between Power and Voltage only holds when the *input and output impedance are equal*

$$A_P|_{\mathrm{dB}} = 10\log\frac{\frac{V_{out}^2}{R_0}}{\frac{V_{in}^2}{R_0}} = 20\log\frac{V_{out}}{V_{in}} = A_V|_{\mathrm{dB}},$$

$$P_{sig}|_{\mathrm{dBm}} = 10\log\left(\frac{P_{sig}}{1\ \mathrm{mW}}\right)$$

An amplifier senses a sinusoidal signal and delivers a power of 0 dBm to a load resistance of 50 Ω. Determine the peak-to-peak voltage swing across the load.

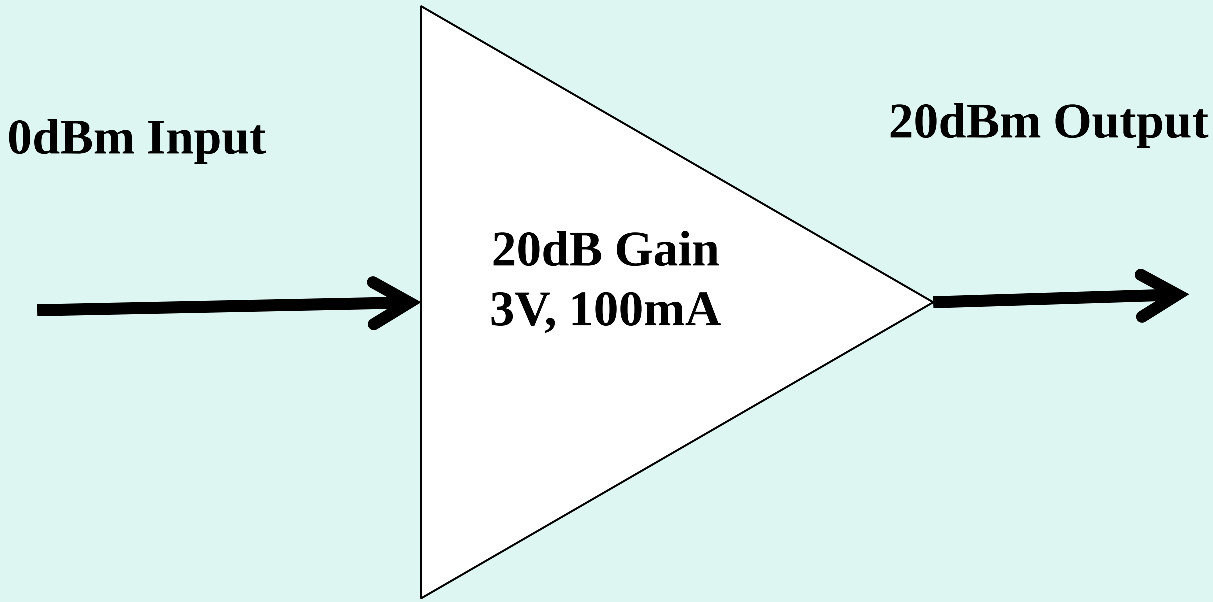
Solution:

$$\frac{V_{pp}^2}{8R_L} = 1\ \mathrm{mW}$$

where R_L = 50 Ω   thus,

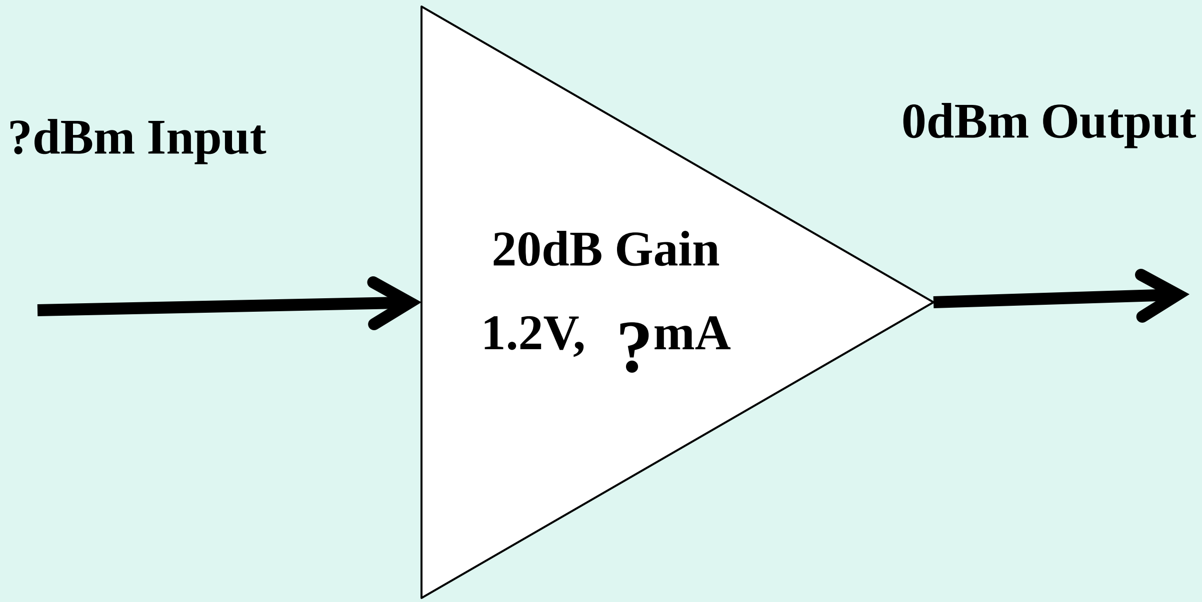
$$V_{pp} = 632\ \mathrm{mV}$$

20dB Gain and 20dBm Power Amplifier



Power Added Efficiency = (Pout – Pin)/DC Power

20dB Gain and 0dBm Power Amplifier



Power Added Efficiency = 30%

Receiver Sensitivity (RXS) = -87dBm

- Receiver sensitivity is defined as the input receive power level at which the BER (bit-error-rate) of a particular receiver equals 0.1%.

- Receiver sensitivity is a function of NF (noise figure) and S/N requirement of the receiver. (This will be covered in details later in the class)

- 0.1% number is chosen as the error rate that the communication quality is still acceptable.

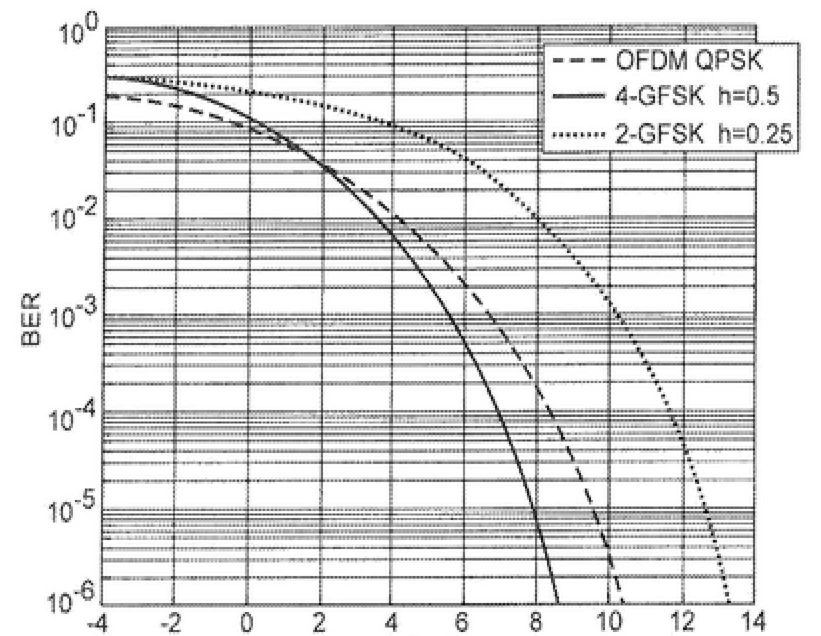
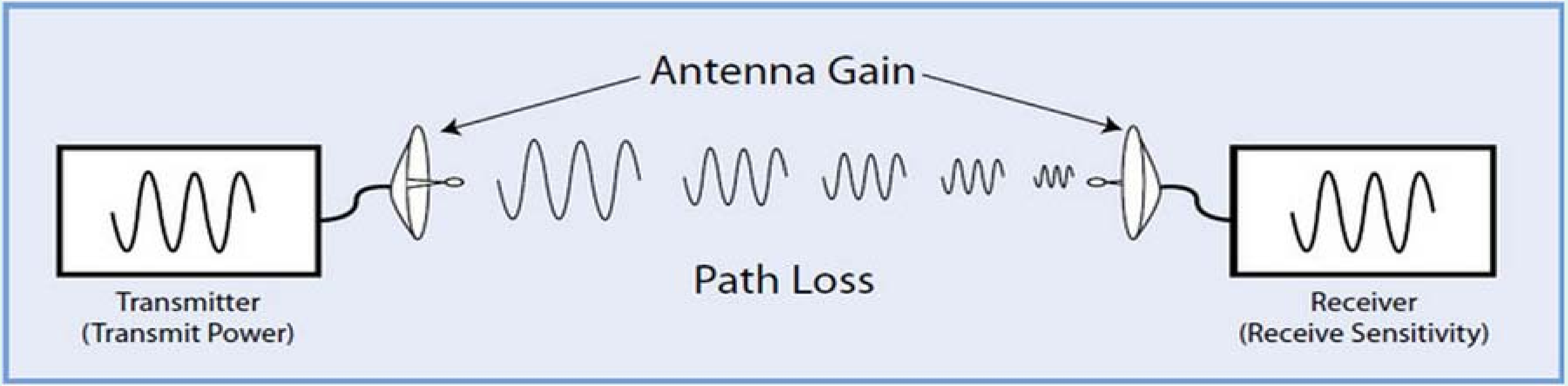


Fig. 8

Link Budget and Communication Distance



A signal sent by the transmitter (TX) is attenuated through the air by path loss, and gets received by the receiver (RX).

Path loss = 40 + 25*log(distance in meter) should be <= link budget (TXP – RXS)

Path Loss (*pathloss*)	Distance (*d*)
50 dB	2.5 m
60 dB	6.3 m
70 dB	16 m
80 dB	40 m
90 dB	100 m
100 dB	250 m
110 dB	630 m

dBm, dB, dBc

dBm: absolute power measurement

dBm = 10 * log (power in mW)

Example: 0dBm is 1mW, -10dBm is 0.1mW, etc…

dB: the difference between two dBm number, or ratio between two power level

dB = 10 * log (power A in mW/power B in mW)

dB = 10 * log (power A in mW) – 10 * log (power B in mW)

Example: 0dBm is 10dB higher then -10dBm.

dBc: dB compared to the carrier

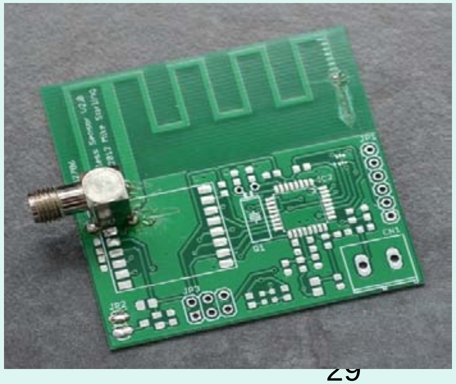
dBc = 10 * log (power A in mW/carrier power in mW)

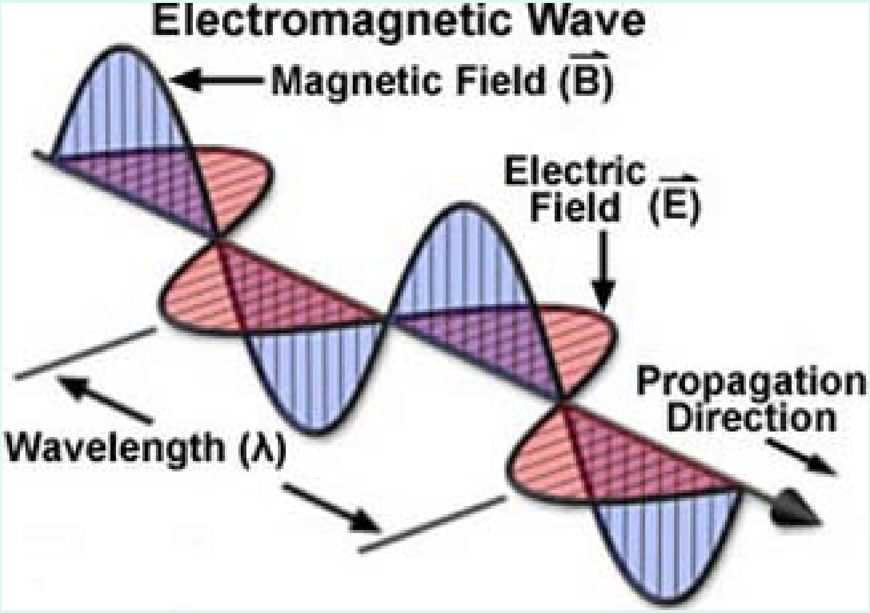
dBc = 10 * log (power A in mW) – 10 * log (carrier power in mW)

Example: adjacent channel power at 2MHz is 30dBc down.

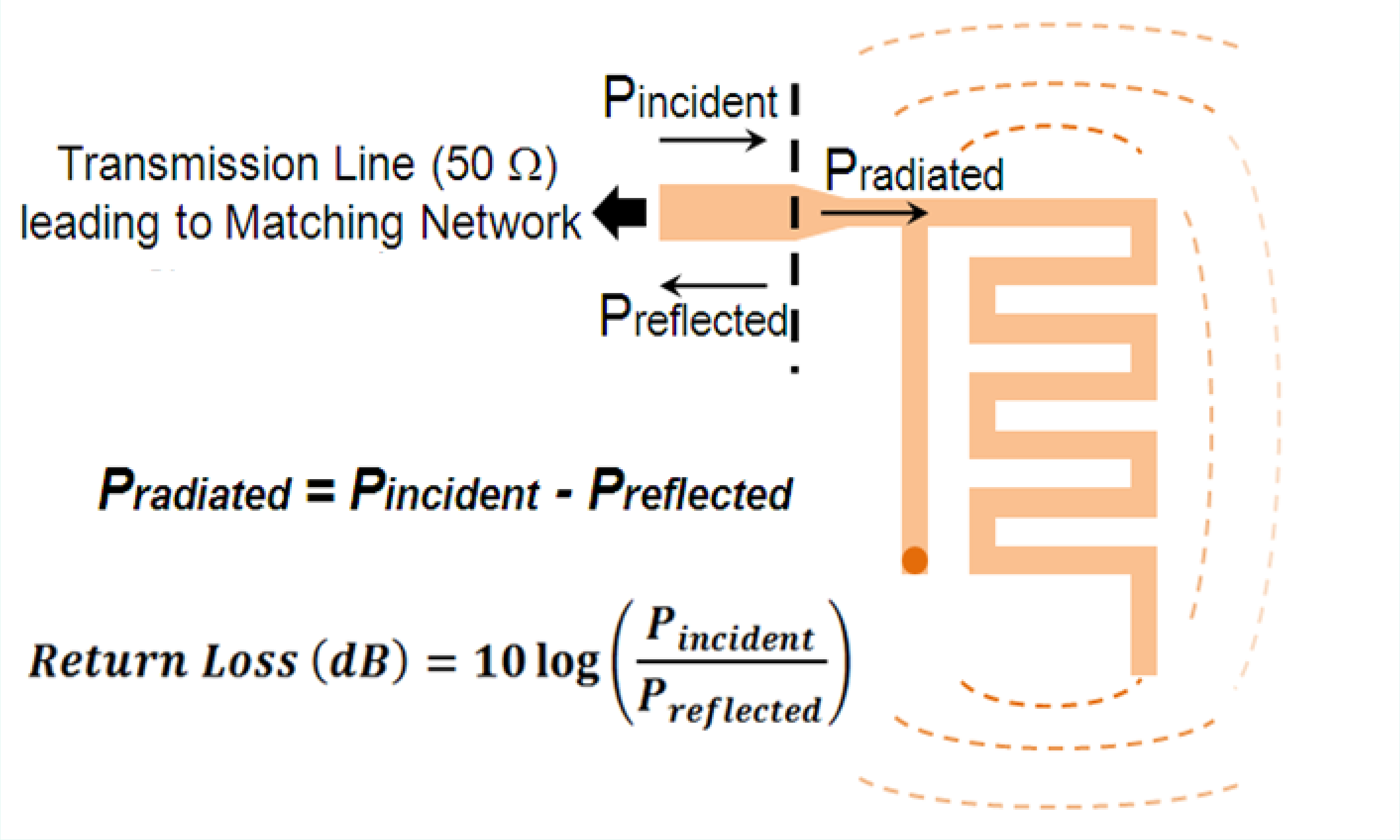
Wireless Communication Through Antenna

- An invisible wire is responsible for the wireless connection which is established through a **radio wave** (frequency).
- **Antenna** converts the electrical signal to the invisible electro-magnetic (EM) wave that can travel through space.



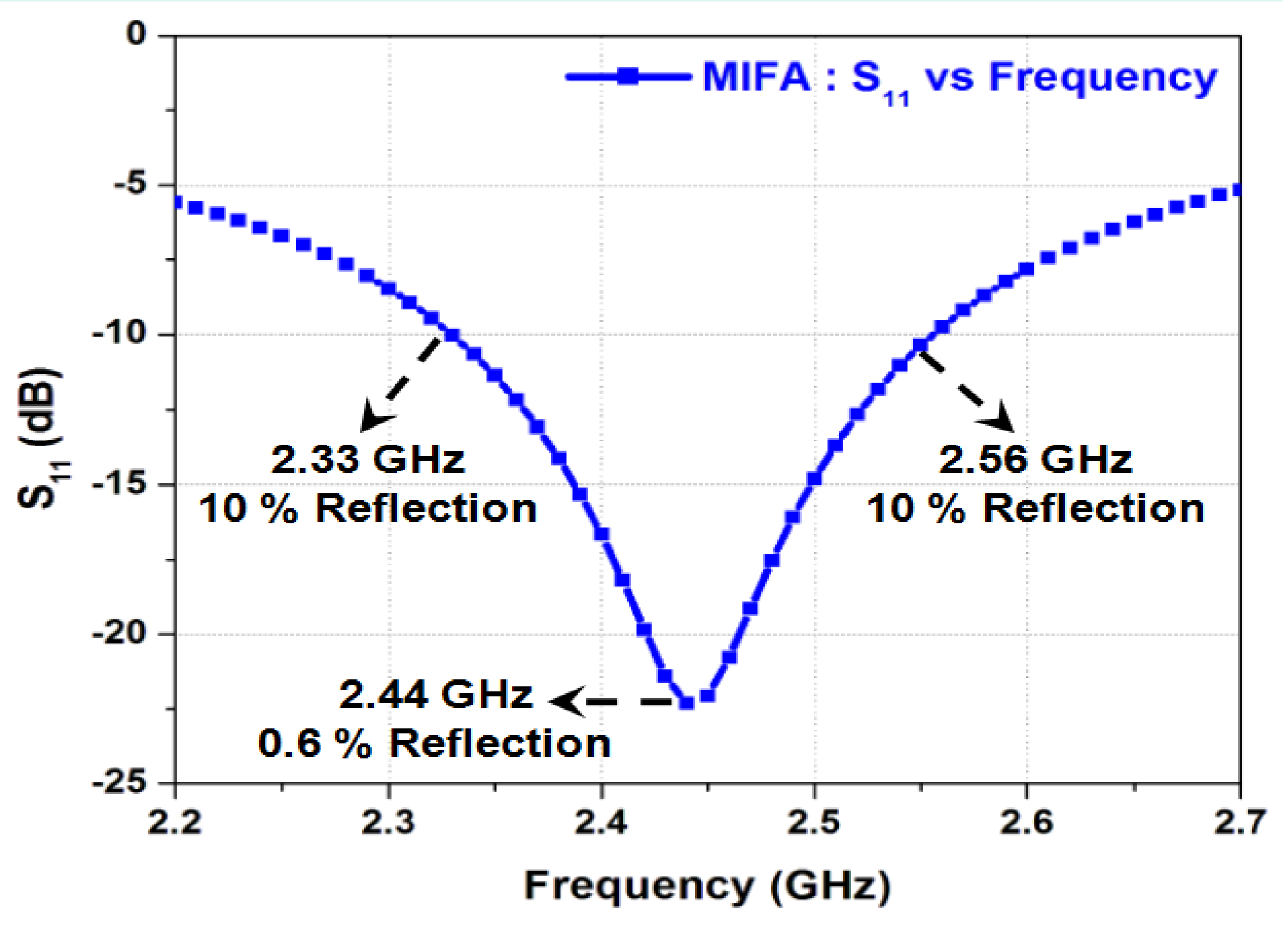


Return loss: Return loss of an antenna indicates how well the antenna is matched to the 50-Ω transmission line (TL).



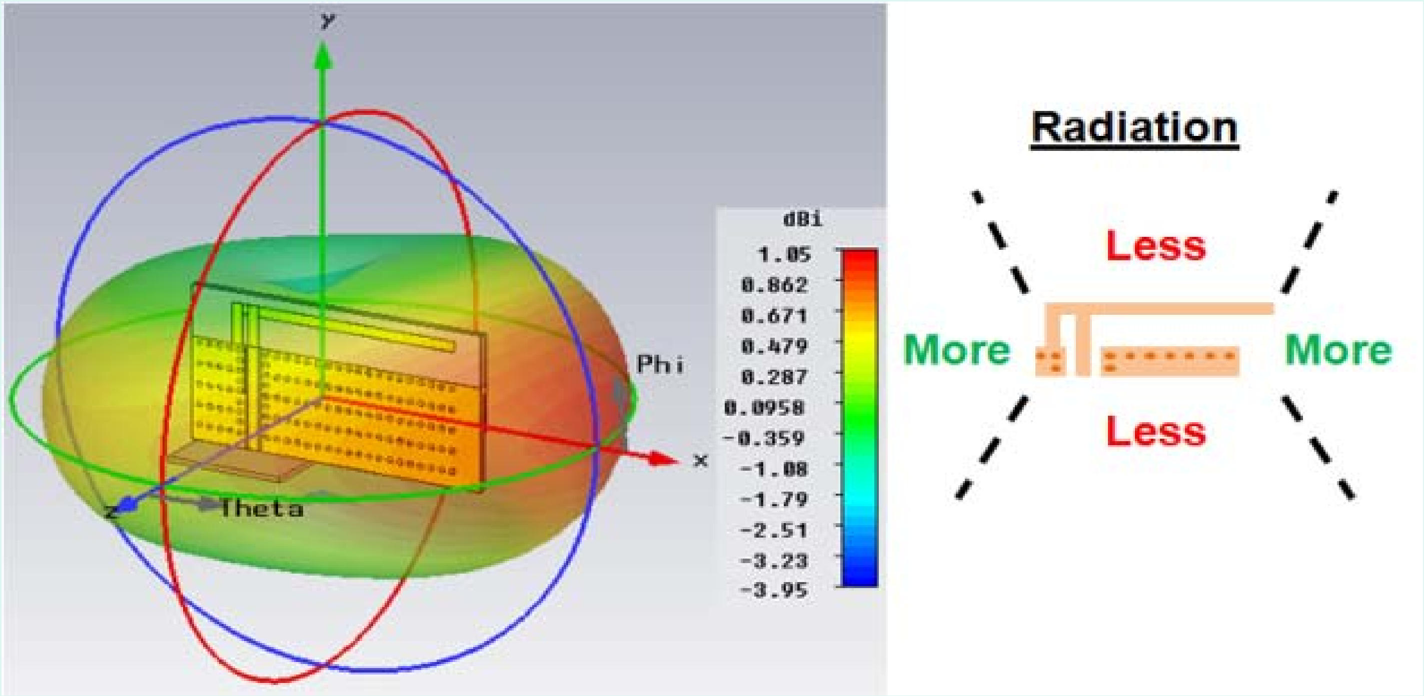
S11 is defined as –1 * Return Loss
e.g. 10dB Return Loss means S11 = -10dB

Bandwidth: Bandwidth indicates the frequency response of an antenna.



Radiation pattern: Radiation pattern indicates the directional property of radiation.

Gain: Gain gives information on radiation in the direction of interest, compared to the isotropic antenna. (in dBi)



Bluetooth Low-Energy Frequency Band

BLUETOOTH SPECIFICATION Version 4.2 [Vol 6, Part A] page 13

Physical Layer Specification

1 SCOPE

Bluetooth Low Energy (LE) devices operate in the unlicensed 2.4 GHz ISM (Industrial Scientific Medical) band. A frequency hopping transceiver is used to combat interference and fading.[1]

An LE radio shall have a transmitter or a receiver, or both.

The LE radio shall fulfill the stated requirements for the operating conditions declared by the equipment manufacturer (see Section A.1 and Section A.2).

The radio parameters shall be measured according to the methods described in the LE RF PHY Test Specification.

This specification is based on the established regulations for Europe, Japan, North America, Taiwan, South Korea and China. The standard documents listed below are only for information, and are subject to change or revision at any time.

The Bluetooth SIG maintains an online database of regulations that apply to Bluetooth technology in the 2.4 GHz ISM band, posted at https://www.bluetooth.org/regulatory/newindex.cfm.

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Bluetooth Low-Energy Frequency Band

Europe:

Approval Standards: European Telecommunications Standards Institute, ETSI
Documents: EN 300 328, EN 301 489, ETS 300-826

Japan:

Approval Standards: Japanese Radio Law, JRL
Documents: Japanese Radio Law: Article 4.3, Article 28, Article 29, Article 38

Radio Equipment Regulations: Article 5, Article 6, Article 7, Article 14, Article 24, Article 9.4, Article 49.20.1.C.2, Article 49.20.1.E.3
Radio Law Enforcement Regulations: Article 6.2, Article 6.4.4.1, Article 7

North America:

Approval Standards: Federal Communications Commission, FCC, USA
Documents: CFR47, Part 15: Sections 15.205, 15.209 and 15.247

Approval Standards: Industry Canada, IC, Canada
Documents: RSS-210 and RSS139

Bluetooth Low-Energy Frequency Band

Taiwan:

Approval Standards: National Communications Commission, NCC
Documents: Low Power 0002 (LP0002); Low-power Radio-frequency Devices Technical Regulations

South Korea:

Approval Standards: Korea Communications Commission, KCC
Documents: Rules on Radio Equipment 2008-116

China:

Approval Standards: Ministry of Industry and Information Technology, MIIT
Documents: MIIT regulation [2002]353