TSEK02: Radio Electronics Lecture 4: Multiple Access Techniques, TX Architectures

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Multiple Access Techniques: chapter 3.6, TX Architectures: chapter 4.3

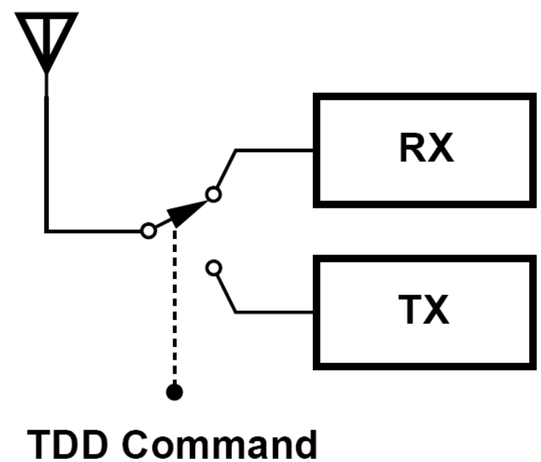
- **Multiple Access Techniques**
  - **Duplex Communication (3.6.1)**
  - Multiple Access Techniques
  - Multiplexing Techniques
- Direct-Conversion Transmitter
- Two-step Conversion Transmitter

Duplex Communication

- In Simplex communications one device transmits and the others just "listen”
  - Broadcasting
  - Pager
  - Remote controllers
- A Duplex system involve two-way communications. Transmission and reception should be possible in both directions
  - Full-Duplex
  - Half-Duplex

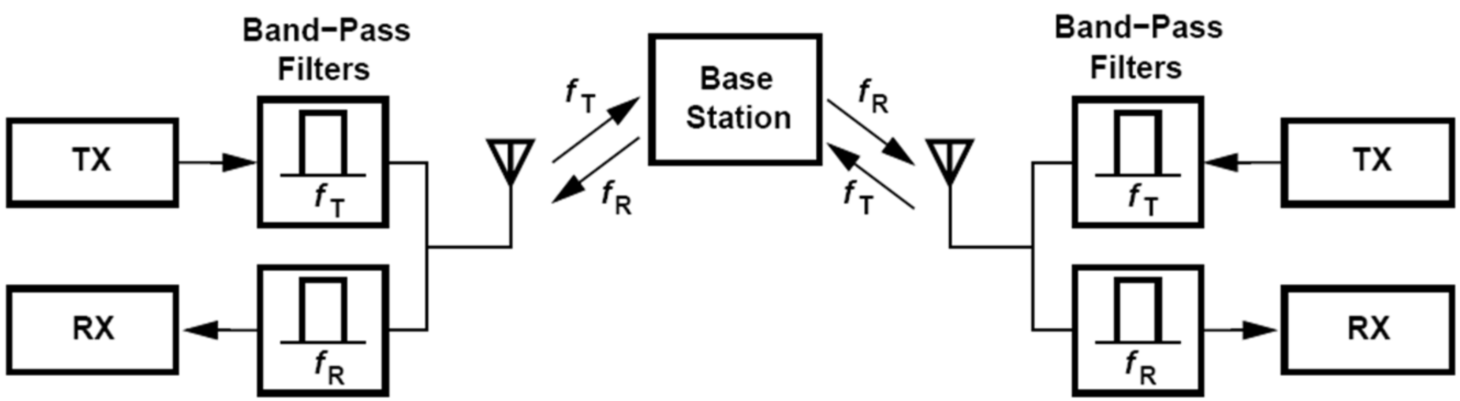
Time-Division Duplexing (TDD)

- Send and receive actions are performed at different times
  - TX and RX operate at the same frequency
  - TX and RX does not interfere because the TX/RX is switched off during RX/TX
  - Allows direct (”peer-to-peer”) communication
  - Strong signals generated by all of the nearby mobile transmitters fall in the receive band, thus desensitizing the receiver.
  - RF switch loss ~ 1 dB



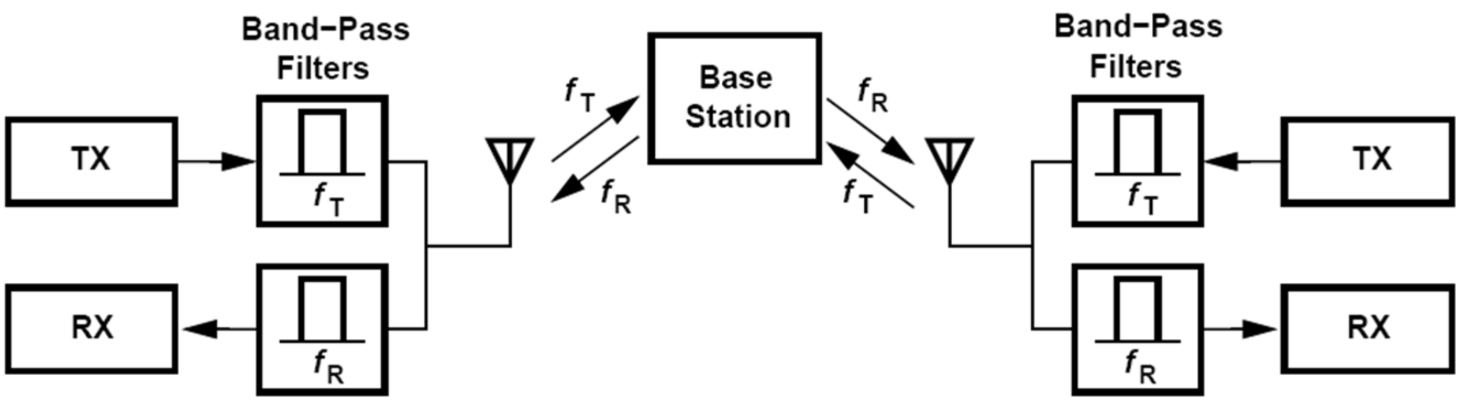
Frequency-Division Duplexing (FDD)

- Send and receive actions are performed at different frequencies (and may be performed simultaneously)
  - TX and RX operate at different frequencies and are isolated by duplexer filters
  - Two pairs of TX/RX are needed in point-to-point communications



Frequency-Division Duplexing (FDD)

- Components of the transmitted signal that leak into the receive band are attenuated by typically only about 50 dB
- Duplexer has higher losses, ~ 3 dB
- High filter requirements (sharp filters)
- Spectral leakage to adjacent channels in the transmitter output



Examples

Standard	Duplex
GSM	TDD
WCDMA	FDD
CDMA2000	FDD
WiMAX	FDD/TDD
LTE	FDD/TDD
WLAN	TDD
DECT	TDD

Frequency bands 4G (and 3G)

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz	–	840 MHz	875 MHz	–	885 MHz	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1452.9 MHz	1475.9 MHz	–	1500.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
…							
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
…							
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD

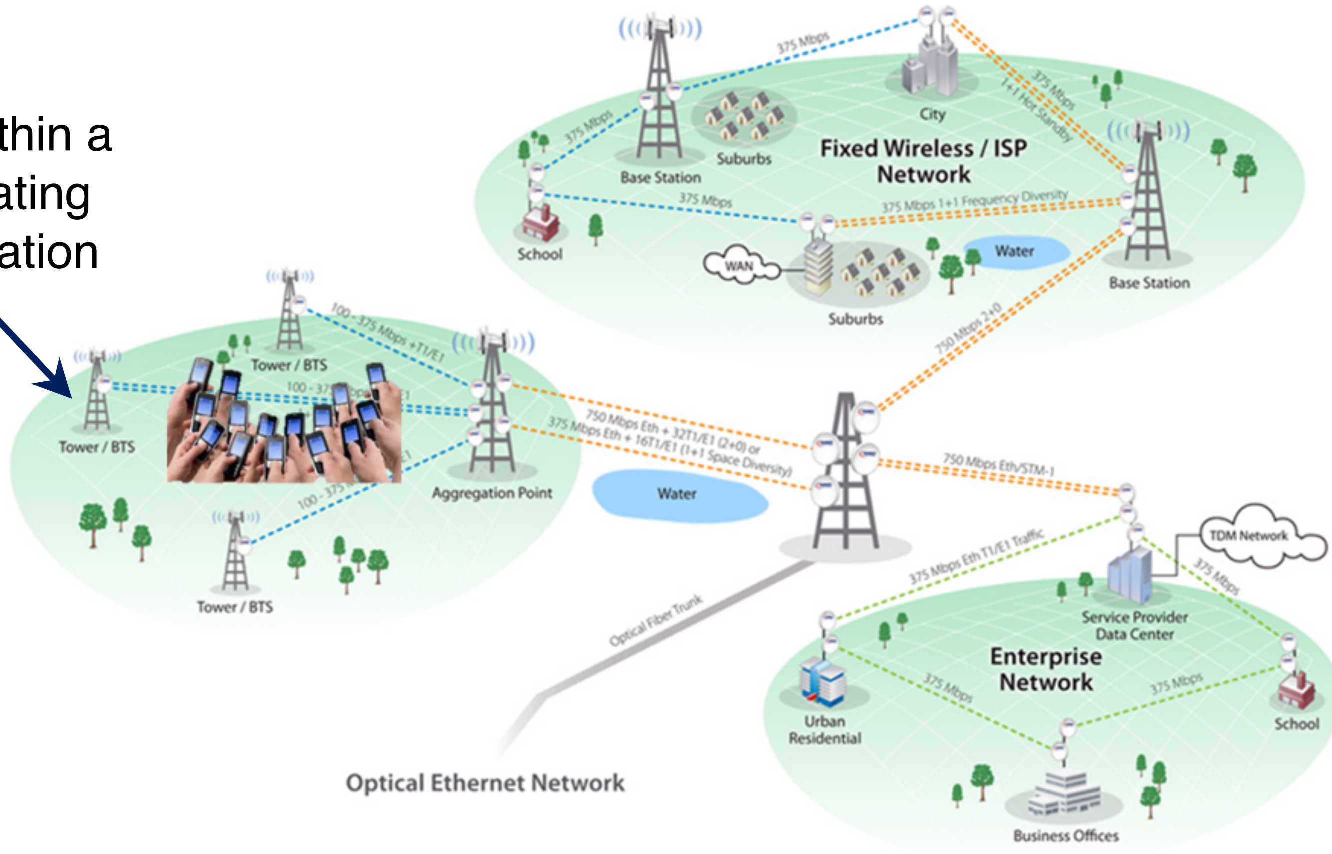
Multiple Access Techniques: chapter 3.6, TX Architectures: chapter 4.3

- Multiple Access Techniques
  - Duplex Communication
  - **Multiple Access Techniques (3.6.2, 3.6.3)**
  - Multiplexing Techniques
- Direct-Conversion Transmitter
- Two-step Conversion Transmitter

Multiple-Access

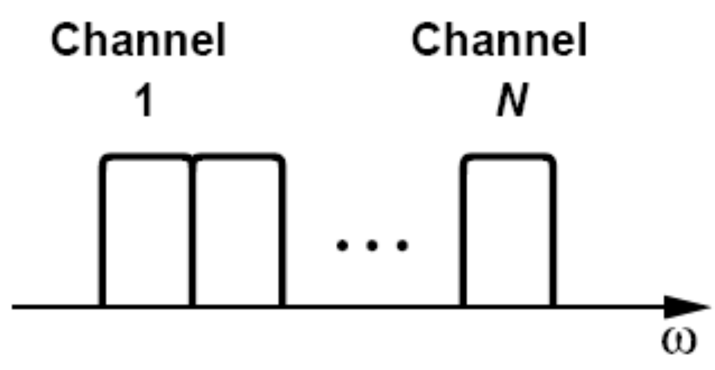
- Used in point-to-multipoint communication systems

mobile users within a cell communicating with the basestation



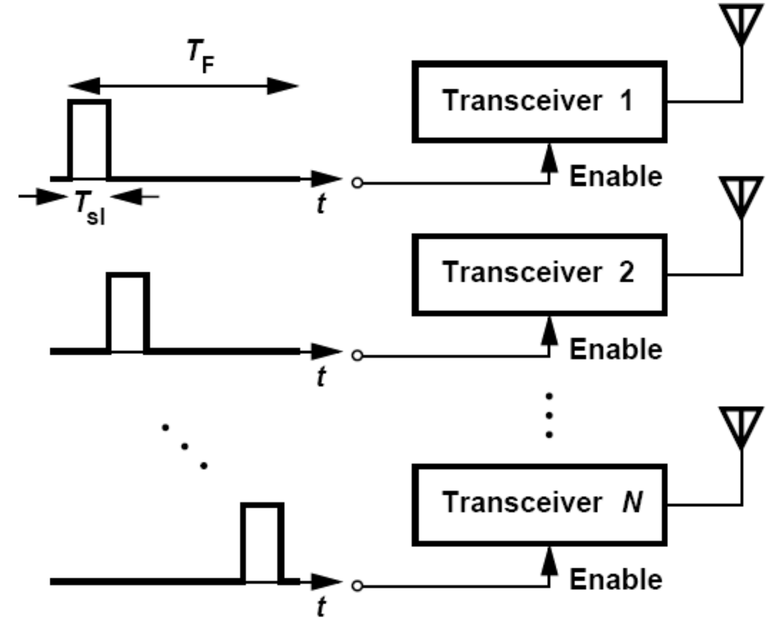
Frequency-Division Multiple Access (FDMA)

- Each user is given a frequency channel and it can only use that for communication.
- The channel information is sent to the user before the actual communication.
- At the end of the communication, the channel becomes available to other users.



Time-Division Multiple Access (TDMA)

- Same band is available to each user. Each user is given a time slot, in which it can communicate
- The mobile still operates in between bursts, but with much less power consumption, e.g. can listen to network commands

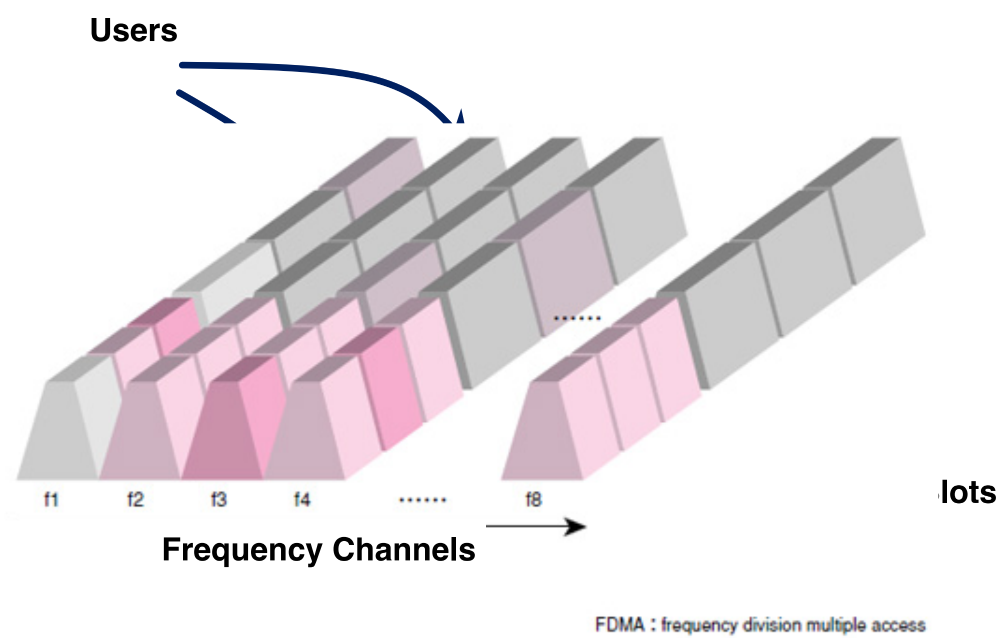


TDMA compared with FDMA

- The power amplifier can be turned off in unused/RX time slots.
- Digitized speech can be compressed in time by a large factor, smaller required bandwidth.
- Even with FDD, TDMA bursts can be timed so the receive and transmit paths are never enabled simultaneously
- More complex due to A/D conversion, digital modulation, time slot and frame synchronization, etc.

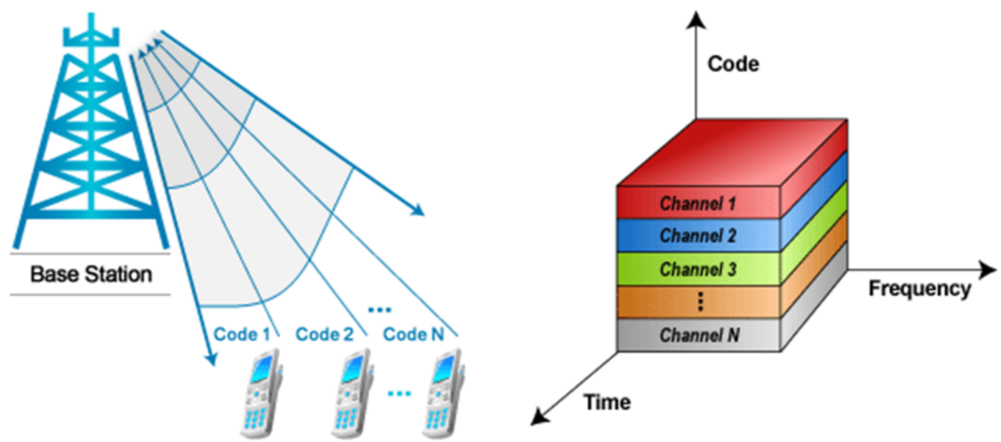
TDMA with FDMA

- In most real TDMA systems, a combination of TDMA and FDMA is used.
- This means each frequency channel is time-shared among many users.
- Ex: GSM 8 time slots, 200 kHz/channel, typ. 25 MHz spectrum



Code-Division Multiple Access (CDMA)

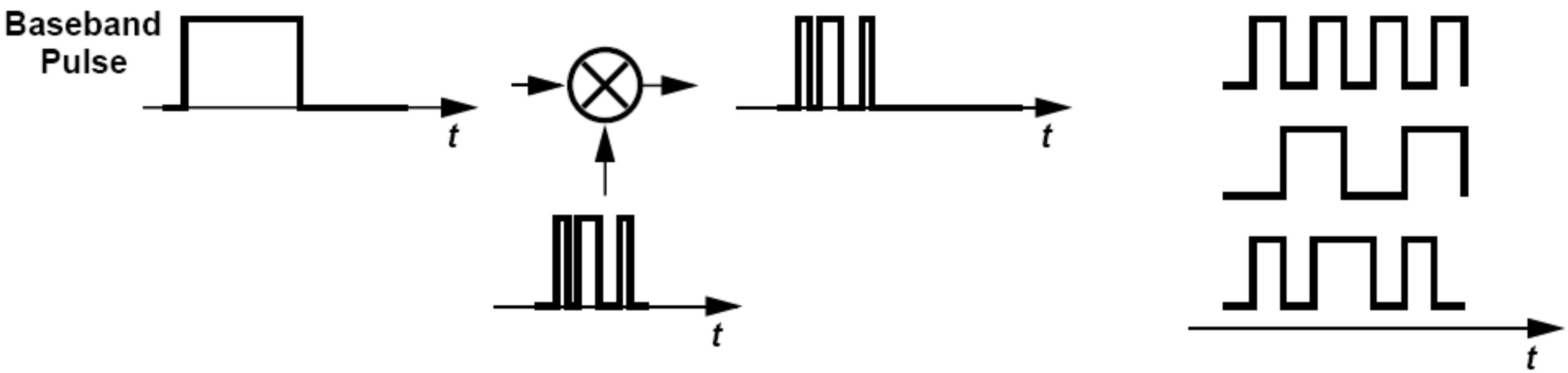
- All users send/receive data at the same time and at the same frequency but in code.
- Similar to the case when many people talk to each other at the same time in the same room but with different languages.



Code-Division Multiple Access (CDMA)

- At each user terminal, the original data bits are multiplied by the code and therefore require a wider bandwidth (”Spread Spectrum”).
- The receiver “decodes” the data by multiplying it by the same code.
- Coding and decoding is performed in the digital domain.
- The radio transmitter sends data with a higher data rate (increased bandwidth).
- In order for the decoding to work properly, received power from all users should be the same at the receiver (adaptive power control).

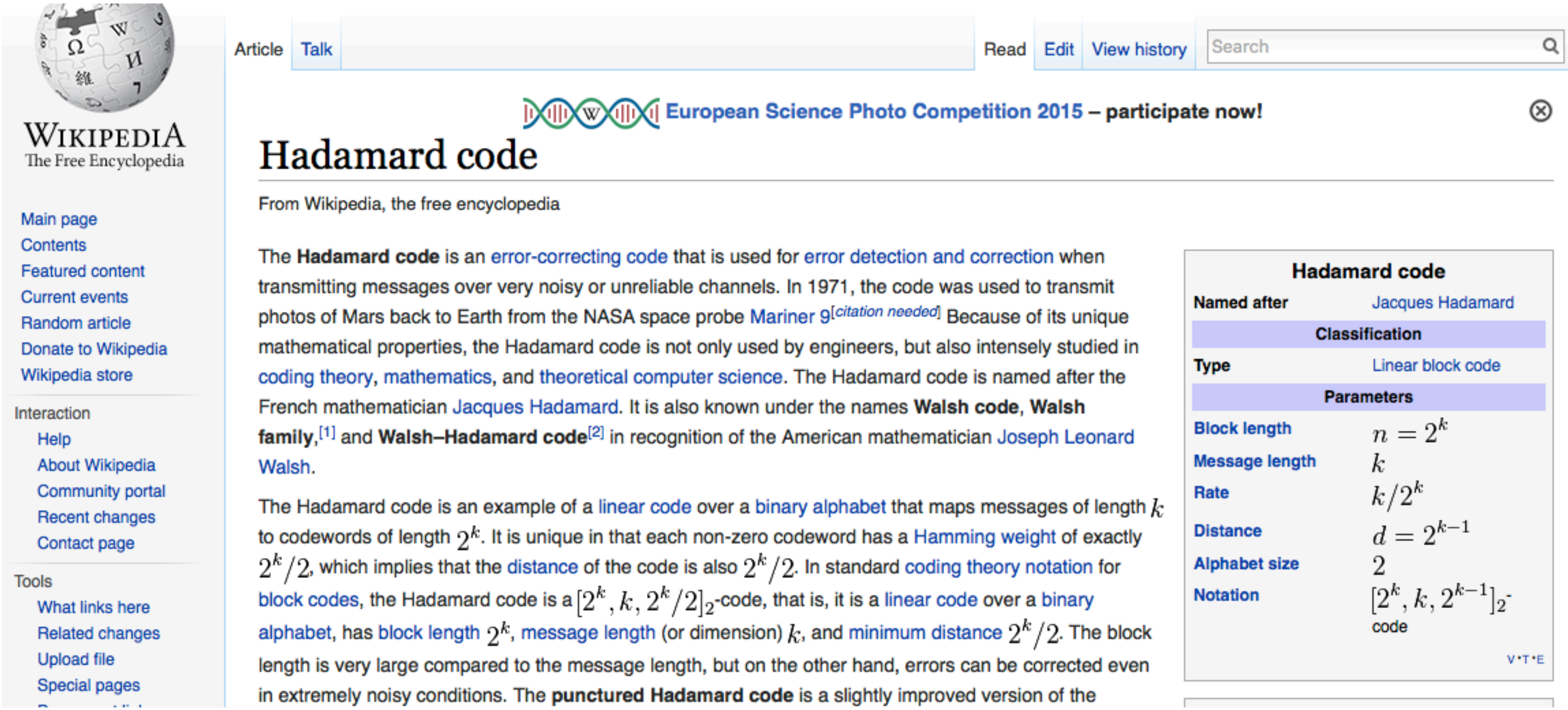
CDMA



Walsh's recursive equation:
$W_1 = 0$

$$W_{2n} = \begin{bmatrix} W_n & W_n \\ W_n & \overline{W_n} \end{bmatrix}$$

- CDMA allows the widened spectra of many users to fall in the same frequency band.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Hadamard code

From Wikipedia, the free encyclopedia

The **Hadamard code** is an error-correcting code that is used for error detection and correction when transmitting messages over very noisy or unreliable channels. In 1971, the code was used to transmit photos of Mars back to Earth from the NASA space probe Mariner 9[citation needed] Because of its unique mathematical properties, the Hadamard code is not only used by engineers, but also intensely studied in coding theory, mathematics, and theoretical computer science. The Hadamard code is named after the French mathematician Jacques Hadamard. It is also known under the names **Walsh code**, **Walsh family**,[1] and **Walsh–Hadamard code**[2] in recognition of the American mathematician Joseph Leonard Walsh.

The Hadamard code is an example of a linear code over a binary alphabet that maps messages of length k to codewords of length 2^k. It is unique in that each non-zero codeword has a Hamming weight of exactly $2^k/2$, which implies that the distance of the code is also $2^k/2$. In standard coding theory notation for block codes, the Hadamard code is a $[2^k, k, 2^k/2]_2$-code, that is, it is a linear code over a binary alphabet, has block length 2^k, message length (or dimension) k, and minimum distance $2^k/2$. The block length is very large compared to the message length, but on the other hand, errors can be corrected even in extremely noisy conditions. The **punctured Hadamard code** is a slightly improved version of the

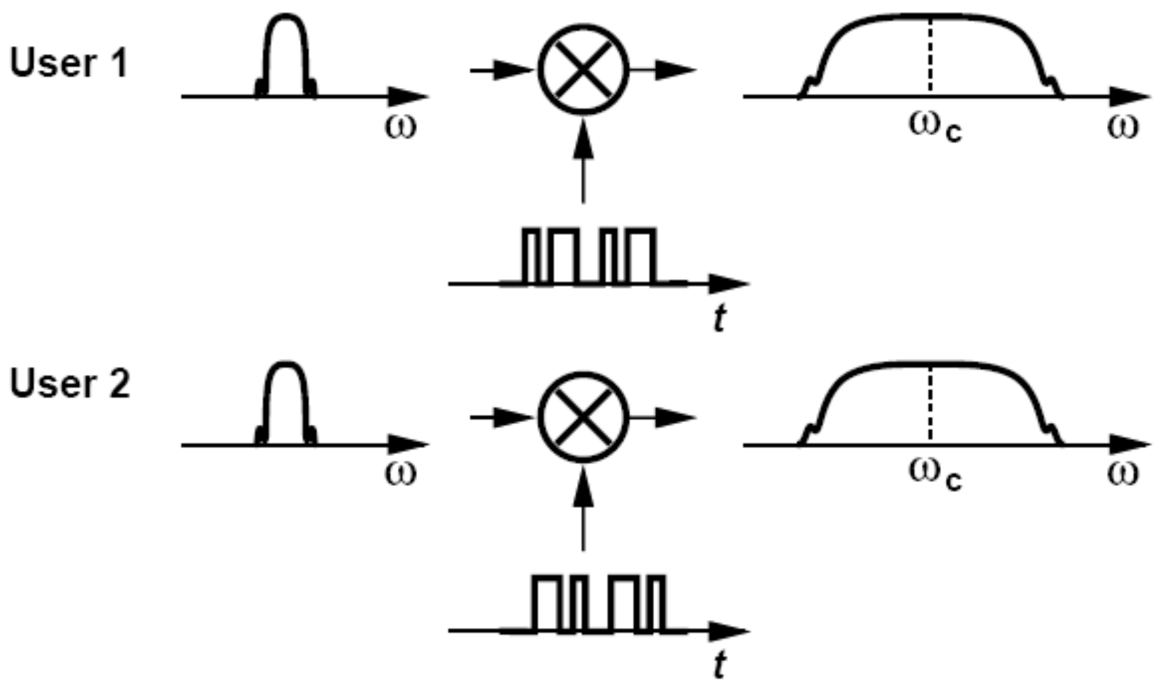
Hadamard code	
Named after	Jacques Hadamard
Classification	
Type	Linear block code
Parameters	
Block length	$n = 2^k$
Message length	k
Rate	$k/2^k$
Distance	$d = 2^{k-1}$
Alphabet size	2
Notation	$[2^k, k, 2^{k-1}]_2$-code

V·T·E

- In modern use, these error correcting codes are referred to as Walsh–Hadamard codes.

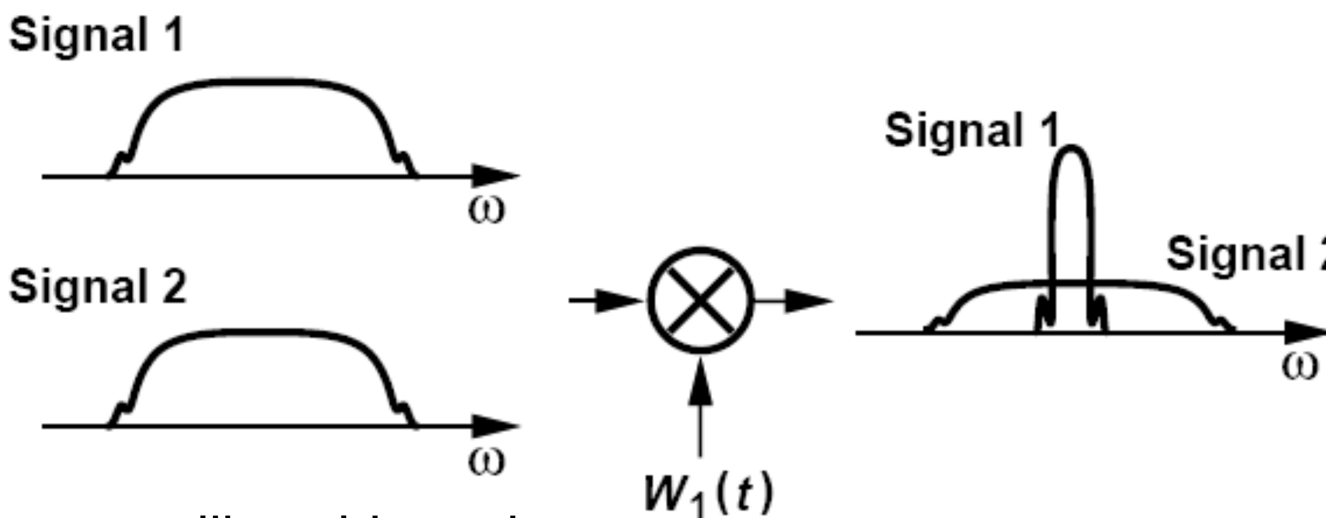
DS Code-Division Multiple Access (CDMA)

- Although BW is higher, CDMA allows the widened spectra of many users to fall in the same frequency band.



Direct-Sequence CDMA: Spectrum and Power

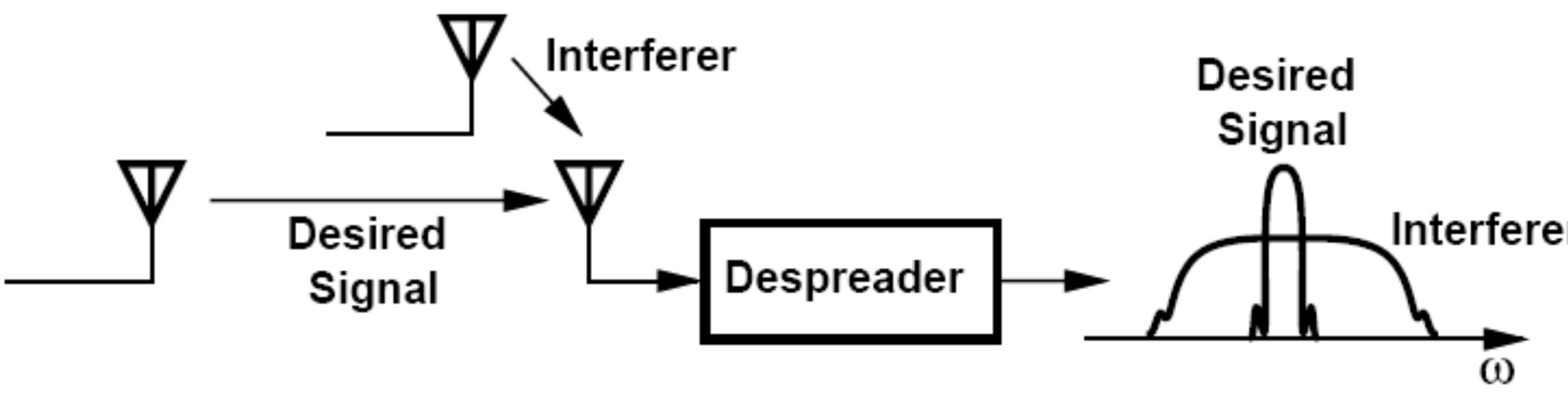
- Demodulation: desired signal is “de-spread”, unwanted signal remains spread.



- Many users: like white noise.
- "Soft" capacity limit.

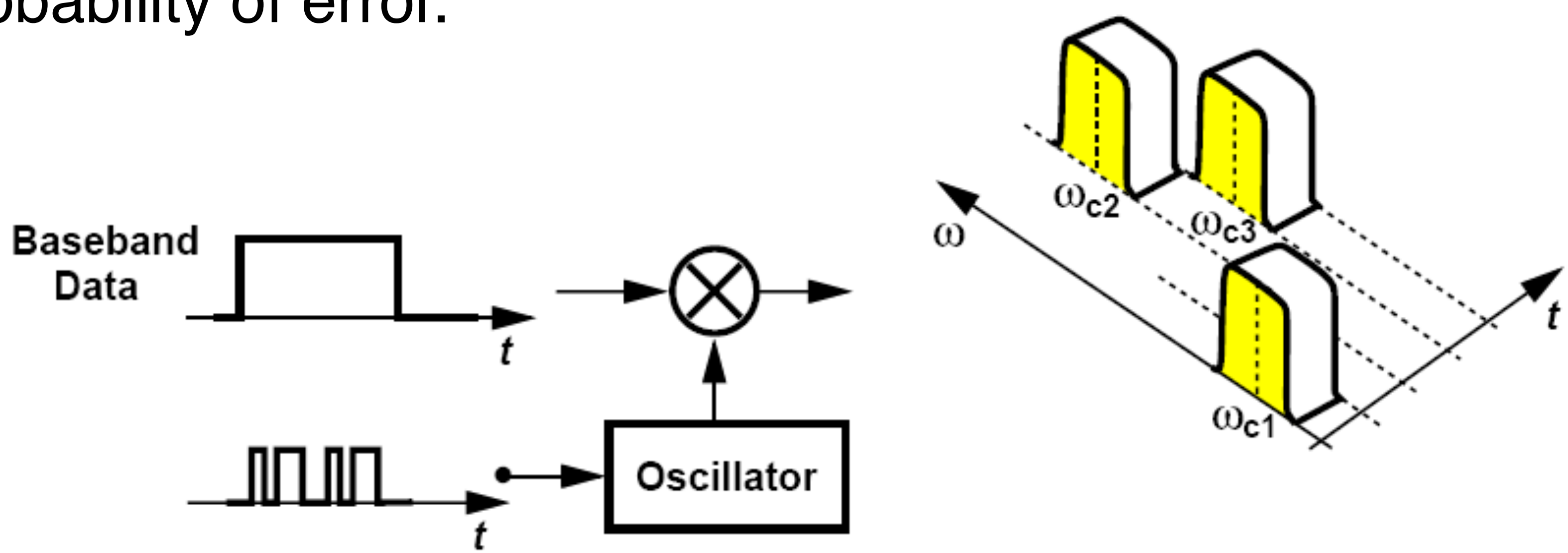
Direct-Sequence CDMA: Spectrum and Power

- Near/Far Effect: one high-power transmitter can virtually halt communications among others: requires power control (from the basestation).



Frequency-Hopping CDMA

- Can be viewed as FDMA with pseudo-random channel allocation.
- Occasional overlap of the spectra raises the probability of error.

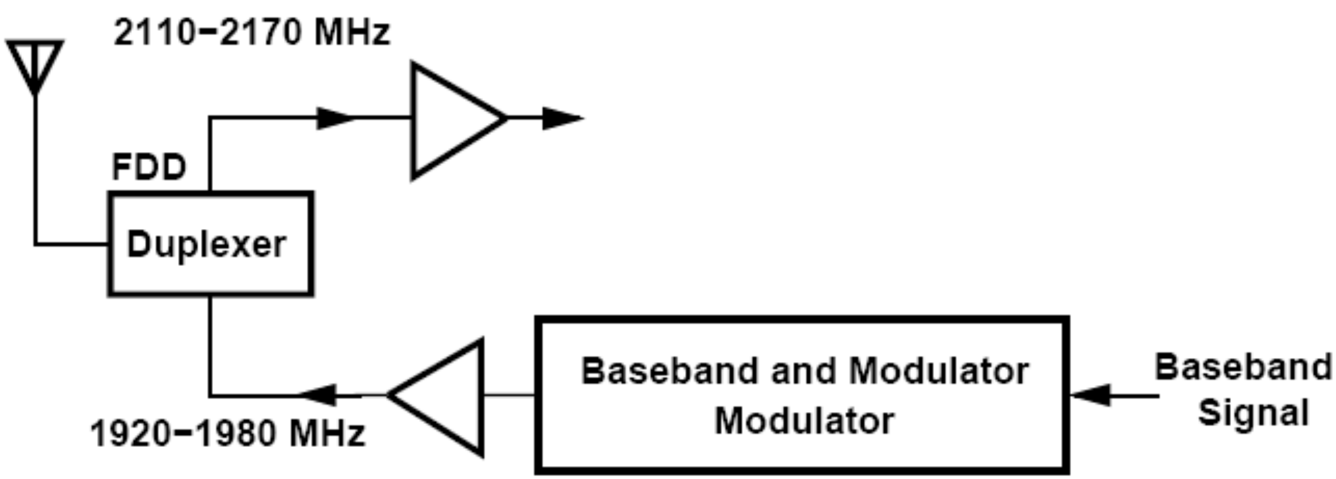


Systems using CDMA

- DS-CDMA: military, IS-95 (2G, USA), WCDMA (3G, Europe/world), CDMA2000 (3G, USA).
- FH-CDMA: Bluetooth.
- GPS.

Wideband CDMA (WCDMA) (3G)

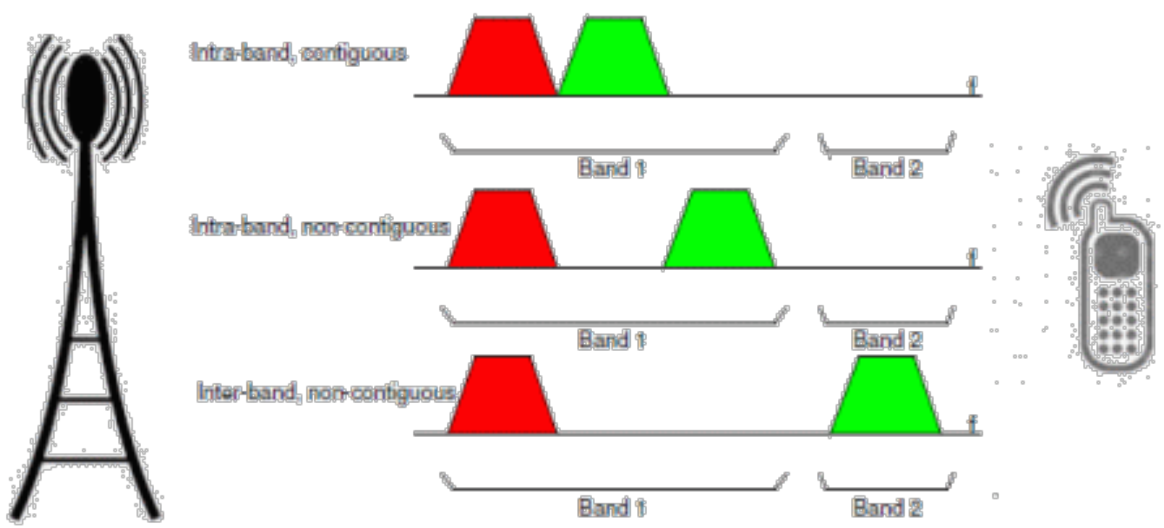
- FDD. Uses BPSK for uplink, QPSK for downlink. With 5 MHz channel width (3.84 MHz effectively), 384 kb/s is possible.



- CDMA, or code division multiple access, can actually be traced back to the 1940s.
- Hollywood actress Hedy Lamarr and composer George Antheil, inspired by the way musical notes are arranged, theorized that multiple frequencies could be used to send a single radio transmission. ”Frequency hopping” could prevent a radio signal from being jammed.
- They patented the idea and gave it to the U.S. government for use in World War II, but it was largely ignored and the patent eventually expired.

Carrier aggregation: using more bands for one communication link

- Carrier aggregation or channel aggregation enables multiple LTE carriers to be used together to provide the high data rates required for 4G LTE Advanced



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  - **Multiplexing Techniques**
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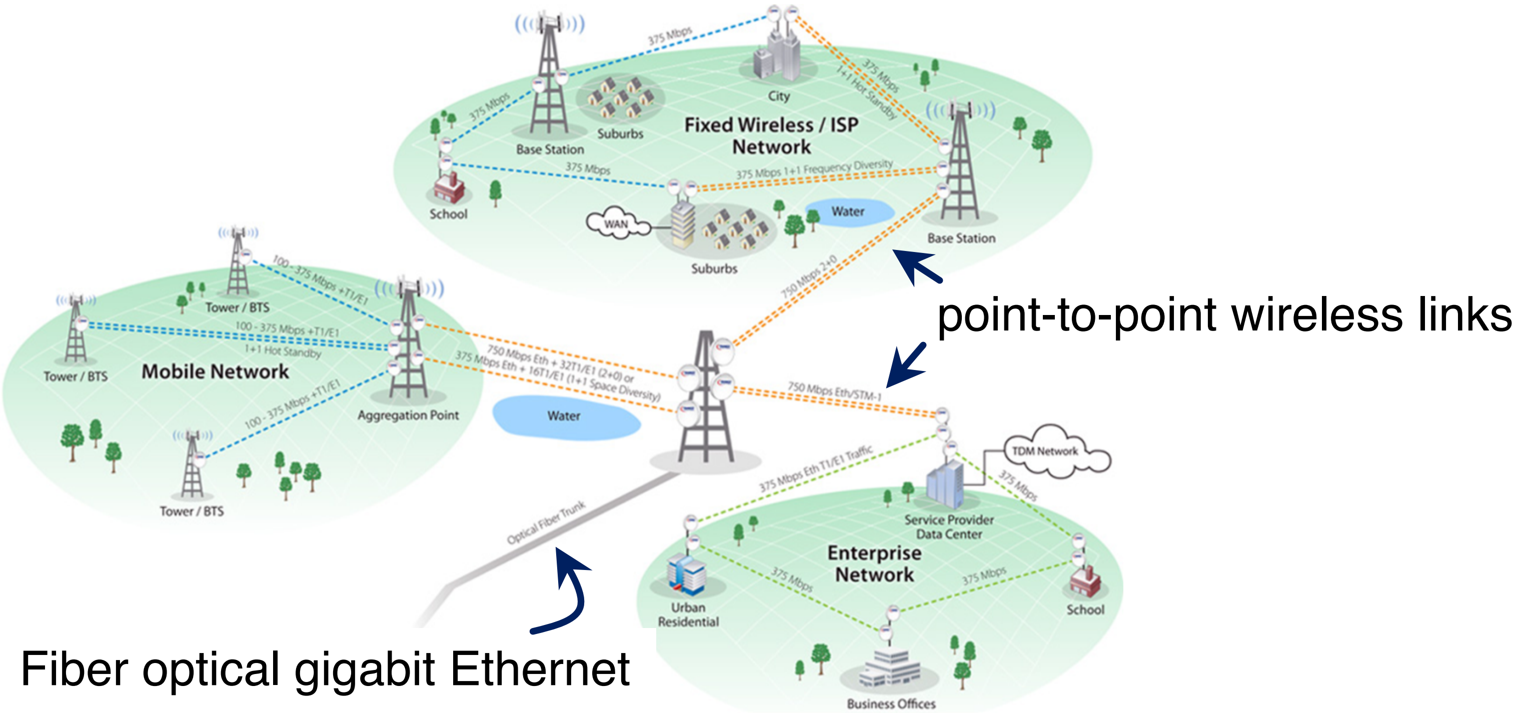
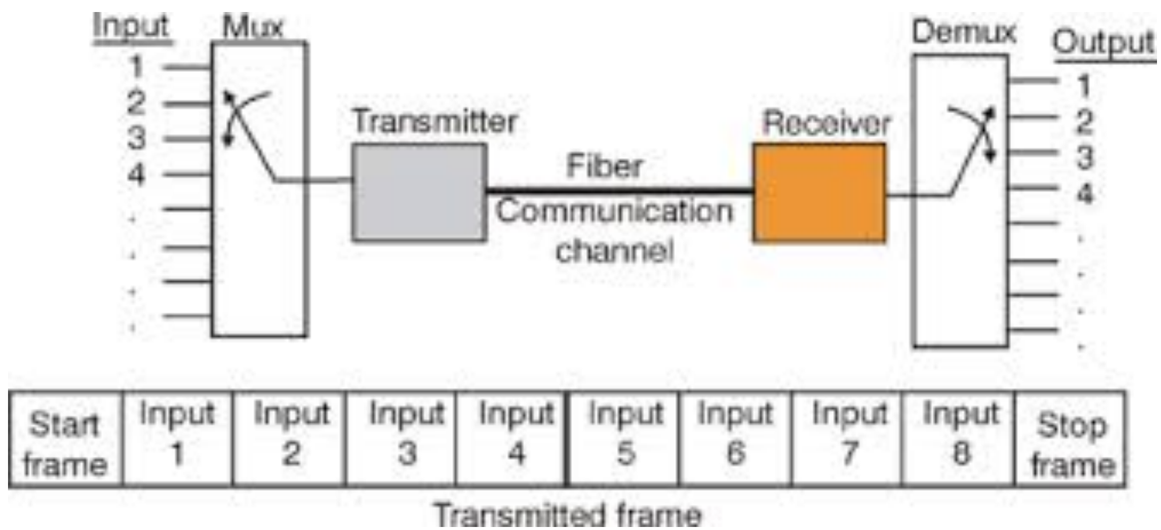
Multiplexing

- Multiplexing is performed when several data sources should be gathered and transferred over a common media



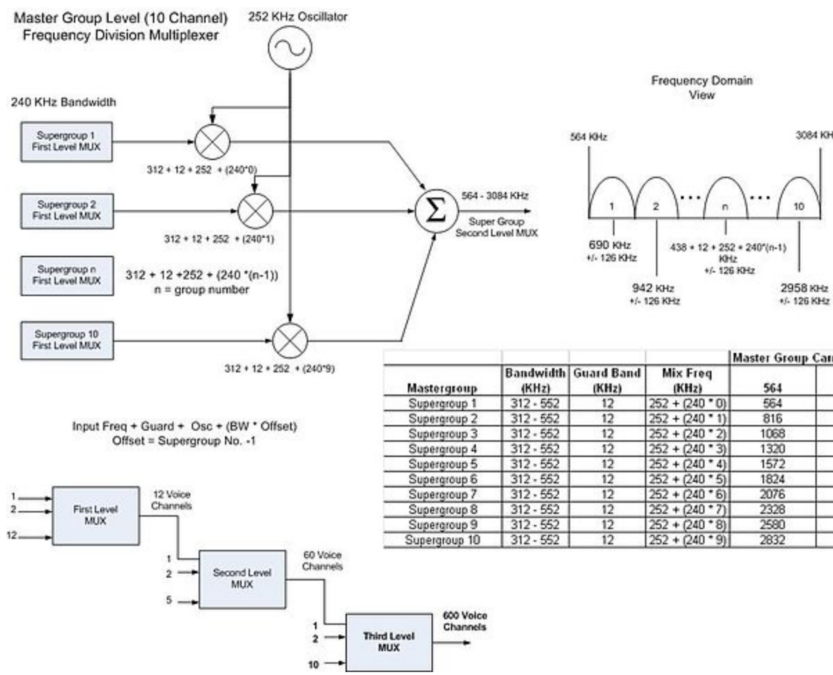
Time-Division Multiplexing

- TDM is a technique to combine several data streams into a higher speed link
- Data from several user is placed in different “time slots” of a “frame”. The frame is transmitted over the link and on the receiver side is de-multiplexed again



Frequency-Division Multiplexing

- In FDM each data stream is placed at different frequency transmitted
- Employed in analog telephone systems



				Master Group Carrier (Khz)	
Mastergroup	Bandwidth (KHz)	Guard Band (KHz)	Mix Freq (KHz)	564	3084
Supergroup 1	312 - 552	12	252 + (240 * 0)	564	816
Supergroup 2	312 - 552	12	252 + (240 * 1)	816	1068
Supergroup 3	312 - 552	12	252 + (240 * 2)	1068	1320
Supergroup 4	312 - 552	12	252 + (240 * 3)	1320	1572
Supergroup 5	312 - 552	12	252 + (240 * 4)	1572	1824
Supergroup 6	312 - 552	12	252 + (240 * 5)	1824	2076
Supergroup 7	312 - 552	12	252 + (240 * 6)	2076	2328
Supergroup 8	312 - 552	12	252 + (240 * 7)	2328	2580
Supergroup 9	312 - 552	12	252 + (240 * 8)	2580	2832
Supergroup 10	312 - 552	12	252 + (240 * 9)	2832	3084

The "backhaul"

- The backhaul portion of the network comprises the intermediate links between the core network, or backbone network and the small subnetworks at the "edge" of the entire hierarchical network. (Wikipedia)

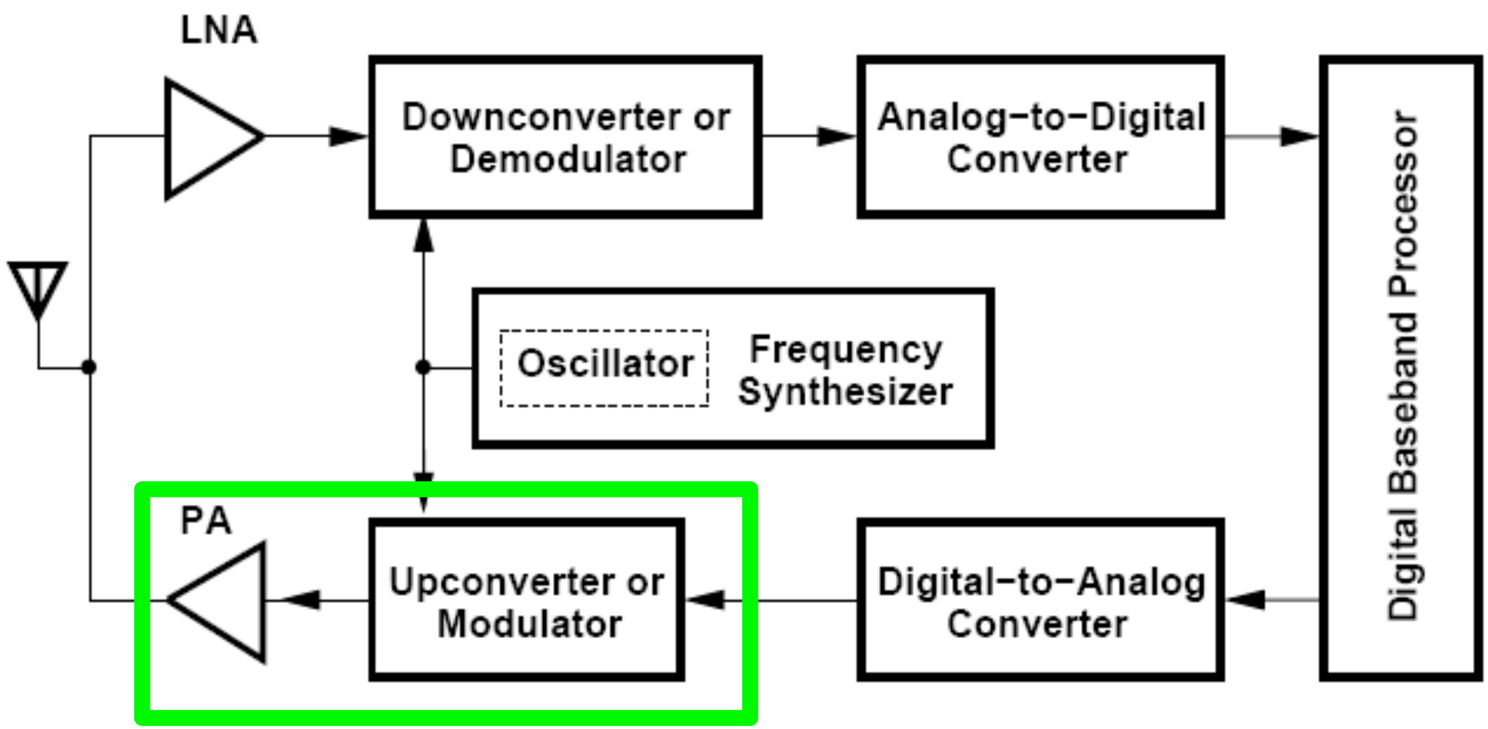
MINI-LINK High Capacity

- **Frequencies:** 7 - 38 GHz
- **Capacity:** 155 + 2 Mbit/s
- **Modulation:** 16 QAM, 128 QAM
- **Traffic Interfaces:** STM-1, OC-3, E1 (way-side)
- **Configurations:**
  - 1+0 and 1+1 (radio)
- **Typical hop length:** 20-30 km
- **Other features:**
  - ATPC (Automatic Transmit Power Control)
  - IP DCN
  - EEM (Embedded Element Manager)

Multiple Access Techniques: chapter 3.6, TX Architectures: chapter 4.3

- Multiple Access Techniques
  - Duplex Communication
  - Multiple Access Techniques
  - Multiplexing Techniques
- **Direct-Conversion Transmitter (4.3.2, 4.3.3)**
- Two-step Conversion Transmitter

Generic RF Transceiver



Shannon's theorem

- **"The achievable data rate of a communication channel is equal to B $\log_2$(1 + SNR)"**, where B denotes the bandwidth and SNR the signal-to-noise ratio (not in dB!). Unit is bits per second (b/s).
- "Information" is thought of as a set of possible messages, where the goal is to send these messages over a noisy channel, and then to have the receiver reconstruct the message with low probability of error, in spite of the channel noise.

  Shannon's main result, the Noisy-channel coding theorem showed that, in the limit of many channel uses, the rate of information that is asymptotically achievable is equal to the Channel capacity, a quantity dependent merely on the statistics of the channel over which the messages are sent. (*Wikipedia*)

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Claude Shannon

From Wikipedia, the free encyclopedia

Claude Elwood Shannon (April 30, 1916 – February 24, 2001) was an American mathematician, electronic engineer, and cryptographer known as "the father of information theory".[1][2]

Shannon is famous for having founded information theory with a landmark paper that he published in 1948. He is perhaps equally well known for founding both digital computer and digital circuit design theory in 1937, when, as a 21-year-old master's degree student at the Massachusetts Institute of Technology (MIT), he wrote his thesis demonstrating that electrical applications of Boolean algebra could construct any logical, numerical relationship.[3] Shannon contributed to the field of cryptanalysis for national defense during World War II, including his basic work on codebreaking and secure telecommunications.

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1 Biography
1.1 Boolean theory and beyond
1.2 Wartime research
1.3 Postwar contributions
1.4 Hobbies and inventions
1.5 Legacy and tributes
2 Other work

Claude Shannon

Claude Elwood Shannon (1916–2001)

Born April 30, 1916
Petoskey, Michigan, U.S.

Shannon is "the father of information theory"

TECH

A Chess-Playing Machine

Electronic computers can be set up to play a fairly strong game, raising the question of whether they can "think"

By Claude E. Shannon on February 1, 1950

Shannon also outlined the first chess playing computer program in 1950

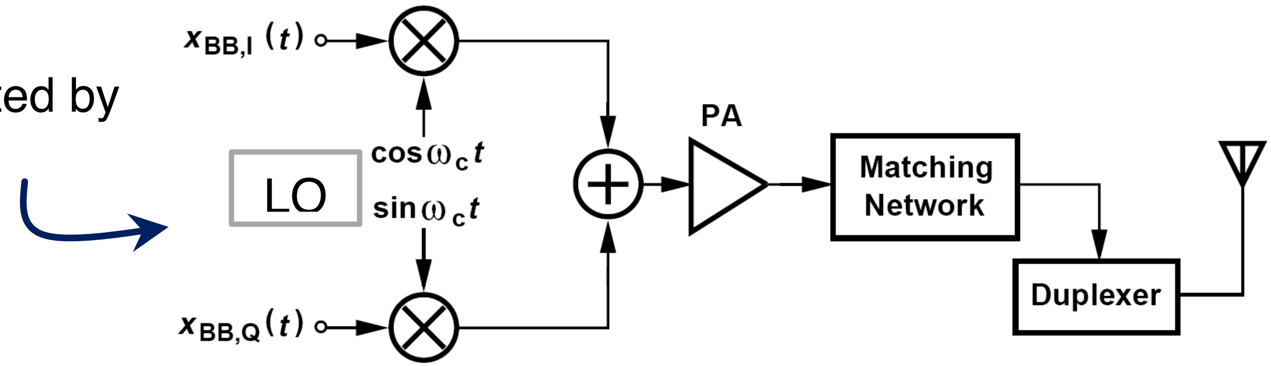
4.3.2 Direct-Conversion Transmitter

- Most modulation schemes can be implemented by quadrature modulators
- Power of the signal needs to be amplified so that the signal can reach the receiver

This architecture is called Direct-Conversion Transmitter

For practical purposes, amplification may be performed in several stages

Carriers are generated by a ”Local Oscillator”



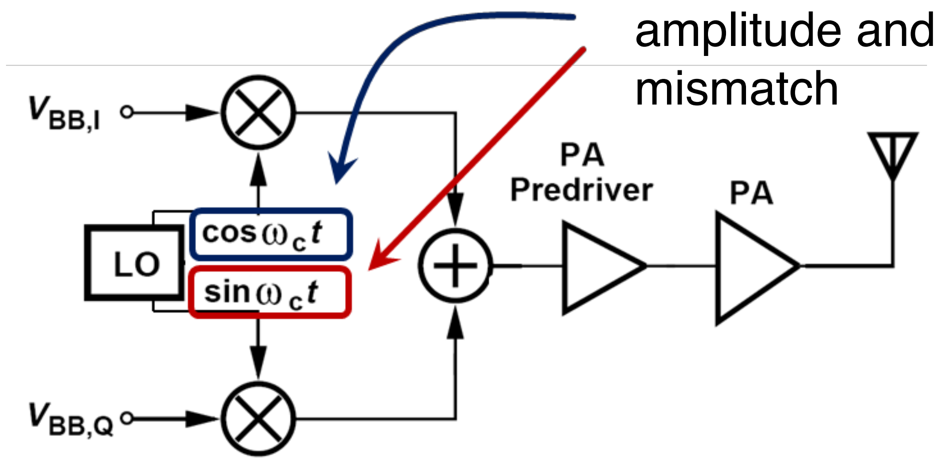
Direct-Conversion Transmitter: Issues

- I/Q mismatch
- Carrier leakage
- Mixer linearity
- TX linearity
- Oscillator pulling

IQ mismatch/imbalance

- The two orthogonal carriers are generated from the same local oscillator by:
  - Quadrature VCO
  - Polyphase filters
  - Frequency division
  - ...

In practice, these signals have amplitude and phase mismatch



IQ mismatch/imbalance

- Let us again consider the quadrature modulated signal:

$$s(t)=I(t)\cos\omega_c t - Q(t)\sin\omega_c t$$

- We introduce an unknown amount of amplitude and phase mismatch between the two carriers

$$y(t)=I(t)\cos\omega_c t - Q(t)\,\varepsilon\sin(\omega_c t+\Delta\theta)$$

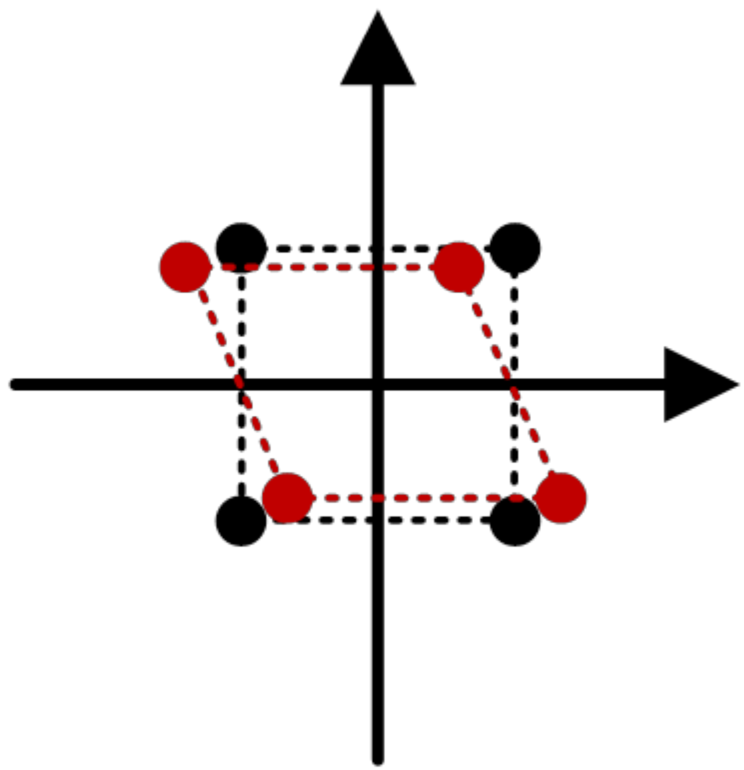
$$=I(t)\cos\omega_c t - Q(t)\,\varepsilon\cos\Delta\theta\sin\omega_c t - Q(t)\,\varepsilon\sin\Delta\theta\cos\omega_c t$$

$$=[I(t) - \varepsilon\sin\Delta\theta\, Q(t)]\cos\omega_c t - [Q(t)\,\varepsilon\cos\Delta\theta]\sin\omega_c t$$

Distortion to the I and Q data

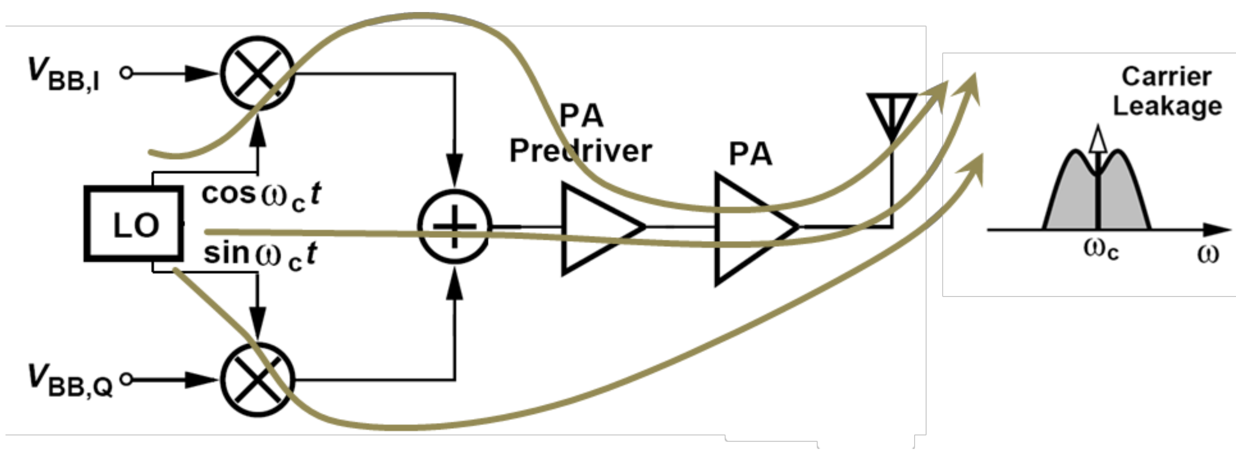
Effect of IQ mismatch on the Constellation

- In presence of IQ mismatch the constellation diagram is tilted



Carrier Leakage

- In-phase and Quadrature data are at baseband (ω=0) and are directly shifted to the carrier frequency
- Carriers are generated by the local oscillator (LO)
- In practice, there are always leakage paths from the LO to the output



Carrier Leakage

- To understand how carrier leakage affects the transmitted signal, consider a quadrature modulated signal:

$$s(t)=I(t)\cos\omega_c t - Q(t)\sin\omega_c t$$

- If a certain amount of the carrier signal leaks to the output it adds to the signal with unknown amplitude and phase:

$$y(t)=I(t)\cos\omega_c t - Q(t)\sin\omega_c t + k\cos(\omega_c t + \phi)$$

$$=I(t)\cos\omega_c t - Q(t)\sin\omega_c t + k\cos\phi\cos\omega_c t - k\sin\phi\sin\omega_c t$$

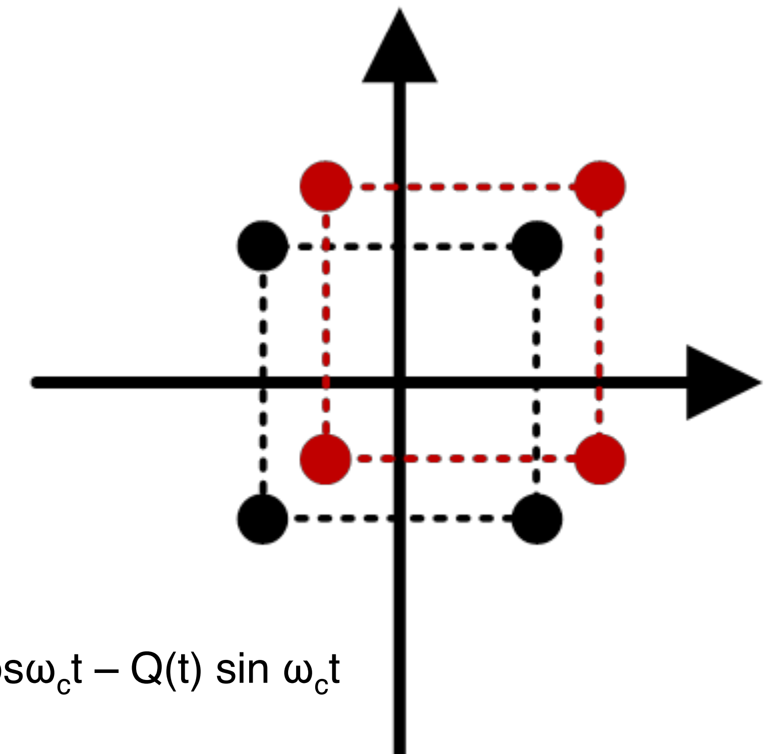
$$=[I(t)+k\cos\phi]\cos\omega_c t - [Q(t)+k\sin\phi]\sin\omega_c t$$

Distortion to the I and Q data

Effect of Carrier Leakage on the Constellation

- Effect of carrier leakage is a shift of origin

$y(t)=[I(t)+ k \cos\phi] \cos\omega_c t - [Q(t)+ k \sin\phi] \sin\omega_c t$

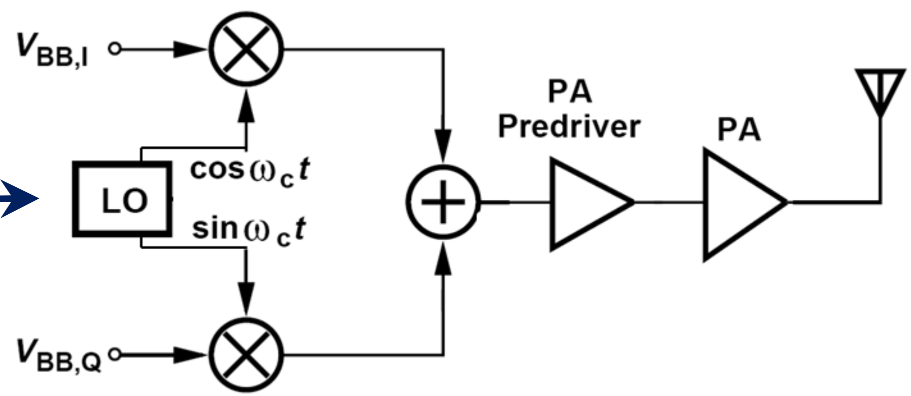


$s(t)=I(t) \cos\omega_c t - Q(t) \sin \omega_c t$

Phase and Frequency Instability

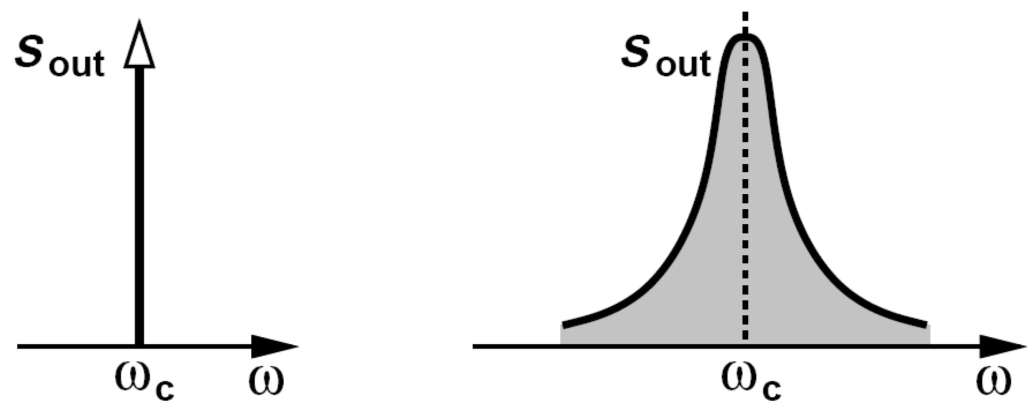
- Local Oscillators exhibit frequency instabilities
  - Short-term frequency instability is referred to phase noise *(next slide)*
  - Long-term frequency instability is referred to frequency drift

Since LO is operating at high frequencies, its phase noise performance is degraded



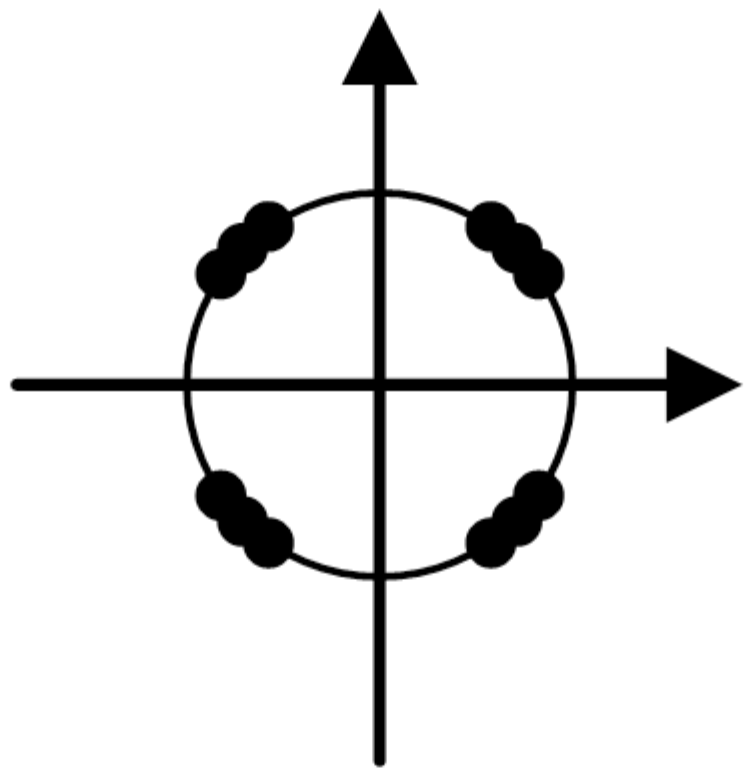
Phase Noise

- The spectrum of an oscillator deviates in practice from an impulse and is "broadened" by the noise of its constituent devices, called phase noise.
- Phase noise bears direct trade-offs with the tuning range and power dissipation of oscillators, making the design more challenging.
- Phase noise is inversely proportional to Q of LC oscillators.



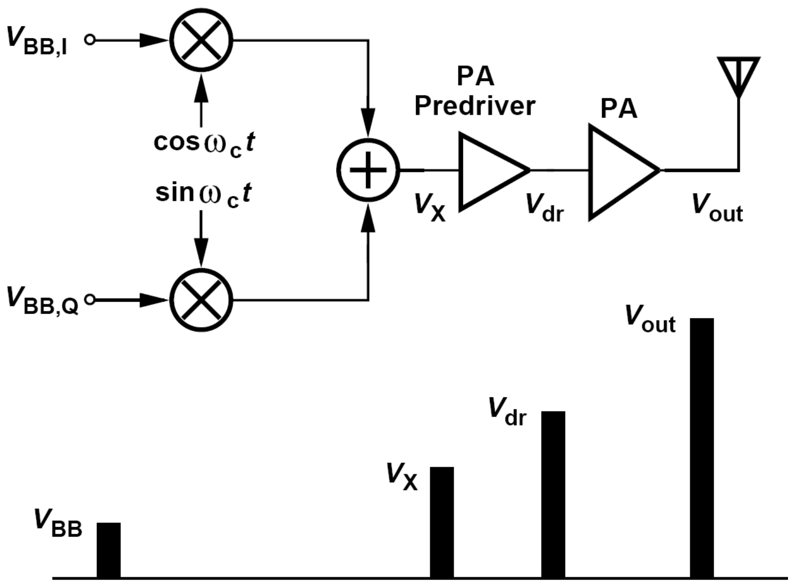
Effect of Phase Noise on the Constellation

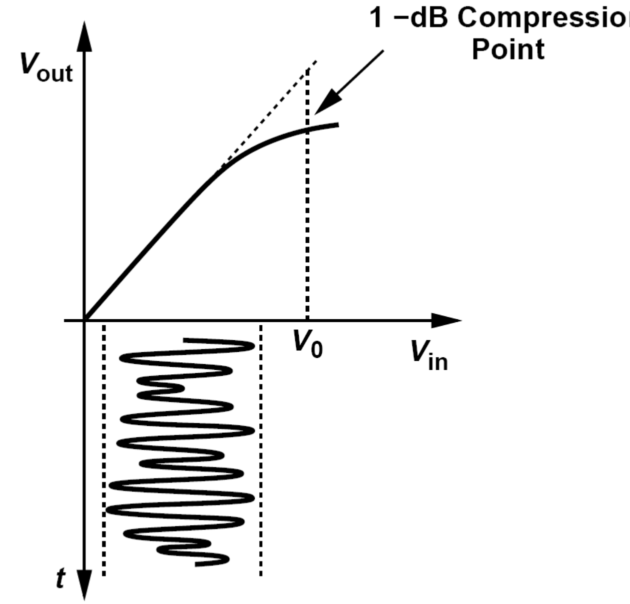
- Effect of phase noise on the constellation diagram:



TX Linearity

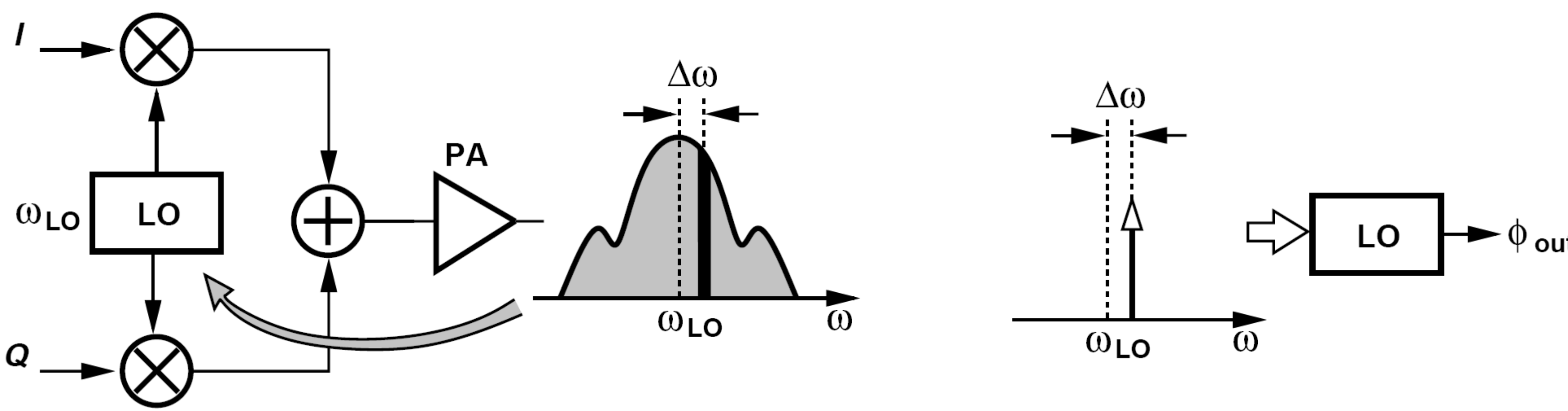
- Typically 20-30 dB gain is needed in the transmitter chain
- Most systems also require adaptive gain control for adjustment of transmitted power



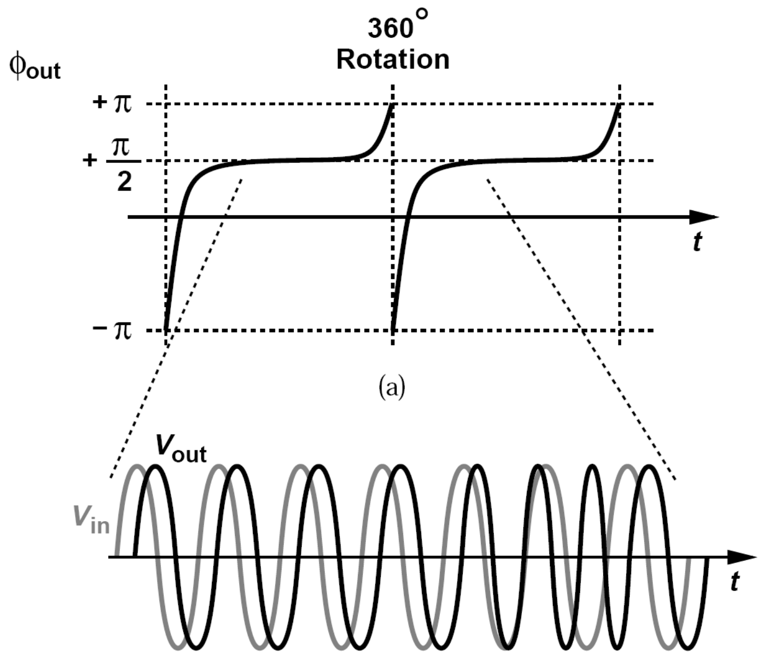


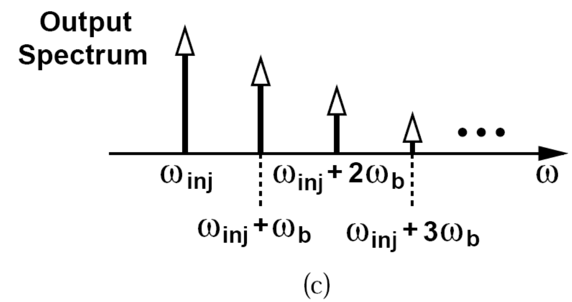
Oscillator Pulling

- The PA output exhibits very large swings, which couple to various parts of the system through the silicon substrate, package parasitics, and traces on the printed-circuit board.
- A fraction of the PA output couples to the local oscillator.



Effect of Oscillator Pulling

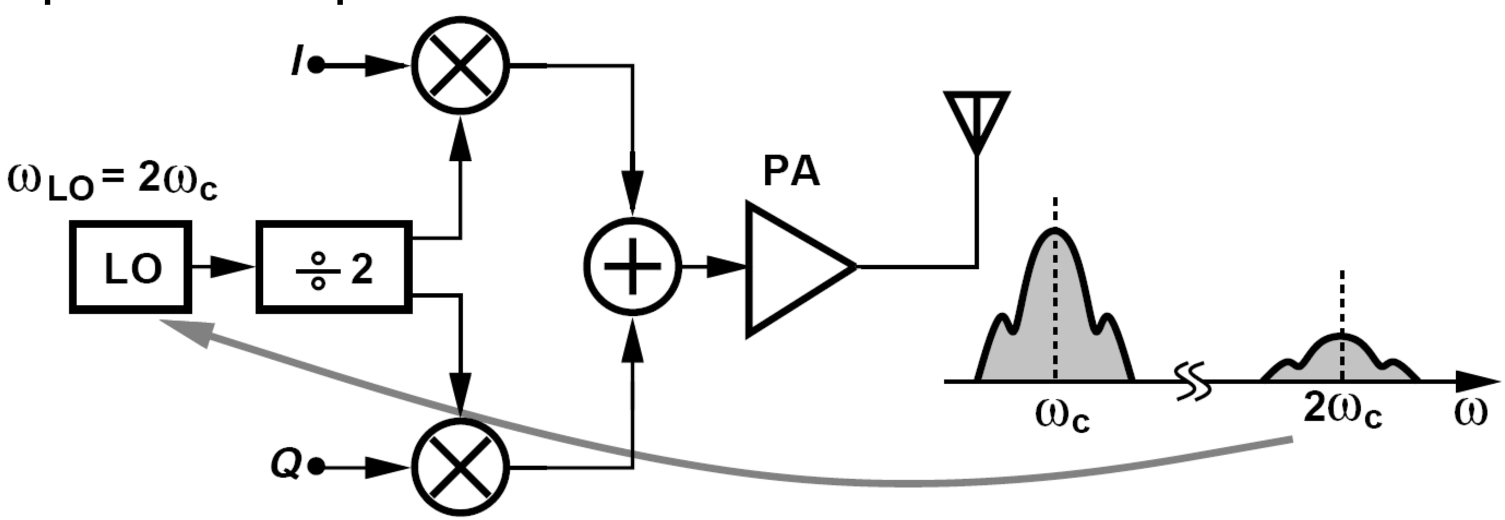




- The output phase of the oscillator, Φ_{out}, is modulated periodically.
- In order to avoid injection pulling, the PA output frequency and the oscillator frequency must be made sufficiently different.

÷2 Direct-Conversion Transmitter (4.3.3)

- Most of today's direct-conversion transmitters avoid an oscillator frequency equal to the PA output frequency by running LO at 2x carrier (below)
- This architecture is popular for two reasons: injection pulling is greatly reduced, and the divider provides quadrature phases of the carrier



Multiple Access Techniques: chapter 3.6, TX Architectures: chapter 4.3

- Multiple Access Techniques
  - Duplex Communication
  - Multiple Access Techniques
  - Multiplexing Techniques
- Direct-Conversion Transmitter
- **Two-step Conversion Transmitter (4.3.4)**

Motivation

- Several of signal impairments which exist in the Direct Conversion Transmission can be reduced by Two-Step Conversion or Heterodyne transmitter architecture

- The word heterodyne actually just means frequency conversion by mixing. Often people talk about superheterodyne (for the RX) when they refer to a two-step frequency conversion.

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Languages

Reginald Fessenden

From Wikipedia, the free encyclopedia

Reginald Aubrey Fessenden (October 6, 1866 – July 22, 1932) was a Canadian inventor who performed pioneering experiments in radio, including the use of continuous waves and the early—and possibly the first—radio transmissions of voice and music. In his later career he received hundreds of patents for devices in fields such as high-powered transmitting, sonar, and television.

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1 Early years
2 Early work
3 Radio work
3.1 Weather Bureau contract and the first audio radio transmission
3.2 Formation of NESCO
3.3 Rotary-spark transmitter and the first two-way transatlantic transmission
3.4 Alternator-transmitter and the first audio radio broadcast
3.5 Continuing work and dismissal from NESCO
3.6 Ongoing influence
4 Later years
5 Death and afterwards
6 Reginald A. Fessenden House
7 Quotations
8 See also
9 Publication
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11 Patents
12 External links

Reginald Fessenden

The Father of Radio Broadcasting

Born	October 6, 1866 East-Bolton, Quebec, Canada
Died	July 22, 1932 (aged 65) Bermuda (buried St. Mark's Church cemetery)
Nationality	Canadian
Occupation	Inventor
Known for	Inventing the Radiotelephony

Fessenden invented the heterodyne (mixer) in 1901 and used it for direction conversion receivers (zero-IF)

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Edwin Howard Armstrong

From Wikipedia, the free encyclopedia
(Redirected from Edwin H. Armstrong)

Edwin Howard Armstrong (December 18, 1890 – January 31, 1954) was an American electrical engineer and inventor. He has been called "the most prolific and influential inventor in radio history".[2] He invented the regenerative circuit while he was an undergraduate and patented it in 1914, followed by the super-regenerative circuit in 1922, and the superheterodyne receiver in 1918.[3] Armstrong was also the inventor of modern frequency modulation (FM) radio transmission.

Armstrong was born in New York City, New York, in 1890. He studied at Columbia University where he was a member of the Epsilon Chapter of the Theta Xi Fraternity. He later became a professor at Columbia University. He held 42 patents and received numerous awards, including the first Institute of Radio Engineers now IEEE Medal of Honor, the French Legion of Honor, the 1941 Franklin Medal and the 1942 Edison Medal. He is a member of the National Inventors Hall of Fame and the International Telecommunications Union's roster of great inventors.

Contents [hide]

1 Early life
2 Early work
3 FM radio
4 Personal life
5 Suicide
6 Legacy
7 Honors
8 Patents

Edwin H. Armstrong

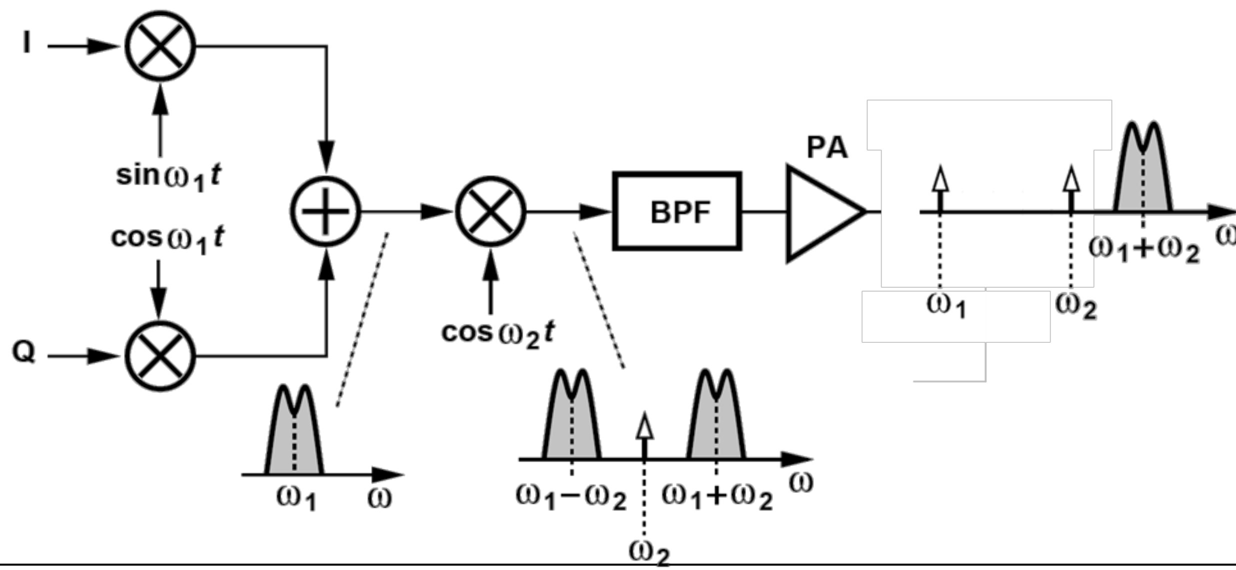
Developed and advanced the utility of FM technology.

Born December 18, 1890
Chelsea, Manhattan, New York, New York, U.S.[1]

Armstrong invented the superheterodyne receiver in 1918

Two-step Conversion Transmitter

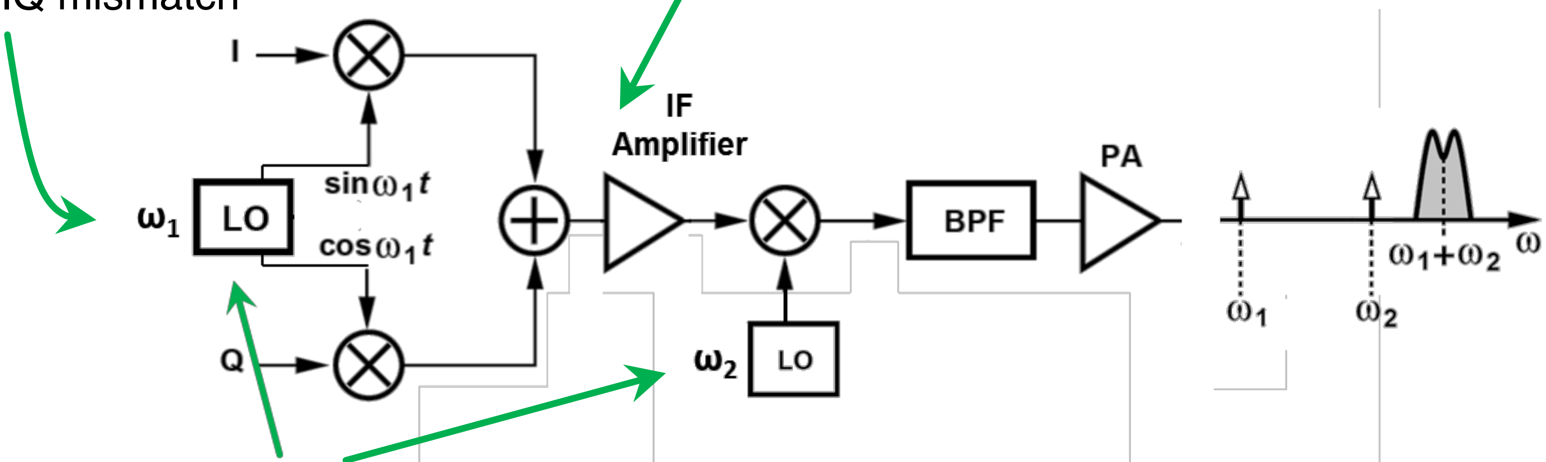
- In this architecture, we intentionally do not choose carrier frequency of the quadrature modulator to be the final transmission frequency, and perform a second frequency up-conversion by ω_2.
- We call ω_1 the intermediate frequency (IF).



Two-step Conversion - Advantage

This LO is operating at low frequency
+ lower phase noise
+ less IQ mismatch

Gain and level control may be much more effectively performed at the intermediate frequency

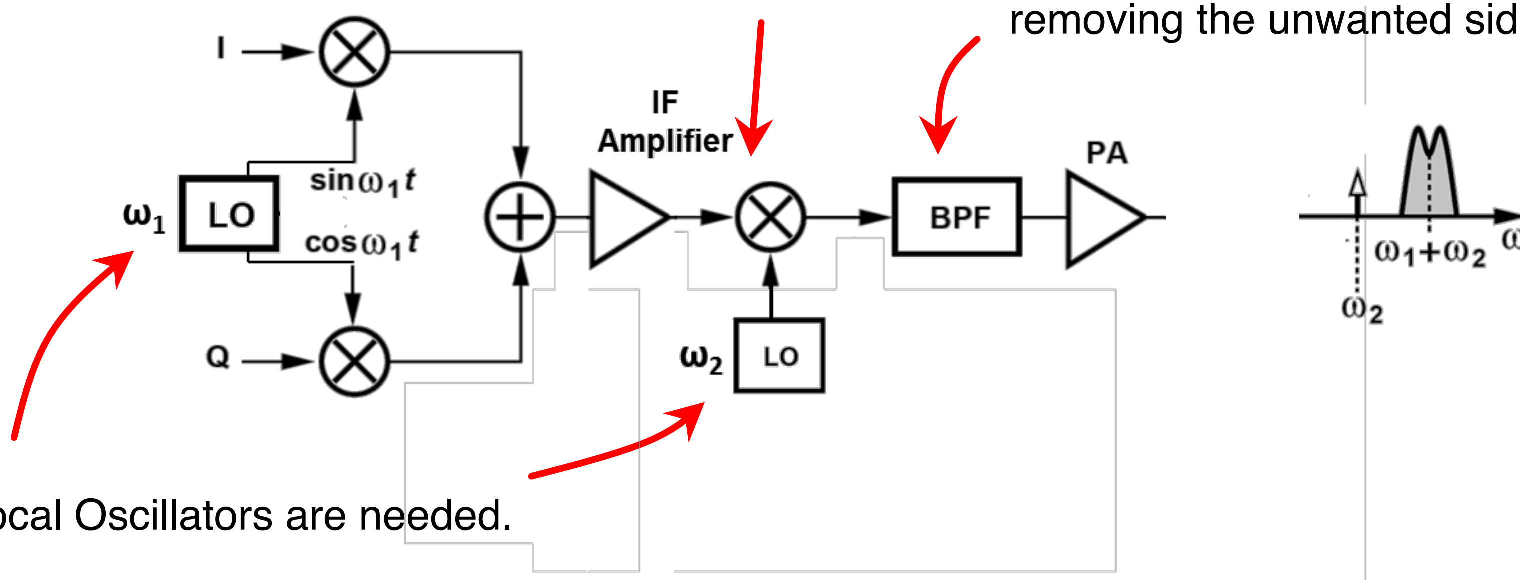


None of the two LO operates at the output frequency so LO leakage does not distort the transmitted signal

Two-step Conversion - Disadvantages

Additional RF mixer

This filter is critical in removing the unwanted sideband

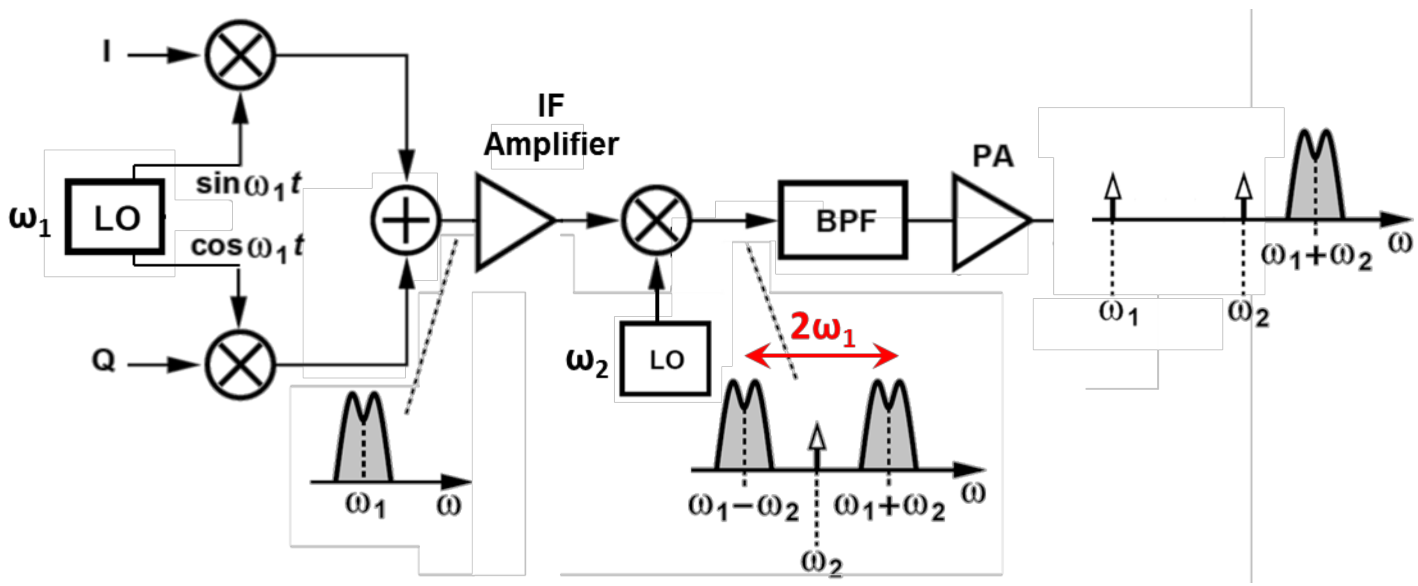


Two Local Oscillators are needed.

Choice of Intermediate Frequency (IF)

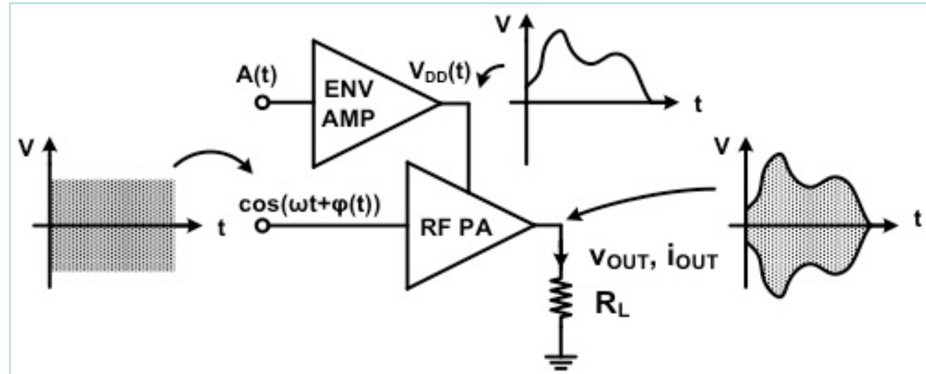
- Low IF
  - Lower phase noise on LO1
  - Less IQ mismatch
  - Higher LO2 and risk for leakage to the output
  - Sharper filtering due to less separation of the two sidebands

Choice of IF is not a trivial task and requires iterative analysis and simulation of the system

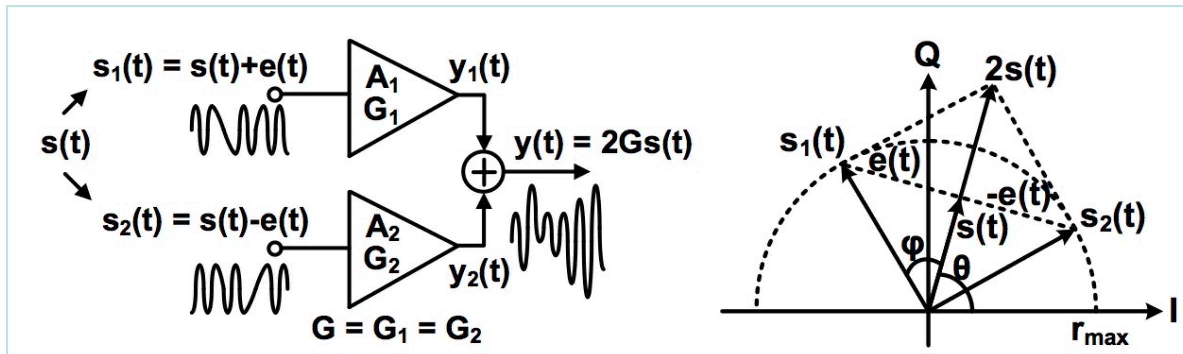


Other Transmitter types

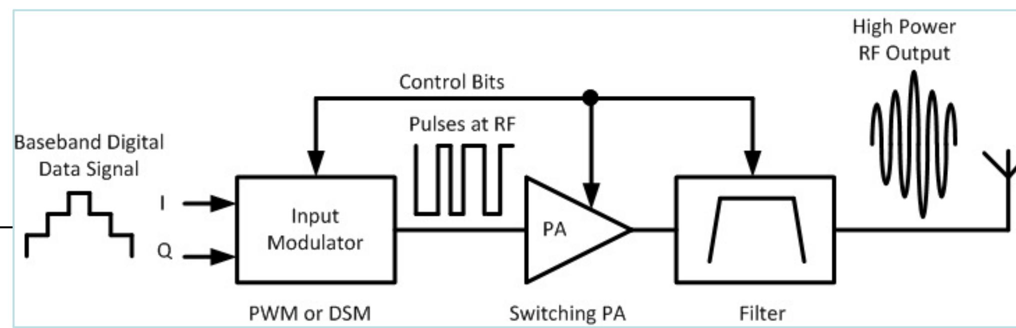
- Envelope tracking



- Outphasing



- Pulse-width modulation



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