EE247
Lecture 27

- Term project student presentations
- Acknowledgements
- Examples of systems utilizing analog-digital interface circuitry (not part of final exam - self study)

Administrative

- Office hours on Frid. Dec. 12th, 3 to 4:30pm @ 477 Cory
- No office hours Thurs. Dec. 11th
- Questions can be asked via email

Term Project Presentations

- **Ping-Chen & James**
- **Rikky & Chintan**
- **Jiash & Maryam**
- **Nam-Seog & Jungdong**
- **Kyoohyun & Kwangmo**
- **Lingkai & Thura**
- **Lauren & Mervin**
- **Abhinav & Jason**
- **Lu Ye**

Acknowledgements

- The course notes for EE247 are based on numerous sources including:
  - Prof. P. Gray's EE290 course
  - Prof. B. Boser's EE247 course notes
  - Prof. B. Murmann's Nyquist ADC notes
  - Fall 2004 & '05 & '06 & '07 EE247 class feedback
  - Last but not least, Fall 2008 EE247 class
    - The instructor would like to thank the class of 2008 for their enthusiastic & active participation!

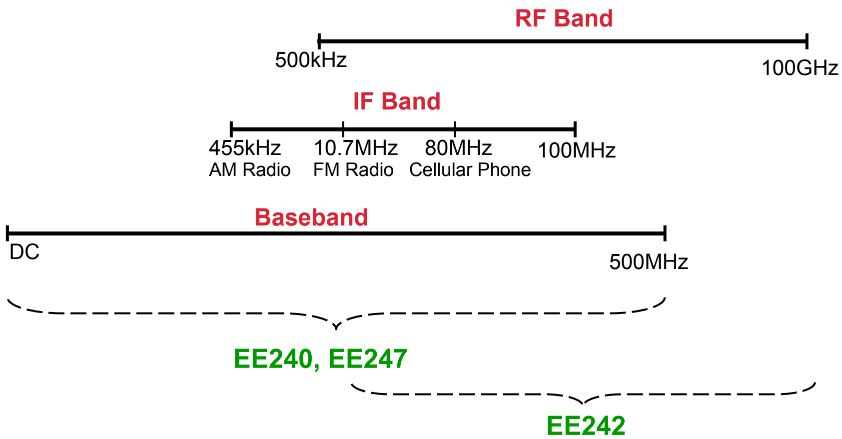
Material Covered in EE247

- Filters
  - Continuous-time filters
    - Biquads & ladder type filters
    - Opamp-RC, Opamp-MOSFET-C, gm-C filters
    - Automatic frequency tuning
  - Switched capacitor (SC) filters
- Data Converters
  - D/A converter architectures
  - A/D converter
    - Nyquist rate ADC- Flash, Interpolating & Folding, Pipeline ADCs,….
    - Self-calibration techniques
    - Oversampled converters

Systems Including Analog-Digital Interface Circuitry (Not Included in Final Exam)

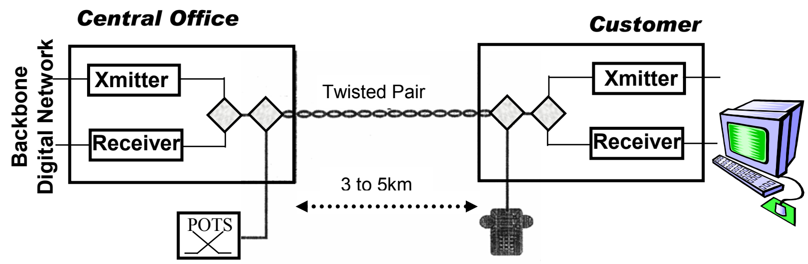
- Wireline communications
  - Telephone related (DSL, ISDN, CODEC)
  - Television circuitry (Cable modems, TV tuners…)
  - Ethernet (10/1Gigabit, 10/100BaseT…)
- Wireless
  - Cellular telephone (CDMA, Analog, GSM….)
  - Wireless LAN (Blue tooth, 802.11a/b/g…..)
  - Radio (analog & digital), Television
- Disk drives
- Fiber-optic systems

E.E. Circuit Course vs. Frequency Range



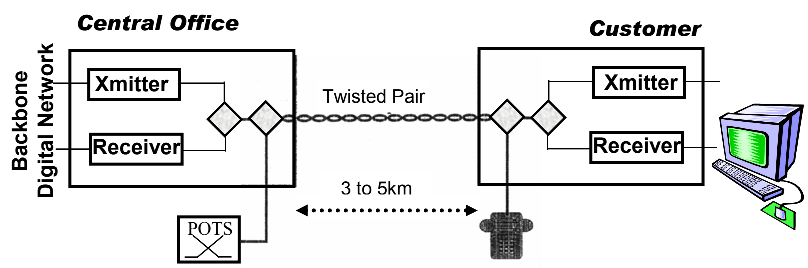
Wireline Communications Telephone Based

Data Transmission Over Existing Twisted-Pair Phone Lines



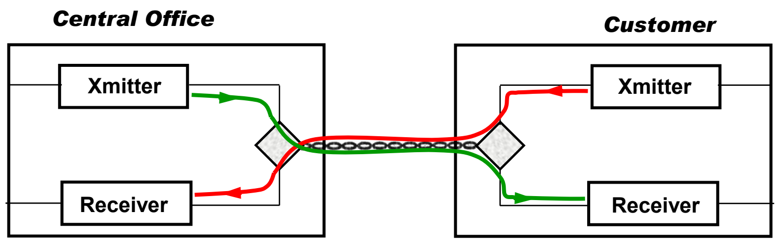
- Data transmitted over existing phone lines covering distances close to 3.5miles
  - Voice-band MODEMs (up to 56Kb/s)
  - ISDN (160Kb/s)
  - HDSL, SDSL,……
  - ADSL (up to 8Mb/s)

Data Transmission Over Twisted-Pair Phone Lines ISDN (U-Interface) Transceiver

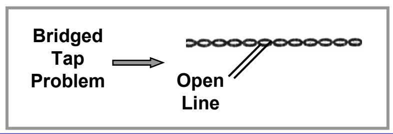


- Full duplex transmission (RX & TX signals sent simultaneously)
- 160kbit/sec baseband data (80kHz signal bandwidth)
- Standardized line code 2B1Q (4 level code 3:1:-1:-3)
- Max. desired loop coverage 18kft (~36dB signal attenuation)
- Final required BER (bit-error-rate) 10^{-7} $\rightarrow$ (min. SNDR=27dB)

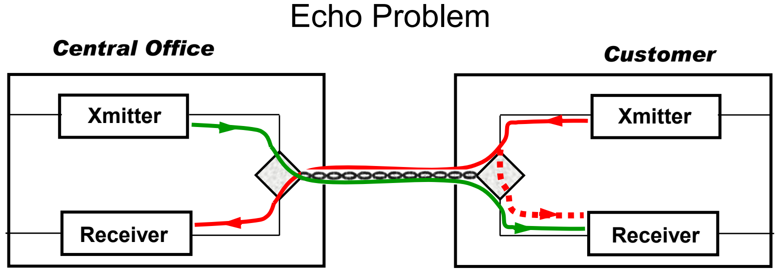
ISDN (U-Interface) Transceiver
Echo Problem



- Transformer coupling to line
  – For a perfectly matched system → no leakage of TX signal into RX path
  – Unfortunately, system has poor matching + complicating factor of bridged-taps

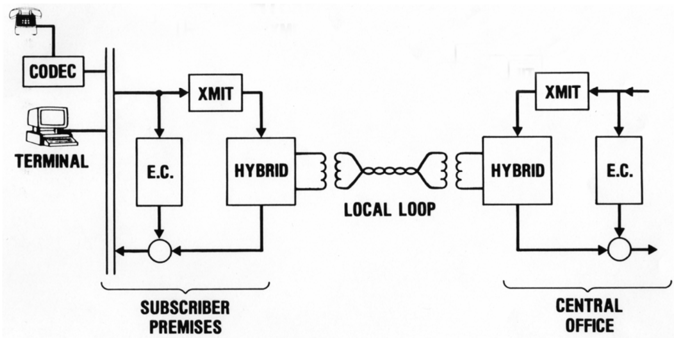


ISDN (U-Interface) Transceiver
Echo Problem



- System full duplex transmission → RX & TX signals sent simultaneous (& at the same frequency band)
  – Leakage of TX signal to RX path (echo)
  – Worst case → echo could be *30dB* higher compared to the received signal!!

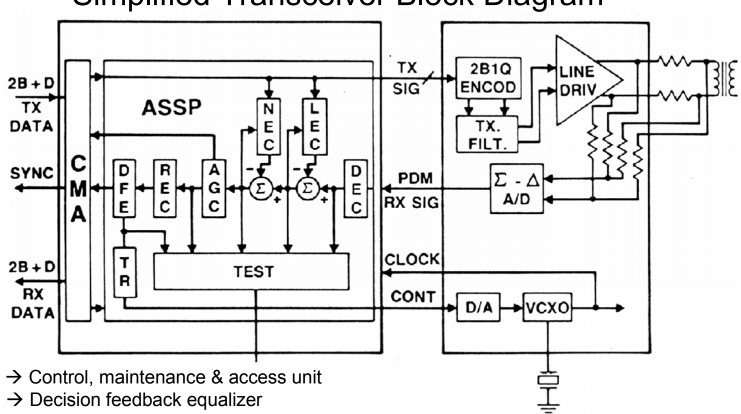
ISDN (U-Interface) Transceiver Echo Cancellation



- Echo cancellation performed in the digital domain
  - Typically echo cancellation performed by transversal adaptive digital filter
  - Any non-linearity incurred by the analog circuitry makes echo canceller significantly more complex

  → Desirable to have high linearity analog circuitry (75dB range)

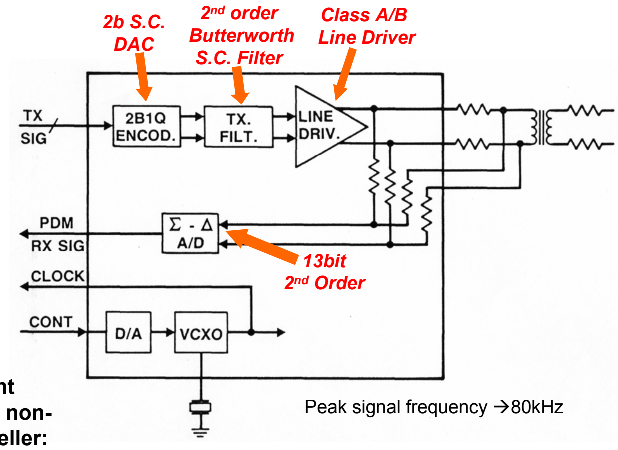
Simplified Transceiver Block Diagram



CMA → Control, maintenance & access unit
DFE → Decision feedback equalizer
DEC → Decimation filter
REC → Reconstruction filter
LEC & NEC →Linear/non-linear echo-canceller

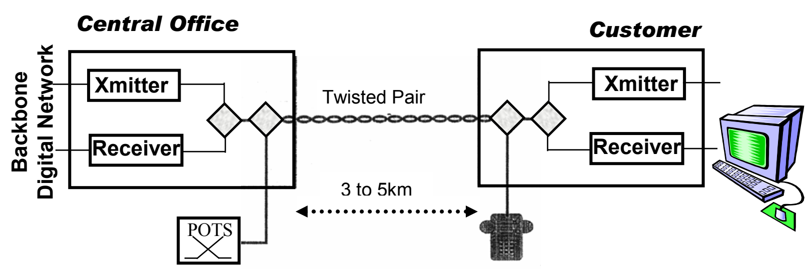
Ref: H. Khorramabadi, et. al"An ANSI standard ISDN transceiver chip set, " *IEEE International Solid-State Circuits Conference,* vol. XXXII, pp. 256 - 257, February 1989

Analog Front-End



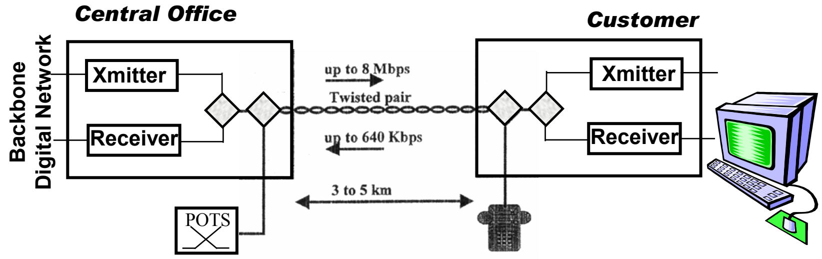
To avoid stringent requirements for non-linear echo canceller:
→ high linearity analog circuitry needed (~ 75dB)

Data Transmission Over Twisted-Pair Phone Lines DSL (Digital Subscriber Loop)



- HDSL &SDSL more like ISDN @ higher frequencies
  - Full duplex transmission with RX & TX signals on the same frequency band

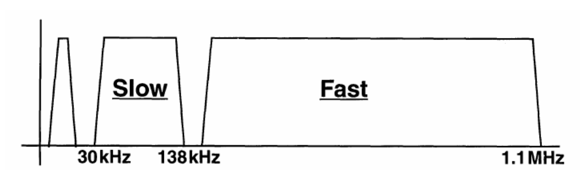
Data Transmission Over Twisted-Pair Phone Lines
ADSL (Asymmetric Digital Subscriber Loop)



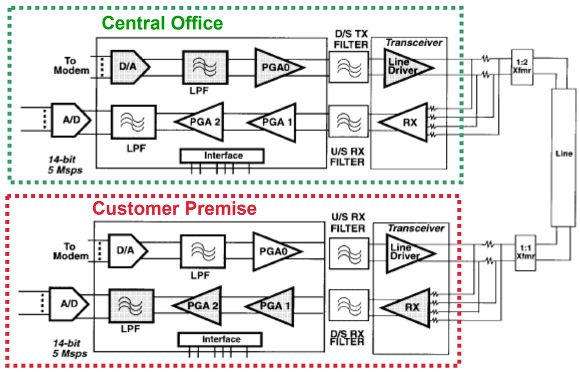
- In USA mostly ADSL → FDM (frequency division multiplex)
  - Signal from CO to customer on a different band compared to customer to CO
    - Echo cancellation can be performed by simple filtering
  - Data rates up to 8Mbps (much higher compared to ISDN)

ADSL Signal Characteristics

- Main difference compared to ISDN: TX & RX signals on different frequency bands
  - Downstream (*fast*, from CO to customer) 138kHz to 1.1MHz
  - Upstream (*slow*, from customer to CO) 30kHz to 138kHz
    - Echo cancellation much easier
- More severe signal attenuation at high frequencies (1MHz DSL v.s. 80kHz ISDN)



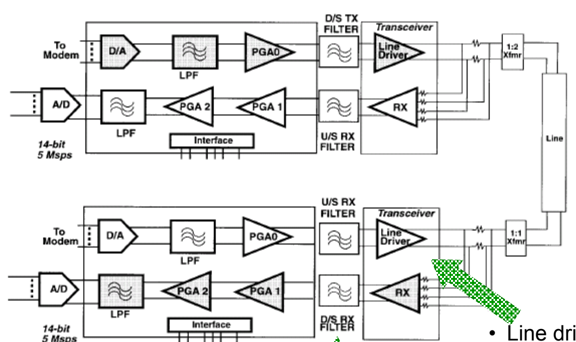
Typical ADSL Analog Front-End



- ADC 16/14b with 14bit linearity, pipeline with auto. calibration @ 5Ms/s
- DAC 16/14b with 14bit linearity, with auto. calibration
- On-chip filters 3rd to 4th order LPF with f_c 1.1MHz for downstream and 138kHz upstream (typically continuous-time type filters with on-chip frequency tuning)

Ref: D.S. Langford, et al, "A BiCMOS Analog Front-End Circuit for an FDM-Based ADSL System," *IEEE Journal of Solid State Circuits,* Vol. 33, No. 9, pp. 1383-1393, Dec. 1998.

Typical ADSL Analog Front-End



- Note: Band selection filters are off-chip due to stringent noise requirements (3nV/rtHz)
  - Discrete LC type

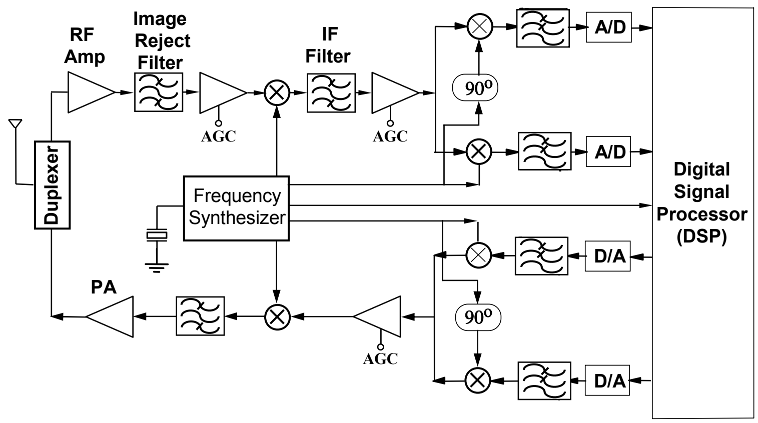
- Line driver on a separate bipolar chip to achieve required high output signal levels with high power efficiency typically +-12V supply

Wireless Communication Circuits

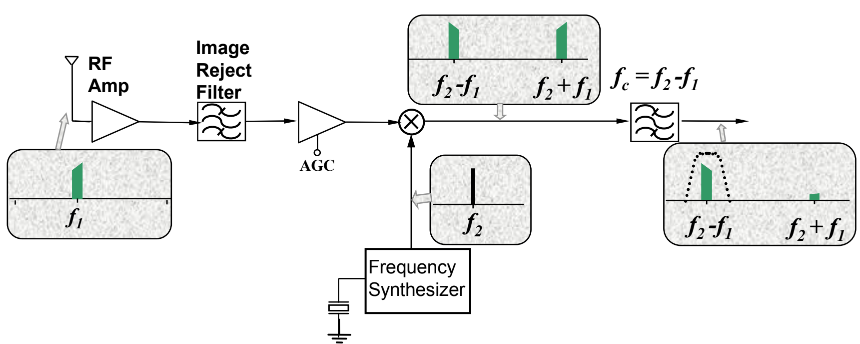
Wireless Circuits

- Differ from wired comm. circuits
  - Includes RF circuitry + IF circuitry + baseband circuits (three different frequency ranges)
  - Signal scenarios in wireless receivers more challenging
  - Requirement for received signal BER in the order of 10^{-3} for voice-only→(min. SNR~9dB)

Typical Cellular Phone Block Diagram

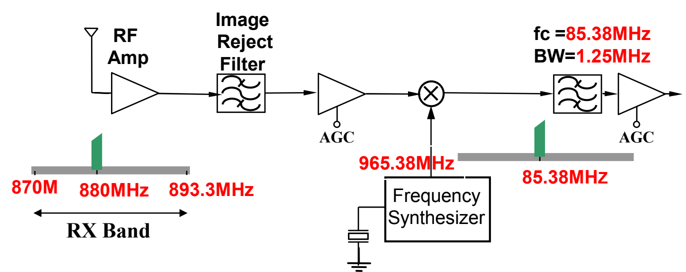


Superheterodyne Receiver



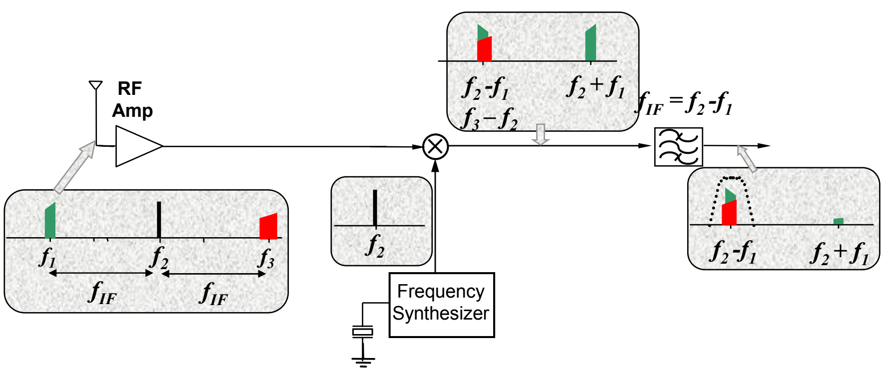
- One or more intermediate frequency (IF)
- Periodic signal at a frequency equal to the desired RX signal + or – IF frequency is provided by a Local Oscillator
- RX signal is frequency shifted to a fixed frequency (IF filter center frequency)

RF Superheterodyne Receiver Example: CDMA Receiver



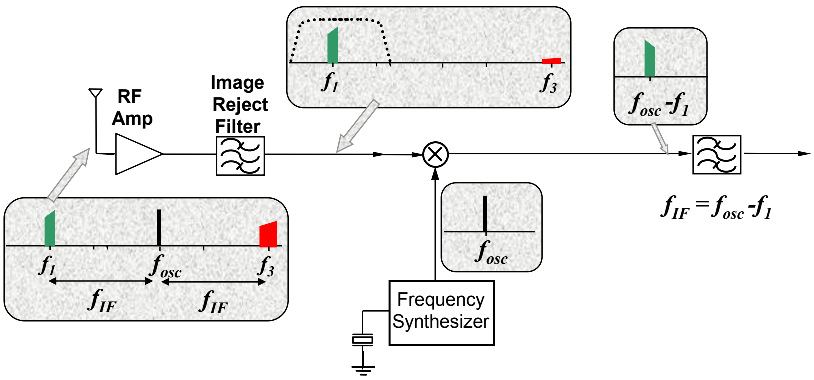
- Received frequency is mixed down to a <u>fixed</u> IF frequency and then filtered with a bandpass filter

Why Image Reject Filter?



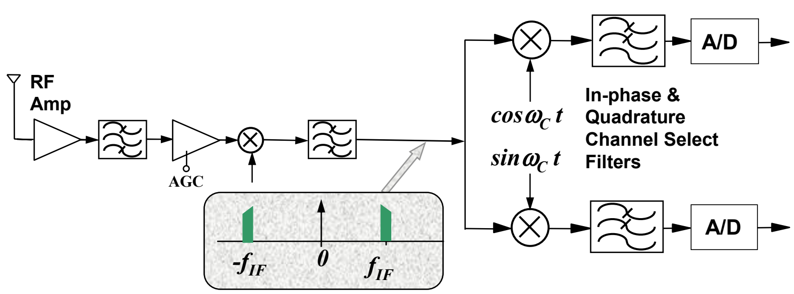
- Any signal @ the image frequency of the RX signal with respect to Osc. frequency will fall on the desired RX signal and cause impairment

Why Image Reject Filter?



- Image reject filter attenuate signals out of the RX band
- Typically, image reject filters are ceramic or LC type filters

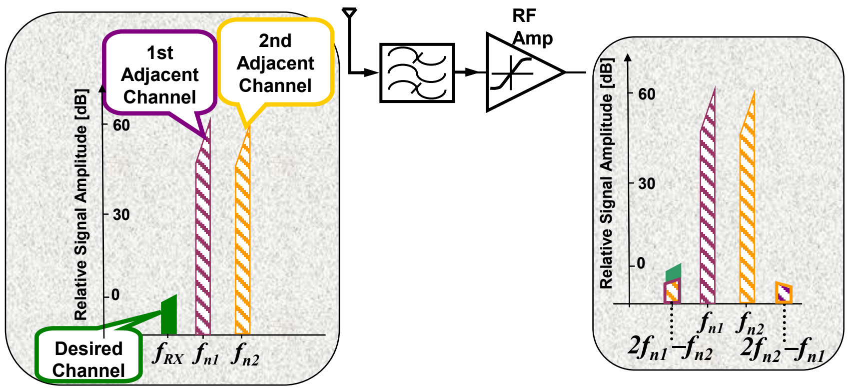
Quadrature Downconversion



- In systems with phase or freq. modulation, since signal is not symmetric around f_{IF} , directly converting down to baseband corrupts the sidebands

  → Quadrature downconversion overcomes this problem

Effect of Adjacent Channels

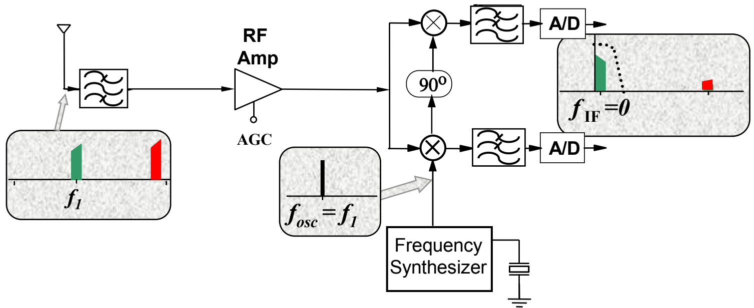


- Adjacent channels can be as much as 60dB higher compared to the desired RX signal!
- Linearity of stages prior and including channel selection filters extremely important

Effect of Adjacent Channels

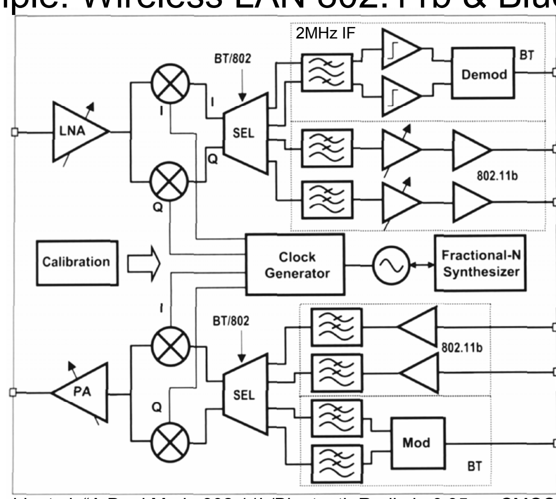
- Due to existence of large unwanted signals & limited dynamic range for the front-end circuitry:
  - Can not amplify the signal up front due to linearity issues
  - Need to allocate amplification/filtering numbers to RX blocks carefully
  - Can only amplify when unwanted signals are filtered adequately
  - System design critical with respect to tradeoffs affecting:
    - Gain
    - Linearity
    - Power dissipation
    - Chip area

Homodyne (Direct to Baseband) Receivers



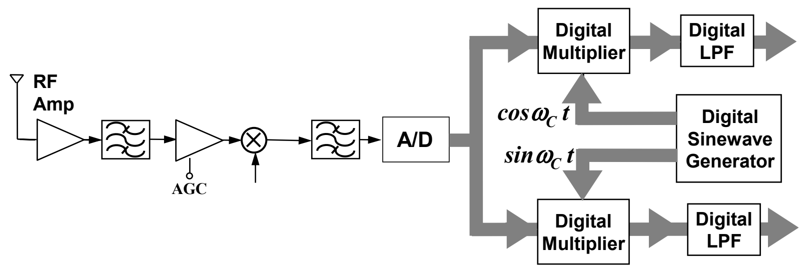
- No intermediate frequency, signal mixed directly down to baseband
- Almost all of the filtering performed at baseband
  - Higher levels of integration possible
  - Issue to be aware of:
    - Requirements for the baseband filters more stringent
    - Since the local oscillator frequency is exactly at the same freq. as the RX signal freq. → can cause major DC offsets & drive the receiver front-end into non-linear region

Example: Wireless LAN 802.11b & Bluetooth



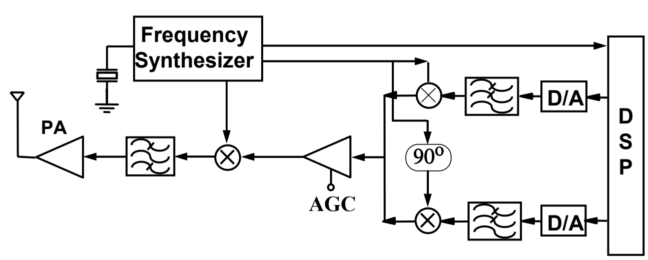
Ref: H. Darabi, et al, "A Dual Mode 802.11b/Bluetooth Radio in 0.35um CMOS," *IEEE ISSCC*, 2003 pp. 86-87.

Digital IF Receiver
(IF sampling)



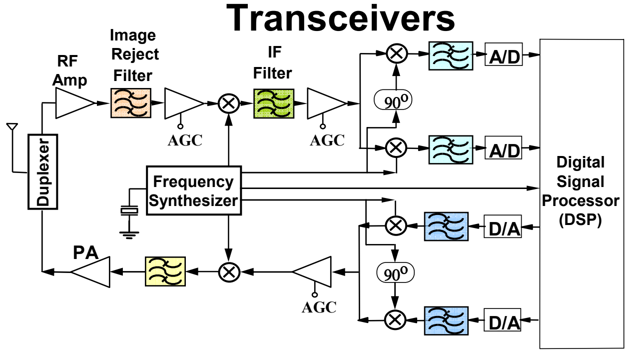
- IF signal is converted to digital →most of signal processing performed in the digital domain
- Performance requirement for ADC more demanding in terms of noise, linearity, and dynamic range!
- With advancements of ADCs could be the architecture of choice in the future

Typical Wireless Transmitter



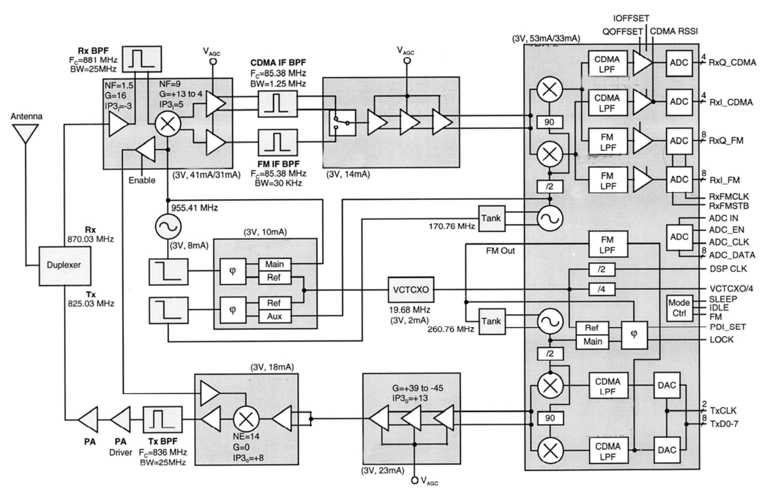
- Transmit signal shipped from DSP to the analog front-end in the form of I& Q signals
- Signal converted to analog form by D/A
- Lowpass filter provides signal shaping
- In-phase & Quad. Components combined and then mixed up to RF
- Power amplifier amplifies and provides the low-impedance output

Analog Filters in Super-Heterodyne Wireless Transceivers



Filters	***Function***	***Type***
RF Filter	Image Rejection	Ceramic or LC
IF Filter	Channel selection	SAW
Base-band Filters	Channel Selection & Anti-aliasing for ADC	Integrated Cont.-Time or S.C.

Example: Dual Mode CDMA (IS95)& Analog Cellular Phone



Example: Dual Mode CDMA (IS95)& Analog Cellular Phone

- Baseband analog circuitry includes:
  - CDMA
    - 4bit flash type ADC clock rate 10MHz
    - 8bit segmented TX DAC clock rate 10MHz (shared with FM)
    - 7th order elliptic RX lowpass filter corner freq. 650kHz
    - 3rd order chebyshev TX lowpass filter corner freq. 650kHz
  - FM (analog)
    - 8bit successive approximation ADCs clock rate 360kHz
    - 5th order chebyshev RX lowpass filter corner frequency 14kHz
    - 3rd order butterworth TX lowpass filter corner frequency 27kHz

Summary

- Examples of systems utilizing challenging analog to digital interface circuitry- in the area of wireline & wireless systems discussed
- Analog circuits still remain the interface → connecting the digital world to the real world!