Design and Development of an Advanced Coherent Radar Depth Sounder

Master's Thesis Defense

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Outline

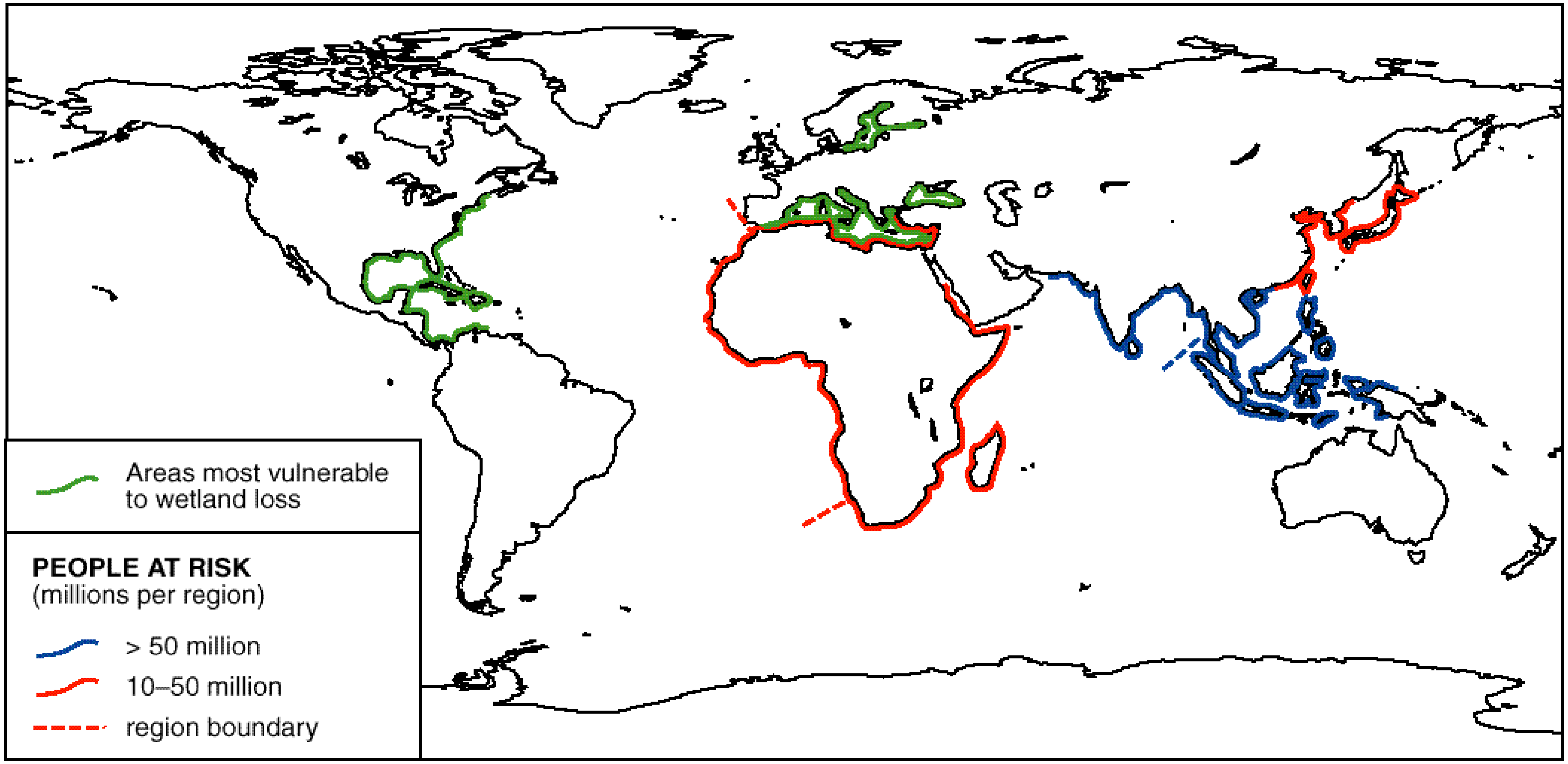
- Significance of ice sheet thickness measurements
- KU radar history
- Next-Generation COherent Radar Depth Sounder (NG-CORDS)
- Advanced COherent Radar Depth Sounder (ACORDS)
- Field experiment results
- Conclusions & future work

Significance of ice sheet thickness measurements

- Sea level increasing 2 mm/year
- Polar ice sheets one of the contributing factors
- Uncertainty in the contribution of polar ice sheets
- Need to assess the mass balance of ice sheets
- Ice thickness a key variable
- 1991 NASA initiative : Program for Arctic Regional Climate Assessment (PARCA)

Significance of ice sheet thickness measurements

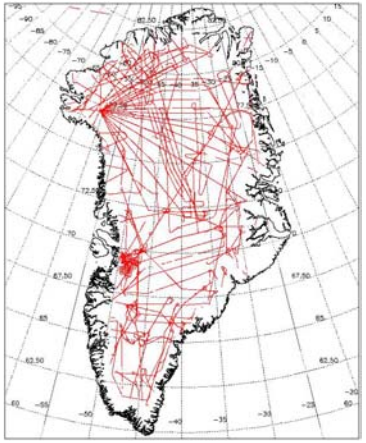
Impact of Sea level rise on coastal regions around the world



Hadley Center for Climate Prediction and Research, UK

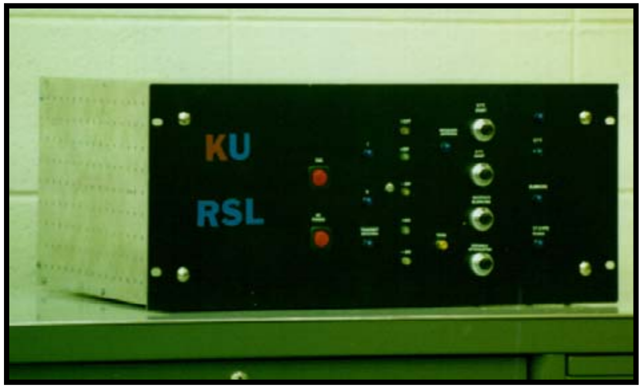
KU radar depth sounder history

- 1980: Coherent Antarctic Radar Depth Sounder (CARDS)
- 1993: KU CARDS operated in Greenland
- 1996: Improved Coherent Antarctic and Arctic Radar Depth Sounder (ICARDS)
- 1997: NG-CORDS
- 1998: Faster digital system
- 1998-2002: 90 % success rate in field experiments



System parameters: NG-CORDS

- Surface Acoustic Wave (SAW) devices

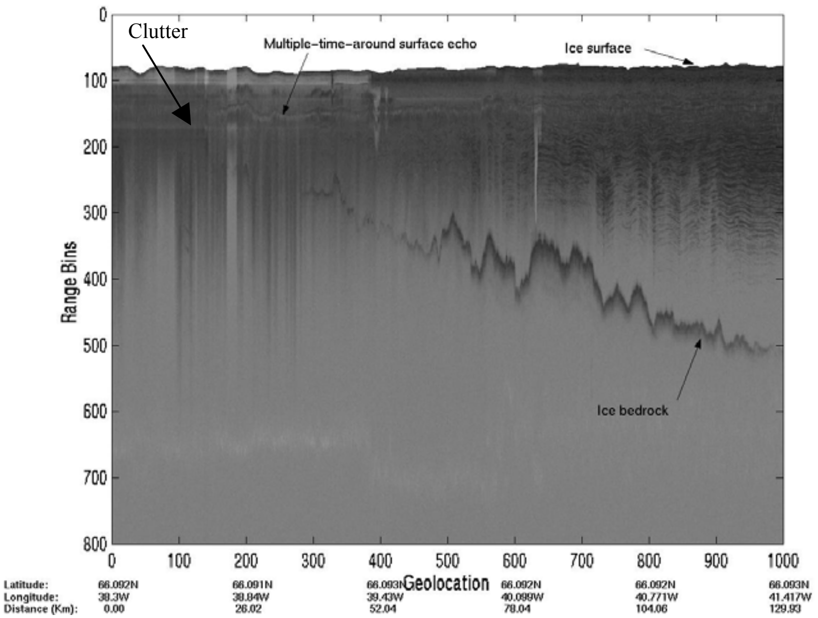


NG-CORDS analog system

Description	Characteristic	Units
Radar Type	Pulse Compression-analog	----
RF Carrier Frequency	150	MHz
RF Up-Chirp Bandwidth	17.00	MHz
Transmitted Pulse Width	1.6	µs
Compressed Pulse Width	60	ns
Range Sidelobes	**< 26**	**dB**
Peak Transmit Power	200	W
PRF	Selectable	KHz
Number of Coherent Integrations	32 – 4,096	----
Number of Incoherent Integrations	0 – 64,000	----
A/D Dynamic Range	12-bit, 72	dB
Sampling Period	53.3 (18.75 MHz)	ns
Range Resolution	4.494	m
Antennas	4-element $\lambda/2$ dipole arrays	

NG-CORDS

- Unsuccessful in sounding few outlet glaciers & transition zones
- Off-vertical surface clutter and surface echoes mask weak basal returns
- Radio echogram from southern Greenland



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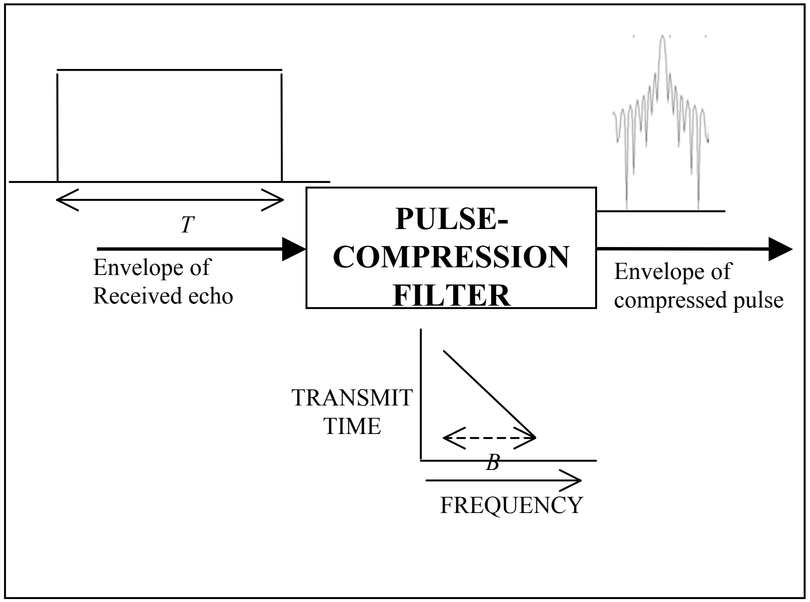
Limitations of NG-CORDS

1) Range sidelobes

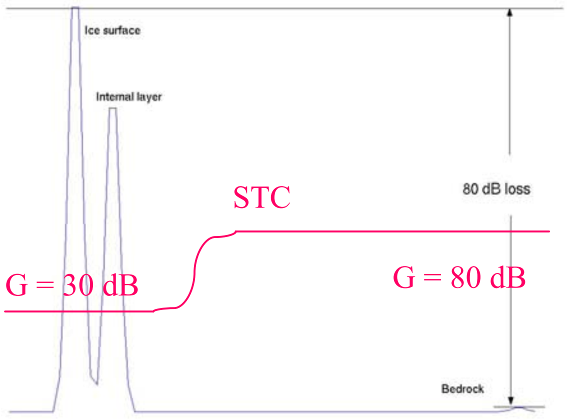
- Formed due to the inherent mechanism of pulse compression
- Masks weak basal returns
- Critical in areas where ice thickness is shallow
- 26 dB sidelobes in NG-CORDS receiver



Limitations of NG-CORDS

2) Sensitivity Time Control (STC)

- Two-way loss in ice > 80 dB
- Mechanism to increase the dynamic range of the receiver
- Time varying gain
- Difficult to deconvolve the system response



3) Analog down conversion

- I-Q demodulator in NG-CORDS receiver
- Amplitude or phase imbalance in the I, Q signals
- Limit the dynamic range of the receiver

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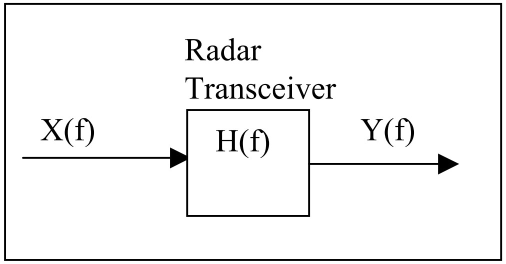
Solutions for NG-CORDS limitations

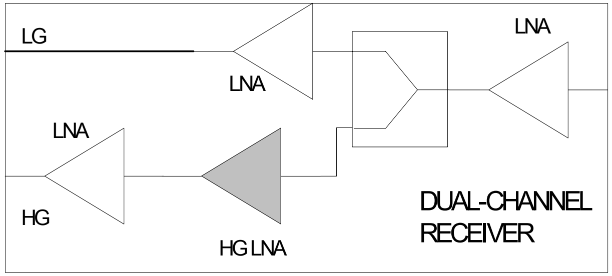
1) Reduce range sidelobes

- Mismatched filter
- Y(f) is a window function
- Input X(f) = Y(f)/H(f)
- Needs a Waveform Generator



2) Dual-channel receiver

- Two gain channels, Low Gain (LG) and High Gain (HG)
- No STC



3) Digital down conversion

- Bandpass sampling
- No analog down conversion

Need for an Advanced COherent Radar Depth Sounder (ACORDS)

- Waveform Generator (WG)
- *Transmitter subsystem*
- *Dual-channel receiver with two different gain channels*
- Data ACquistion system (DAC) capable of undersampling

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System parameters: ACORDS

Description	**Characteristic**	**Units**
Radar Type	Pulse Compression **(digital)**	----
RF Carrier Frequency	150	MHz
RF Chirp Bandwidth	17.00	MHz
Transmitted Pulse Width	**Selectable (0.2 – 10)**	**µs**
Range Sidelobes	**< 36**	**dB**
Peak Transmit Power	200	W
PRF	Selectable	KHz
Number of Coherent Integrations	32 – 1024	----
Number of Incoherent Integrations	0 – 64,000	----
A/D dynamic range	12-bit, 67	dB
Receiver Dynamic Range	>110	dB
Sampling Period	**18.182 (55 MHz)**	**ns**
Range Resolution	4.494	m
Antennas	4-element λ/2 dipole arrays	

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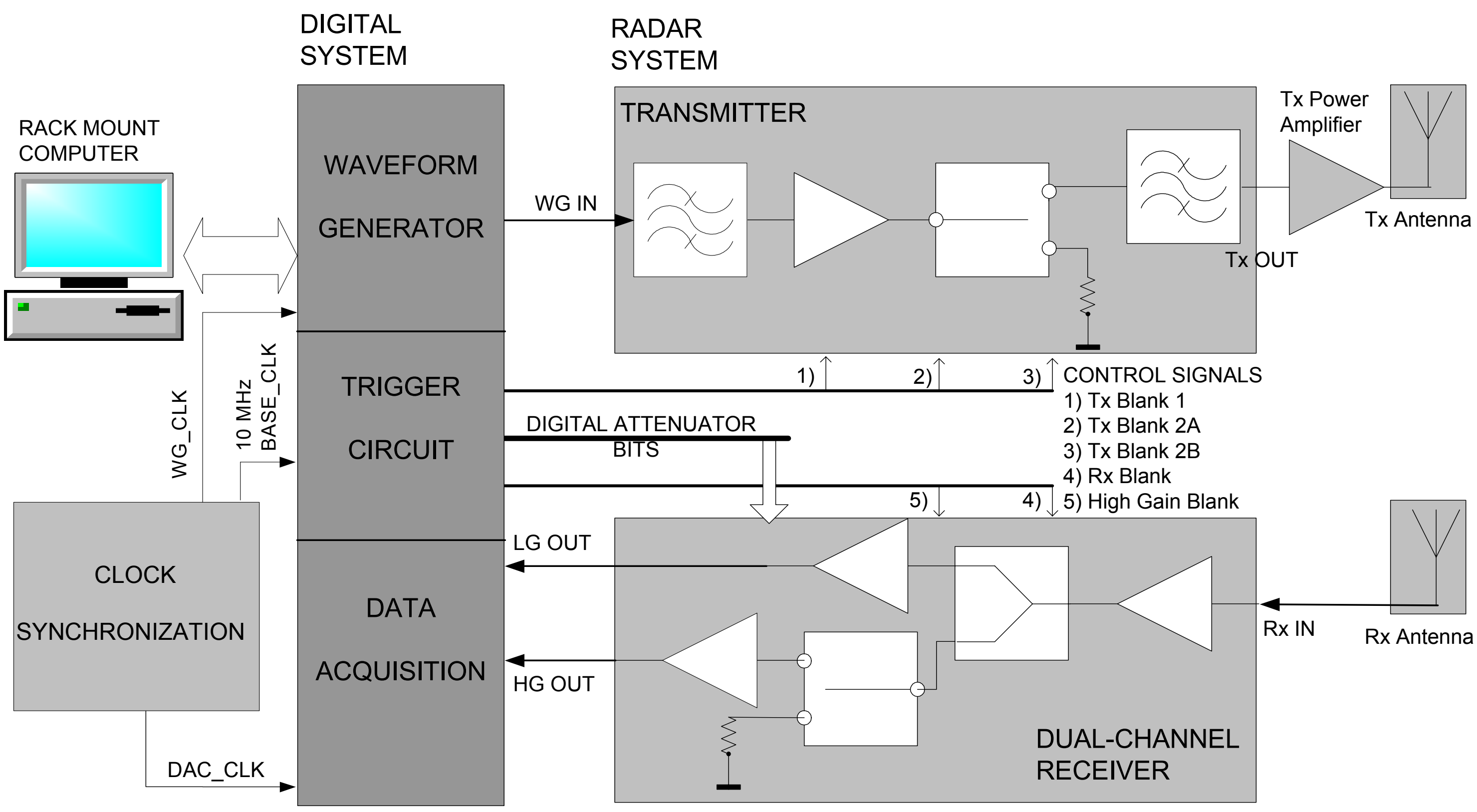
ACORDS block diagram



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Selection of clocks for WG & DAC: ACORDS

- Nyquist theorem requires sampling frequency to be at least 320 MHz
- Bandpass sampling allows a sampling rate at least twice the signal bandwidth
- ACORDS simultaneously oversamples and undersamples
- To avoid aliasing, sampling frequency is constrained by the following equations

$$\frac{2f_l}{k-1} \geq f_s \geq \frac{2f_u}{k}$$

$$f_s \geq 2B \;\&\; 2 \leq k \leq \frac{f_u}{B},$$

f_s – sampling frequency

f_l – lower frequency (140 MHz)

f_u – higher frequency (160 MHz)

k – positive integer

K	Range of f_s (MHz)
2	160.00 – 280.00
3	**106.67 - 140.00**
4	80.00 – 93.33
5	64.00 – 70.00
6	**53.33 - 56.00**
7	45.71 - 46.67

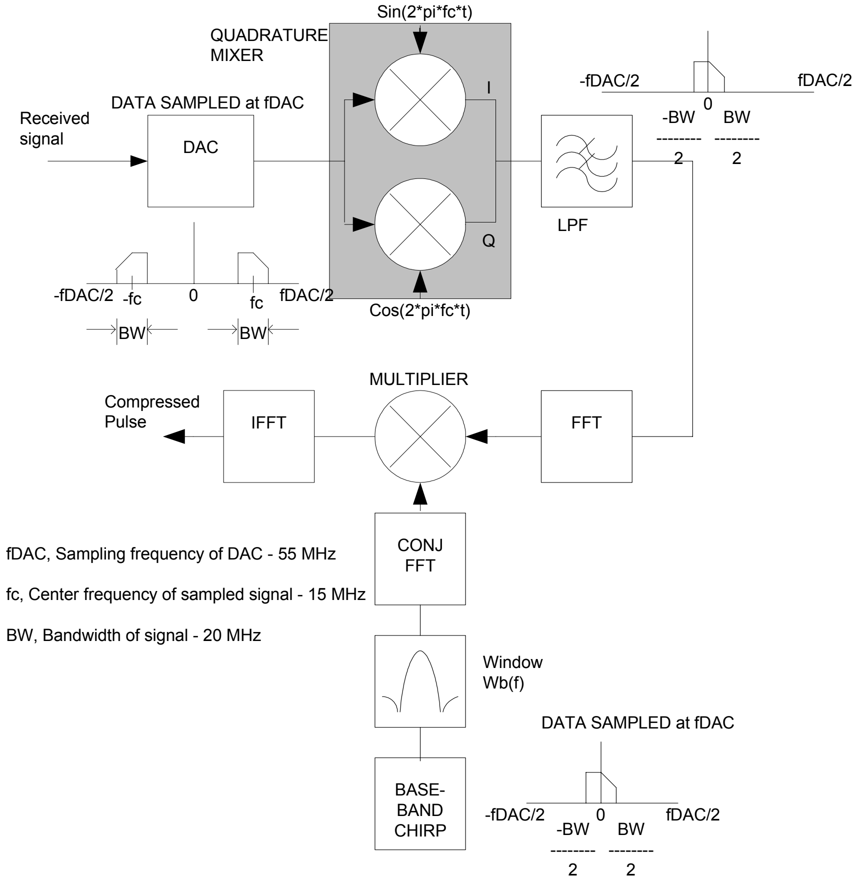
Selected

f_{WG} – WG_CLK (110 MHz)

f_{DAC} – DAC_CLK (55 MHz)

Digital pulse compression: ACORDS

- NG-CORDS: SAW compressor
- ACORDS: digitally implemented
- Compression gain, $10*\log10(BW x T) = 16$ dB
- Compressed pulse width, $1/BW$
- Control on frequency weighting



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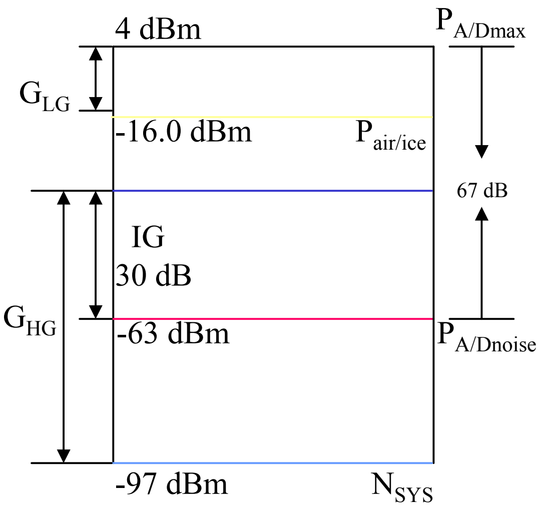
Derivation of receiver gain: ACORDS

HG channel gain (G_{HG})

- High sensitivity
- Need at least 1000 coherent integrations
- $N_{SYS} + G_{HG} = P_{A/Dnoise} + IG$
- $G_{HG} = 64$ dB

LG channel gain (G_{LG})

- $P_{air/ice} + G_{LG} = P_{A/Dmax}$
- $G_{LG} = 20$ dB



Designed dual-channel receiver

- 80 dB gain in HG channel
- 44 dB gain in LG channel

ACORDS transmitter design

Consists of

1) Waveform Generator

- Uses Analog Devices 16-bit AD9777 as oversampling D/A converter
- First order harmonic image of the baseband chirp selected
- Generates a 140-160 MHz chirp at –7 dBm
- Transmit pulse width and window function can be programmed

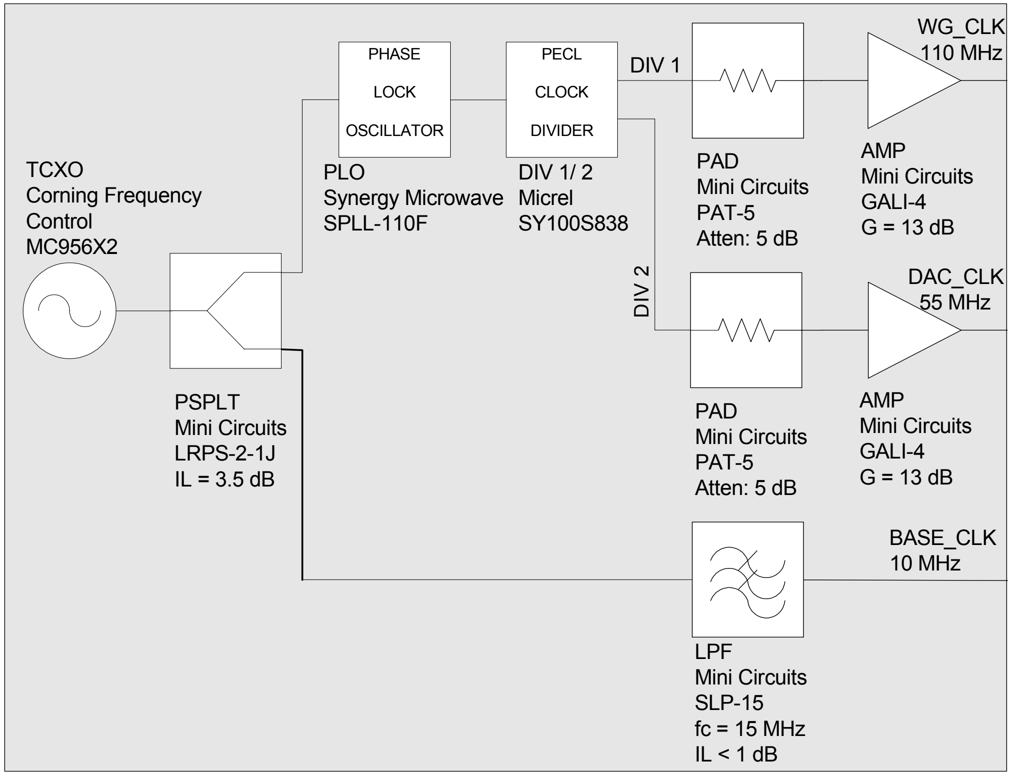
2) Transmitter

Clock synchronization section

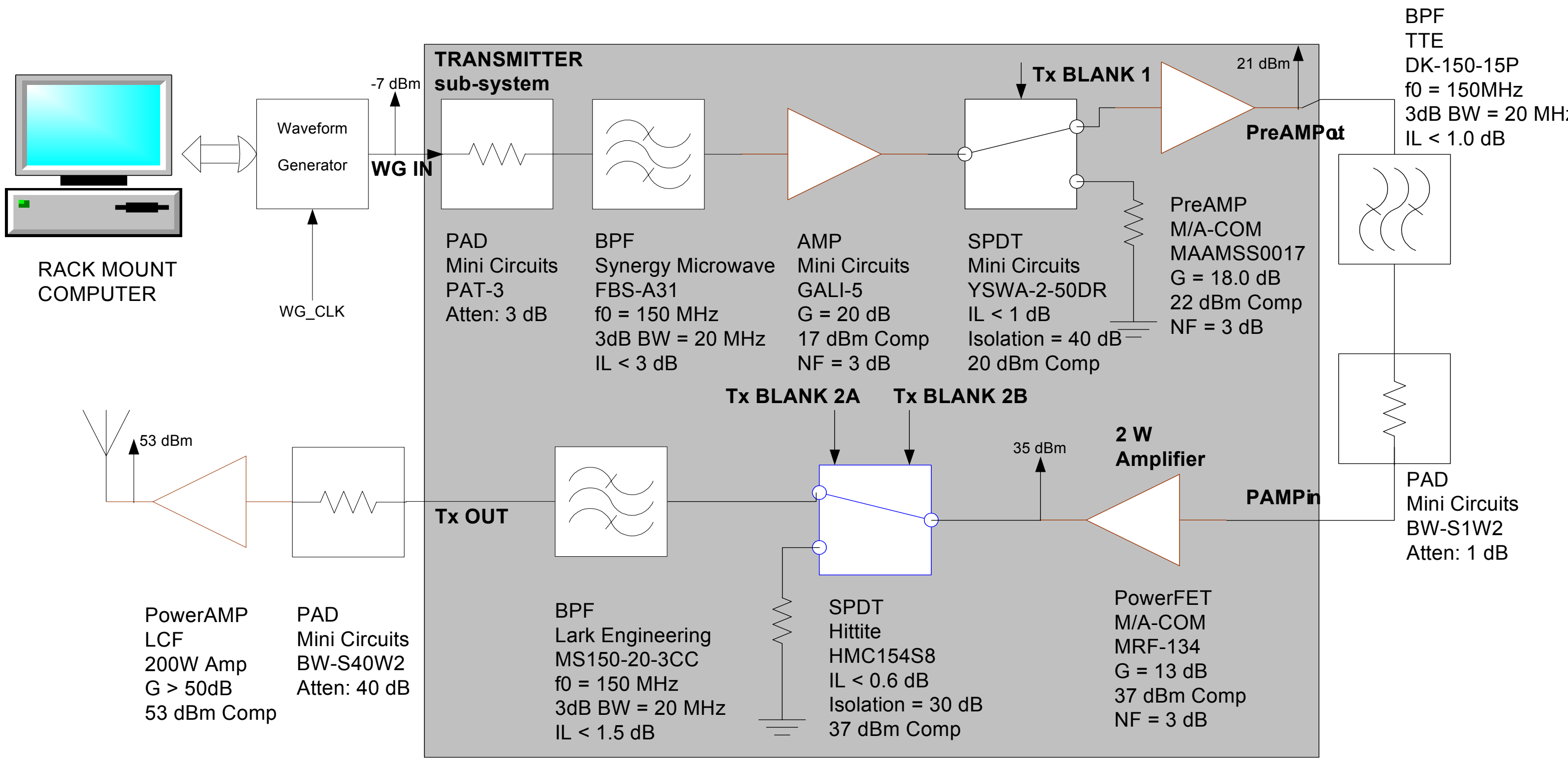
Transmitter RF section

Clock synchronization section design: ACORDS

- Generates clocks for the digital system
  - Trigger section – 10 MHz sinusoid
  - WG - 110 MHz PECL signal
  - DAC – 55 MHz PECL signal
- Whole system synchronized to the base clock
- All surface-mount except LPF



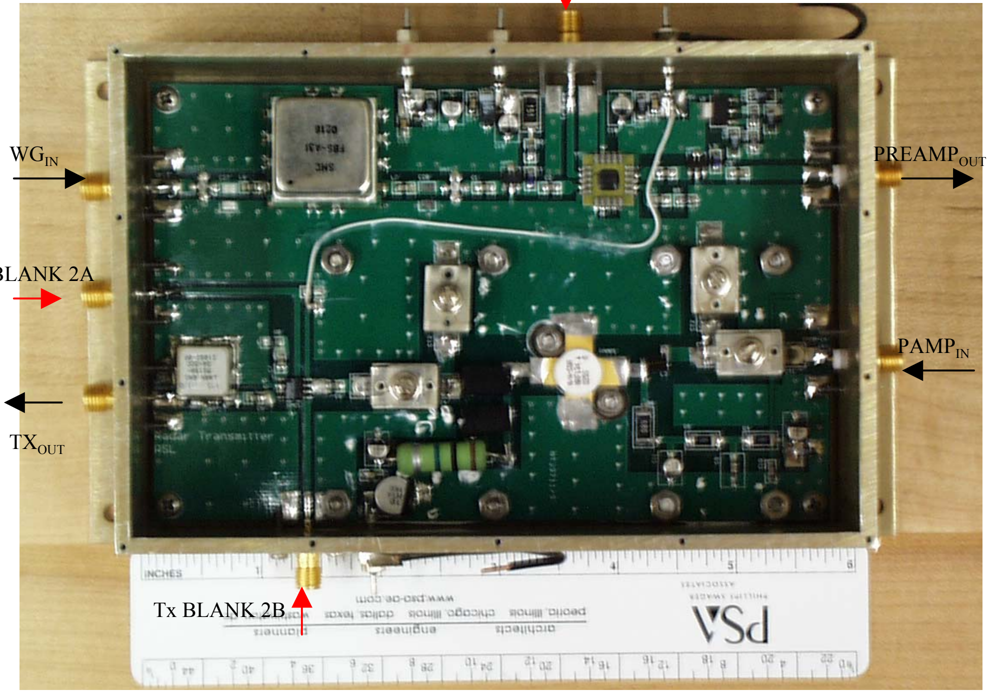
Transmitter RF section design: ACORDS

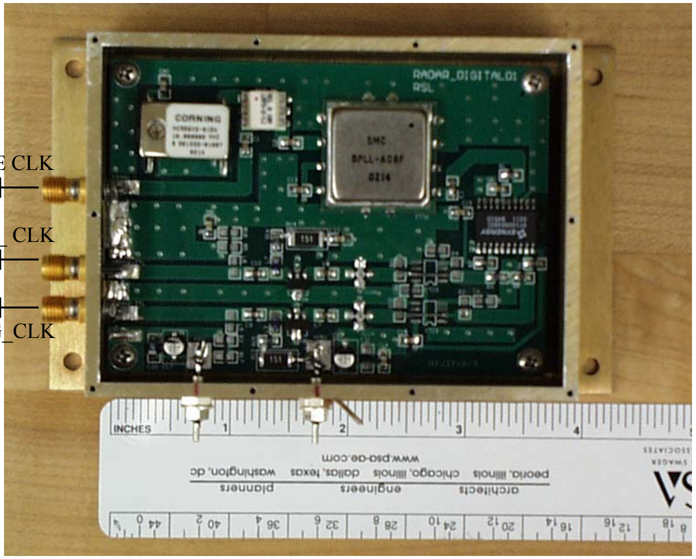


ACORDS Transmitter construction

- Protel 99 for schematic entry and Printed Circuit Board (PCB) layout
- Transmitter sub-system section
  - Designed on a 3.6’’ x 5.6’’ two layer FR4 board using microwave techniques
  - Aluminum block as heat sink
  - Packaged in a 4’’ x 6’’ standard RF enclosure
- Clock synchronization section
  - 2.6’’ x 3.6’’ two layer FR4 board
  - Packaged in a 3’’ x 4’’ enclosure

ACORDS Transmitter module

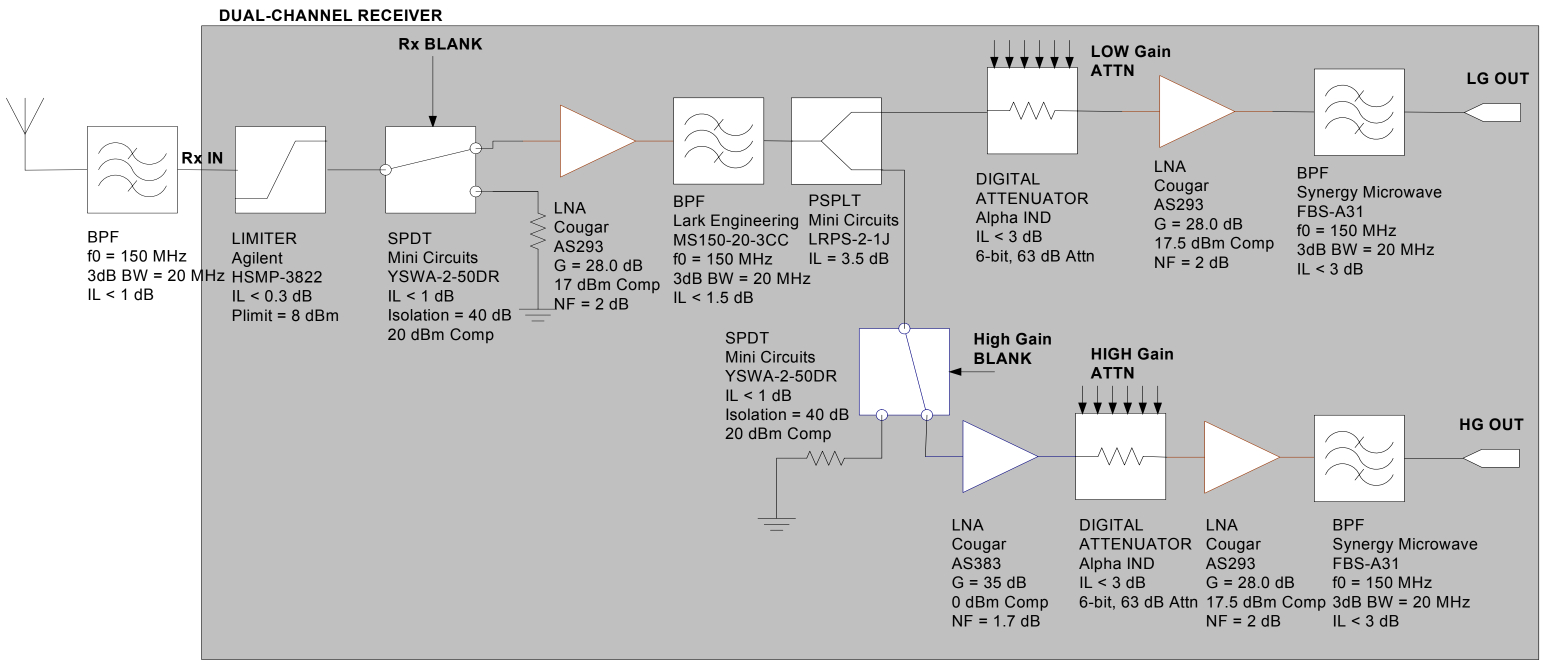




ACORDS dual-channel receiver design

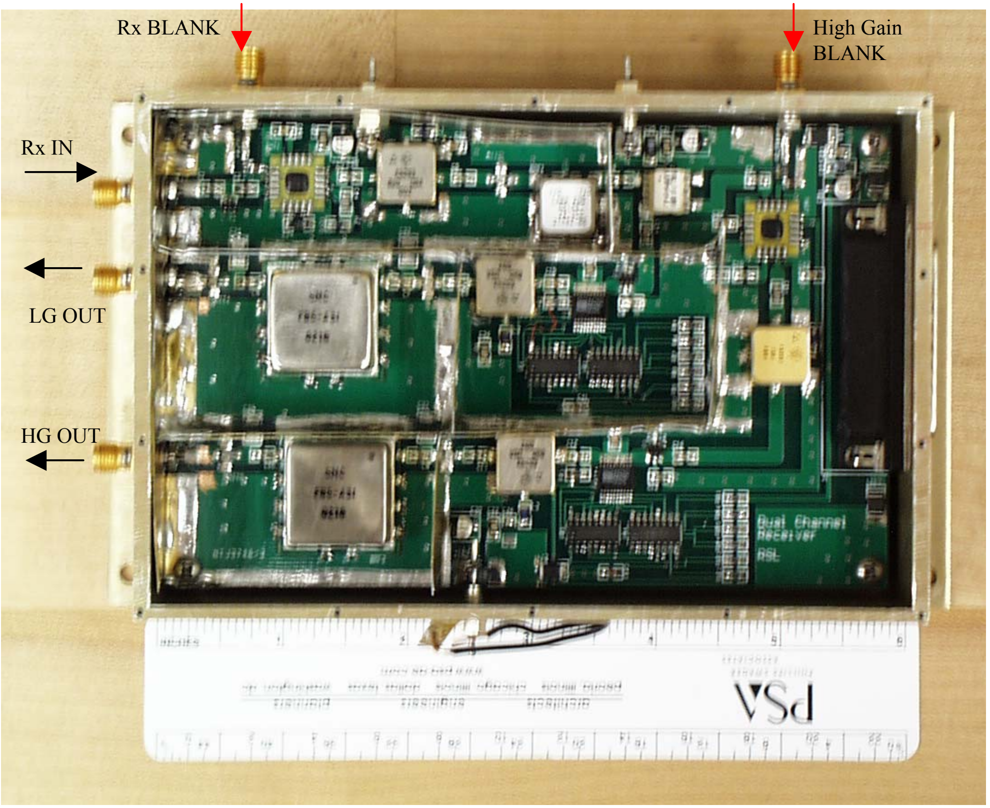
- Consists of RF section only
- LG channel - 44 dB gain, HG channel - 80 dB gain
- Amplifiers from Cougar Components selected
- Two RFICs combined to form 6-bit, 63 dB attenuator
- Gain controlled by a digital attenuator in each channel

Block diagram of the receiver RF section: ACORDS



ACORDS receiver RF module

- Receiver RF section
  - Designed on a 3.6’’ x 5.6’’ two layer FR4 board
  - Packaged in a 4’’ x 6’’ standard RF enclosure
- Internal RF shielding
- 25-pin DB connector



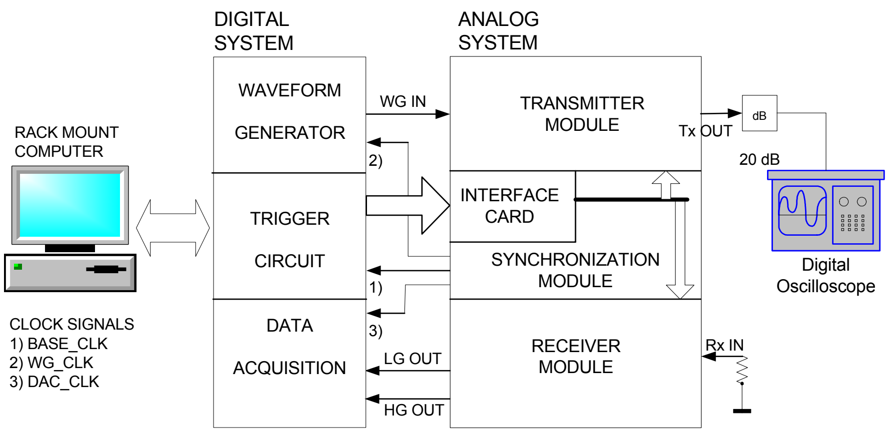
ACORDS digital system

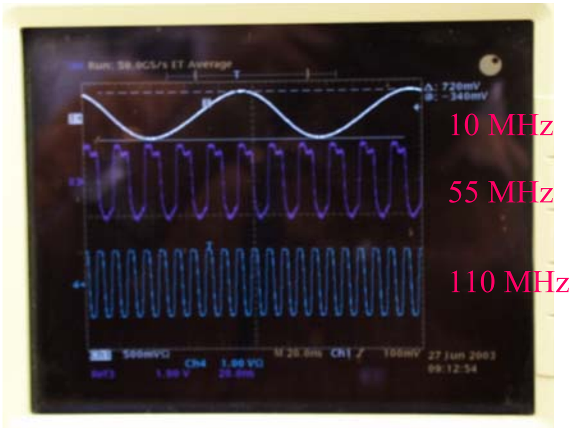
- Developed by Torry Akins
- Three modules
  1) Waveform generator
  2) Trigger circuit
  3) Data acquisition
- Advantages over existing digital system
  - Digital chirp waveform generation
  - Undersampling of LG and HG channel outputs
  - Complete control over radar system
- Universal Serial Bus (USB) interface with host computer

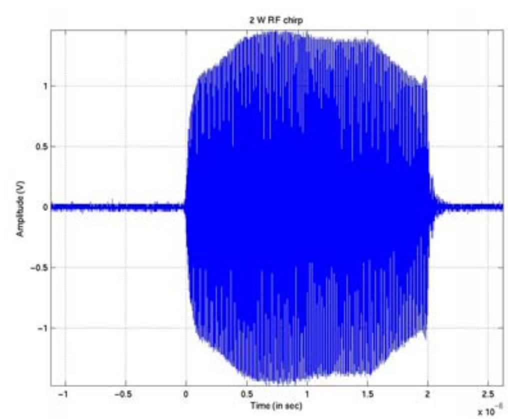
ACORDS analog system

- Linear power supply, individual modules housed in an 18'' x 24'' x 7'' chassis
- Interface card
- Chassis – common electrical ground

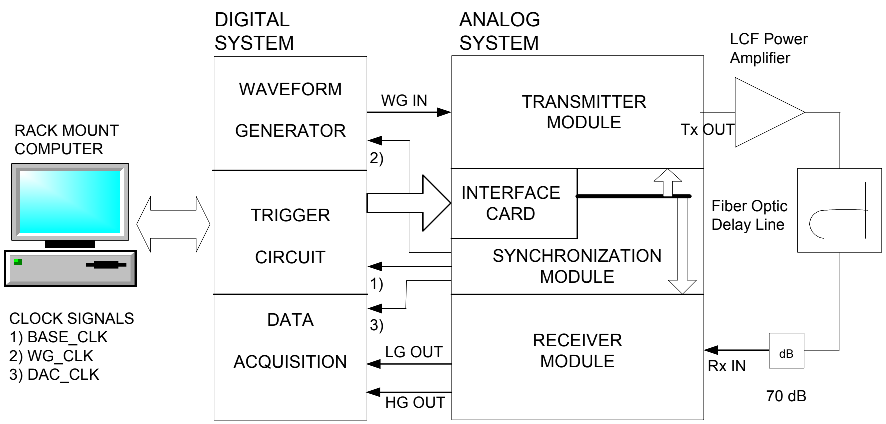
Laboratory testing of the ACORDS system

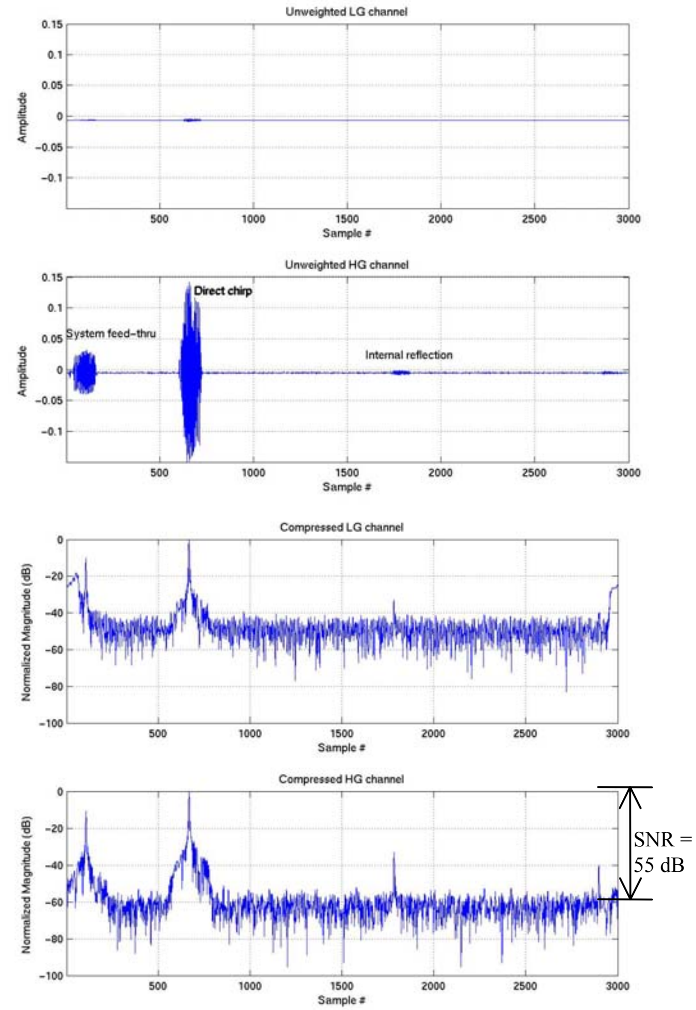






Loop-back test of the ACORDS system





- Practical loop sensitivity (dB)
  - SNR + delay-line attenuation + pad
  - 194 dB
  - Increased by transmitting a long pulse width
- Sidelobe performance
  - 16 dB below main lobe without weighting

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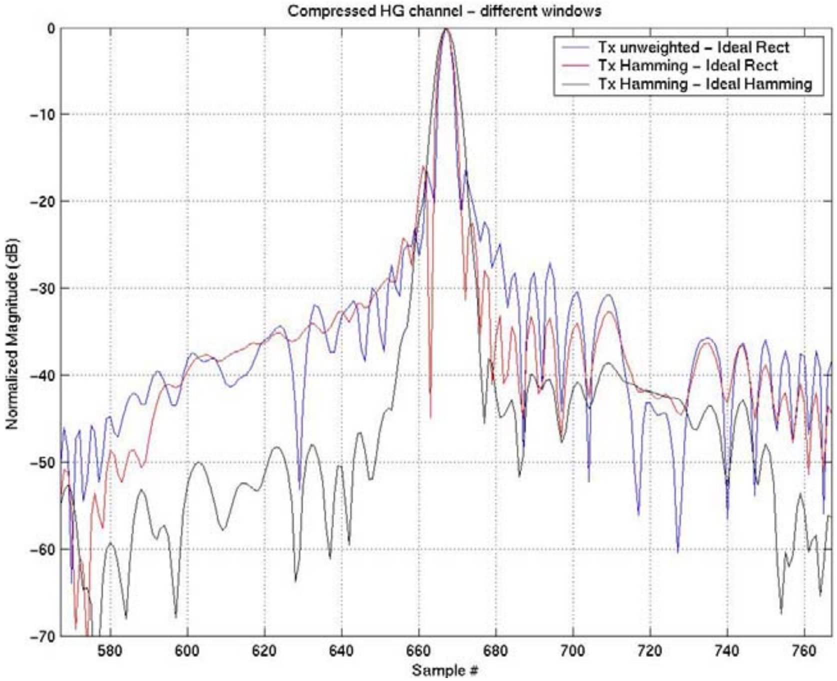
Compression results with different windows

- Tested for different windows
- Sidelobe performance

  36 dB below main lobe

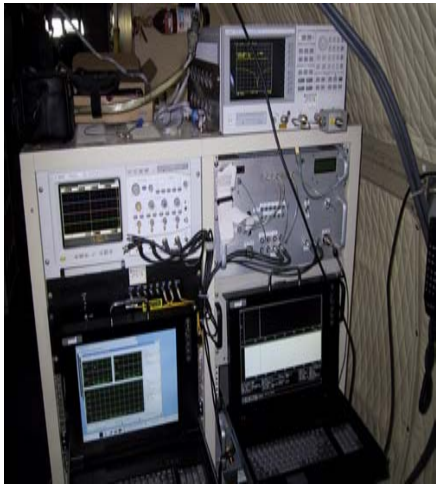


Field experiment of the ACORDS system

- 2003 field season
- Installed on NASA P3 aircraft
- Common radar settings of ACORDS
- Three different cases
  - Good internal layering
  - Glacier in northern Greenland
  - Glacier in southern Greenland
- Data processing included
  - Pre-integrations

  Raw data
  - Compensation for gain difference
  - Pulse compression
  - Post coherent & incoherent averages

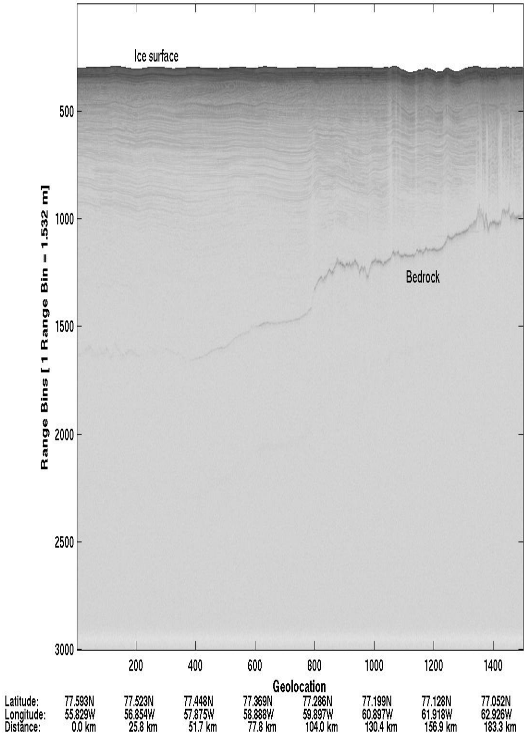
  First order processed data



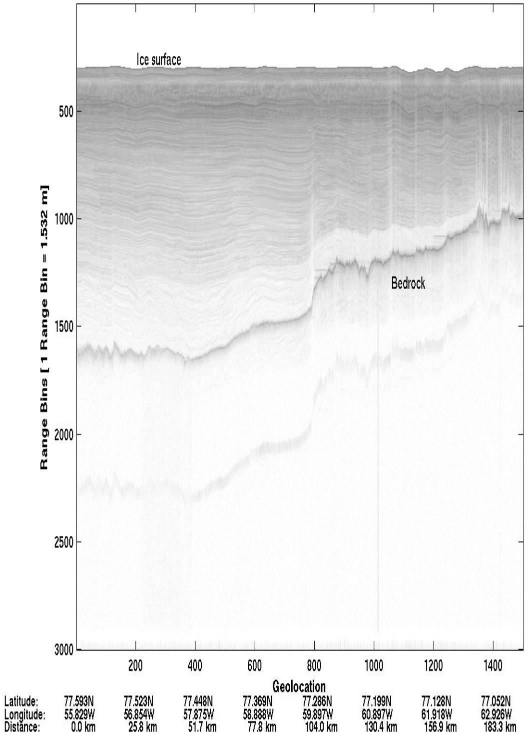
Description	Characteristic	Units
Tx pulse width	3.0	μs
Tx weighting	Hamming	-
LG attenuation	36	dB
HG attenuation	20	dB

Radio echogram with good layering: Results

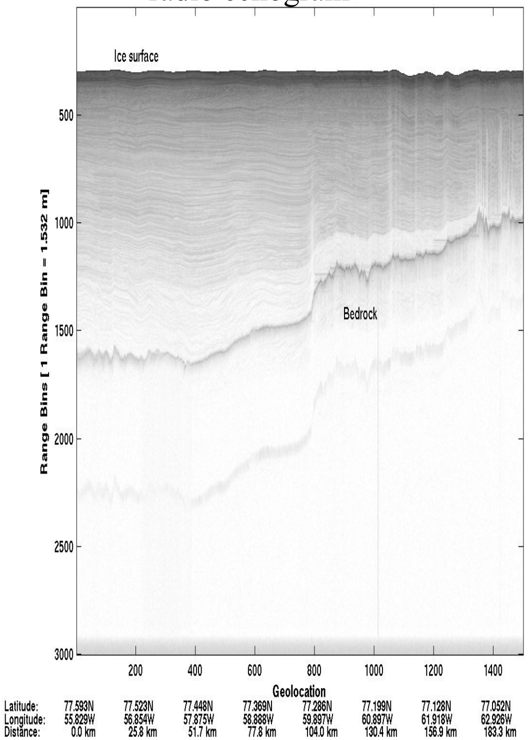
LG radio echogram



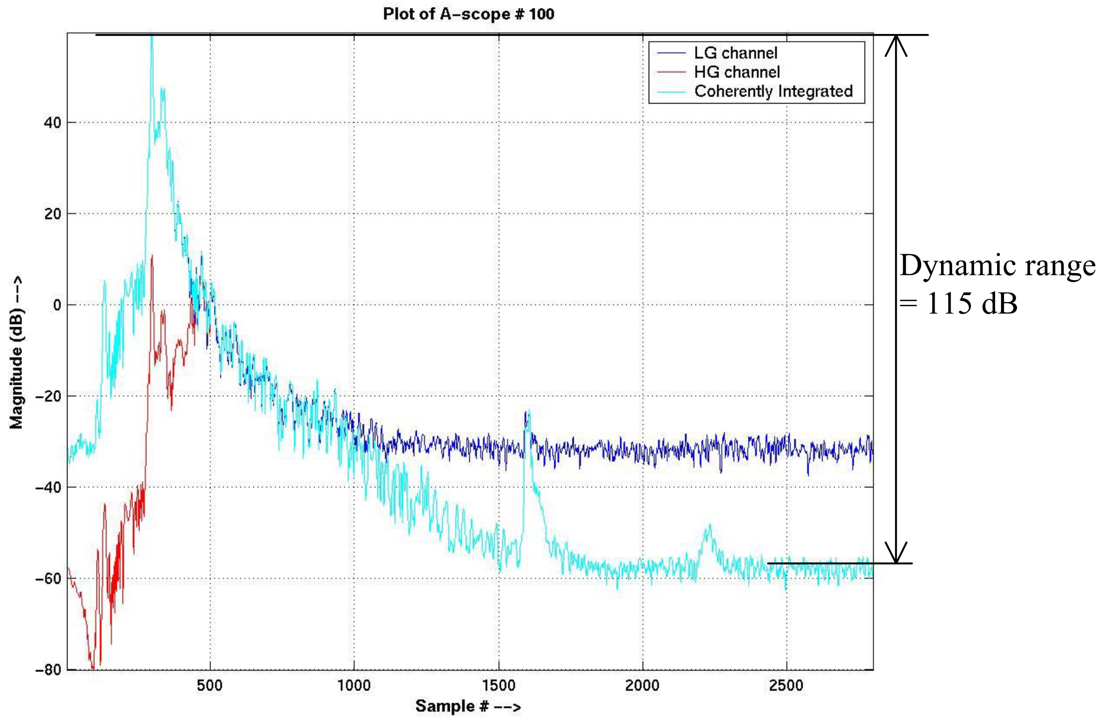
HG radio echogram



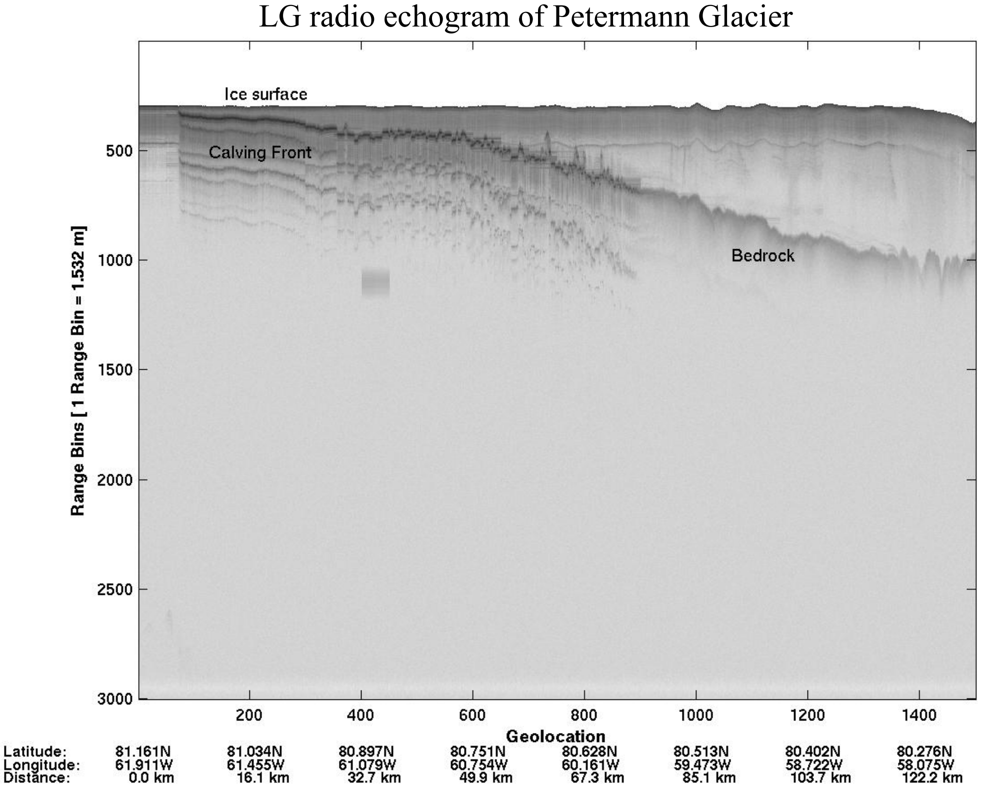
Coherently integrated radio echogram



Amplitude-scope comparison: Results



Radio echogram over Petermann Glacier: Results



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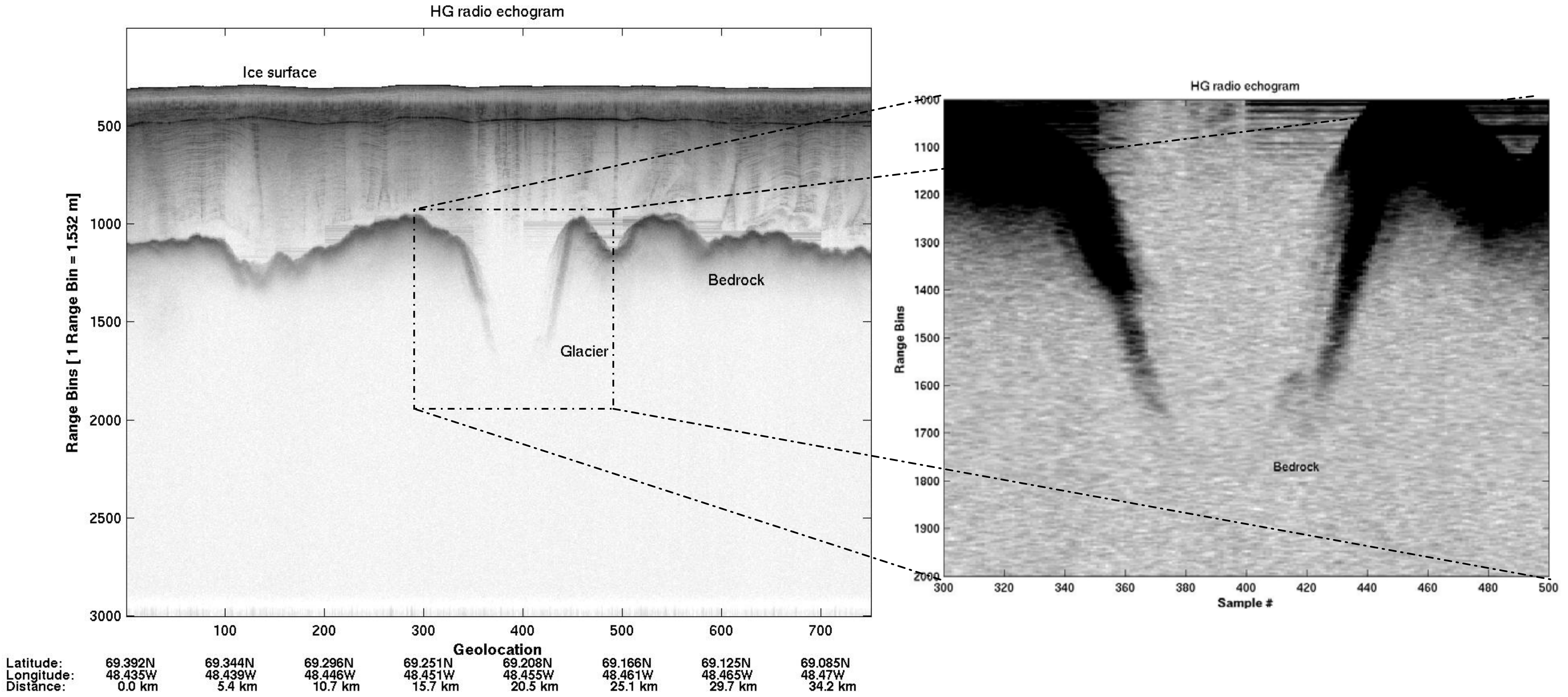
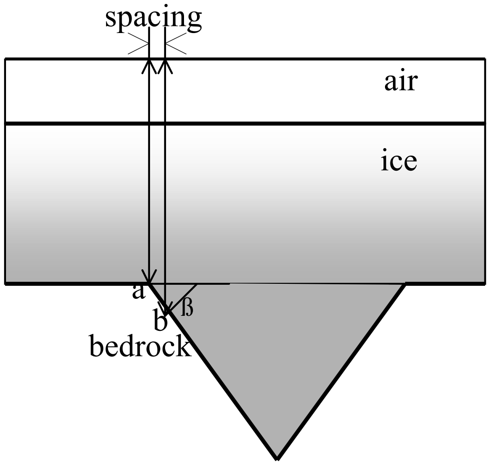
Radio echogram over Jacobshavn Glacier: Results



Summary of results

- LG and HG echograms integrated
- Good control over gain
- Performance over Jacobshavn glacier similar
    - Post-coherent integrations canceling out the bedrock in the channel
        - Two-way phase shift exceeds 45 degrees between adjacent samples
        - Phase compensation needed
    - Post-incoherent integrations insufficient



Conclusions

- Designed and developed
  - Transmitter sub-system
  - Dual-channel receiver
- Integrated in an rack-mount chassis
- Tested with the digital system
- ACORDS performance
  - Reduced sidelobes by 9 dB
  - Improved loop sensitivity
- Easy to operate
- Tested successfully in 2003 field experiment

Future recommendations

- Integrate 200 W power amplifier with transmitter sub-system
- Apply deconvolution techniques to correct for system effects
- Develop an algorithm that takes in to account the slope of the bedrock before coherent integrations
- Reduce number of pre-coherent integrations

Questions?

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