

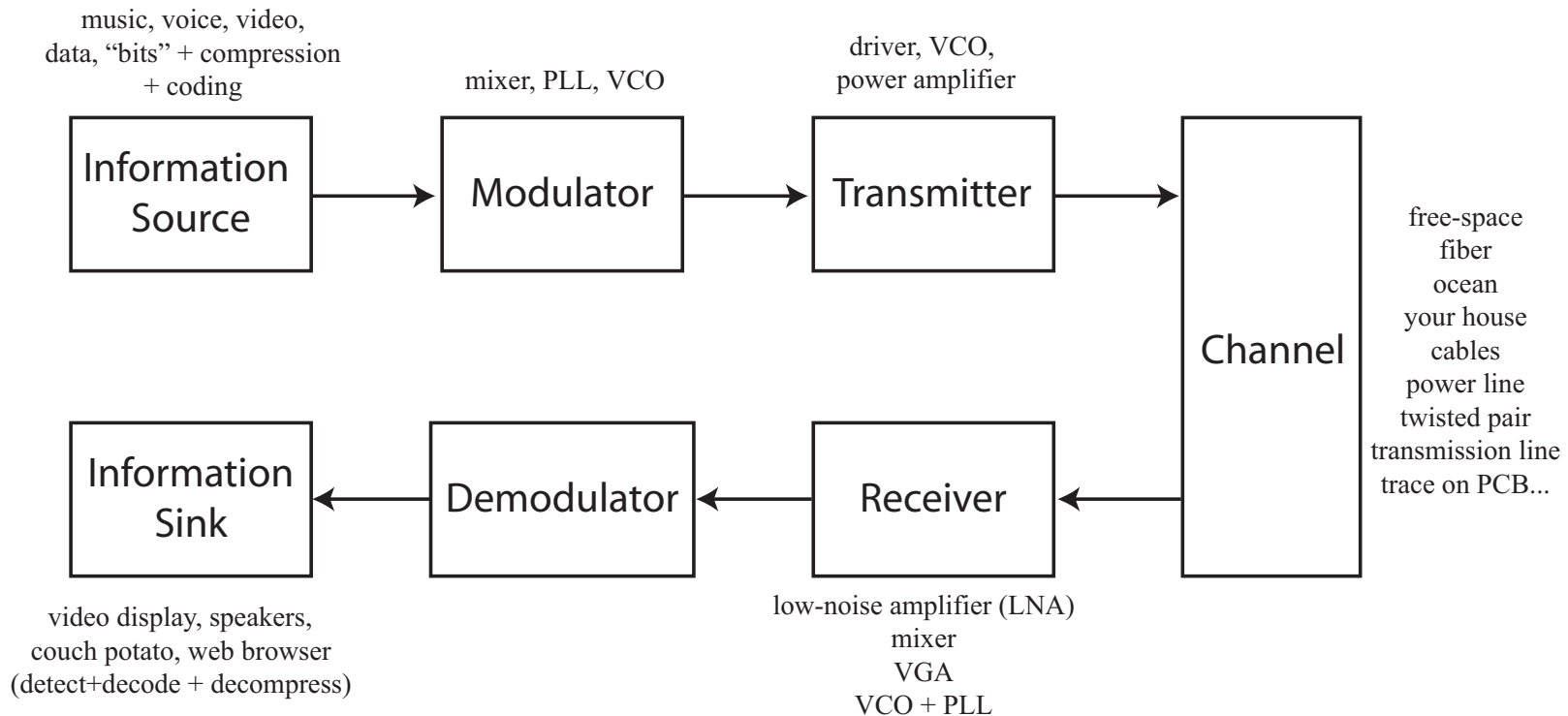
Lecture 1: Communication Circuits

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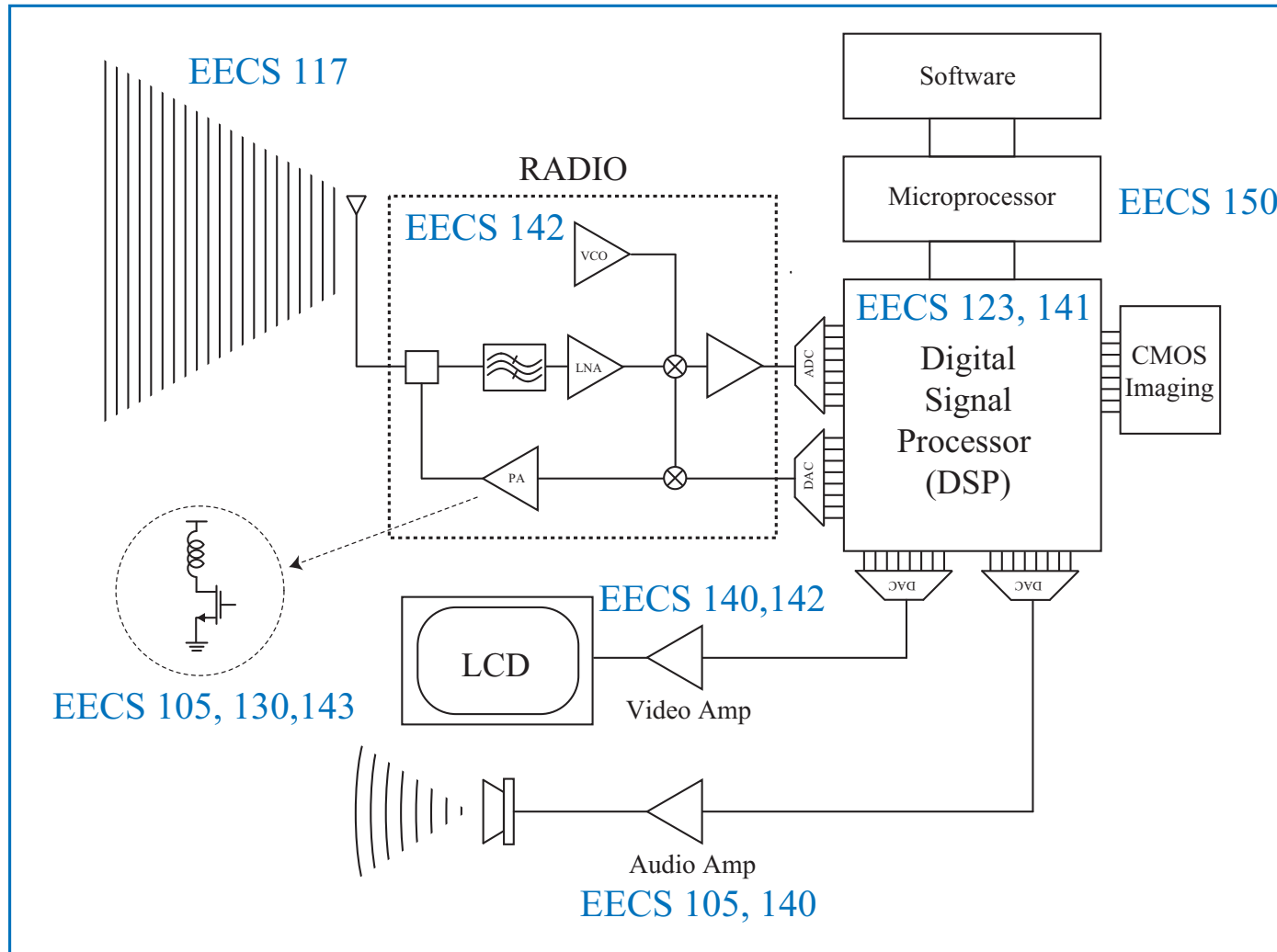
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Block Diagram of Communication System



- A typical communication system can be partitioned into a transmitter, a channel, and a receiver.
- In this course we will study the circuits that interface from the channel to the receiver/transmitter. These circuits are at the “front-end” of the transceiver and operate at high frequency.
- The baseband circuits are responsible for encoding, compression, modulation, demodulation, and detection. These circuits are typically implemented in digital form.

A Cell Phone

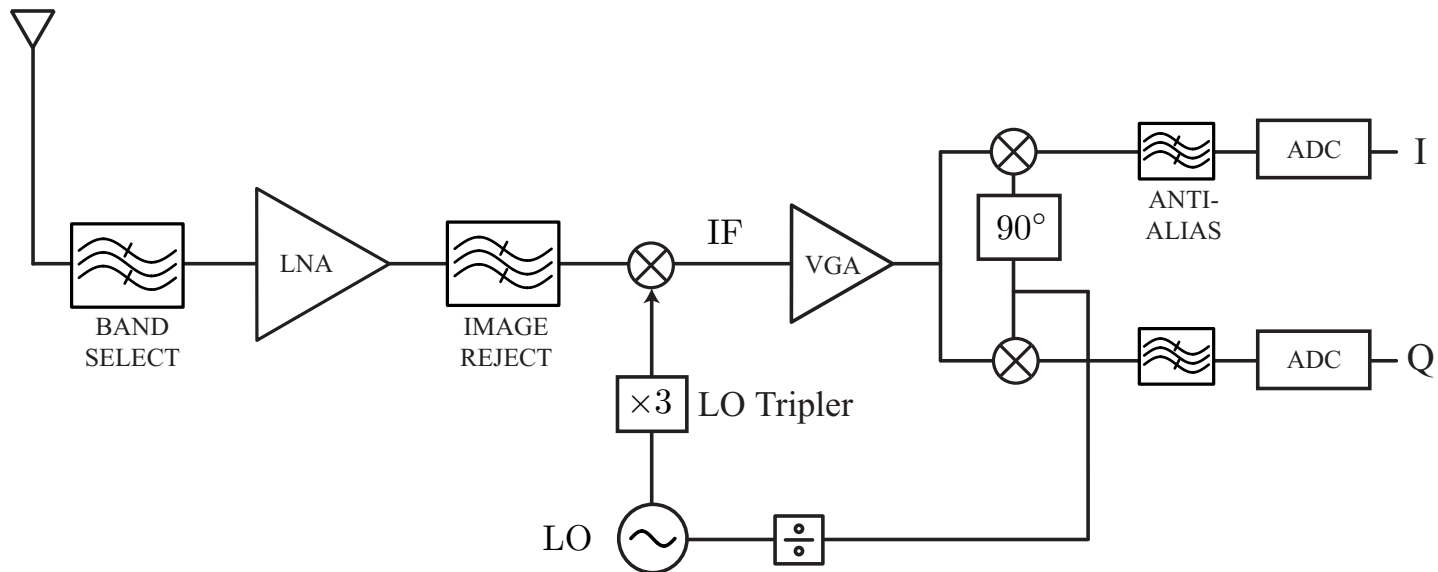


ENTIRE SYSTEM: EECS 120, 126, 121

Non-Linear and Time Varying Circuits

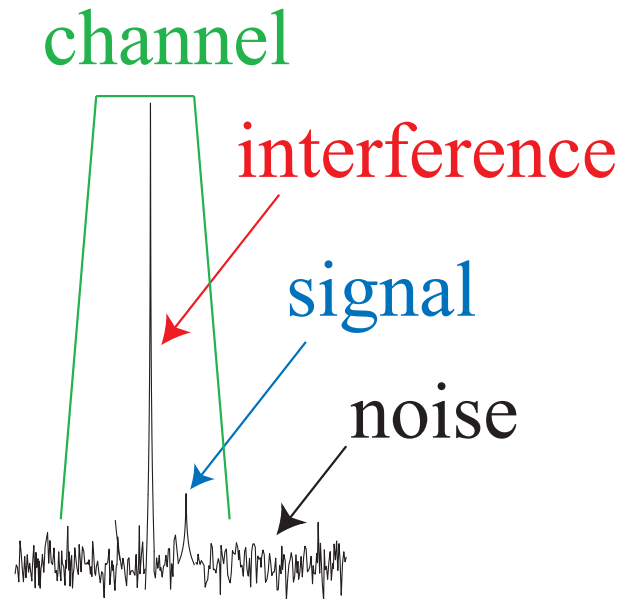
- EECS 142 pre-requisites: EECS 105, 120, 140. EECS 126 (226) is optional but it gives you insight into the mathematical details of “noisy” signals.
- From 140 you should review feedback amplifiers and frequency response. From EECS 120 you should review linear system theory, Fourier series and transforms.
- In 142 we build on EECS 140 to build wideband, tuned, linear, and high dynamic range amplifiers. We’ll spend a great deal of time analyzing the frequency performance, the noise, and the linearity of the amplifier.
- Much of this course is fundamentally about *non-linear* and *time-varying* circuits. While in some circuits we’ll strive to eliminate sources of non-linearity (amplifiers), in other circuits we’ll embrace the non-linearity (oscillators, mixers).

Zoom in on Receiver



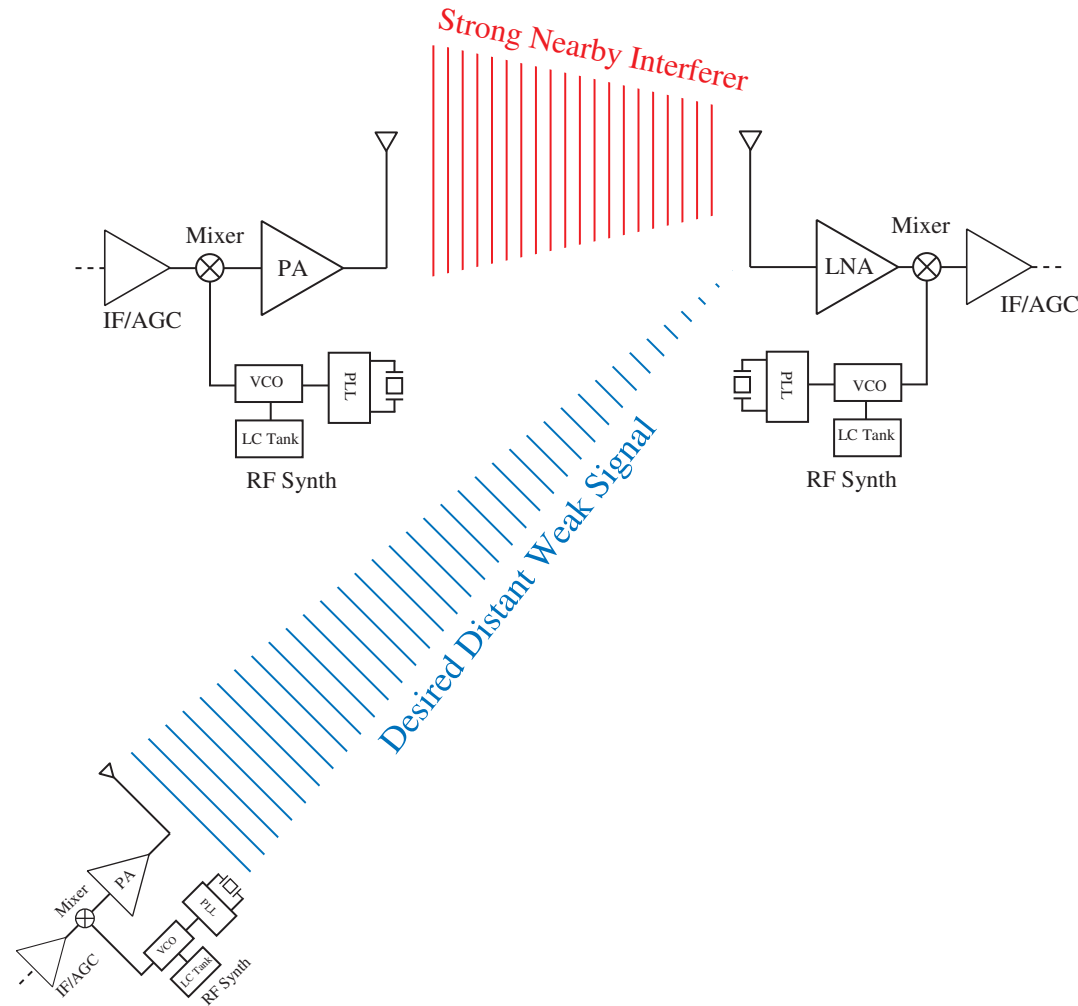
- This is a generic super-heterodyne receiver. There are several important *active* and *passive* blocks in this system. Passive blocks include switches, filters, and resonators. Active building blocks include:
 - LNA: Low noise amplifier
 - LO: “Local” Oscillator
 - VGA: Variable Gain Amplifier (or PGA for programmable gain amplifier)
 - ADC: Analog to Digital Converter
 - DSP: Digital Signal Processor

The Spectrum Seen by a Receiver



- Note that the desired signal is often much weaker than other signals. In addition to out of band interfering signals, which can be easily filtered out, we also must contend with strong in-band interferers. These nearby signals are often other channels in the spectrum, or other users of the spectrum.
- The dynamic range of a wireless signal is VERY large, on the order of 80 dB. The signal strength varies a great deal as the user moves closer or further from a base-station (access point).
- Due to multi-path propagation and shadowing, the signal strength varies in a time varying fashion.

Don't Throw Out the Baby with the Bathwater!



- Interference often appears in a near-far situation shown above. The receiver is far away from the base-station and so it must detect a weak signal. Unfortunately, a nearby transmitter is blasting away producing a strong “blocker” signal.

Goal of a Communication System: Amplification

- The power in communication systems is often measured in the dBm scale, or the log power measured relative to a 1 mW reference. E.g. a power level of 10 mW can be expressed as 10 dBm

$$10 \cdot \log \left(\frac{10 \text{ mW}}{1 \text{ mW}} \right) = 10 \text{ dBm}$$

- On your laptop or cellular phone, you can often see the signal strength expressed in dBm units.
- Amplification of weak signals is a major goal of a communication system. Amplification is not easy since the signals are often only marginally larger than the intrinsic noise. Additionally, high gain for the interference signals can easily “rail” our amplifiers unless we carefully filter them out.
- Say your WLAN on your laptop is receiving a signal with strength -70 dBm. This corresponds to a power of $P = 10^{-10} \text{ W} = 100 \text{ pW}$. The voltage on the antenna can be approximated by

$$P = \frac{V^2}{2Z_0}$$

- where $Z_0 = 50\Omega$, the antenna impedance. Solving for V

$$V = \sqrt{2Z_0P} = \sqrt{2 \cdot 50 \cdot 10^{-10}} = 10^{-4} \text{ V} = 100 \mu\text{V}$$

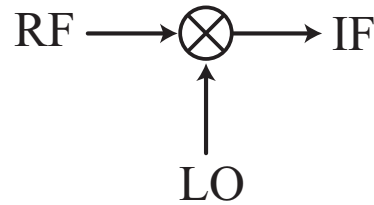
Goals: Filtering

- A cell phone can work with even smaller signals. For instance for $P = -100$ dBm, or $P = 10^{-13}$ W, we have

$$V = \sqrt{100 \cdot 10^{-13}} = \sqrt{10} \times 10^{-6} \sim 3 \mu\text{V}$$

- This is indeed a tiny signal. We need a voltage gain of about 10^5 to bring this signal into the range for baseband processing.
- Now imagine an interference signal of strength -40 dBm, or about 3 mV. This may seem like a small signal, but it effectively limits the gain of our system to about 1000. Unless we employ a very high resolution ADC (expensive, bulky, power hungry), we must filter out this interference.

Goals: Frequency Translation



- Frequency translation is a non-linear or time-varying operation. An LTI system cannot do this!
- The received signal can be represented in the following form

$$V_r = A(t) \cos(\omega_c t + \phi(t))$$

- The frequency ω_c is the “carrier frequency” since the modulation rides on top of this signal. The term $A(t)$ represents the amplitude modulation, or AM. The term $\phi(t)$ is the phase modulation (PM). Frequency modulation, or FM, can also be achieved through $\phi(t)$

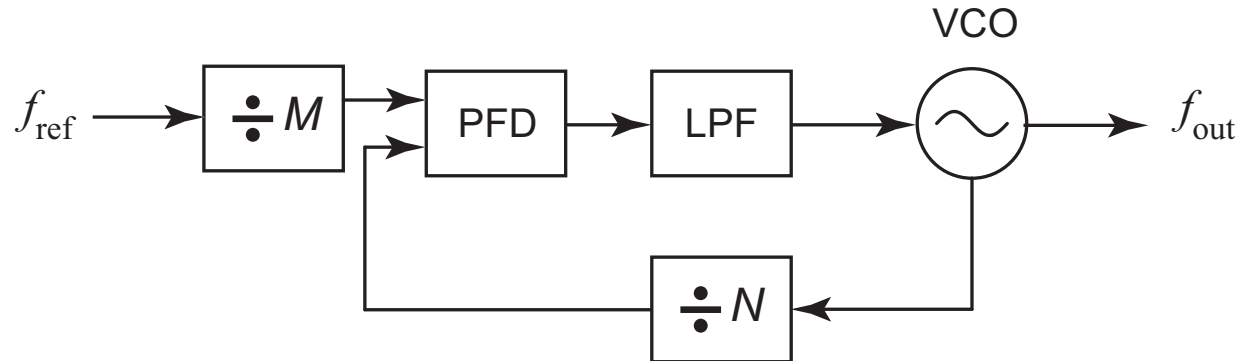
$$A \cos(\omega_c t + \delta\omega \int_0^t m(t) dt)$$

- where $m(t)$ is the normalized modulation waveform and $\delta\omega$ is the maximum frequency deviation.
- E.g. in broadcast television we use AM for the video and FM for audio. A digital modulation scheme may involve AM, FM, PM, or some combination.

Carrier Frequency

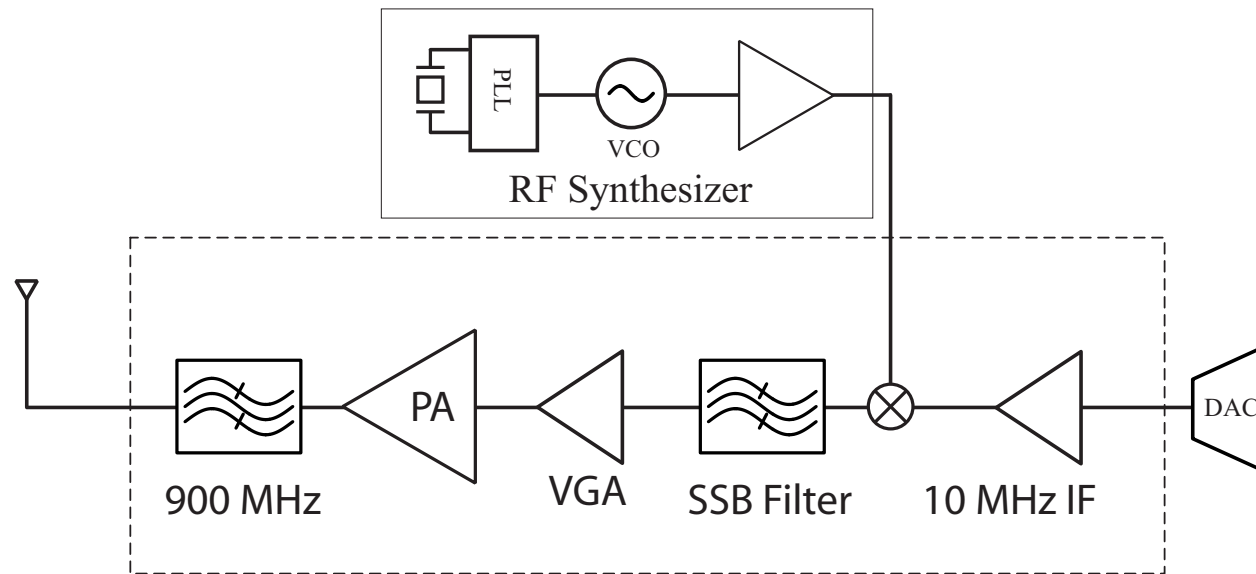
- How is the RF carrier chosen? Often it's a legal requirement (FCC in the U.S.), since the spectrum is a shared resource. Other considerations include propagation characteristics and antenna size. The Eiffel Tower is used as a radio transmitter!
- Finally, the bandwidth of the modulating signal is an important characteristic. Most information sources are baseband in nature, where we arbitrarily define the bandwidth BW as the highest frequency of interest. This usually means that beyond the BW the integrated energy is negligible compared to the energy in the bandwidth.
- The bandwidth of some common signals:
 - High fidelity audio: 20 kHz
 - Uncompressed video: ~ 10 MHz
 - 802.11 b/g WLAN: 22 MHz
- Some common carrier frequencies
 - 100 MHz, FM radio
 - 600 MHz, UHF television
 - 900 MHz, 1.8 GHz, cellular band
 - 2.4 GHz, 5.5 GHz WLAN
 - 3-10 GHz, proposed “ultra-wideband” (wireless USB)

Frequency Synthesis



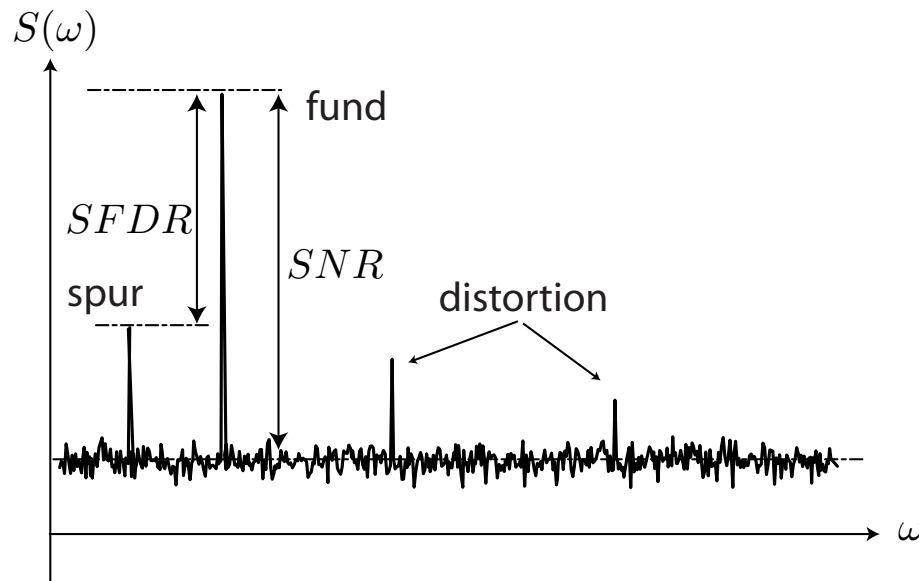
- Since carrier frequencies are used for RF modulation, a transmitter and receiver need to synthesize a precise and stable reference frequency. Since the reference frequency changes based on which “channel” is employed, the synthesizer must be tunable. Think of the tuning “knob” on an FM receiver.
- The reference signal is generated by a voltage-controlled oscillator (VCO) and “locked” to a much more stable reference signal, usually provided by a precision quartz crystal resonator.
- A phase-locked loop (PLL) synthesizer is a feedback system employed to provide the locking and tuning. It employs a frequency divider, a phase/frequency detector, and filtering to achieve this goal.

Zoom in on Transmitter



- This is a generic heterodyne transmitter. In addition to passive filters and switches, we have the following important active building blocks include:
- DAC: Digital to Analog Converter
- Mixer: Up-conversion mixer
- VGA: To select desired output power
- Frequency Synthesizer: Synthesize carrier frequency
- PA: Power Amplifier

Transmitter Spectrum



- The transmitter must amplify the modulated signal and deliver it to the antenna (or cable, fiber, etc) for transmission over the communication medium.
- Generating sufficient power in an efficient manner for transmission is a challenging task and requires a carefully designed power amplifier. Even the best RF power amplifiers do this with only about 60% efficiency.
- The transmitted spectrum is also corrupted by *phase noise* and distortion. Distortion products generated by the amplifier often set the *spurious free dynamic range*.

Topics: High Speed and Wideband Amplifiers

- Review of frequency response (140)
- Gain bandwidth product
- Feedback amplifiers
- Applications:
 - Fiber optic front-end
 - Instrumentation
 - IF gain stages
 - Ultra-wideband receiver
- Tuned amplifiers and matching networks
 - Review of RLC networks and resonance
 - Tuned amplifiers
 - L-matching networks
 - Π /T and multi-section L matching networks
 - Capacitive and inductor transformers
 - Magnetic transformers
 - Optimal amplifier design (maximum gain, stability, matching)
- Technology: CMOS and BJT, SiGe HBT, (MESFET, JFET)

Topics: Noise in Electronic Amplifiers

- Source of noise
- Input/output referred noise
- Noise figure of an amplifier
- Low noise amplifier design (LNA)
- Noise figure of a cascade of amplifiers
- Applications:
 - LNA for receiver
 - Instrumentation
 - IF amplifiers
- Technology: BJT, HBT, CMOS, SOI, MESFET, JFET

Topics: Distortion in Amplifiers

- Source of distortion in electronic circuits
- Device characteristics and large signal models
- Distortion reduction techniques
- Measurement of distortion (harmonic, inter-modulation, cross-modulation)
- Effect of feedback on distortion

Topics: Mixers and Oscillators

- Mixers:
 - Frequency translation/conversion
 - Voltage-switching mixers
 - Current commutating mixers
 - Conversion gain, terminal impedances
- Oscillators:
 - Analysis and design
 - Amplitude and frequency stability
 - Concept of negative resistance
 - Waveform distortion
 - Oscillator topologies (Colpitts, Hartley, Clapp, Cross-coupled,...)

Topics: Power Amplifiers

- Different classes of operation (Class A, B, C ...)
- Switching mode Class D
- Power gain , efficiency
- Linearity, device stress