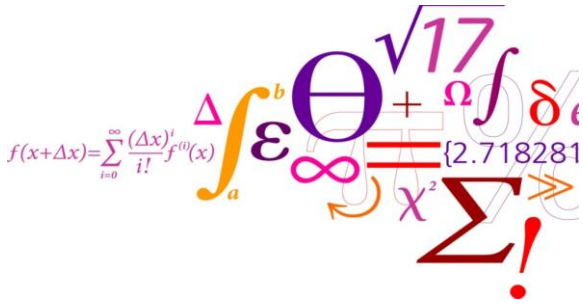
Research scanners at CFU

by Borislav Tomov,
CFU



Center for Fast Ultrasound Imaging
Department of Health Technology

Why

- Commercial scanner : video out
- Comm. scanner + research interface : RF BF data
- Research scanner: full access to setup and RF channel data

How

- Setup of emission sequences (frames)
- Setup of transmit
- Setup of receive
- Setup of image processing/navigation

2-channel sampling system (1991)

ADC:
20MHz
12-bit

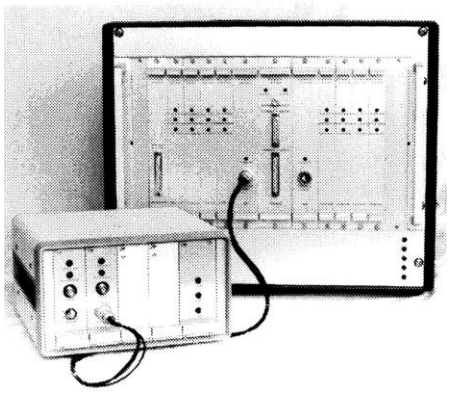
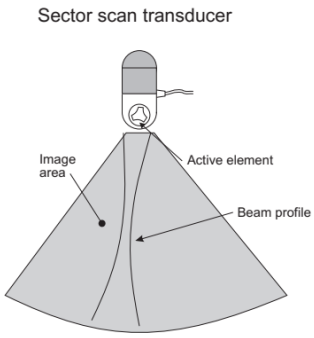


Photo out of paper by Jensen/Mathorhe, 1991

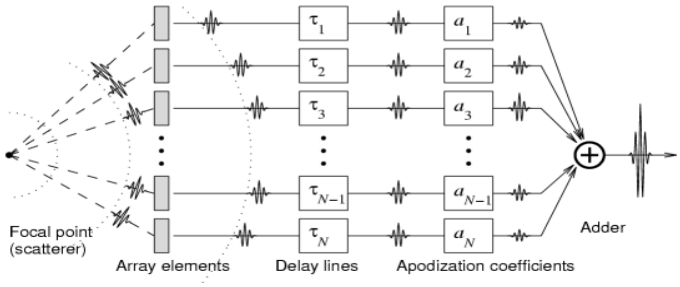


Drawing by J. A. Jensen, 1996

RASMUS (2001)

Remotely
Accessible
Software programmable
Multi-channel
Ultrasound
System

Purpose of RASMUS



- Flexible transmission
- Storage of data for later experimental beamforming
- Real time processing and imaging for orientation

Block diagram

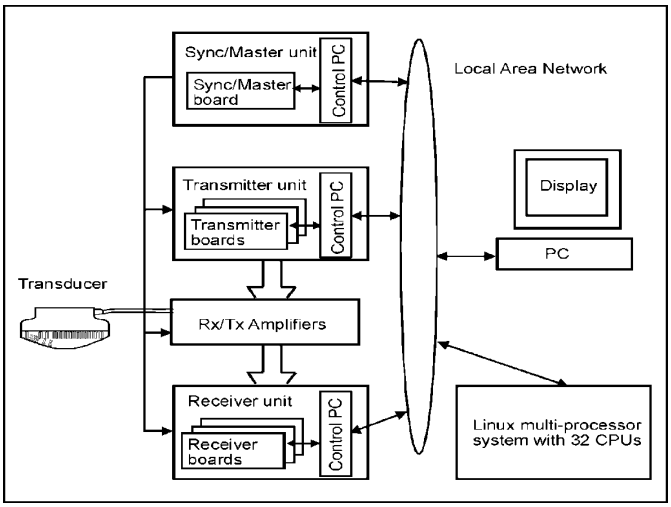
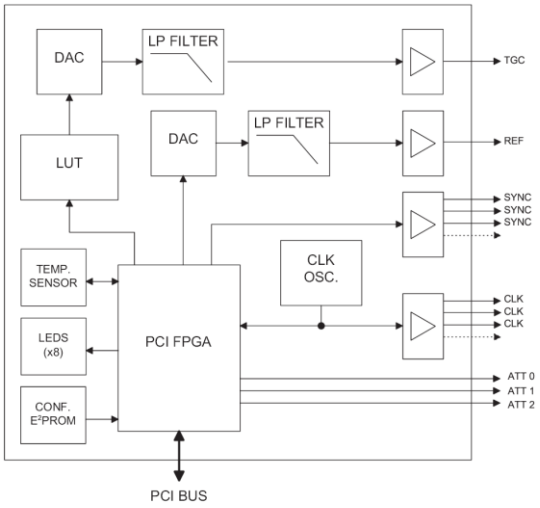


Diagram out of paper by Jensen et al., 1999

Construction

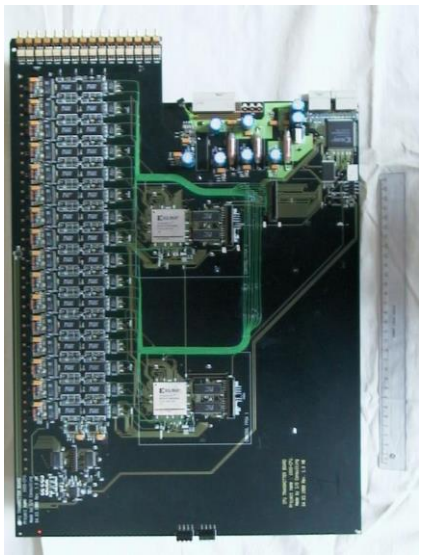
Photo by J.A. Jensen, 2002

Timing board

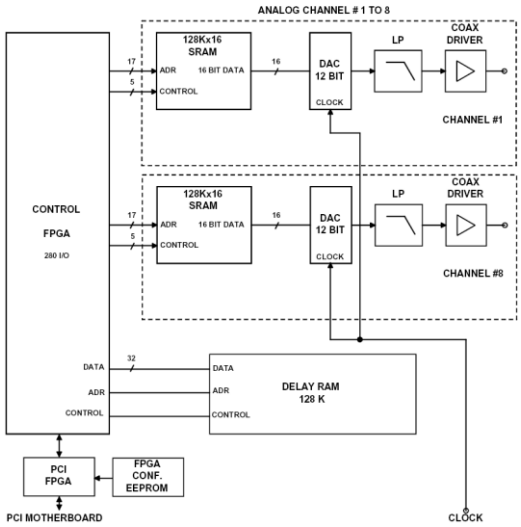


Transmitter boards

- DAC: 40 MHz, 12-bit
- 256 kB per channel waveform RAM
- Independent waveforms for each channel and emission
- 16 channels/board
- 128 channels in total



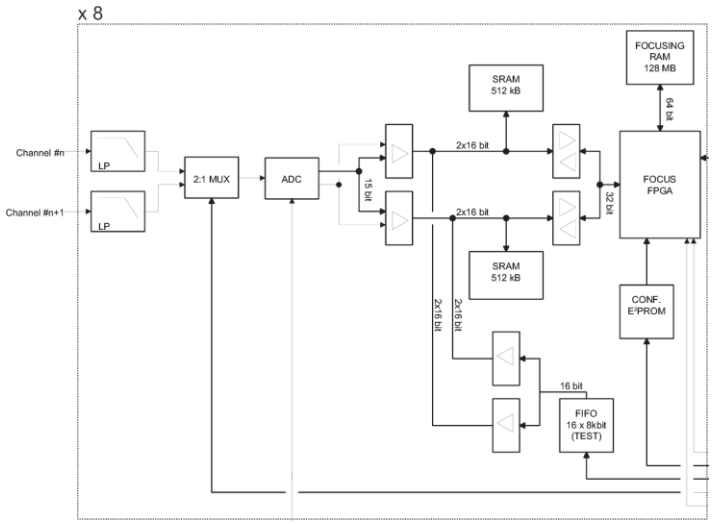
Transmitter boards

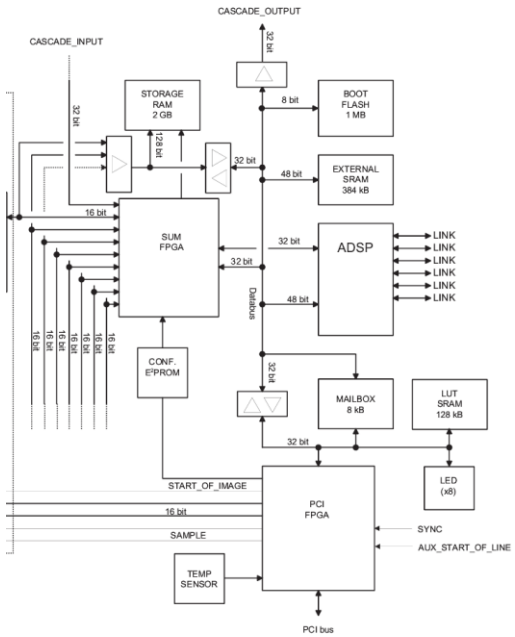


Receiver boards

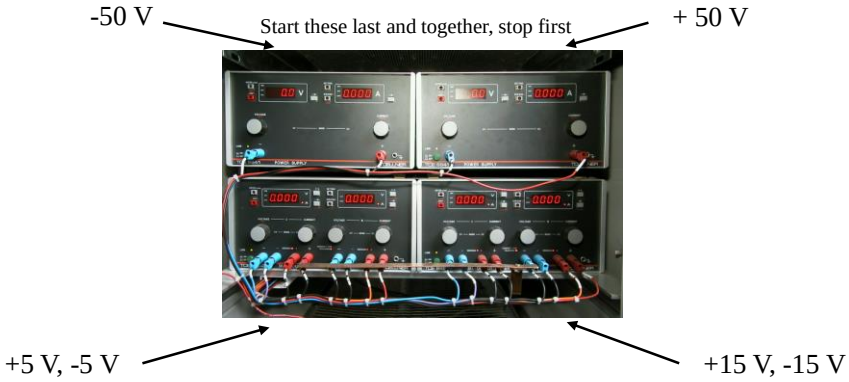
- 8 channels per board
- 2-to-1 multiplexing
- ADC: 40 MHz, 12-bit
- 256 MB RAM per channel (3 seconds of real time data, 2 GB)

Receiver boards





Power supplies



Outline-software

- Organization
- Commands
  - Initialization and closing
  - Setup - general commands
  - Setup - timing board
  - Setup - transmitter
  - Setup - receiver
  - Acquisition
  - Reading data

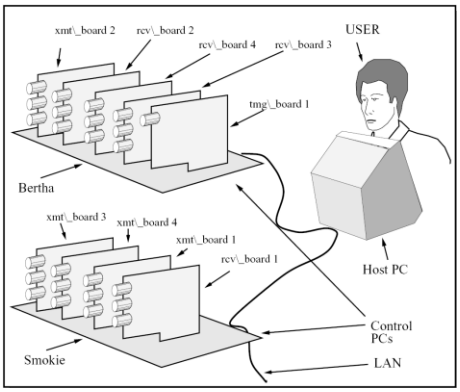
Software organization

Host PC:

- user sits at it
- runs Matlab
- C library functions called from Matlab

Control PC:

- contains RASMUS boards
- runs drivers
- runs execution server ”sys_master_ctrl”



Initialization and closing

sys_init([*file_name*, [*show_logo*,[*interrupt*]]])
- Uses /home/*username*/.syslib by default

sys_end
- Releases the command server for other users and the memory used by Matlab

sys_abort
- Stops the command server

Setup - general

sys_set_param(*parameter_name*, *parameter_value*)
- For now, **c** and $\mathbf{f_s}$ (default 1540 and 40e6)

sys_set_no_lines(*number_lines* [, *skipped*, *sampled*])

sys_set_sampling_interval(*start_depth*, *end_depth*)

sys_set_fprf(*pulse_repetition_frequency*)

tr_bk8802, tr_bk8804, tr_general, xmt_set_no_samples(*n*)

Setup-timing board

tmg_ref_voltage(*voltage*)
- reference voltage for the TGC amplifiers

tmg_set_attn(*attenuation _code*)
- attenuation of the transmit amplifiers.

tmg_tgc2(*gain_values*)
- 0 to 48 (in dB), 1 value per microsecond

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Setup- transmitter

xmt_set_ref_v(*voltage*)

xmt_center_focus(*line_numbers*,*point_coordinates* [, *frame_no*])

xmt_focus(*line_numbers*,*point_coordinates* [, *frame_no*])

xmt_excitation(*samples_normalized*)

xmt_apodization(*line_no*, *apodization* [, *frame_no*])

xmt_mode(*continuous_mode*, *use_external_trigger*)

Setup-receiver

rcv_center_focus(*line_numbers*, *point_coordinates*)

rcv_focus(*line_no*, *switch_pos*, *times*, *focal_points*)

rcv_dynamic_focus (*line_no*, *switch_pos*, *time*, *angle_xz*, *angle_yz*)

rcv_apodization (*line_no*, *times*, *values*)

rcv_mode(...)

Acquisition

tmg_measure(*no_images*)

Reading data

rcv_get_current_image(*brd_no*)

rcv_set_current_image(*offset*, *relative*)

rcv_storage_read_sampled(*channel_numbers*, *image_no*, *line_no*, *to_double*)

rcv_storage_read_summed(*board_no*, *image_no*, *lines_no*, *'class_name'*)

2001 - Rasmine

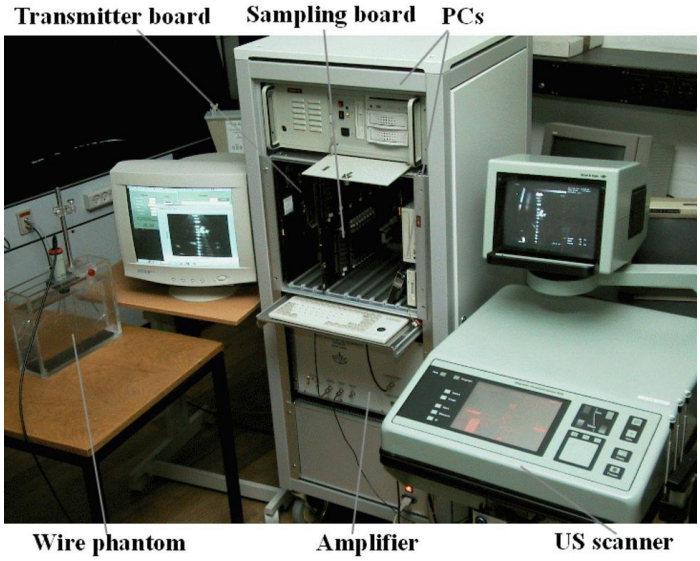
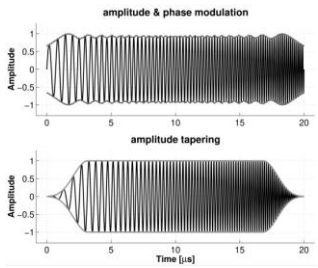
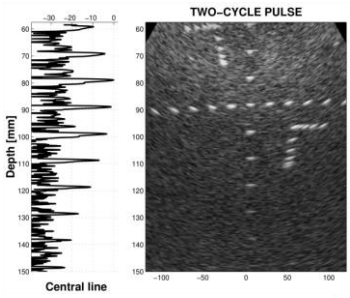
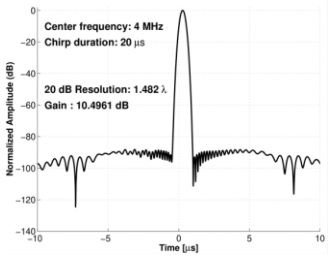


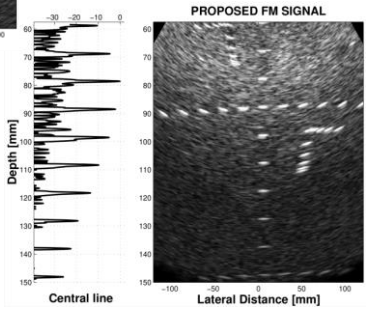
Photo by Thanassis Misaridis,
2001

Rasmine - results









Research by T. Misaridis
(1999,2000)

SARUS (2010)

Synthetic
Aperture
Real–time
Ultrasound imaging
System

Purpose of SARUS

- It is an experimental ultrasound imaging system:
  - Flexible transmit side – 1024 independent channels, up to 4096 samples at 70 MHz, up to 8192 different excitations per channel
  - Flexible receive side – selective sampling on 0 to 16 channels per board (0, 4 or higher even numbers), 1024 channels in total, 1 second continuous sampling at 70 MHz
  - Real-time preview / navigation capability - also using SA imaging
  - Transportable

Architecture

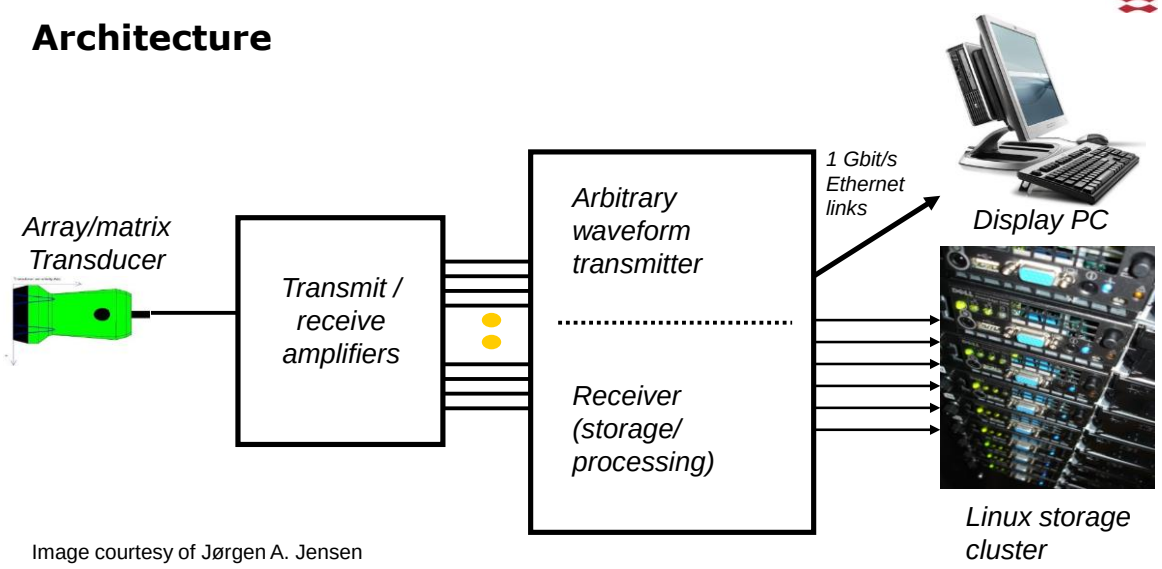
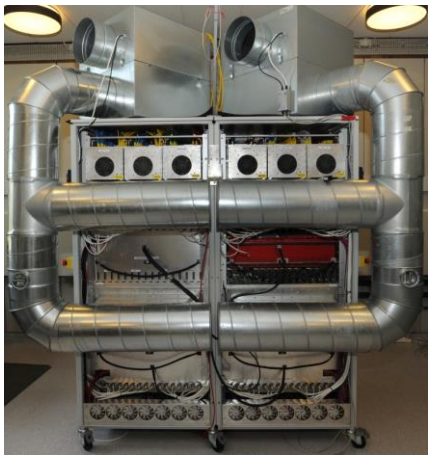


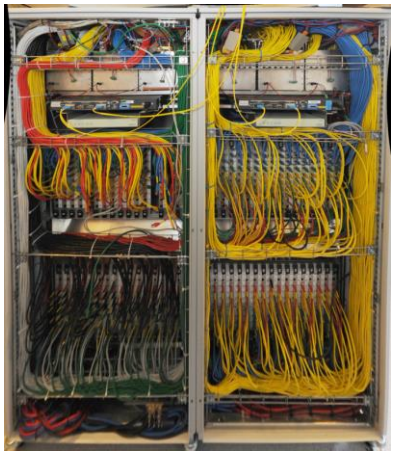
Image courtesy of Jørgen A. Jensen

Hardware components

- Digital acquisition / processing boards
  - 64 boards x 16 channels, 1 board is timing ctrl
  - Distributed in 4 racks / 2 cabinets
- Transmit / receive amplifiers
  - 128 amplifier boards in 6 boxes, up to 24 brd. per box
- 6 B-K transducer connectors (5 x 192 ch. and 1 x 64 ch.)
- Cabling – 512 cables

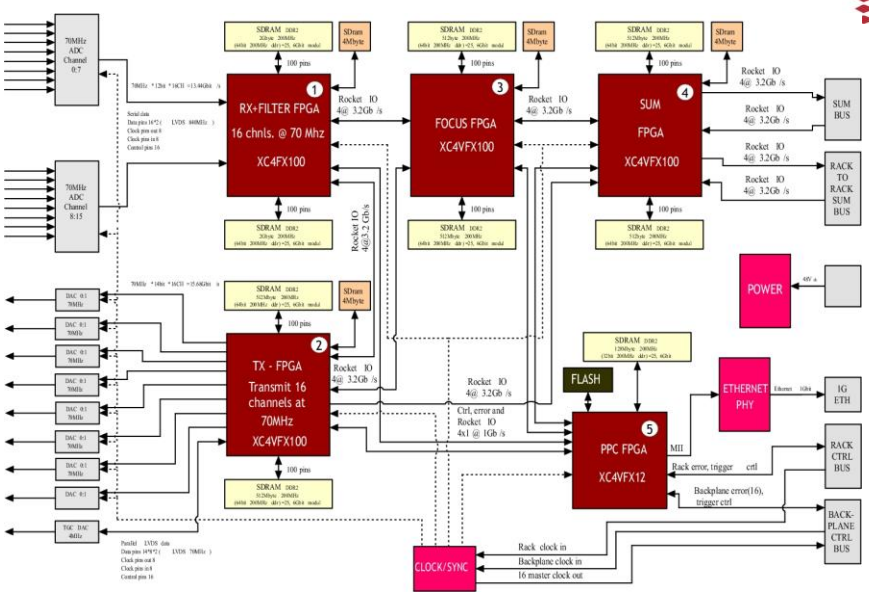
Initial cooling setup



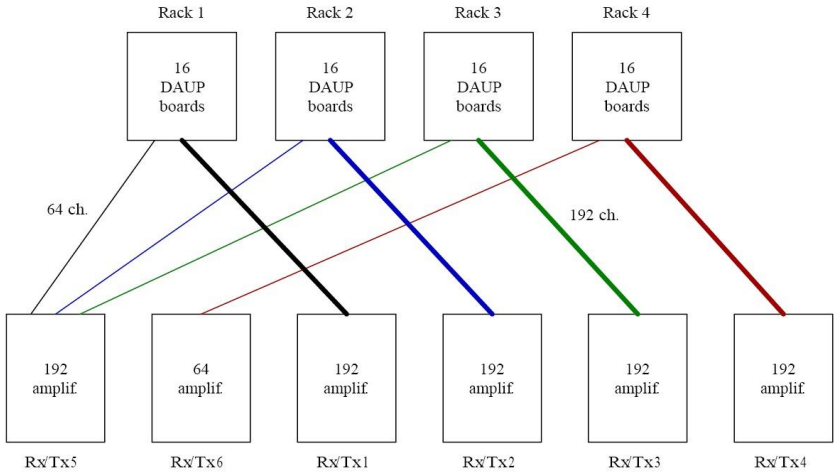


Photos by M. F. Rasmussen, 2012

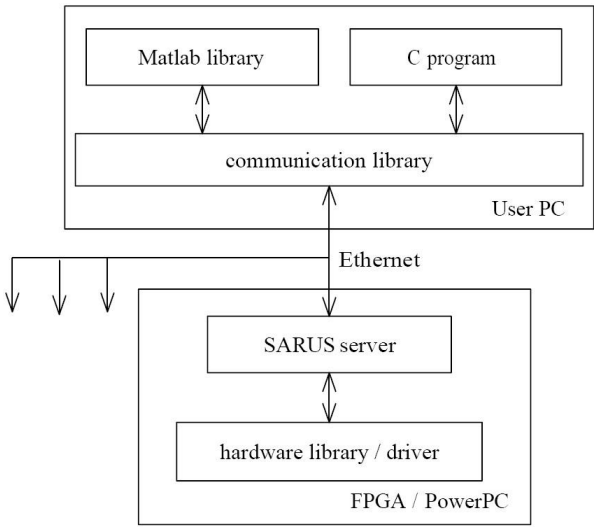
DAUP board



Cable connections



Software structure



Concepts/terms

- Image – a pretty picture for display, made of lines
- An emission provides data for one image line, or for a whole low-resolution image in SA imaging.
- Frame – a set of emissions that accomplish the task of providig data for a B-mode image, color flow map, etc.
- A sequence is made of frames in a chain
  /// nowadays, people call a frame sequence

General SARUS commands

- *sarus_init(file_name)*
- *sarus_end*
- *sarus_clear*
- *sarus_reset_fpgas*

Geometry and timing setup commands

- *sarus_use_transducer(xdc_name, serial_num,flags)*
- *sarus_set_speed_of_sound(c)*
- *sarus_create_frame(no_emissions[,...])*
- *sarus_set_tprf(tprf_array)*
- *sarus_set_fprf(fprf_scalar)*

Transmitter setup using virtual sources

- *sarus_xmt_define_excitation(vector)*
- *sarus_xmt_define_virtual_source(start_e, end_e, weights, delays, wavetype, prop_dir_focus, use_fine_delay)*
- *sarus_xmt_define_virtual_source_rc(....)*
- *sarus_xmt_set_emission_vs(em, virt_srcs, ha, weights)*

Receiver setup

- *sarus_set_sampling(emissions, start_d, end_d, elements_store, elements_process)*
- *sarus_set_sampling_rc(emissions, start_d, end_d, elements_store, elements_process)*
- *sarus_set_sampling_times(emissions, start_t, end_t, elements_store, elements_process)*
- *sarus_tgc(emissions, tgc_vector), 5 / microsec.*
- *sarus_set_decimation(dec_factor,use_avg)*

Reading data

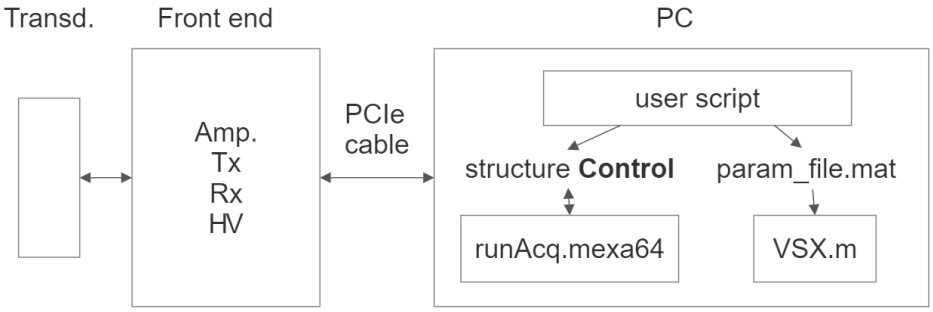
- *sarus_read_element_data(elements, frame, em)*
- *sarus_read_frame_data(frame, st_em, no_em...)*
- *sarus_read_single_channel(ch_idx, no_frm...)*

Saving data

- *sarus_set_description_file(file_name)*
- *sarus_set_emission_types(frm_type, em_type,fr)*
- *sarus_set_scan_object(par_name, par_value)*
- *sarus_save_data_set2(no_seq[, path, struct])*
- *sarus_compress_acquisition(path)*

2020 – Vantage 256

Vantage control structure



Vantage setup parameters

- Resource
- Trans
- TW
- TGC
- TX
- Receive
- Event
- SeqControl
- TPC

- PData
- Media
- Recon
- Process
- UI

Vantage interaction/control

- Structure Control:
  - field Command
  - field Parameters

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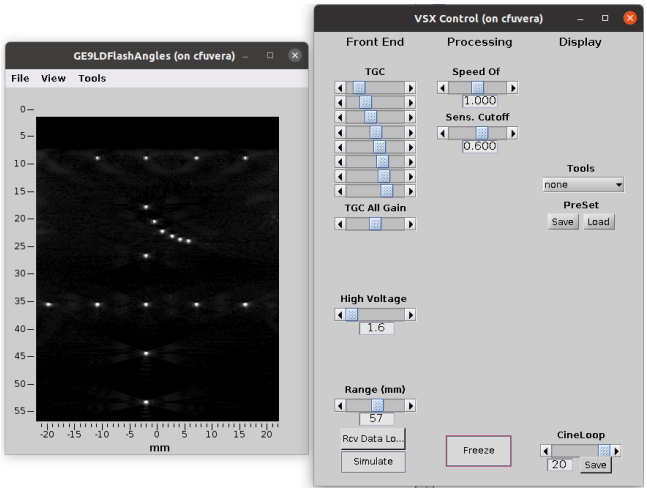
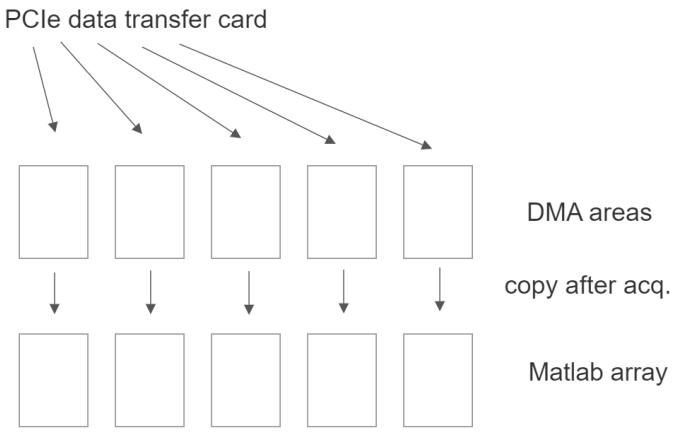
Vantage GUI (default)



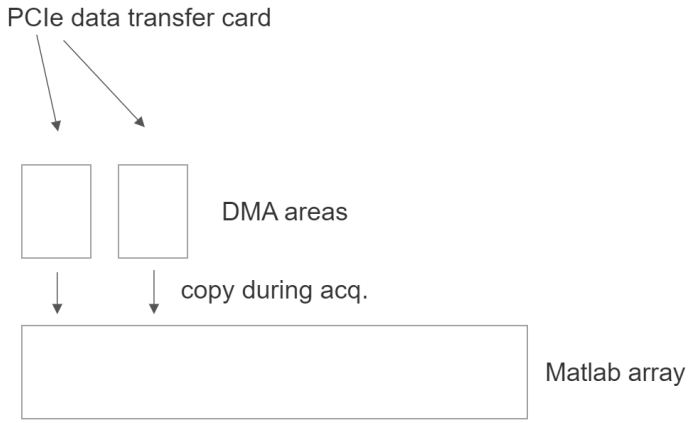
Vantage data transfer mechanism (default)



Vantage system hardware limitations

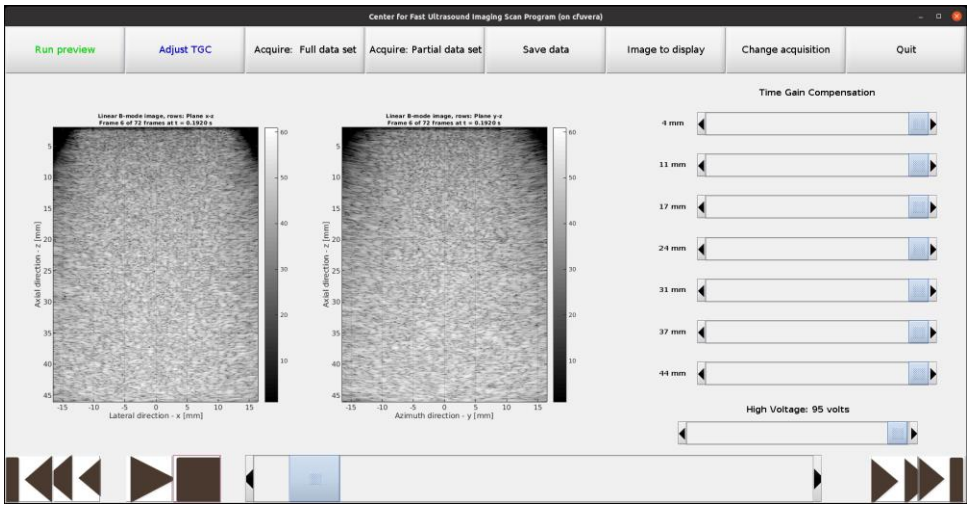
- 132 000 emissions, at Fprf=5000 gives 26 seconds
- PC RAM utilization < 50 % with default data transfer mechanism
- DMA transfer size > 64 MB for performance, 2GB max (at CFU: 1.7 GB),
- 3-level transmit
- Tx apodization result not visible
- Tx waveform synthesis has discrete center frequency values
- PC RAM allocation takes 1 sec/GB
- The PC runs a non-real-time OS, GUI operations eat time, disturb acq.

Vantage data transfer mechanism (CFU)



By idea of Ron Daigle (Verasonics)

CFU_scan



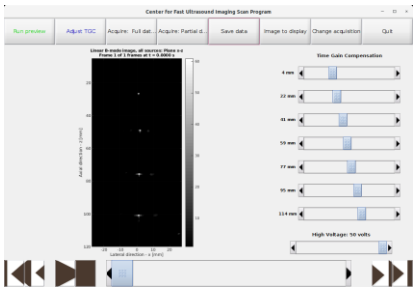
Scanner parameters

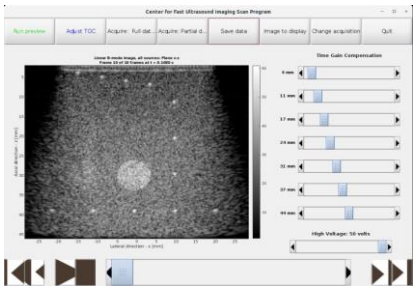
Scanner	**2-ch. system**	**RASMUS**	**SARUS**	**Vantage 256**	**ULA-OP**
In use since, year	1991	2000	2010	2020	-
Channels	2	128	1024	256 (x4)	356
Fs, MHz	20	40	70	62.5	78
RAM, GB	7-12 MB	16	128	PC*	80
Throughput, GB/s	0.04	5.12	143.36	3.5 (max. 6.6)	40
Sampling time, s	0.17	3.4	0.9	160*	2
Transmit	-	Linear	Linear	3-level	Linear
Preview	No	Yes	Yes	Yes	Yes (USB 3)
Mobile	Yes	Yes	No	Yes	Yes

*Vantage PC config. at CFU: 512 GB RAM

Excercise

- Start CFU_scan
- Perform a scan of a wire (1 frame) and a tissue phantom (10 frames)
- Save the RF data
- Beamform it using your own beamformer
- Display the images with correct axes and dynamic range of 60 dB.





How to extract emission data

To extract emission data, use the function:
[filtered_samples, t_start, rx_fs, elem_positions, vsrc_position, c] =
load_scan_data(*path_data*, *frame_index*, *em_idx*),
where the output is:

- filtered_samples - RF data with matched filter applied
- t_start - start time of the RF data
- rx_fs - sampling frequency of the recorded RF data
- elem_position - element positions [N x 3], containing X, Y and Z
- vsrc_position - position of the virtual source
- c - speed of sound in the phantom