Applications of RF and Microwave Sampling to Instrumentation and Measurement

Mark Kahrs
Dept. of Electrical Engineering
University of Pittsburgh
Pittsburgh, PA 15261
e-mail: kahrs@ee.pitt.edu
Talk outline

• Sampling principles & tradeoffs
• Applications
  – Oscillography
  – Sampling Voltmeters
  – Network Analyzers
  – Microwave Counters
  – Time Domain Reflectometry
  – Computer assisted measurements
• Future directions
• Conclusion
Why sample?

- **Problem:** Input exceeds instrument limitations
  - 40 Gbit/s optical fiber transmission
  - 60 GHz wireless LANs
  - ~5-8 picosecond pulse rise times
  - 150-200 GHz $f_{\text{max}}$ in front end circuits

- **Solution:** Downsampling to lower frequency
  - Fast sample and hold
Sampling Principles & Tradeoffs

**Principles**

1. Input waveform is repetitive
2. Fast switch (gate) charges a capacitor
3. Gate is *strobed* by a narrow pulse
4. Strobe trigger is generated by the time base

**Tradeoffs**

1. Input circuitry affects waveform shape
2. Gate (aperture) time is not instantaneous
3. Strobe waveform is not a perfect $\delta$
4. Time base has drift and jitter
Early pre-history (pre 1950s)

• Hospitalier (1904) *Ondograph*
  – revolving mechanical switch charges a condensor
  – discharged into a coil that moves the pen

• Norgaard & Hansen (1940)
  – linear sweep gates the grid of the CRT
  – input can be mixed or heterodyned
Oscillography: Early history (1950s)

- Janssen (Philips, 1950)
- McQueen (1952)
- Sugarman (1957)
- Chaplin (1959)
- Reeves (1959)

Technological Improvements:
- Faster gates
- Faster strobes
- Better dynamic range
Oscillography: Commercial Introduction (1960s)

The instrument ... combines great bandwidth and high sensitivity with basic ease and simplicity of operation. It is in every sense of the word a general purpose instrument.

(W. R. Hewlett, 1960, HP Journal)

**Technological Improvements**

- Faster gates
- Faster strobes
- Better triggering
- Better sweep control

- Lumatron
- HP 185A + 187A + 188A
- Tektronix type N (500 series plugin)
- Tektronix 661 + 4S + 5T
Oscillography: Technology improvement (1960s)

- **HP 1411A/143x** (140 mainframes)
  - New 2 diode sampler (12.4 GHz) (Grove, 1965)
  - Used extensively by NBS for TDNA

- **Tektronix 1S series** (500 mainframes)
  - 1S1 (1965)
  - 1S2 TDR unit (1967)

- **Tektronix 3S + 3T series** (560 mainframes)
  - S4 traveling wave sampler (Frye, 1968)
  - 3T2 random sampling time base
Random sampling

Problem: Trigger delay line distorts

Solution: Use time interval measurement

• Nahman and Frye (1964)
  – Move delay from vertical input to time base

• Horňák (1965, 1969)
  – Horizontal position derived from separate time base

• Frye (Tektronix, 1973) 3T2 & 7T11
  – Combined random/equivalent time
Oscillography: Technology Improvement

• **Gate designs**
  – Sampling bridge asymmetry (Benson, 1971)
  – Better trigger pickoff (Lockwood, 1971)
  – Dual samplers for TDR & VNA (Agoston, et al., 1986; Bradley, 1996)
  – High impedance input (MESFET)
  – Josephson junctions (Hamilton, et al., 1979)

• **Blowby**: Transmission of high freq. inputs through the open gate
  – Circuit improvements: balanced gates, compensation networks
  – Traveling wave gate bias control (Agoston, 1986)

• **Kickout**: Feed-through of strobe to input connector
  – Insert isolator in front of gate
Oscillography: Time bases

Problem: Analog nonlinearities
Solution: Digital control

- Gated counter/interval timer (Agoston, Tektronix, 1986)
- Picosecond resolution (Dobos, Tektronix) (1988, 1994)
- Phase correction (Dobos, Tektronix, 2001)
Oscillography: Time bases

Problem: Missing waveforms
Solution: Coherent time base

- Strobe predictor with random jitter (Andrews, 1973)
- PLL + VCO + DAC (Agoston, Tektronix, 1986)
- Microwave Transition Analyzer (MTA) (Marzalek, et al., 1991):
  FFT + sampling strobe synthesizer
- Coherent timebase (Reynolds, Slizynski, 1998)
- Triggered Time Interpolation (Kimura, et al., 2001)
Oscillography: *Nonlinear Transmission Line*

**Problem:** SRD $t_r$ limited

**Solution:** Use NLTL

*NLTL combinations…*

- NLTL + sampler: Rodwell (1988)
- NLTL + sampler + bridge: Marsland (1990)
- Wafer probe: Shakouri (1993)
- 480 fs pulse: Van der Weide (1994)
- PSPL sampling gate: Agoston, et al.
Sampling Voltmeters

- **Spencer (1949)**
  - Gate connected to VTVM

- **Hewlett-Packard (1960s)**
  - HP 8405A [vector voltmeter] (Yen, 1964)
  - HP 3406A [scalar, incoherent] (Boatwright, 1964)

- **McCracken (1969)**
  - Phase point sampling voltmeter

- **Mirri, et al. (1994)**
  - Randomized vector voltmeter
Network Analyzers: SRD driven Sampling gate

*S parameter measurements*

- HP 8410A (1967)
  - Grove sampler
- Wiltron
  - False locking (Kapetanic, 1990)
  - Bias control distortion compensation (Grace, Kapetanic, Liu, 1990)
- Integrated VNA
  - Marsland (1990)
  - Wohlgemuth, et al. (1999)
Network Analyzers: VNNA & LSNA

Problem: *Measurement of nonlinear regions of operation*

Solution: *Use non-ratioed (absolute) measurements*

- **Vector(ial) Nonlinear Network Analyzer**
  - Sine Generator + Oscilloscope (7854):
    Sipilä, Lehtinen, Porra (1988)
  - Harmonic Generator + VNA: Lott (1989)
  - Oscilloscope + VNA: Kompa, van Raay (1990)
  - 4 channel Oscilloscope (54120T) + couplers:
    Van den Broeck, Verspecht (1992)

- **Large Signal Network Analyzer**
  - Van Damme, et al. (2000)
  - Scott, et al. (2002)
Microwave Counters

• **Techniques**
  – Prescaling (non-sampler)
  – Heterodyne (non-sampler)
  – Transfer Oscillator
    • Phase locks lower frequency oscillator to input
    • Single sampler (Chu, 1975)
  – Harmonic Heterodyne
    • Combines heterodyne with transfer oscillator method
    • Single sampler + microprocessor (Peregrino, Throne, 1977)

• **Gate improvements**
  – Thin film gate (Merkelo, 1971)
  – Thin film hybrid (Sayed, 1980)
  – GaAs gate (Gibson, 1986)
Time Domain Reflectometry

- Non sampling
  - Dévot (1948)
  - Bauer (Siemens) (1962)

- Sampling
  - HP 1415A (1964)
    - 50 ps pulser
    - 188A gate
  - Frye (Tektronix) (1965)
  - Differential
    - McTigue & Duff (1996)
    - McEwan (1995)
  - 2.3 ps TDR (NLTL)
Computer Assisted Measurements

- **Computer interfaces: digital signal processing**
  - CAOS (Stuckert, 1969)

- **Time base correction due to jitter and drift**
  - Deconvolution: Gans (1983)
  - Phase demodulation: Verspecht (1994)

- **Deconvolution & Normalization of sampler**
  - Sampler Characterization
    - Nose-to-nose (Rush, Verspecht, 1990-1995; Scott)
    - Analytic model (Remley, Williams)
Future improvements

(courtesy of M. Rodwell, UCSB)

• **Sampling Oscilloscopes**
  – Improved timebase stability and flexibility in triggering
  – Better time bases: PLL, DDS, …
  – Network-analyzer-like calibration procedures

• **Network Analysis**
  – combined accuracy, frequency coverage, and cost
  – better calibration methods needed for testing above 300 GHz $f_t$ and $f_{\text{max}}$
Acknowledgements

- J.R. Andrews (PSPL)
- N.S. Nahman
- Acoustics Lab, HUT
- Fulbright
Conclusion

The End