A new general purpose high performance HF Radar.

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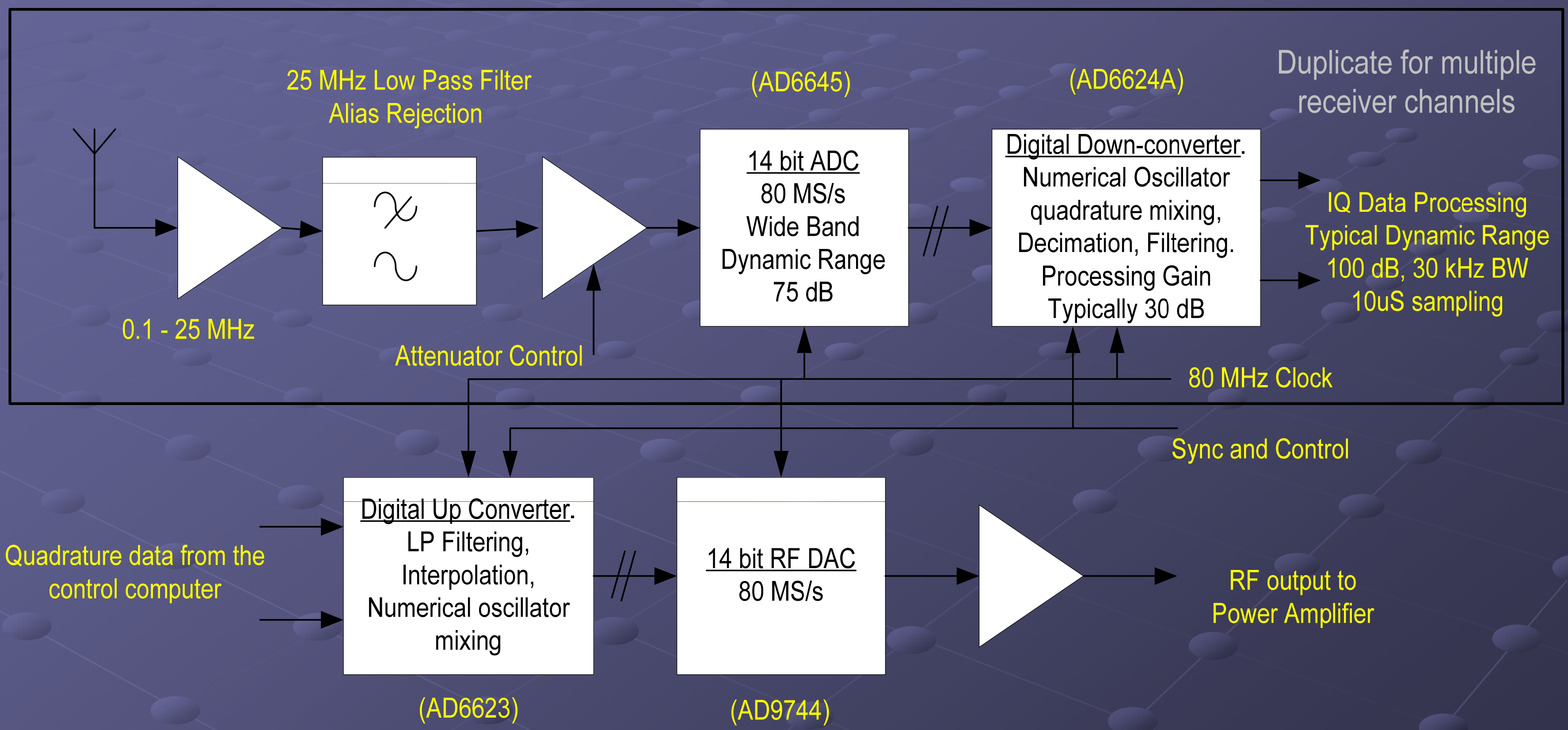
Objectives

- An earlier system was built at NOAA/SEC with NSF support in the late 1970's. Some are still in use. A later presentation today covers the operation at Tromso.
- Then, as now, the objectives for the system are:
  - A flexible software controlled coherent pulse sounder of the ionosphere, supporting receiving antenna arrays, and covering the 0.1 – 25 MHz frequency range.
  - An open software and hardware design, exposing the whole digital raw data, and making it easy for the user to add their appropriate analysis software, or use other available software (e.g. for Dynasonde processing).
  - Matched transmitter and receiver pulse shaping and linear amplification to optimize the data return and minimize potential interference to other HF spectrum users.

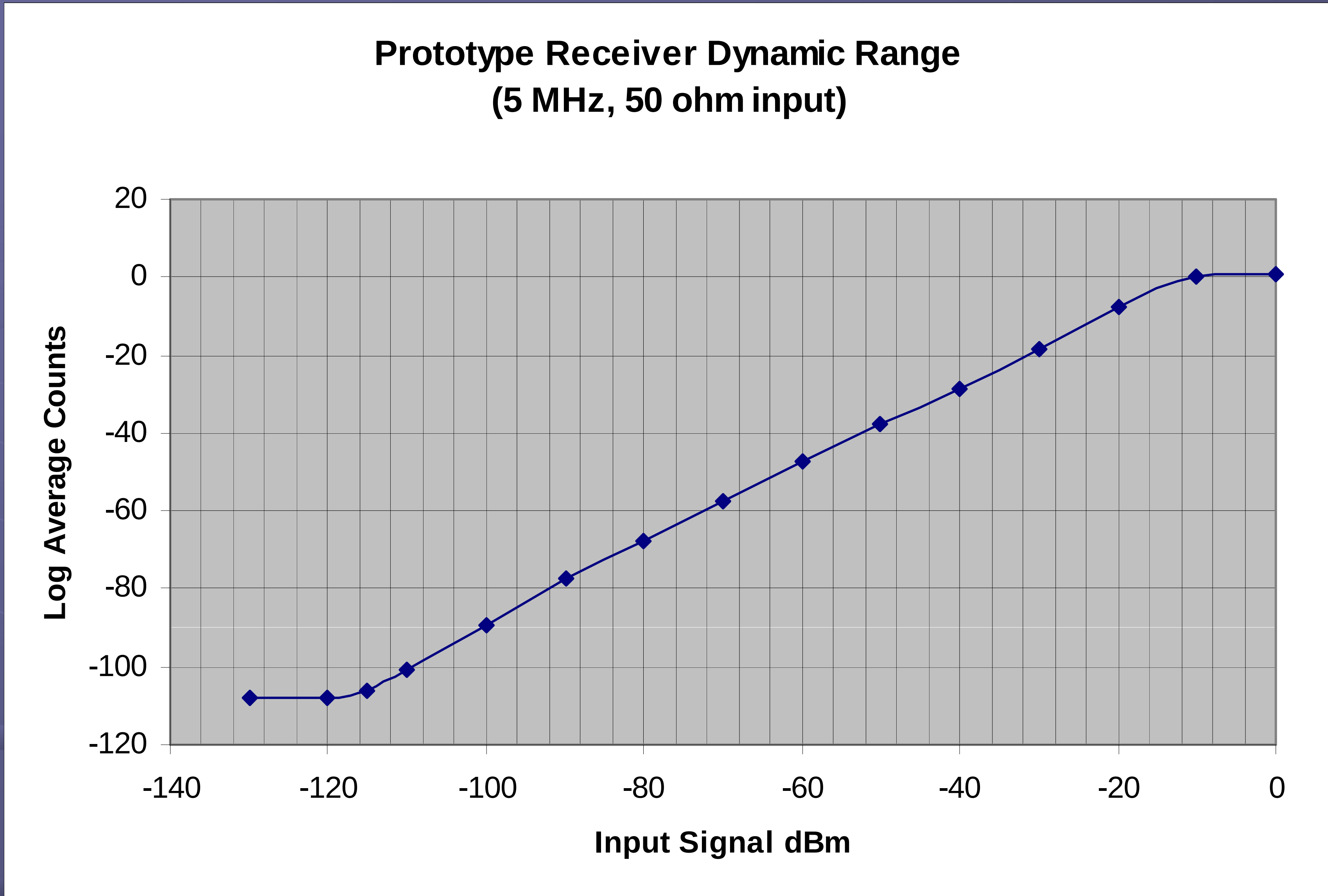
System design concepts.

- Direct digital down-conversion (DDC) is employed in the receiver and digital up-conversion (DUC) in the transmitter exciter to provide major advantages over prior analog designs.
  - Flexible FIR filtering provides a flat group delay response, and stable amplitude and phase matching between parallel receiver channels for antenna array processing, as well as matching between the transmitted pulse and receiver response.
  - A large receiver dynamic range with linear IQ processing.
  - A low component count minimizes the cost and size constraints to parallel receiver channel systems compared to analog designs.
  - Software control of frequency and bandwidth enables cognitive radio principles to be implemented for coexistence with other services or adaptive data acquisition.

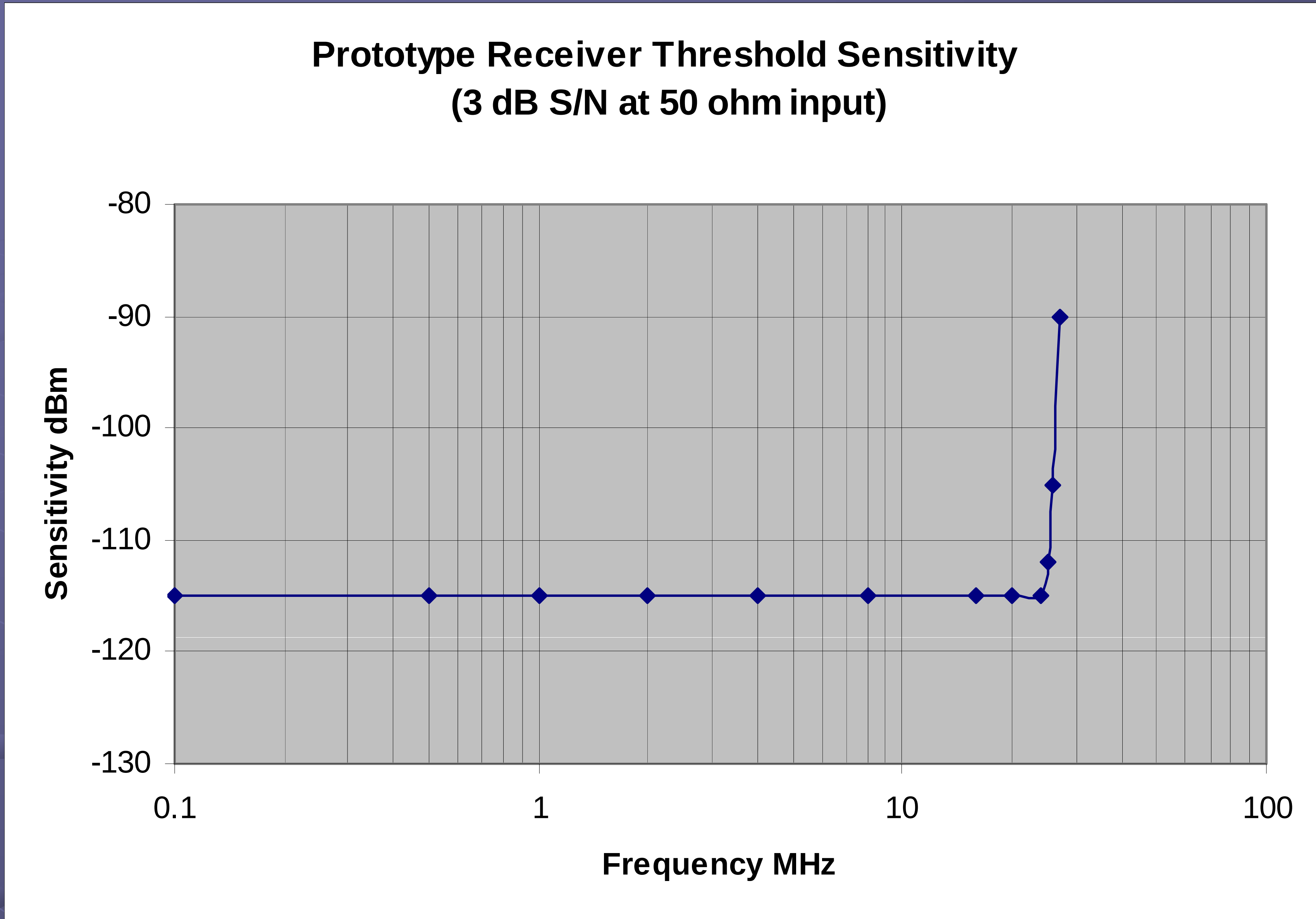
RF section block diagram



The Digital Up-Converter and Digital Down-Converters are single chip subsystems similar to the "Gray Chips"



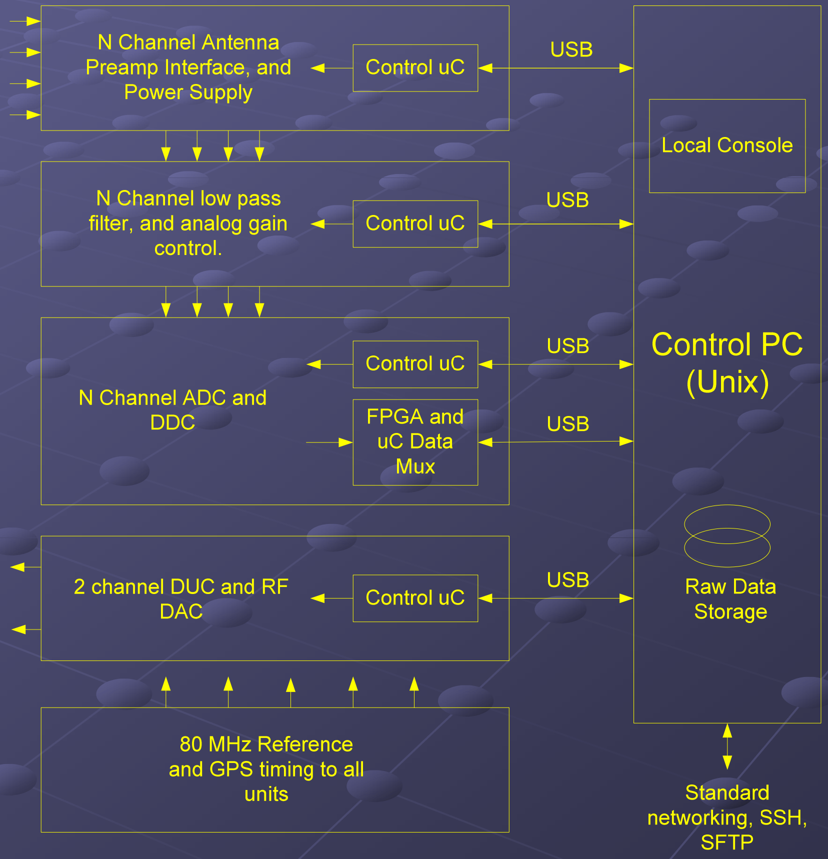
Prototype Receiver Dynamic Range
(5 MHz, 50 ohm input)
20
0
-20
-40
-60
-80
-100
-120
-140
-120
-100
-80
-60
-40
-20
0
Log Average Counts
Input Signal dBm



Prototype Receiver Threshold Sensitivity
(3 dB S/N at 50 ohm input)
-80
-90
-100
-110
-120
-130
Sensitivity dBm
0.1
1
10
100
Frequency MHz

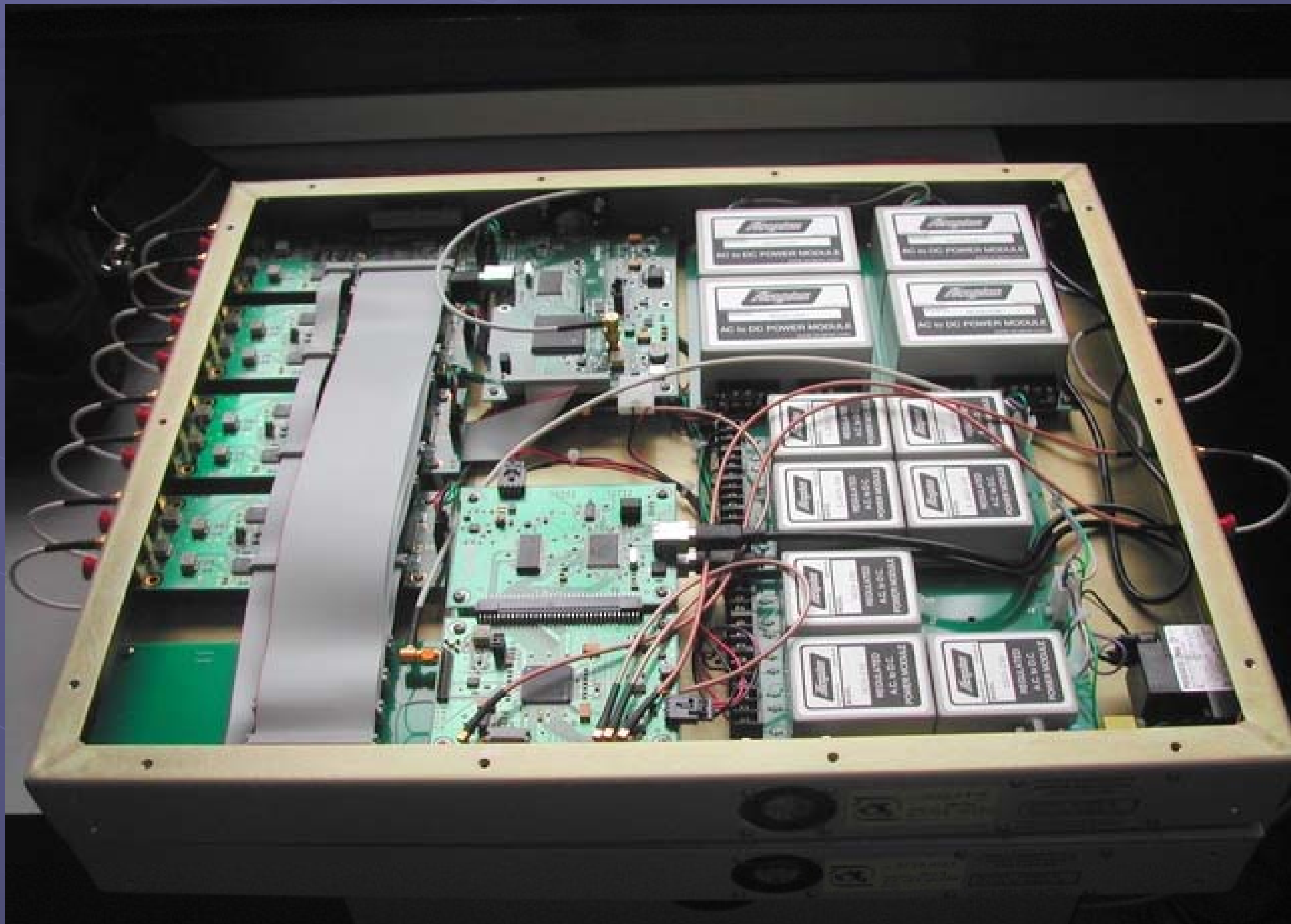
System Architecture

- 5 rack 1U chassis support up to 8 receive channels and two transmit channels.
- Each chassis has an independent state and timing control microcomputer (uC) with a USB connection to the main control computer.
- UT timing is controlled by a GPS clock providing interrupts to all uC.
- IQ data is multiplexed by an FPGA and forwarded via a USB connection to the control computer.
- The frequency reference is either from a low phase noise 80 MHz OCXO, or a disciplined Rubidium standard for bi static operation.
- External system control and data transfer is via TCP/IP networking



All units are 1U Rack Chassis that are self contained for power supplies.

8 channel receiver ADC and DDC chassis



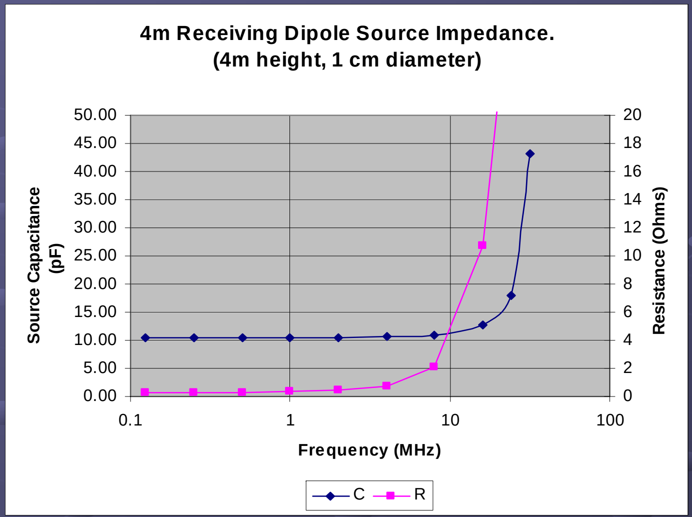
Receiving Array Antenna

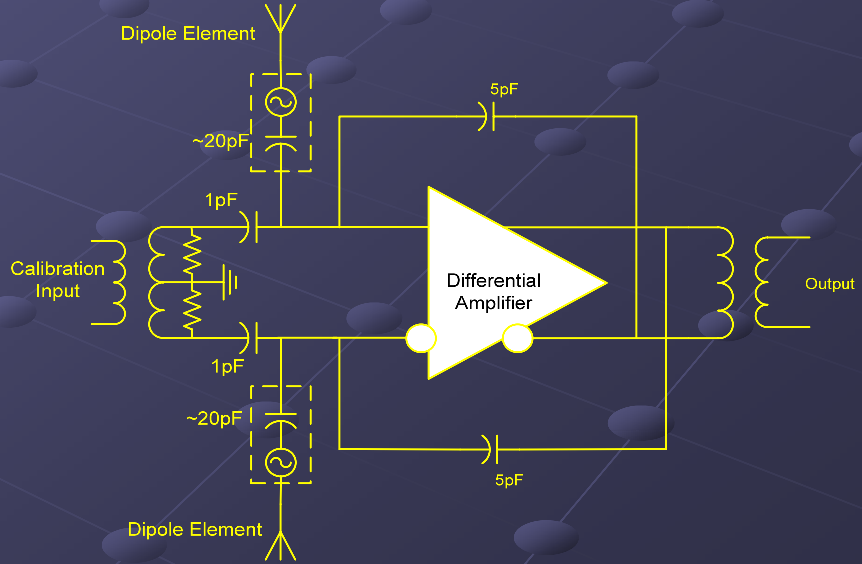
- The HF Radar has traditionally used elevated electrically short dipoles for the receiving array.
- These have the advantage, compared to loop antennas, of providing some discrimination against vertically polarized AM broadcast band signals.
- A new high performance preamplifier has been developed to provide atmospheric noise limited performance and wide dynamic range over the 0.1 – 25 MHz range from a 4m long dipole.
- Calibration signals are distributed to the preamplifiers by phase matched cables and become a standard part of the data.

Jicamarca

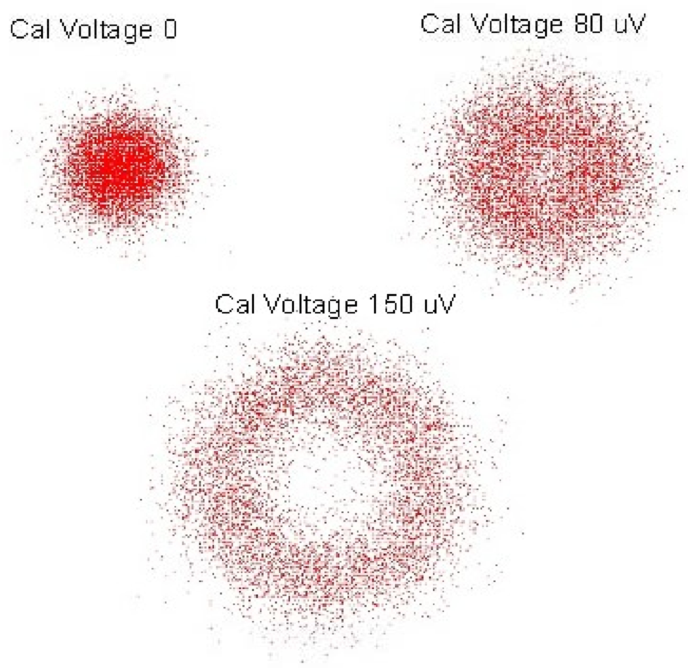
New Dipole Antenna Preamplifier.

- A 4m dipole has a substantially capacitive source impedance up to > 10 MHz.
- The preamplifier uses a balanced charge sensitive configuration to provide a flat response and high linearity.
- Calibration is applied directly to the summing junctions making it directly relatable to the induced dipole voltage.





Real world receiver threshold sensitivity

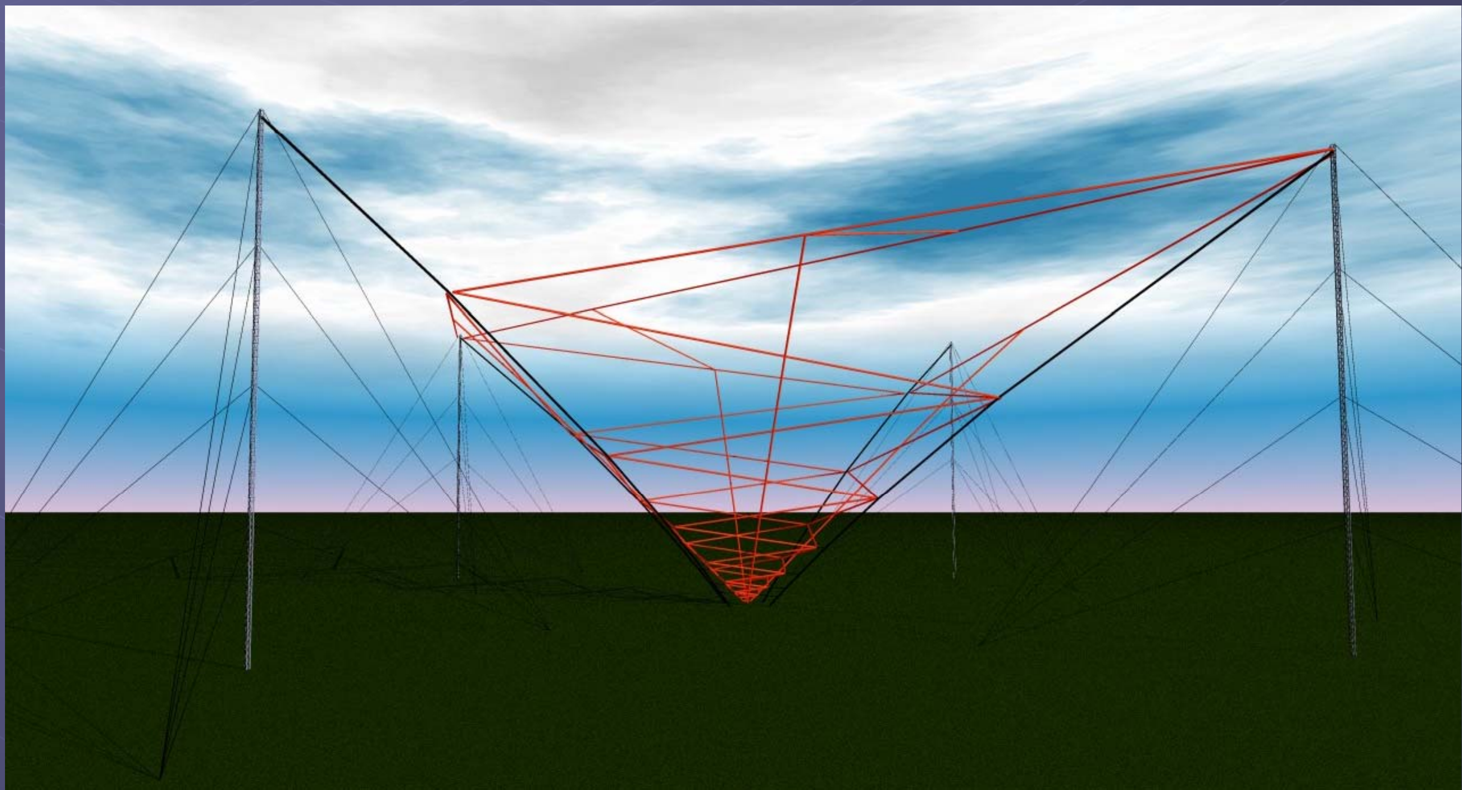


Sensitivity - Clear Frequency 5.4 MHz - full radio spectrum present

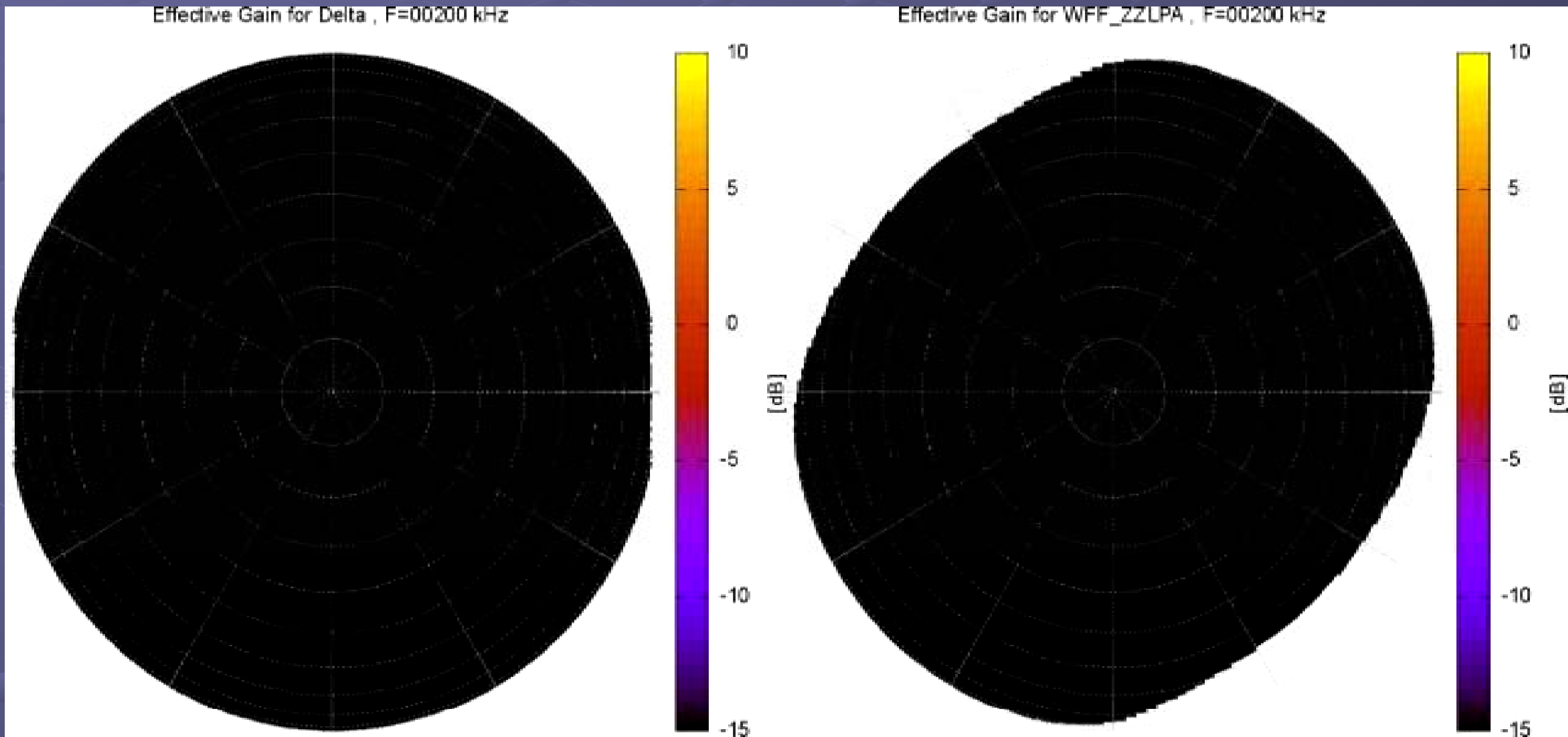
These are plots of the IQ output vector from the receiver when connected to the Antenna Preamplifier installed outdoors at a 3m height with a 4m dipole. The full radio spectrum including the AM broadcast band is present at the input to the receiver. A clear frequency was selected at approximately 5.4 MHz and a cw signal slightly offset from the tuned frequency is inserted via the calibration input and a 10dB attenuator. The amplitude is adjusted to just equal the received noise. A calibration voltage of 80 uV is equal to a horizontal field strength of ~ 1.2 uV/m.

Transmitting Antenna Development

- In parallel with this program, an NEC modeling program has been undertaken to develop an optimized version of the 4 tower, vertex down LPA to provide uniform sky illumination with the Radar. This has been installed at two sites and is further described in Poster Paper GP2-GH.3 this afternoon, entitled "TRANSMIT ANTENNA FOR IONOSPHERIC SOUNDING APPLICATIONS"



Effective gain v Frequency Delta compared with LPA



System Flexibility

- The autonomy of the receiver and transmitter sections make the system very suitable for bi-static applications.
- Selectable 50 ohm antenna inputs are available for alternative receiving antennas.
- A very wide range of pulse widths and periods, receiver bandwidths and sampling rates are available through software control.
- Coded pulse operation is fully supported in the exciter system.
- A second independently tuned parallel DDC is available in each receiver channel.
- The receiver ADC inputs potentially have a 200 MHz bandwidth making the adaption to VHF radar systems possible with suitable Nyquist sub band filtering and exciter up-conversion.

System Control Software

- The control computer is an x86 system running Debian Unix.
- All software for the x86 control computer, and the micro-computer's is written in high level C under open source licensing and follows standard Unix conventions for organization.
- The raw data for each frequency and range is a separate 16 bit linear word for I and Q. The 16 bits can be selected from within the 24 bit DDC processing output or a quasi FP format is available.
- The total raw data from a full frequency and range sweep with 8 receiver channels can approach 1 GB in size. Local application data processing in a separate analysis computer is recommended to reduce the data volume.

Analysis Software.

- Open source ionogram processing, based in part on earlier HF Radar software, is being developed by a number of groups.
- Proprietary analysis software is available for “Dynasonde” applications.
- The raw data file format is open, contains extensive metadata, and should make it straightforward for investigators to develop their own analysis programs.

Deployments

- A total of 12 of the new systems are currently being built.
- New systems are deployed at NASA Wallops Island; Jicamarca, Peru; and (shortly) Boulder, Colorado.
- The balance will be deployed under NOAA and LISN/Boston College programs.
- An additional system may go to Tomsk, Russia.
- If funding becomes available we hope that the original HF Radar systems currently installed at Tromso, Norway; Bear Lake, Utah and (shortly) Svaalbard; can be replaced.

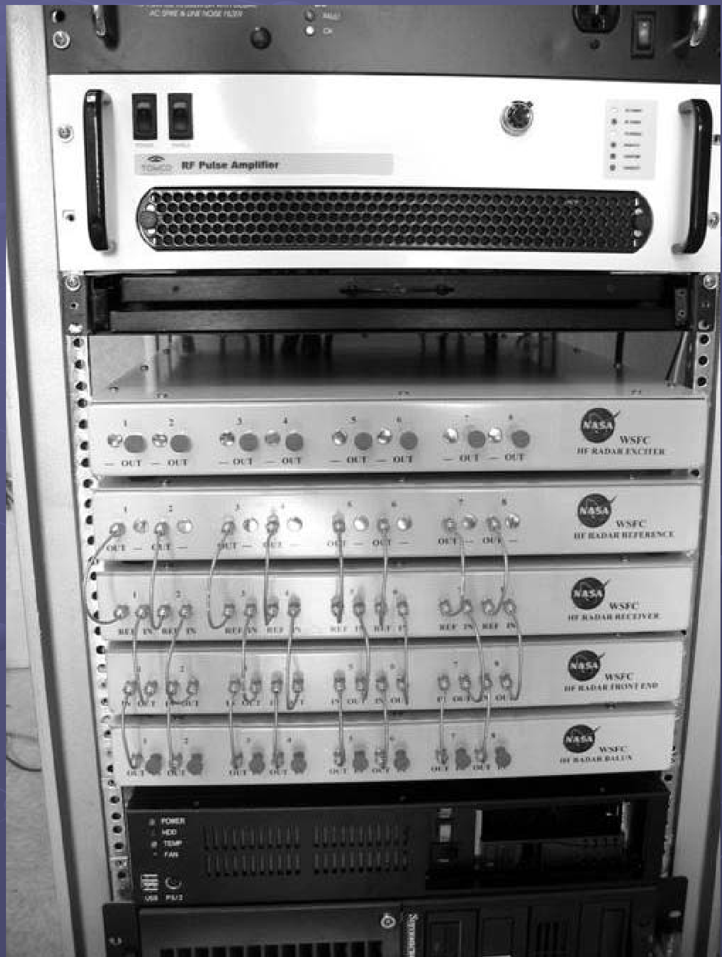
8 channel System Installation

High Power Amplifier –
Optionally 1,2 or 4 kW →

Transmitter Exciter →

ADC, DDC and Data →
Multiplexor

Receiving Antenna →
Preamplifier PSU and
Balun chassis.

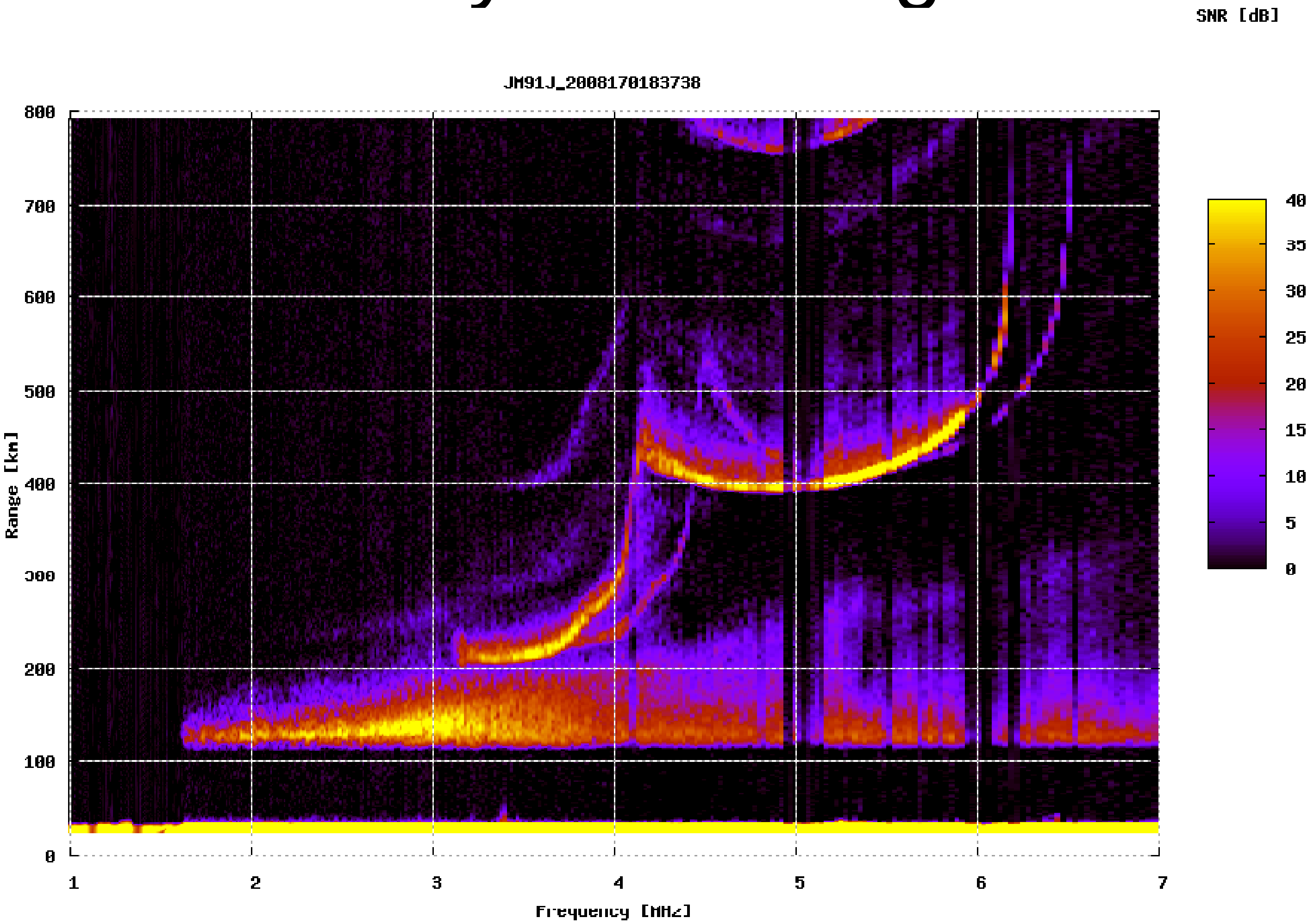


← Reference Oscillator
and GPS Timing

← Nyquist filters, Analog gain
and Attenuator control

← Control Computer, x86
2 GB RAM, 500 GB Disk

Example raw data – SNR Processing Jicamarca daytime – single channel.



Note: SNR > 40 dB, F2 Layer Irregularities,F1 Layer Dynamics, Slant-E, Electrojet

Acknowledgements

- My co-authors: Bob Livingston for all the detailed system design and construction, and Terry Bullett for obtaining the funding and guiding the program.
- Funding for the hardware and software development program was provided by the USAF SBIR Phase II Contract F19628-03-C-0019 awarded to Scion Associates and NASA Grant NNG04WF11I.
- The use of the DDC and DUC chip subsystems for this type of application was described in 2000 by N. C. Davies in IEE Conference Publication 474 pp249-256 “A high performance software radio”.

Then and Now!

9 Track Tape →

InterData 8/16
Minicomputer
1uS cycle time →
32 kB Core

Preprocessor and →
Radar Controller

10 MB Hard Disc →

1980

←10 kW Class AB Power Amplifier

2008

A new general purpose high performance HF Radar.

Thank You!

Questions?

An expanded version of the conference paper is available as a handout or a pdf file.

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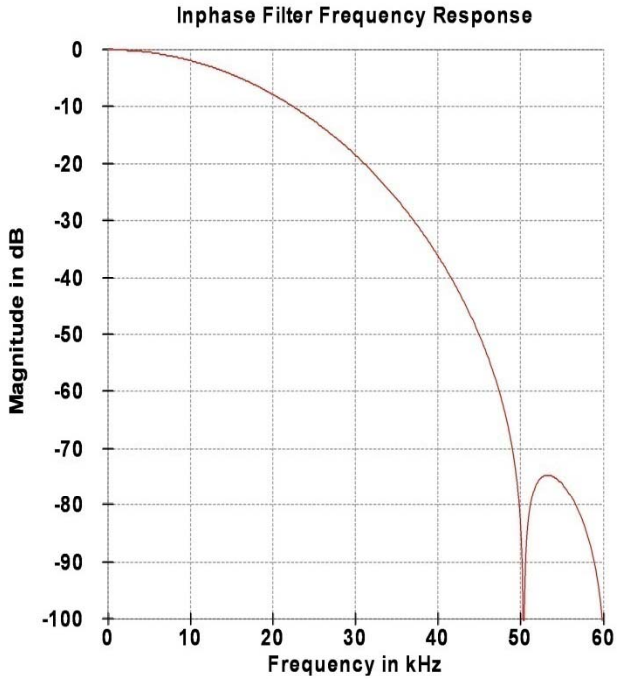

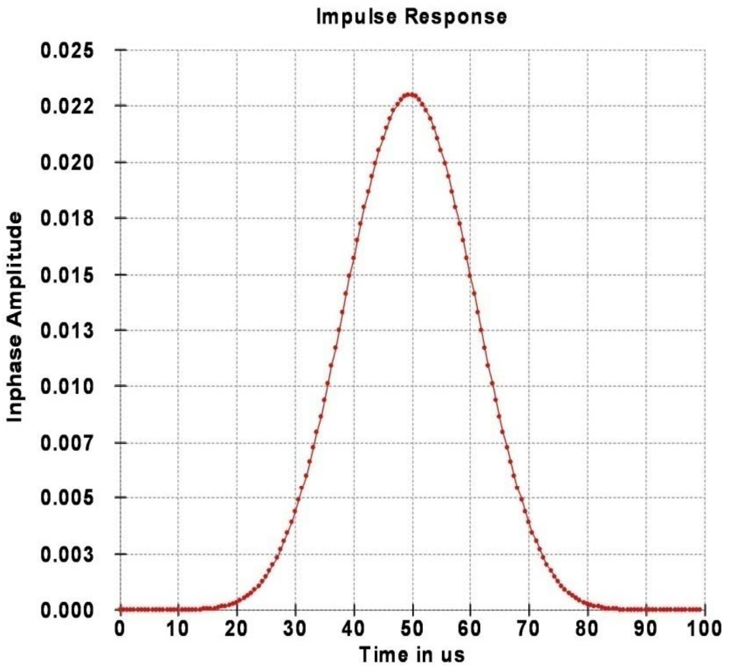

Typical Receiver band-pass and impulse response for vertical sounding. Raised Cosine ^4