Description of Class

- Lecture 1 – Introduction and Fundamentals
- Lectures 2 & 3 – Radio Architecture and Design Considerations
- Lectures 4 & 5 – Receiver System Analysis and Design
- Lectures 6 & 7 – Transmitter System Analysis and Design
- Lectures 8 & 9 – RF System Design Examples
- Lecture 10 – Summary and Survey of Applications
- Final Exam

- Topic is bridge between engineering of microwave devices and components with application
- For this class, the application is Communications
Classic System Development Cycle

1. Understand Customer Requirements, Develop System Concept and Validation Plan
2. Develop System Specification and System Verification Plan
3. Expand Specifications into “Design-to” Specifications and Verification plan
4. Evolve “Design-to” Specifications into “Build-to” Documentation and Inspection Plan
5. Fab and Assemble to “Code-to” and “Build-to” Documentation
6. Inspect “Build-to” Documentation
7. Assemble and Perform Verification to “Design-to” Specifications
8. Integrate System and Perform System Verification to Performance Specifications
9. Demonstrate and Validate System to User Validation Plan
10. Integrate System and Perform System Verification to Performance Specifications
11. Understand Customer Requirements, Develop System Concept and Validation Plan

Decomposition and Definition

Synthesis and Validation
RF Transceivers - Examples

- Mobile Communications Systems
  - GSM
  - CDMA
  - WCDMA
- WLAN
  - 802.11
- Bluetooth
  - WPAN
- GPS
- Ultra Wideband Communications (UWB)
- Satellite Transponders
  - Transceivers
  - Transponders
Example Transceiver

Figure 3.1. Block diagram of a superheterodyne full-duplex transceiver
RF Systems Engineering Examples

• Key to Success in Wireless Systems is Cross Discipline Knowledge
  – Incorporate digital, DSP, and system on a chip (SOC) designs
  – Impending integration of voice, data, image, internet, GPS, etc.
• In mobile phone systems, RF system design of the transceiver is tightly associated with development of ICs
• Relevant ICs must be designed and developed according to selected radio architecture
  – Requirements Flow Down to Individual Components
• Digital baseband demodulator performance and processing gain establishes allowed noise figure of RF receiver for a defined sensitivity
• Group Delay Distortion of Channel Filtering Impacts Minimum Requirement of Signal-to-Noise/Interference SNIR to Achieve Desired BER
• RF Receiver AGC is closed in the digital baseband
• Transmitter power level controlled by digital baseband
• DC offset and I/Q imbalance are compensated by means of adjusting baseband digital signal levels
Dynamic range and resolution impacts gain control and filtering requirements of RF.
RF/Microwave System Architecture is established and evolved
Satellite Transmission Link - iteration

Uplink Frequency

Downlink Frequency

SFD, $G_{sr}/T_s$

Min

Max

FD

$P_{out}$

$L_D$

$G_{er}/T_e$

$EIRP_e$

$P_e$

HPA

$L_U$

RCVR

$P_{in}$

CAMP

$B$

$P_{out}$

$G_{st}$

$EIRP_s$

Max

Min

TwTA

Power Characteristic

$G_{s}=\frac{\text{Min}}{\text{Max}}$

$P_s$, $G_{st}$, $EIRP_s$

LNA
Satellite Transmission Link - iteration

- **Satellite Transmission Link Diagram**
  - **Uplink Frequency**
    - SFD, $G_{sr}/T_S$
  - **Downlink Frequency**
    - $P_s$, $G_{st}$, EIRP$_s$
  - **Power Characteristic**
    - Frequency bandwidth to limit IM products

**Diagram Elements**
- **HPA**
- **LNA**
- **RCVR**
- **IMUX**
- **OMUX**
- **TWTA**
- **OMUX**
- **FD**
- **P$_{out}$**
- **P$_{in}$**
- **$G_r/T_e$**
- **Frequency Characteristic**
- **FC**
- **B**
- **$G_e$**
- **EIRP$_e$**
- **$L_U$**
- **$L_D$**
Satellite Transmission Link - final architecture

Redundancy switches to achieve reliability and beam selection
Transceiver Budgets

- EIRP and G/T
- Gain/Loss
- Noise Figure
- Input Losses
- G/T Stability
- SFD Variation over Frequency
- Output Power and Losses
- EIRP Stability
- Frequency Response and Rejection
- Gain Slope
- Group Delay
- Group Delay Ripple
- Group Delay Stability
- Phase Shift
- AM/PM Transfer and Conversion
- Amplitude Linearity
- Overdrive
- G/T Degradation
- Coherent Self Interference
- Transmit Power Loading
- General Spurs
- Specific Spurs
- Passive Intermodulation
- Peak Power for Multipactor
- RF Susceptibility
- Antenna Isolations
Requirements Flowdown - EIRP

- **EIRP**
  - **Repeater Output Power**
    - **TWTA Output Power**
    - **Repeater Output Losses**
  - **Antenna Gain**
    - **Antenna Losses**
    - **Antenna Pointing**
    - **Antenna Directivity**

- **Component Losses**
Requirements Flowdown - System Noise Temp

• G/T required for the system
  – Antenna Gain - Gives G
  – T is the System Noise Temperature. It takes all system noise into account.
  • Imposes requirements on feeder network losses and receiver noise temperature

\[ T_1 = T_A + T_F \left( \frac{1}{L_F} - 1 \right) + \left[ \frac{T_{Rx}}{L_F} \right] \]

\[ T_2 = \frac{T_A}{L_F} + T_F \left( \frac{L_F}{L_F} - 1 \right) + \frac{T_{Rx}}{L_F} + T_{Rx} \]

\[ = T_A + T_F \left( \frac{1}{L_F} - 1 \right) + \left[ T_{Rx} \cdot \frac{L_F}{L_F} \right] \]
Signal Level -100 dBW (10^-10 watt)

20 dBW (100 watt)

Signal amplified by 120 dB (trillion times)

Requirements Flowdown - Gain/Loss
Specification of Component Requirements

Wireless Comm Hardware

- Antennas
- Receivers
- Input Multiplexers
- Channel Amplifiers
- Linearizers
- Traveling Wave Tubes
- Output Multiplexers
- Switches
Key Satellite Transponder Component: LCAMP / TWTA

- Channel amplifier (CAMP) provides medium power amplification and gain control

- Linearizer is sometimes needed to improve transponder linearity when high power amplifier (HPA) is operated in the non-linear region

- HPA provides the final stage of high power amplification
  - Traveling Wave Tube Amp (TWTA)
  - Solid State Power Amp (SSPA)

- HPA typically is the main contributor to signal distortion due to its non-linear characteristics when operated near saturation
Power Amp Transfer Characteristics (TWTA)

Power In (dBm) vs. Power Out (dBm)

Phase Shift vs. Input Power Back Off

C/3IM = Carrier to 3rd order IM ratio

TWTA operated in linear region

TWTA operated near Saturation
Linearized TWTA Characteristics

Pre-distortion + TWT AM/AM = Linearized AM/AM

OBO, dB vs. IBO, dB

Phase Pre-distortion + TWT AM/PM = Linearized AM/PM

Phase Rotation vs. IBO, dB
Background Information

- Linear Systems & Transformations
- Non-linear System Representation and Analysis
- Noise and Random Processes
- Antennas
- Digital Baseband Systems
Linear Time-Invariant Systems

- Completely Characterized by Impulse Response

\[ h(t) = L(\delta(t)) \]

where

\[ \phi(t_0) = \int_{-\infty}^{\infty} \phi(t) \delta(t - t_0) dt \]
Other Basic Background Topics

- Power in Periodic Signal – Parseval
- Fourier Series
- Fourier Transforms – Transform Properties
  - Linearity, Convolution, Modulation, Time Shift, Parseval
- Frequency Response of LTI Systems
  - Amplitude Response
  - Phase Response
  - Gain
Other Basic Background Topics

• Signals in RF System design are usually modulated carriers processed in band-pass systems
• Define Bandwidth of System
• Define phase delay and group delay