A System Prototyping, Summary, and Further Studies

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- Review.
  - Modulation, Demodulation, and PSD
  - Digital BB/IF Modem
  - ADC, DAC, and the Nyquist Sampling Theorem
  - Upsampling and Interpolation Viewed in TD and FD
  - Downsampling and Decimation Viewed in TD and FD

- Preview.
  - Example: MIMO Channel Sounder Prototyping
  - Summary
  - Further Studies

- MIMO Channel Sounder
  - What is a channel sounder?
    - A **communication channel** can be viewed **as a system** with unknown parameters.

    - A **channel sounder** is an electrical equipment
      - that **measures the responses of the channel to sounding or probing signals** and, sometimes,
      - that includes as a part of the sounder a digital signal processing algorithm to **extract the unknown channel parameters from the measurement data**.

– What is a MIMO channel?

  * a multiple-input multiple-output (MIMO) system

  * Given a **propagation channel** for wireless communications, the use of multiple Tx and multiple Rx antennas turns it to a **radio channel** that can be viewed as a MIMO system.

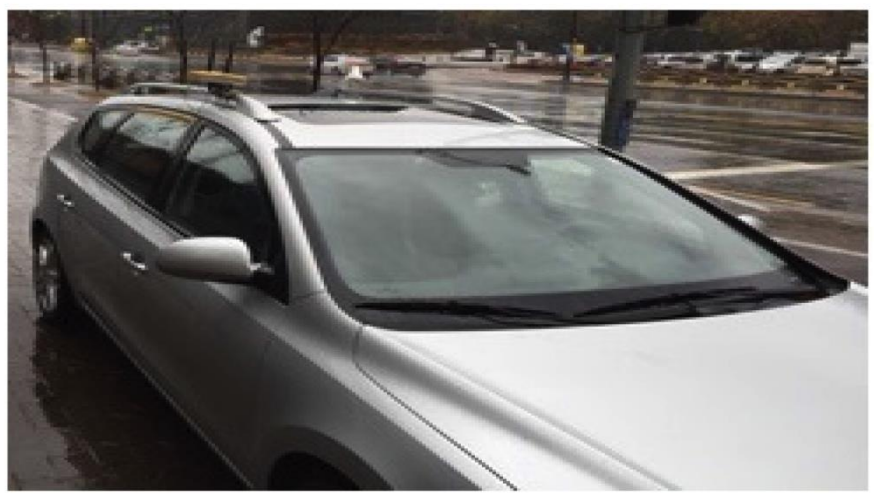
– Why MIMO channel sounding?

* It is claimed that, given the same **propagation channel**, the MIMO radio channel has an increased capacity than SISO, SIMO, and MISO radio channels.

* It is of interest to check how much of the claimed increase in capacity can actually be attained.

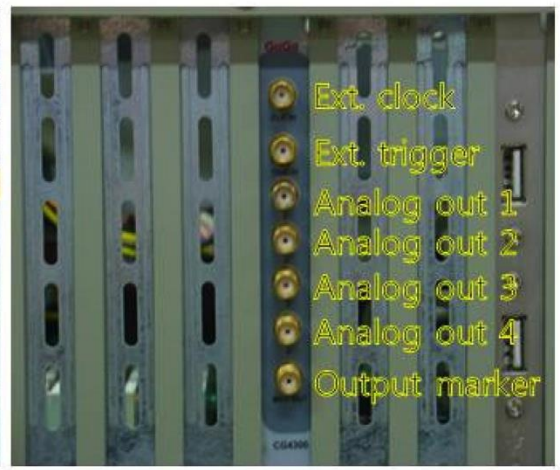
* A MIMO channel sounder is needed that supports
  - synchronized signal transmission using multiple Tx antennas and
  - synchronized signal reception using multiple Rx antenna.

- Channel
  - frequency allocation
    - A WiBro band at 2.3765 GHz with around 20 MHz bandwidth is available.
    - The band was originally allocated to the Hanaro Telecom, who retreated from the deployment project.
    - We have acquired **a license as a low-power radio station** and been renewing it.
    - It is next to other WiBro bands and an ISM band at 2.4 GHz.
  - indoor, outdoor, mobile



- Tx
  - A multi-channel signal generation board is expensive.
    - channel
    - As the number of channels increases, the price skyrockets.
  - Gage's CompuGen (CG) 4300 is a 4-channel arbitrary waveform generator at an affordable price.

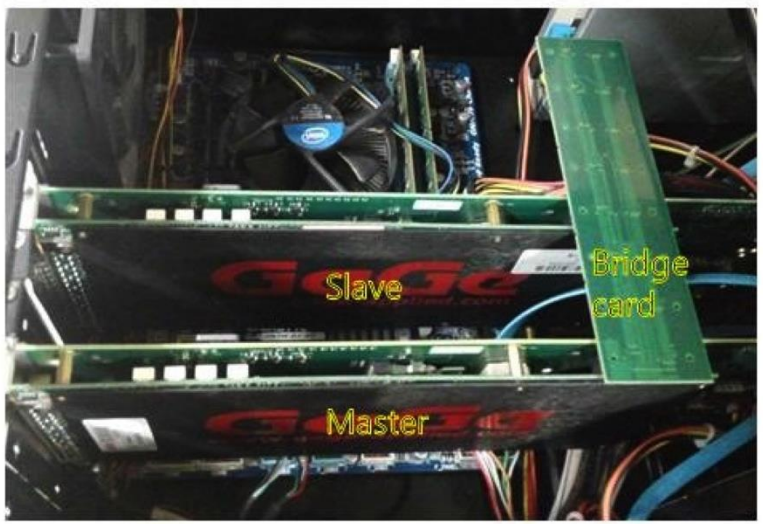
<CG4300 installed in an industrial PC>



<Connectors for CG4300>

    - Conversion rate = 300 MS/s is enough.
    - Resolution = 12 bits/S is enough.
    - Memory size = 1 MS/channel is rather small.

- Rx
  - A multi-channel signal acquisition board is also expensive.
  - Gage's CompuScope (CSE) 1242 is a 4-channel acquisition board at an affordable price that also allows an upgrade to **Master-Slave mode**.



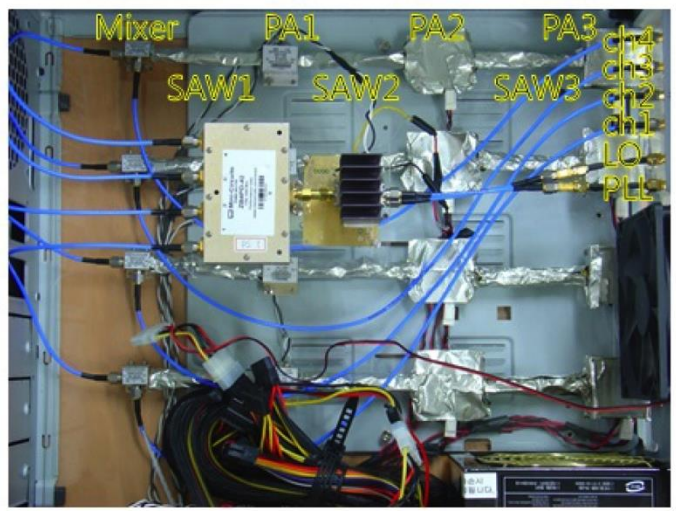
<Upgraded CSE1242 installed in a PC>

<Connectors for CSE1242>

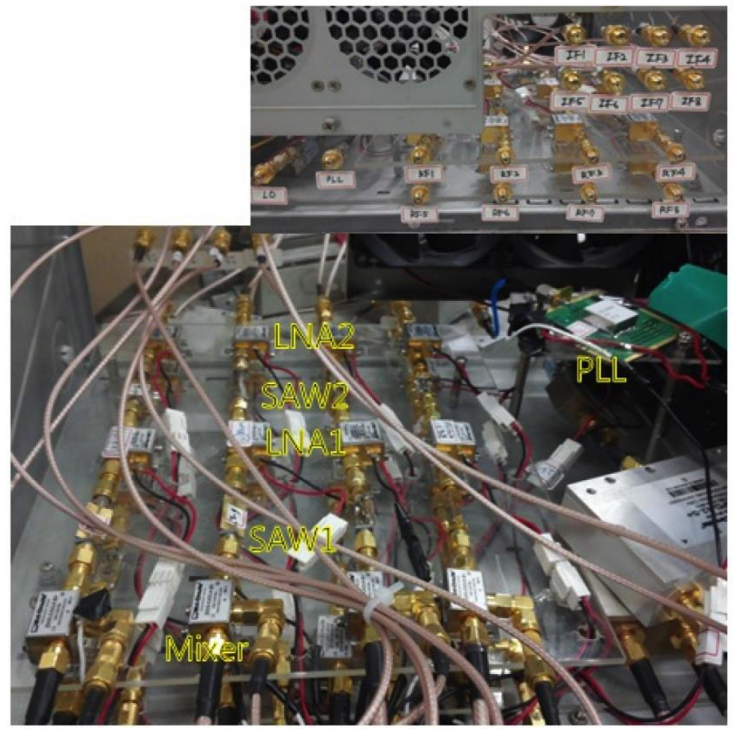
  * Sampling rate = 200 MS/s
  * Resolution = 12 bits/S
  * Memory size = 256 MS/channel

- Number of Antennas
  - We use a CG4300 to generate 4 synchronized IF signals with max bandwidth 20 MHz.
    * If we generate BB signals, then only 2 complex BB signals can be generated.
  - We use two CSE1242s in Master-Slave mode to sample 8 IF signals synchronously.
    * If we sample BB signals, then only 4 complex BB signals can be sampled.
  - Thus, we have a 4×8 MIMO channel.

- RF Chain Boxes
  - 4 RF chains in a Tx chain box
  - 8 RF chains in an Rx chain box
  - Mini-Circuits' power amplifier, LNA, mixer, power splitter
  - ASB's PA, LNA, SAWNICS' RF SAW filter

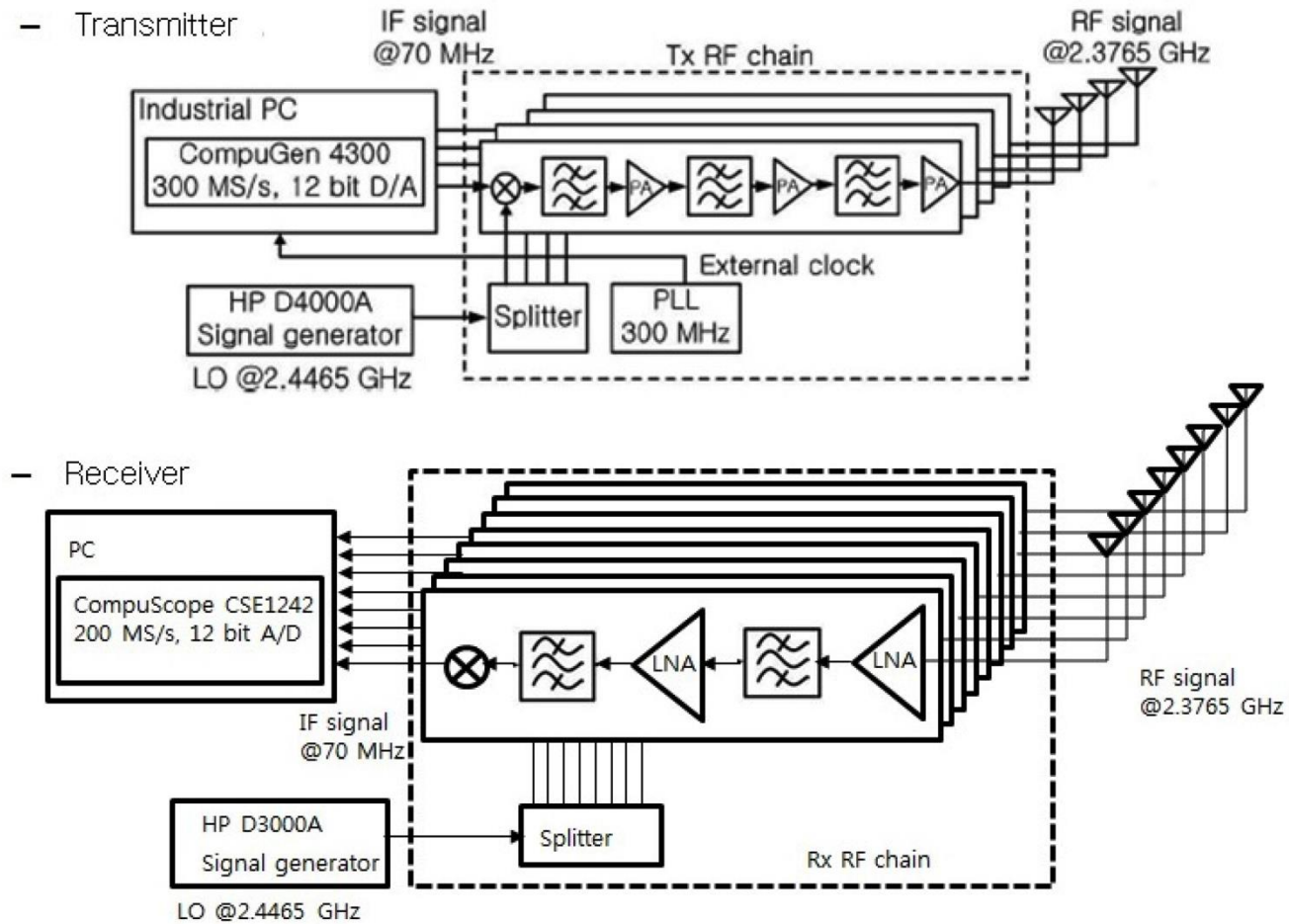


<Tx RF chain box>



<Rx RF chain box>

- Block Diagram
  - LOs: HP D4000A and HP D3000A signal generators
  - lower-side tuning, high-side conversion



- Sounding Signals
  - BPSK
    - $f_{\mathrm{IF}} = 70$ MHz
    - m-sequences with period 1023 are BPSK modulated.
    - $1/T = 20$ Msymbols/sec
    - square-root raise cosine pulse with excess bandwidth 0.22
    - M = 15 [samples/symbol] interpolation
  - OFDM
    - $f_{\mathrm{IF}} = 70$ MHz
    - QPSK pilot symbols are transmitted.
    - FFT size = 512
    - number of subcarriers = 320
    - subcarrier spacing = 24.4 kHz
    - CP length = 1.6 μs

- Summary
  - Course Objectives: The objectives are to let
    - senior-level undergraduate students,
    - first-year graduate students,
    - researchers, or
    - engineers in Electrical Engineering

    obtain

    1) the basic analytical skills required to analyze and design a modem for modern digital communication systems,

    2) and the fundamental understanding on communication systems that may help them study advanced topics and consequently perform quality research in the area of digital communications.

1) the basic analytical skills required to analyze and design a modem for modern digital communication systems,

* Fourier analysis
  - CTFS, CTFT, DTFS, DTFT
  - LTI system and impulse response

* probability, random variable, random vectors, and random processes
  - independence among multiple random variables
  - correlation between two random variables
  - real and complex Gaussian random variables and vectors
  - characterization of random process in TD
  - wide-sense stationary random process and its PSD
  - LTI filtering of a random process and output PSD
  - AWGN, ACGN, proper-complex AWGN

2)-1 and the fundamental understanding on communication systems that may help them study advanced topics and consequently perform quality research in the area of digital communications.

* modulation, demodulation
  - complex baseband representation of real bandpass signals and processes
  - quadrature and polar modulators
  - direct up-conversion and multi-stage up-conversion
  - quadrature demodulator
  - direct down-conversion and multi-stage down-conversion
  - image-band problem and IR filter

2)-2 and the fundamental understanding on communication systems that may help them study advanced topics and consequently perform quality research in the area of digital communications.

* digital modulation and PSD
  - ASK, PSK
  - PAM, QAM
  - OQPSK, MSK, DS-CDMA
  - OFDM

* digital BB/IF modem
  - ADC, DAC, Nyquist theorem
  - upsampling and interpolation
  - downsampling and decimation

- Further Studies
  - Digital Communication Systems: Receiver Design and Performance Analysis
    - Channel Modeling
      - propagation channel, radio channel, RF channel, digital channel
      - multipath fading
      - WSSUS channel model
      - frequency-flat vs. -selective channels
    - Receivers and Their Performance
      - QAM and Nyquist condition for zero ISI
      - linear and decision-feedback equalizers
      - MLSD
      - bit-by-bit MAP detection

– Statistical Signal Processing
  * Detection
  * Estimation

– Information Theory
  * data compression: lossless vs. lossy
  * data transmission: channel coding

– Linear Algebra
– Error-Control Coding
– Optimization
– Space-Time Wireless Communications
– etc.