HASI - PWA

Calibration Document

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CHANGE RECORD

Issue	Rev.	Date	Changed Para.	Remarks
Draft	0	25.11.2004	all	N/A
Draft	1	14.12.2004		

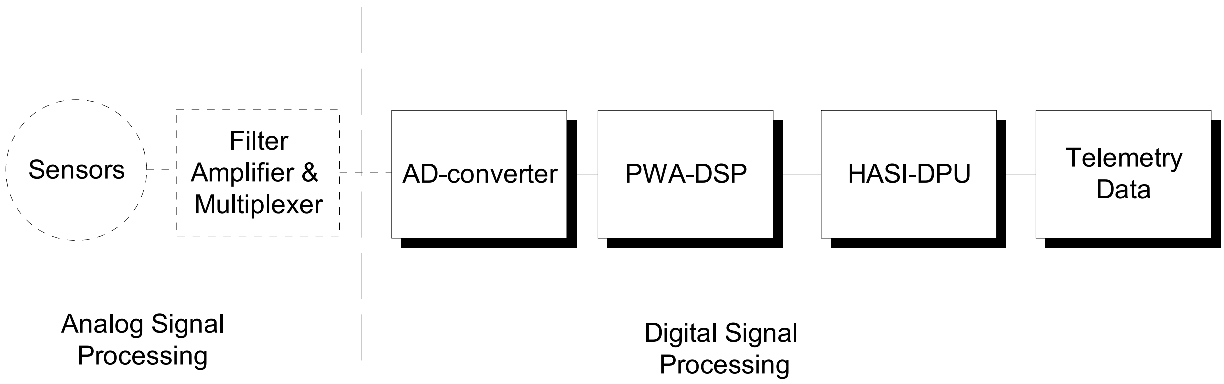
TABLE OF CONTENTS

1 Scope

This document is intended to describe details of the Digital Signal Processing of the PWA-instrument onboard the Huygens Probe and to describe the approach of analogue calibration and measurement timing.

The main scope is the definition of the individual steps performed by the software and description of the resulting numerical scaling of telemetry data. The fixed-point Digital Signal Processor (DSP) used for the calculations onboard the PWA-instrument inherits a need of number scaling for computations to optimize the numerical resolution of the computed results. Sometimes the computations may look disorientated, but each step has been optimized to reach best numerical resolution in the DSP.
For each measurement or experiment at least two sorts of equations are shown: the first equation gives the numerical computation of telemetry data for and particular input signal and the second inverse equation allows back-computation from telemetry data to input signals. The equations given in this document are absolutely true for **all existing PWA-models** and are independent of environmental influences.

The analog calibration values included in the document are valid for the flight model only, whereas the procedure of calibration stays the same for any model.
All these analog calibrations are implemented the m_pwa data processing tool,
Including calibrations for different PWA models as well.



The whole document is based on the document “HASI-PWA properties of digital signal processing”, Issue 2. Rev. 2, by Peter Falkner.

2 PWA Science Data Packets

For PWA Science Data, 5 different types of science data packets do exist:

Type 131: ACDC: contains Schumann, AC-Spectrum and Lightning measurements

Type 132: ACDCAU: contains Schumann, AC-Spectrum, Lightning, Acoustic Spectrum and Acoustic Burst measurements

Type 133: RAE: contains Radar Spectrum and Altitude measurements

Type 134: MI: contains Mutual Impedance measurements

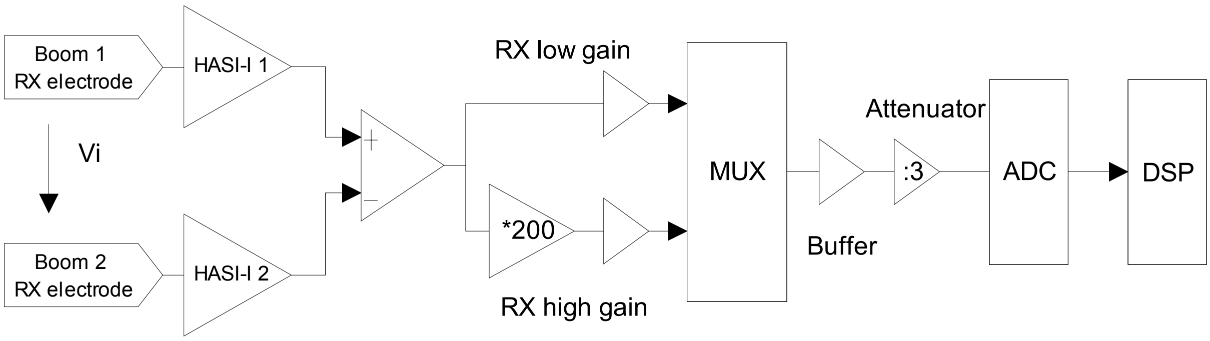
Type 135: RP: contains Relaxation Probe Measurements

For details refer to HASI-PWA-FM-DOC-016 (HASI-PWA Software Data Format Definition, Issue 2, Rev. 2)

3 AC/DC-Science Data Packet

The AC/DC Science Data Packet contains 3 different types of data: Schumann, AC spectrum and Lightning data.

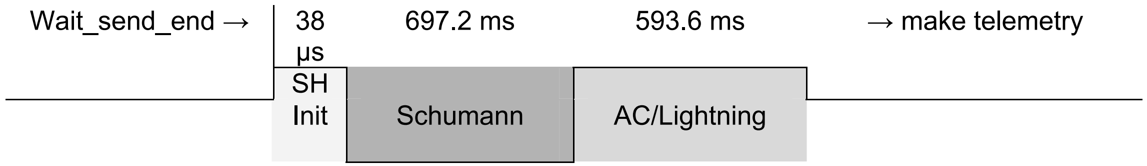
3.1 Block diagram for Schumann, AC Spectrum and Lightning measurement



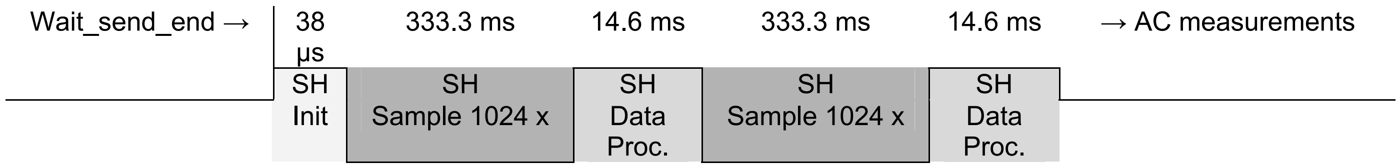
Sequence of measurements: 1) Schumann
2) AC (Spectrum + Lightning)

Timing of ACDC measurements:

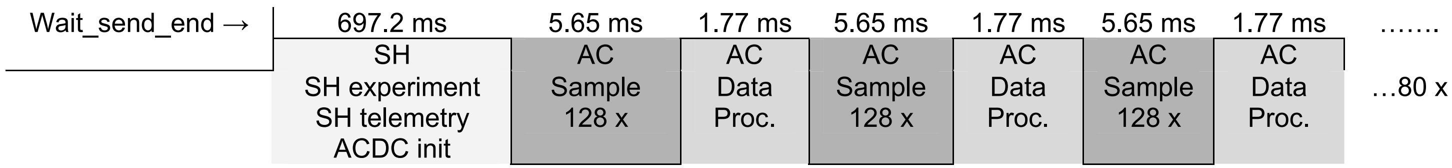
<u>Complete ACDC experiment:</u>



<u>Schumann:</u>



<u>AC:</u>



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3.2 Schumann Data (type 131)

Measurement principle:

- sample 2 x 1024 points with 3.072 kHz
- calculate 2 x 1024 point FFT -> calculate 2 power spectres
- calculate the average of the two power spectres
- logarithmic compression and offset
- transfer the first 32 lines (without DC line) of the averaged power spectrum to telemetry

3.2.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \cdot \frac{1}{15} = 3.072khz$		
Gain	Receiver High Gain only (+46 dB)		
Telemetry Data	32 Lines (Line1 - Line 32), format: 8.0 unsigned		
Spectral range	$\frac{f_{s\max}}{15} \cdot \frac{1}{1024}$ to $\frac{f_{s\max}}{15} \cdot \frac{33}{1024}$	3 Hz - 99 Hz	(.1)
Resolution	$\frac{f_{s\max}}{15} \cdot \frac{1}{1024}$	≈ 3 Hz per line	(.2)
Conversion to Decibel	$\frac{TM - 5.1198}{32} \cdot 20 = 20 \cdot \log_{10}(S)$		(.3)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM - 5.1198}{32}}$		(.4)
Conversion to ADC input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 5.1198}{32}}$		(.5)

Processing:

- 2 times {take 1024 samples → scale (1/4) → calculate 1024p-FFT → calculate power Spectrum}
- Sum of 2 power spectra
- Pre scale (divide by 2)
- Logarithmic compression + Offset Value (0x570)
- Result: 512 Spectral Lines (Line 0 - Line 511), only 32 are transferred

Numerical Scaling:

Sample input scaling	1 / 4	ASHIFT BY- 2
1024p-FFT	512	N / 2
power spec – pre scaling	2^{-8}	ASHIFT BY –8
multiply in ADSP2100	2	used for X^2
2-times integration	2	2 times sum
log – pre scale	2^{-1}	ASHIFT BY –1
conversion 32.0 to 16.16	2^{-16}	log input is in 16.16 format
log output 8.8 format + offset	log () + offset	offset = 0x570 = 1392 / 2^8 (converted in 8.8 format)
log post scale	2^{-4}	ASHIFT BY –4 (converted to 12.4 format)
transfer to 82C55 (lower byte)	2^8	only lower 8 bits are Transferred

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 512 \cdot 2^{-8})^2 \cdot 2 \cdot 2 \cdot 2^{-1} \cdot 2^{-16} \right] + 0x570 \cdot 2^{-8} \right.$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{1}{2^{17}} \right] + 87$$

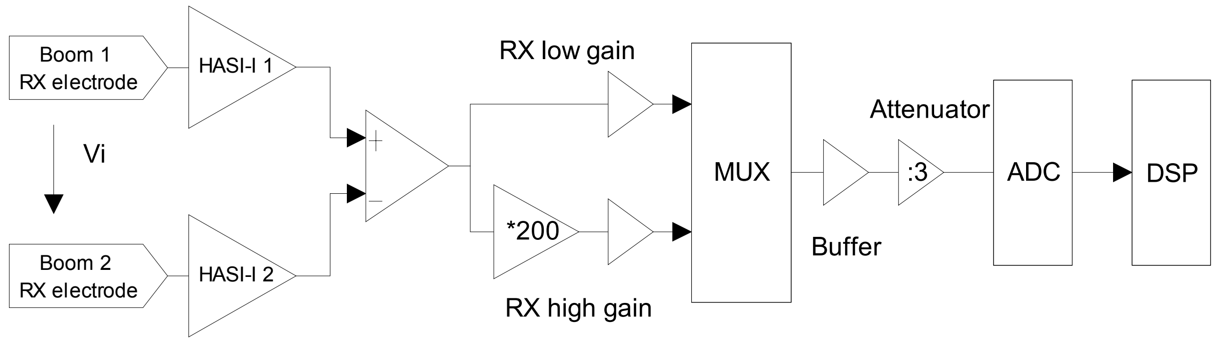
$$TM = 32 \cdot \log_{10}(S) + 5.11984118$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	5.1198	0x05	0x0001	137.3 µV_p	0 dB
max[1]	149.61	0x95	0x7FFF	4.5 V_p	90 dB

[1] This maximum number is referred to pure sine wave amplitudes. With other signals the resulting amplitude (after FFT) may be higher than the given max. value!

3.2.2 Analogue Calibration of Schumann data (type 131)



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator) for receiver high gain only (as there is **no receiver low gain Schumann measurement**)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

Calibration process :

- Calculate average value from boom1 and boom2 transfer functions for receiver high gain (RXH)
- Calculate gain on the Schumann (type 131) data frequency bins by interpolation (3-99 Hz with 3 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **sh131rxh.cal** (see attachment)

3.2.3 Analogue + Digital Calibration of Schumann data (type 131) within m-pwa software:

- Calculate amplitudes at all Schumann frequency bins at the ADC-input out of Schumann telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 5.1198}{32}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (SH131rxh.cal for RX high gain)

for RXH: $s_{rxh} = s_{ADC}$ - sh131rxh.cal

Result: voltage measured at the RX electrodes in dBV_{peak} versus frequency
(dB relative to 1 V_{peak} versus frequency in Hz)

3.3 Integrated AC-Spectrum (type 131)

Measurement principle:

- sample 80 x 128 points with 23.04 kHz

(attention:7.4 ms from start sampling 128 points to start sampling next 128 points ->1.777ms gaps)

- calculate 80 x 128 point FFT -> calculate 80 power spectras
- calculate the average of the 80 power spectras
- logarithmic compression and offset
- transfer all 64 lines of the averaged power spectrum to telemetry

3.3.1 <u>Digital Data Processing:</u>

Sampling frequency	$fs_{\max} \cdot \frac{1}{2} \approx 23.04khz$		(.7)
Telemetry Data	64 Lines (Line0 - Line 63), 8.0 unsigned		
Spectral range	DC to $\frac{f_{s\max}}{2} \cdot \frac{64}{128}$	0 Hz - 11.520 kHz	(.8)
Resolution	$\frac{f_{s\max}}{2} \cdot \frac{1}{128}$	≈ 180 Hz per line	(.9)
Conversion to Decibel	$\frac{TM - 7.581}{32} \cdot 20 = 20 \cdot \log_{10}(S)$		(.10)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM - 7.581}{32}}$		(.11)
Conversion to ADC input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 7.581}{32}}$		(.12)

Processing

- {Take 128 samples → apply Hamming window → scale by 1/4→ calculate 128p FFT → calculate power spectra} Repeat 80 times
- Integrate 80 power spectra's
- Scale by 1/16
- Logarithm ( ) + offset value
- Result: 64 spectral lines (line 0 - line 63)

Hamming Window

The samples are weighted with a Hamming window. This is done to reduce the so-called picked fence effect or spectral leakage. But the window (like every window) has an effect on the resulting amplitude, where the ratio of the "real" (= applied signal) amplitude to the estimated amplitude depends on frequency, but is roughly 1.88 : 1 for a pure sine wave, on channel[2].
To demonstrate the effect: if you apply a sine wave signal with amplitude equal 1.0 the Hamming weighted FFT will give an amplitude of 1/1.88 = 0.53.
If the signal is off-channel[3], the amplitude is spread on separate frequency bins, where the ratio of amplitudes depends on the location of the signal frequency in respect to FFT-frequency bins.
To demonstrate the effect: if you apply a sine wave signal with amplitude equal 1.0 and a frequency exact between two frequency bins, the Hamming weighted FFT will give two amplitude of roughly 0.28 on the frequency bins left and right of the actual frequency.
In the following paragraph "Numerical Scaling" the reduction of sine wave on-channel signals is taken into account and equations **Error! Reference source not found.** and **Error! Reference source not found.** are compensated for on-channel signals. Off-channel signals will show levels, which are around 1.7 dB smaller.

[2] On channel means commensurate or N-periods of the signal is equal window length (where N is a integer number)
[3] Off-channel means non-commensurate or N-periods of the signal are not equal window length (where N is a integer number).

Numerical Scaling

software	scaling	computation	format
Hamming window multiply	1	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Amplitude reduction due to Hamming[4]	0.533		
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
FFT	64	N / 2	16.0
power spec – pre scaling	2^{-5}	ASHIFT BY –5	11.5
multiply in ADSP2100	2	used for X^2	
80-times integration	80	80 times sum	
log – pre scale	2^{-4}	ASHIFT BY –4	
conversion 32.0 to 16.16	2^{-16}	log input is 16.16 format	16.16
log output 8.8 format + offset	log()+offse t	offset = 0x570 = 1392 / 2^8 (converted in 8.8 format)	8.8
log post scale	2^{-4}	ASHIFT BY –4 (converted to 12.4 format)	4.4
transfer to 82C55 (lower byte)	2^8	only lower 8 bits are Transferred	8.0 unsigned

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 0{,}533 \cdot 64 \cdot 2^{-5})^2 \cdot 2 \cdot 80 \cdot 2^{-4} \cdot 2^{-16} \right] + 0x57 \right.$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{1.425}{2^{17}} \right] + 87$$

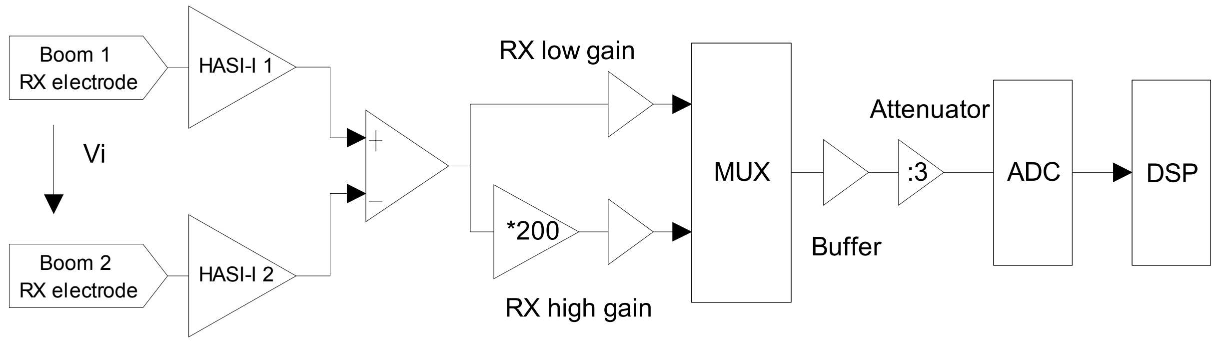
$$TM = 32 \cdot \log_{10}(S) + 7.581$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	7.581	0x07	0x0001	137.3 μV_p	0 dB
max[5]	152.07	0x98	0x7FFF	4.5 V_p	90 dB

[4] See discussion “Hamming window”, two paragraphs above.
[5] This maximum number is referred to pure sine wave amplitudes. Other signals may give higher values (after FFT)!

3.3.2 Analogue Calibration of integrated AC spectrum (type 131):



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXL.ada
BOOM2RXL.ada
BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

Calibration process :

- Calculate average value from boom1 and boom2 transfer functions for receiver low gain (RXL) and receiver high gain (RXH)

- Calculate gain on the AC field (type 131) data frequency bins by interpolation (0Hz – 11.52 kHz with 180 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **ac131rxl.cal**
ac131rxh.cal
(see attachment)

3.3.3 Analogue + Digital Calibration of integrated AC spectrum data (type 131) within m-pwa software:

- Calculate amplitudes at all AC frequency bins at the ADC-input out of AC/DC telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-5.1198}{32}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (ac131rxl.cal for RX low gain, ac131rxh.cal for RX high gain)

for RXL: $s_{rxl} = s_{ADC}$ - ac131rxl.cal
for RXH: $s_{rxh} = s_{ADC}$ - ac131rxh.cal

Result: voltage measured at the RX electrodes in dBV_{peak} versus frequency
(amplitude in dB relative to 1 V_{peak} versus frequency in Hz)

3.4 Lightning = AC Burst (type 131)

Measurement principle:

- take the 80 power spectras calculated during 3.4 (AC spectrum type131)
  (80 x 128p FFT, sampling frequency =23.04 kHz)

- within every single spectrum sum up lines to get mean power values for 3 frequency ranges:

  f1 = Σ(Line 1 to Line 16)/16 (without DC line!) (sum of 16 lines)
  f2 = Σ(Line 17 to Line 32)/16 (sum of 16 lines)
  f3 = Σ(Line 33 to Line 63)/32 (sum of 31 lines)

- logarithmic compression and offset

- transfer power of 80 x 3 spectral ranges to telemetry

3.4.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \cdot \frac{1}{2} \approx 23.04khz$		(.14)
Telemetry Data	80 x 3 Spectral Ranges		
Ranges	f1: $\frac{fs_{\max}}{2} \cdot \frac{1}{128}$ to $\frac{fs_{\max}}{2} \cdot \frac{17}{128}$	180Hz - 3.06 kHz	(.15)
	f2: $\frac{fs_{\max}}{2} \cdot \frac{17}{128}$ to $\frac{fs_{\max}}{2} \cdot \frac{33}{128}$	3.06 kHz - 5.94 kHz	(.16)
	f3: $\frac{fs_{\max}}{2} \cdot \frac{33}{128}$ to $\frac{fs_{\max}}{2} \cdot \frac{64}{128}$	5.94 kHz - 11.52 kHz	(.17)
Conversion to dB	$TM \cdot 6 = 20 \cdot \log_{10}(S)$		(.18)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM*6}{20}}$		(.19)
Conversion to ADC input signal	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$		(.20)

Processing

{take 128 samples → apply Hamming window → scale by 1/4 → calculate 128p FFT → calculate power spectra}[6]
gives 64 spectral lines (line0 - line63)
f1=Σ(line1 to line16)/16 (Sum of 16 Lines)
f2=Σ(line17 to line32)/16 (Sum of 16 Lines)
f3=Σ(line33 to line63)/32 (Sum of 31 Lines)
Logarithmic compression + Offset Value (0xd80) }
- REPEAT 80 times
- Result: 80 x 3 Spectral Ranges (f1(t0),f2(t0),f3(t0),....,f1(t79),f2(t79),f3(t79))

Numerical Scaling

software	scaling	computation	format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
FFT	64	N / 2	16.0
power spec – pre scaling	2-5	ASHIFT BY –5	11.5
multiply in ADSP2100	2	used for X2	32.0
Scaling	2-4	LSHIFT BY-4	32.0 or 33.0
extra scaling for 32 lines	0 , 2-1	ASHIFT BY –1 (only for 32 lines)	32.0
conversion 32.0 to 16.16	2-16	log input is 16.16 format	
log output 8.8 format + offset	log()+offset	offset = 0xD80 = 3456 / 28 (converted in 8.8 format)	8.8
log post scale	2	ASHIFT BY –7	8.8 → 15.1
mask lower 4 bit		AND 0x0F	3.1

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 64 \cdot 0.533 \cdot 2^{-5})^2 \cdot 2 \cdot 2^{-4} \cdot 2^{-16} \right] + (\right.$$

$$TM = 2 \cdot \log_{10}\left[S^2 \cdot \frac{0.284}{2^{21}} \right] + 27$$

$$TM = 4 \cdot \log_{10}(S) + 13.26$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex) Theoretically	TM (hex) practically[7]	DSP input (hex)	ADC-input (V)	dB
min	13.26	0x0D	0x**10**	0x0001	137.3 μV_p	0 dB
max[8]	31.32	0x**1**F	0x**1**F	0x7FFF	4.5 V_p	90 dB

[6] This calculation is done already during AC-Spectra processing!
[7] see note 1
[8] This maximum number is referred to pure sine wave amplitudes. Other signals may give

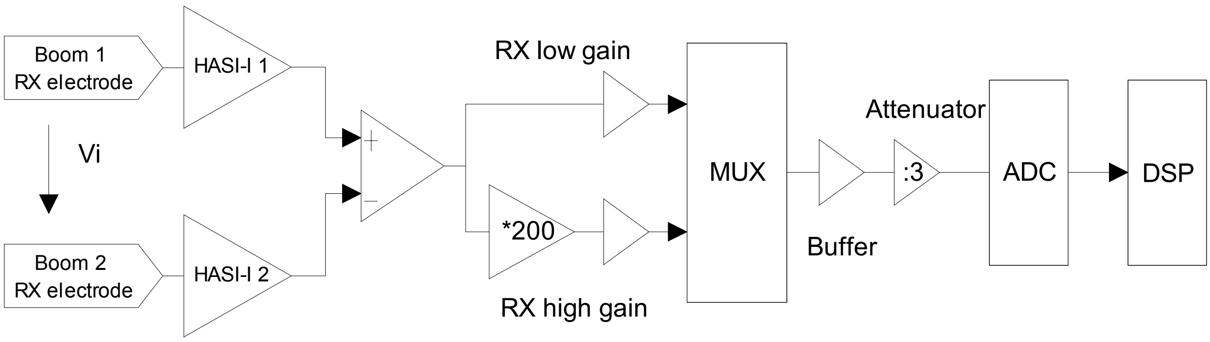
note1: The limited resolution of the fixed point DSP adds some small amount of noise to the results, which gives after integration of 16 or 32 lines considerable increase of the numbers given in the table above. The effort to make an analytical calculation of this effect is considered to be to high, hence a simulation using the DSP-simulator was done to verify the calculation performed in the "real" DSP. The results of the simulation are given in the following table.
note2: The second digit is always 1 (for all values between min and max) and therefore not transmitted in the telemetry data (like a "hidden 1"). But it has to be taken into account!

Results from runs with ADSP simulator:

DSP Input (hex)	TM (hex)	dB
0000	0x00	0 dB
0004	0x01	6 dB
000C	0x02	12 dB
0400	0x09	36 dB
4000	0x0E	84 dB
6000	0x0E	84 dB
1E00	0x0F	90 dB
7FFF	0x0F	90 dB

higher values (after FFT)!
A square wave signal with an amplitude greater than 0x730C gives a result of 0x20 in the telemetry. Due to the masking with 0x0F it can not be distinguished from 0x00 !

3.4.2 Analogue Calibration of Lightning data (type 131):



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXL.ada
BOOM2RXL.ada
BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

- Timing measurements performed with a PWA-D and PWA-A bread board model

Calibration process:

- Take files ac131rxl.cal and ac131rxh.cal (see 3.3.2)

- Calculate average gain for the 3 Lightning frequency ranges out of ac131rxl.cal and ac131rxh.cal

- Results **li131rxl.cal**
li131rxh.cal
(see attachment)

- timing: distance of lightning measurements = 7.432 ms (7.4 ms taken for calibration)
Result: **li131_ti.cal** (see attachment)

3.4.3 Analogue + Digital Calibration of Lightning data (type 131) within m-pwa software:

- Calculate amplitudes for all 3 Lightning frequency ranges at the ADC-input out of Lightning telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$$ …………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (li131rxl.cal for RX low gain, li131rxh.cal for RX high gain)

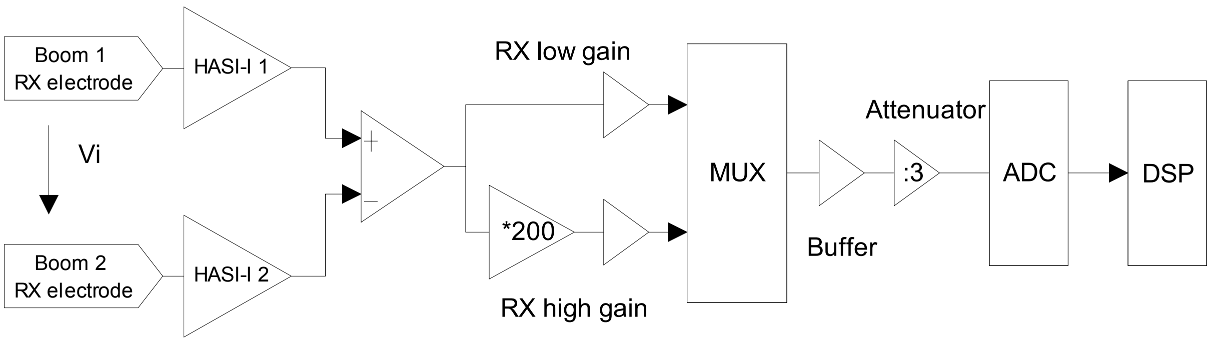
for RXL: $s_{rxl} = s_{ADC}$ - li131rxl.cal
for RXH: $s_{rxh} = s_{ADC}$ - li131rxh.cal

Result: mean voltage measured for the lightning (type 131) frequency ranges at the RX electrodes in dBV_{peak} versus time (amplitude in dB relative to 1 V_{peak} versus time in seconds)

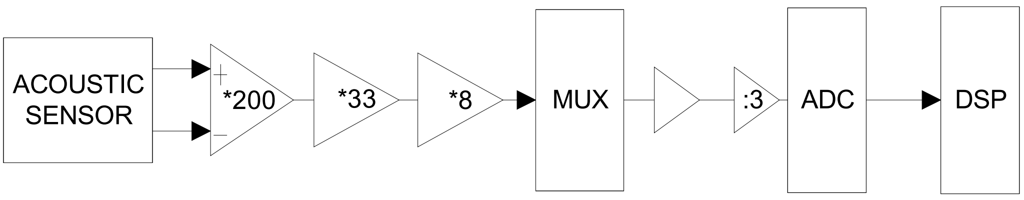
4 AC/DC/AU-Science Data Packet

The AC/DC/AU Science Data Packet contains 5 different types of data:
Schumann spectrum, AC spectrum, Lightning (AC burst) data,
Acoustic spectrum and Acoustic burst data.

4.1 Block diagram for Schumann, AC Spectrum and Lightning measurement



4.2 Block diagram for ACU measurement

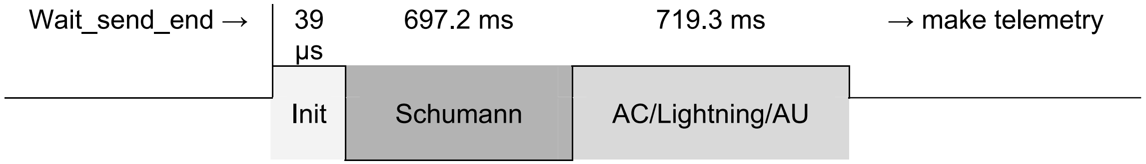


4.3 Sequence and timing of ACDCAU measurements

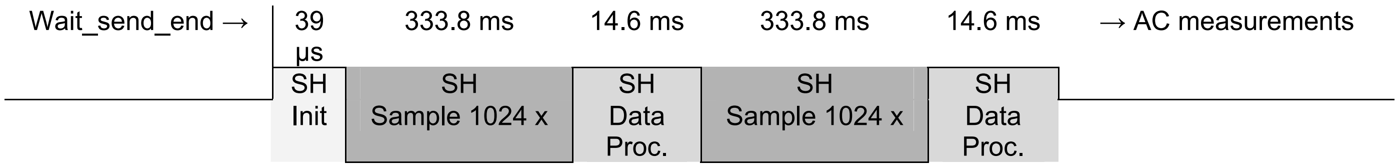
Sequence of measurements: 1) Schumann
2) AC (Spectrum + Lightning) + AU (Spectrum + Burst)

Timing of ACDCAU measurements:

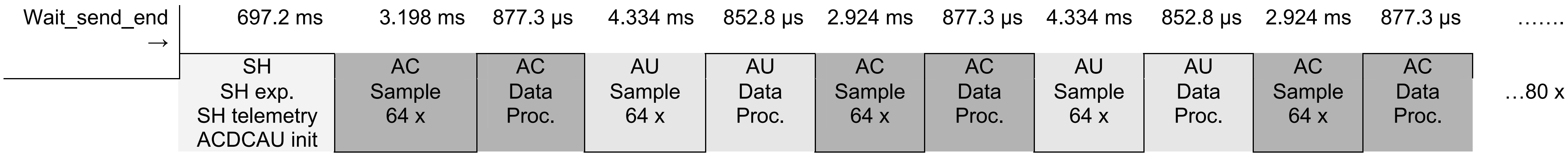
Complete ACDCAU experiment:



Schumann:



ACAU:



Note 1: the first AC sampling was measured to take 3.198 ms, all others 2.924 ms
Note 2: AC data processing takes 1.055 ms for full scale inputs (FFT processing takes longer for higher input signals)

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4.4 Schumann Data (type 132)

Measurement principle:

- sample 2 x 1024 points with 3.072 kHz
- calculate 2 x 1024 point FFT -> calculate 2 power spectras
- calculate the average of the two power spectras
- add always 2 lines together (skip DC line, L1 = L1+L2, L2= L3+L4,….L16=L31+L32)
- logarithmic compression and offset
- transfer the resulting 16 lines to telemetry (-> frequency resolution only 6 Hz)

4.4.1 Digital Data Processing:

Sampling frequency	$\frac{fs_{\max}}{15} \approx 3.072 khz$	(.22)
Gain	Receiver High Gain only (+46 dB)	
Telemetry Data	16 Lines (Line 0 - Line 15), 8.0 unsigned	
Spectral range	$\frac{f_{s\max}}{15} \cdot \frac{1}{1024}$ to $\frac{f_{s\max}}{15} \cdot \frac{33}{1024}$ (3 Hz - 99 Hz)	(.23)
Resolution	$\frac{f_{s\max}}{15} \cdot \frac{1}{512} \approx 6Hz$ per Line	(.24)
Conversion to Decibel	$\frac{TM - 5.1198}{32} \cdot 20 = 20 \cdot \log_{10}(S)$	(.25)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM - 5.1198}{32}}$	(.26)
Conversion to ADC-input signal	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 5.1198}{32}}$	(.27)

Processing

The processing of Schumann Data in AC/DC/AU-data packets is the same as for AC/DC-data packets, except that the frequency resolution is reduced by a factor of 2. Adding two and two spectra lines together does this.

- 2 times {take 1024 samples → scale (1/4) → calculate 1024p-FFT → calculate power Spectrum}
- Sum of 2 power spectra
- Pre scale (divide by 2)
- Result: 512 Spectral Lines (Line 0 - Line 511)
- Add 2 Lines together (Skip L0; Line1=L1+L2, Line2=L3+L4, Line3=L5+L6,...; Line16=L31+L32)
- Logarithm( ) + Offset Value (0x570)
- Result: 16 Spectral Lines (Line 0 - Line 15)

Numerical Scaling

software	scaling	computation
Sample input scaling	1 / 4	ASHIFT BY- 2
1024p-FFT	512	N / 2
power spec – pre scaling	2^{-8}	ASHIFT BY –8
multiply in ADSP2100	2	used for X^2
2-times integration	2	2 times sum
log – pre scale	2^{-1}	ASHIFT BY –1
conversion 32.0 to 16.16	2^{-16}	log input is in 16.16 format
log output 8.8 format + offset	log () + offset	offset = 0x570 = 1392 / 2^8 (converted in 8.8 format)
log post scale	2^{-4}	ASHIFT BY –4 (converted to 12.4 format)
transfer to 82C55 (lower byte)	2^8	only lower 8 bits are Transferred

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 512 \cdot 2^{-8})^2 \cdot 2 \cdot 2 \cdot 2^{-1} \cdot 2^{-16} \right] + 0x570 \cdot 2^{-8} \right.$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{1}{2^{17}} \right] + 87$$

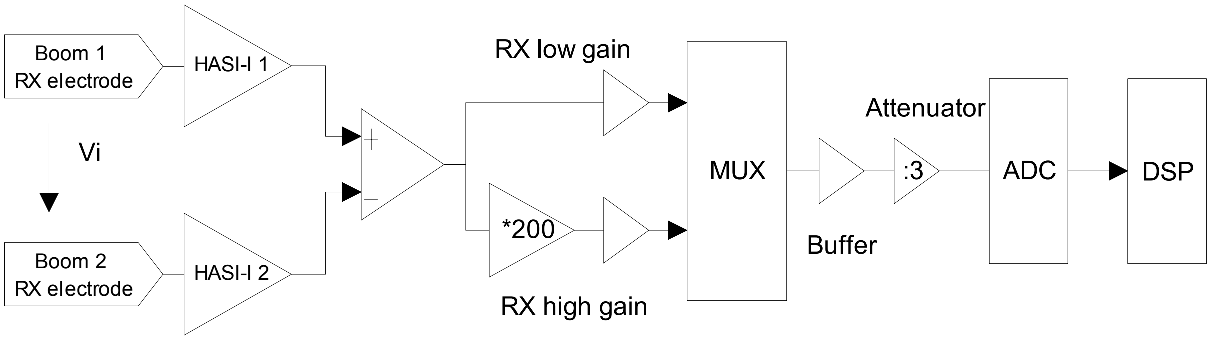
$$TM = 32 \cdot \log_{10}(S) + 5.11984118$$

TM … value transferred in telemetry; S … Input sample (range: ±1 to $\pm 2^{15}$)

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	5.1198	0x05	0x0001	137.3 μV_p	0 dB
max[1]	149.61	0x95	0x7FFF	4.5 V_p	90 dB

[1] This maximum number is referred to pure sine wave amplitudes. The resulting amplitude (after FFT) may be higher wit other signals.

4.4.2 Analogue Calibration of Schumann data (type 132)



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator) for receiver high gain only (as there is **no receiver low gain Schumann measurement**)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

Calibration process :

- Calculate average value from boom1 and boom2 transfer functions for receiver high gain (RXH)
- Calculate gain on the Schumann (type 132) data frequency bins by interpolation (3-99 Hz with 6 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **sh132rxh.cal** (see attachment)

4.4.3 Analogue + Digital Calibration of Schumann data (type 132) within m-pwa software:

- Calculate amplitudes at all Schumann frequency bins at the ADC-input out of Schumann telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 5.1198}{32}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (SH132rxh.cal for RX high gain)

for RXH: $s_{rxh} = s_{ADC}$ - sh132rxh.cal

Result: voltage measured at the RX electrodes in dBV_{peak} versus frequency
(dB relative to 1 V_{peak} versus frequency in Hz)

4.5 Integrated AC-Spectrum (type 132)

Measurement principle:

- sample 80 x 64 points with 23.04 kHz
(attention: 9 ms from start sampling 128 points to start sampling next 128 points -> 6 ms gaps)
- calculate 80 x 64 point FFT -> calculate 80 power spectras
- calculate the average of the 80 power spectras
- logarithmic compression and offset
- transfer all 32 lines of the averaged power spectrum to telemetry

4.5.1 Digital Data Processing:

Sampling frequency	$\frac{fs_{\max}}{2} \approx 23khz$		(.29)
Telemetry Data	28 Lines (Line1 - Line 28), 8.0 unsigned		
Spectral range	$\frac{f_{s\max}}{2} \cdot \frac{1}{64}$ to $\frac{f_{s\max}}{2} \cdot \frac{29}{64}$	360 Hz - 10.44 kHz	(.30)
Resolution	$\frac{f_{s\max}}{2} \cdot \frac{1}{64}$	≈ 360 Hz per Line	(.31)
Conversion to Decibel	$\frac{TM - 7.5}{32} \cdot 20 = 20 \cdot \log_{10}(S)$		(.32)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM-7.5}{32}}$		(.33)
Conversion to ADC-input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-7.5}{32}}$		(.34)

Processing

- 64 samples -> divide by 4 -> Hamming Wind. -> calculate 64p-FFT -> calculate power spectra
- Sum of 80 power spectra
- Pre scale (divide by 16)
- Logarithm( ) + Offset Value (0x570)
- Result: 32 Spectral Lines (Line 0 - Line 31)

Numerical Scaling

Software	Scaling	Computation	Format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
64p-FFT	32	N / 2	16.0
power spec – pre scaling	2^{-4}	ASHIFT BY –4	15.4
multiply in ADSP2100	2	used for X^2	
80-times integration	80	80 times sum	
log – pre scale	2^{-4}	ASHIFT BY –4	
conversion 32.0 to 16.16	2^{-16}	log input is 16.16 format	16.16
log output 8.8 format + offset	log()+offset	offset = 0x570 = 1392 / 2^8 (converted in 8.8 format)	8.8
log post scale	2^{-4}	ASHIFT BY –4 (converted to 12.4 format)	4.4
transfer to 82C55 (lower byte)	2^8	only lower 8 bits are transferred	8.0 unsigned

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 0{,}533 \cdot 32 \cdot 2^{-4})^2 \cdot 2 \cdot 80 \cdot 2^{-4} \cdot 2^{-16} \right] + 0x570 \cdot 2 \right.$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{1.425}{2^{17}} \right] + 87$$

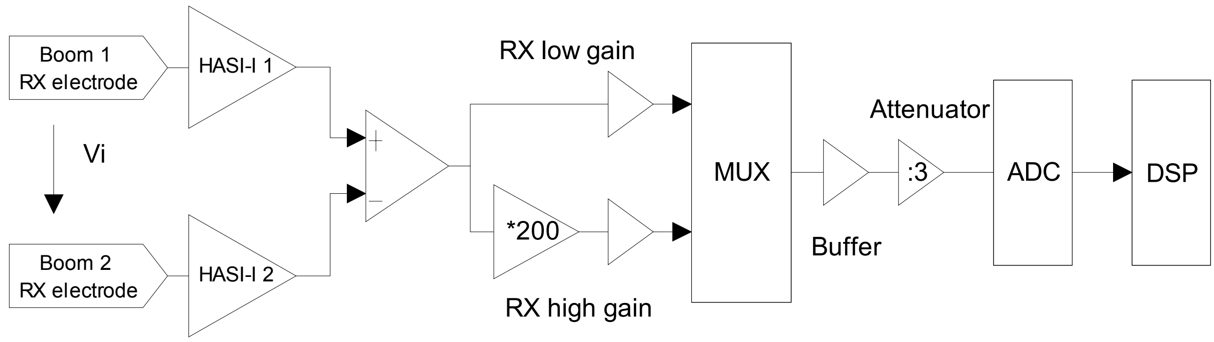
$$TM = 32 \cdot \log_{10}(S) + 7.5$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	7.5	0x07	0x0001	137.3 µV_p	0 dB
max[2]	152.07	0x98	0x7FFF	4.5 V_p	90 dB

[2] This maximum number is referred to pure sine wave amplitudes. Other signals may give higher values (after FFT)!

4.5.2 Analogue Calibration of integrated AC spectrum (type 132):



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXL.ada
BOOM2RXL.ada
BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

Calibration process :

- Calculate average value from boom1 and boom2 transfer functions for receiver low gain (RXL) and receiver high gain (RXH)

- Calculate gain on the AC field (type 132) data frequency bins by interpolation (360Hz – 10.44 kHz with 360 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **ac132rxl.cal**
ac132rxh.cal
(see attachment)

4.5.3 Analogue + Digital Calibration of integrated AC spectrum data (type 132) within m-pwa software:

- Calculate amplitudes at all AC frequency bins at the ADC-input out of AC/DC telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM - 5.1198}{32}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (ac132rxl.cal for RX low gain, ac132rxh.cal for RX high gain)

for RXL: $s_{rxl} = s_{ADC}$ - ac132rxl.cal
for RXH: $s_{rxh} = s_{ADC}$ - ac132rxh.cal

Result: voltage measured at the RX electrodes in dBV_{peak} versus frequency (amplitude in dB relative to 1 V_{peak} versus frequency in Hz)

4.6 Lightning = AC Burst (type 132)

Measurement principle:

- take the 80 power spectras calculated during 4.5 (AC spectrum type132)
  (80 x 64p FFT, sampling frequency =23.04 kHz)
- within every single spectrum sum up lines to get mean power values for 3 frequency ranges:
  f1 = Σ(Line 1 to Line 16)/16 (without DC line!) (sum of 16 lines)
  f2 = Σ(Line 17 to Line 32)/16 (sum of 16 lines)
  f3 = Σ(Line 33 to Line 63)/32 (sum of 31 lines)

- logarithmic compression and offset
- transfer power of 80 x 3 spectral ranges to telemetry

4.6.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \cdot \frac{1}{2} \approx 23.04khz$		(.36)
Ranges	f1: $\frac{f_{s\max}}{2} \cdot \frac{1}{64}$ to $\frac{f_{s\max}}{2} \cdot \frac{9}{64}$	360Hz - 3.24 kHz	(.37)
	f2: $\frac{f_{s\max}}{2} \cdot \frac{9}{64}$ to $\frac{f_{s\max}}{2} \cdot \frac{17}{64}$	3.24kHz - 6.12 kHz	(.38)
	f3: $\frac{f_{s\max}}{2} \cdot \frac{17}{64}$ to $\frac{f_{s\max}}{2} \cdot \frac{32}{64}$	6.12 kHz - 11.52 kHz	(.39)
Telemetry Data	80 x 3 Spectral Ranges		
Conversion to dB	$TM \cdot 6 = 20 \cdot \log_{10}(S)$		(.40)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM*6}{20}}$		(.41)
Conversion to ADC input signal	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$		(.42)

Processing

- [take 64 samples -> scale (divide by 4) -> apply Hamming Window -> 64p FFT -> Power Spectrum
- gives 32 Spectral Lines (L0 - L31)
- f1=Σ(L1 to L8)/8 Sum of 8 Lines
  f2=Σ(L9 to L16)/8 Sum of 8 Lines
  f3=Σ(L17 to L31)/16 Sum of 15 Lines
- Logarithm( ) + Offset Value (0xd80)] **Repeat 80 times**
- Result: 80 x 3 Spectral Ranges (f1(t0), f2(t0), f3(t0), ..., f1(t79), f2(t79), f3(t79))

Numerical Scaling

software	scaling	computation	format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
64p-FFT	32	N / 2	16.0
Power spec – pre scaling	2-4	ASHIFT BY –4	12.4
Multiply in ADSP2100	2	used for X2	32.0
Scaling	2-3	LSHIFT BY-3	32.0 or 33.0
Extra scaling for 32 lines	0 , 2-1	ASHIFT BY –1 (only for 32 lines)	32.0
Conversion 32.0 to 16.16	2-16	log input is 16.16 format	
Log output 8.8 format + offset	log()+offset	offset = 0xD80 = 3456 / 28 (converted in 8.8 format)	8.8
Log post scale	2	ASHIFT BY –7	8.8 → 15.1
Mask lower 4 bit		AND 0x0F	3.1

$$TM = \left\{ \log_{10} \left[(S \cdot \frac{1}{4} \cdot 32 \cdot 0.533 \cdot 2^{-4})^2 \cdot 2 \cdot 2^{-3} \cdot 2^{-16} \right] + (\right.$$

$$TM = 2 \cdot \log_{10} \left[S^2 \cdot \frac{0.284}{2^{20}} \right] + 27$$

$$TM = 4 \cdot \log_{10}(S) + 13.86$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex) Theoretically	TM (hex) practically[3]	DSP input (hex)	ADC-input (V)	dB
min	13.86	0x0D	0x**10**	0x0001	137.3 μV_p	0 dB
max[4]	31.32	0x**1**F	0x**1**F	0x7FFF	4.5 V_p	90 dB

Note1: The limited resolution of the fixed point DSP adds some small amount of noise to the results, which gives after integration of 16 or 32 lines considerable increase of the numbers given in the table above. The effort to make an analytical calculation of this effect is considered to be to high, hence a simulation using the DSP-simulator was done to verify the calculation performed in the "real" DSP. The results of the simulation are given in the following table.
Note2: The second digit is always 1 (for all values between min and max) and therefore not transmitted in the telemetry data (like a "hidden 1"). But it has to be taken into account!

---

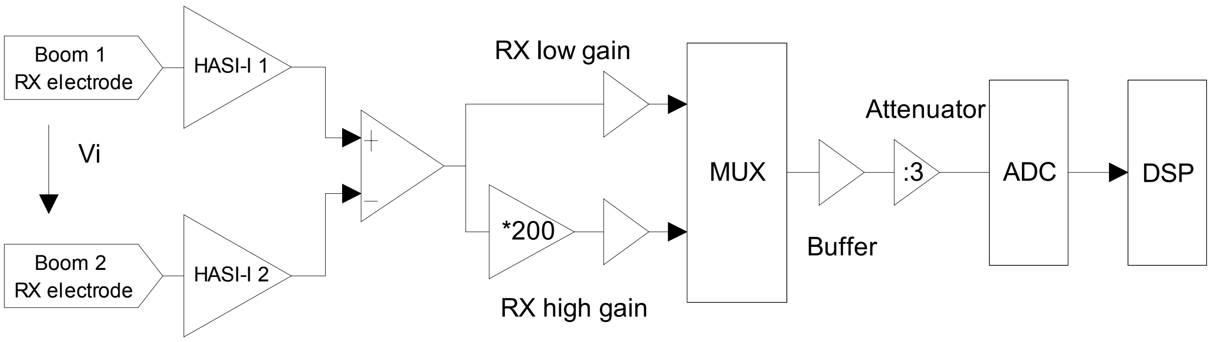
[3] see note 1
[4] This maximum number is referred to pure sine wave amplitudes. Other signals may give higher values (after FFT)!
A square wave signal with an amplitude greater than 0x730C gives a result of 0x20 in the telemetry. Due to the masking with 0x0F it can not be destinguished from 0x00 !

Results from runs with ADSP simulator:

DSP Input (hex)	TM (hex)	dB
0000	0x00	0 dB
0004	0x01	6 dB
000C	0x02	12 dB
001C	0x03	18 dB
0400	0x0A	60 dB
4000	0x0E	84 dB
6000	0x0F	90 dB
7800	0x0F	90 dB
7C00	*0x11*	*6 dB*
7FFF	*0x20*	*0 dB*

Note: the last two lines in the previous table give wrong results. This is due to the fact that full scale input signals lead to a wrap around in the data result. That means, that signals with very high amplitude can not be distinguished from signals with very low amplitudes!

4.6.2 Analogue Calibration of Lightning data (type 132):



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXL.ada
BOOM2RXL.ada
BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

- Timing measurements performed with a PWA-D and PWA-A bread board model

Calibration process:

- Take files ac132rxl.cal and ac132rxh.cal (see 4.5.2)

- Calculate average gain for the 3 Lightning frequency ranges out of ac132rxl.cal and ac132rxh.cal

- Results **li132rxl.cal**
li132rxh.cal
(see attachment)

- timing: distance of lightning measurements = 8.9881 ms (9.0 ms taken for calibration)
Result: **li132_ti.cal** (see attachment)

4.6.3 Analogue + Digital Calibration of Lightning data (type 132) within m-pwa software:

- Calculate amplitudes for all 3 Lightning frequency ranges at the ADC-input out of Lightning telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$$ …………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (li132rxl.cal for RX low gain, li132rxh.cal for RX high gain)

for RXL: $s_{rxl} = s_{ADC}$ - li132rxl.cal
for RXH: $s_{rxh} = s_{ADC}$ - li132rxh.cal

Result: mean voltage measured for the lightning (type 132) frequency ranges at the RX electrodes in dBV_{peak} versus time (amplitude in dB relative to 1 V_{peak} versus time in seconds)

4.7 Acoustic spectrum

Measurement principle:

- sample 80 x 64 points with 15.36 kHz

(attention: 9 ms from start sample 128 points to start sample next 128 points -> 6 ms gaps)

- calculate 80 x 64 point FFT -> calculate 80 power spectras
- calculate the average of the 80 power spectras
- logarithmic compression and offset
- transfer all 32 lines of the averaged power spectrum to telemetry

4.7.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \cdot \frac{1}{3} \approx 15.36khz$		(.44)
Spectral range	$\frac{f_{s\max}}{3} \cdot \frac{1}{64}$ to $\frac{f_{s\max}}{3} \cdot \frac{28}{64}$	240 Hz - 6.72 kHz	(.45)
Resolution	$\frac{f_{s\max}}{3} \cdot \frac{1}{64}$	≈ 240 Hz per Line	(.46)
Telemetry Data (TM)	Line1 - Line 28	28 Lines, 8.0 unsigned	

Conversion to Decibel	$\frac{TM - 26.84}{32} \cdot 20 = 20 \cdot \log_{10}(S)$	(.47)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM-26.84}{32}}$	(.48)
Conversion to ADC-input signal	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-26.84}{32}}$	(.49)

Processing

- 64 samples -> divide by 4 -> Hamming Wind. -> 64p FFT -> Power Spectrum
- Integration of 80 power spectra
- Divide by 16
- Logarithmic compression + Offset Value (0x570)
- Result: 32 Spectral Lines (Line 0 - Line 31)

Numerical Scaling

software	scaling	computation	format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1	ASHIFT BY 0	16.0
64p-FFT	32	N / 2	16.0
power spec – pre scaling	2-4	ASHIFT BY –4	15.4
multiply in ADSP2100	2	used for X2	
80-times integration	80	80 times sum	
log – pre scale	2-4	ASHIFT BY –4	
conversion 32.0 to 16.16	2-16	log input is 16.16 format	16.16
log output 8.8 format + offset	log()+offset	offset = 0x570 = 1392 / 28 (converted in 8.8 format)	8.8
log post scale	2-4	ASHIFT BY –4 (converted to 12.4 format)	4.4
transfer to 82C55 (lower byte)	2^8	only lower 8 bits are Transferred	8.0 unsigned

$$TM = \left\{\log_{10}\left[(S \cdot 0{,}533 \cdot 32 \cdot 2^{-4})^2 \cdot 2 \cdot 80 \cdot 2^{-4} \cdot 2^{-16}\right] + 0x570\right.$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{1.425}{2^{13}}\right] + 87$$

$$TM = 32 \cdot \log_{10}(S) + 26.84$$

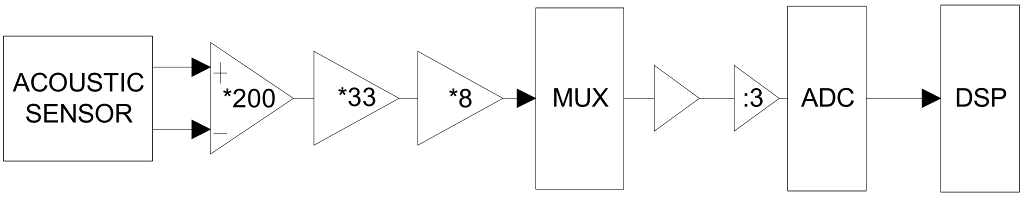
TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	26.84	0x1A	0x0001	137.3 μV_p	0 dB
sat[5]	152.07	0x98	0x3FFF	1.125 V_p	78 dB
max[6]	171.33	0xAB	0x7FFF	4.5 V_p	90 dB

[5] This is the maximal possible input value before saturation occurs.

[6] There is no input scaling done for ACU signals (because they are expected to be very small). Therefore full-scale signal of ADC could saturate FFT processing. But this will never happen, since the audio pressure levels will never be reached to give full-scale ADC signals.

4.7.2 Analogue Calibration of integrated ACU spectrum :

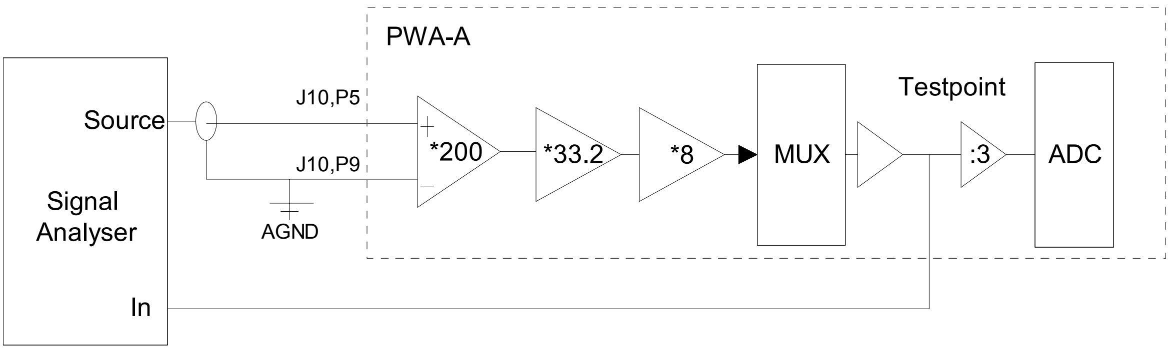


Measurement principle: Vented Gage (with reference open to atmosphere)
SI-membrane with resistor bridge

FM-Sensor: Sensitivity: 0.289mV/mBarVG = 2.89µV/Pa VG (measured by manufact.)
FS-Sensor: Sensitivity: 0.275mV/mBarVG = 2.75µV/Pa VG (measured by manufact.)

For analogue calibration, the following Flight Model measurements have been taken into account:

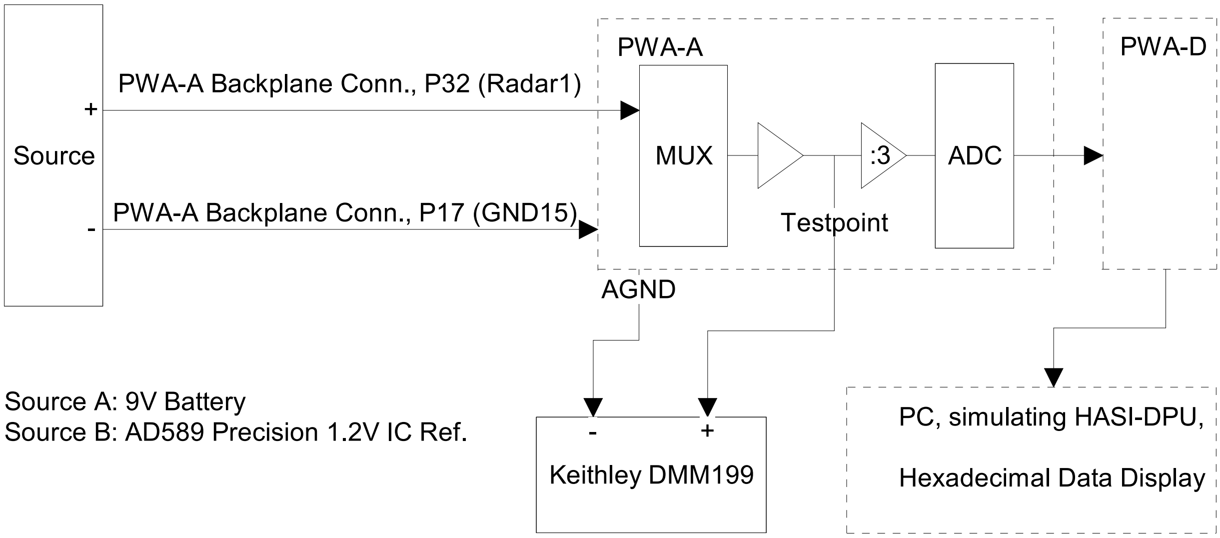
- Sensitivity: 0.289mV/mBarVG = 2.89µV/Pa VG (measured by manufact.)
- Transfer functions:



Files:

FM: acufm.prn (20.5.95, B&K2012) -> data extracted manually from printout -> fmacu_bk.asc
FS: acup5fs.dat (9.2.97, B&K2012) -> ASCII generated with B&K -> fsacu_bk.asc
BAL: acu5.dat (17.11.95, HP35665A) -> ASCII generated with ‘sdftoasc.exe’ -> acu5.asc

- Separate measurements of the gain of the attenuator on PWA-A FM
  (in front of ADC, not included in the transfer function):



-

Measured attenuator gain:

FM: 0.34 = -9.37042166 dB (see FM-ADP)

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, at IWF Graz.

<u>Calibration process :</u>

- Take fsacu_bk.asc transfer function for acoustic amplifier (equal to fm)

- Calculate gain on the ACU spectrum frequency bins by interpolation
  (240Hz – 6.72 kHz with 240 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **au.cal**
  (see attachment)

4.7.3 Analogue + Digital Calibration of integrated ACU spectrum data within m-pwa software:

- Calculate amplitudes at all ACU frequency bins at the ADC-input out of ACU telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-26.84}{32}}$$ …………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (au.cal)

$s_{ACU} = s_{ADC}$ - au.cal

Result: voltage measured at ACU sensor output in dBV_{peak} versus frequency
(amplitude in dB relative to 1 V_{peak} versus frequency in Hz)

- calculate sound pressur level

$p_{ACU} = s_{ACU}$ - 20*log10(sensitivity [V/Pa]*p0[Pa])
= s_{ACU} - 20*log10(0.00000289*0.00002)

Result: Sound pressure measured by ACU sensor in dB_{SPL} versus frequency
(amplitude in dB relative to p0=20µPa versus frequency in Hz)

4.8 Acoustic Burst

Measurement principle:

- take the 80 power spectras calculated during 4.7 (ACU spectrum) (80 x 64p FFT, sampling frequency =15.36 kHz)
- within every single spectrum sum up lines to get mean power values for 2 frequency ranges:
  f1 = Σ(Line 1 to Line 8)/8 (without DC line!) (sum of 8 lines)
  f2 = Σ(Line 9 to Line 24)/16 (sum of 16 lines)

- logarithmic compression and offset
- transfer power of the first 20 (of 80) x 2 spectral ranges to telemetry

4.8.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \cdot \frac{1}{3} \approx 15.36khz$		(.51)
Spectral range	$\frac{f_{s\max}}{3} \cdot \frac{1}{64}$ to $\frac{f_{s\max}}{3} \cdot \frac{25}{64}$	240 Hz - 6.96 kHz	(.52)
	f1: $\frac{f_{s\max}}{3} \cdot \frac{1}{64}$ to $\frac{f_{s\max}}{3} \cdot \frac{9}{64}$	240Hz - 2.16 kHz	(.53)
	f2: $\frac{f_{s\max}}{3} \cdot \frac{9}{64}$ to $\frac{f_{s\max}}{3} \cdot \frac{25}{64}$	2.16kHz - 6 kHz	(.54)
Telemetry Data	2 Ranges x 20 (the first 20 of 80 measurements)		
Conversion to Decibel	$TM \cdot 6 = 20 \cdot \log_{10}(S)$		(.55)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM*6}{20}}$		(.56)
Conversion to ADC-input signal	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$		(.57)

Processing

- 64 samples -> divide by 4 -> Hamming Wind. -> 64p FFT -> Power Spectrum
- 32 Spectral Lines (L0 - L31)
- f1=Σ(L1 to L8)/8 (Sum of 8 Lines)
  f2=Σ(L9 to L24)/16 (Sum of 16 Lines)
- Logarithmic compression + Offset Value (0xd80)
- repeat 80 times
- Result: 80 x 2 Spectral Ranges (f1(t0),f2(t0),....,f1(t79),f2(t79))

Numerical Scaling

Software	Scaling	Computation	Format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
64p-FFT	32	N / 2	16.0
Power spec – pre scaling	2-4	ASHIFT BY –4	12.4
Multiply in ADSP2100	2	used for X2	32.0
Scaling	2-3	LSHIFT BY-3	32.0 or 33.0
Extra scaling for 32 lines	0 , 2-1	ASHIFT BY –1 (only for 32 lines)	32.0
Conversion 32.0 to 16.16	2-16	log input is 16.16 format	
Log output 8.8 format + offset	log()+offset	offset = 0xD80 = 3456 / 28 (converted in 8.8 format)	8.8
Log post scale	2	ASHIFT BY –7	8.8 → 15.1
Mask lower 4 bit		AND 0x0F	3.1

$$TM = \left\{ \log_{10}\left[(S\cdot\frac{1}{4}\cdot 32\cdot 0.533\cdot 2^{-4})^{2}\cdot 2\cdot 2^{-3}\cdot 2^{-16} \right] + (\right.$$

$$TM = 2\cdot\log_{10}\left[S^{2}\cdot\frac{0.284}{2^{20}} \right] + 27$$

$$TM = 4\cdot\log_{10}(S) + 13.86$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex) Theoretically	TM (hex) practically[7]	DSP input (hex)	ADC-input (V)	dB
min	13.86	0x0D	0x**10**	0x0001	137.3 μV_p	0 dB
max[8]	31.32	0x**1**F	0x**1**F	0x7FFF	4.5 V_p	90 dB

Note1: The limited resolution of the fixed point DSP adds some small amount of noise to the results, which gives after integration of 16 or 32 lines considerable increase of the numbers given in the table above. The effort to make an analytical calculation of this effect is considered to be to high, hence a simulation using the DSP-simulator was done to verify the calculation performed in the "real" DSP. The results of the simulation are given in the following table.

Note2: The second digit is always 1 (for all values between min and max) and therefore not transmitted in the telemetry data (like a "hidden 1"). But it has to be taken into account!

[7] see note 1

[8] This maximum number is referred to pure sine wave amplitudes. Other signals may give higher values (after FFT)!

A square wave signal with an amplitude greater than 0x730C gives a result of 0x20 in the telemetry. Due to the masking with 0x0F it can not be destinguished from 0x00 !

Results from runs with ADSP simulator:

DSP Input (hex)	TM (hex)	dB
0000	0x0	0 dB
0001	0x01	6 dB
0003	0x02	12 dB
001C	0x0	18 dB
0400	0x0	36 dB
1000	0x0E	84 dB
1FFF	*0x10*	*0 dB*
6400	*0x1F*	*90 dB*
7800	*0x1F*	*90 dB*
7C00	*0x1F*	*6 dB*
7FFF	*0x20*	*0 dB*

Note: the last five lines in the previous table give wrong results. This is due to the fact that full scale input signals lead to a wrap around in the data result. That means, that signals with very high amplitude can not be distinguished from signals with very low amplitudes! In practical use this is no problem, because the Acoustic sensor will most probably not deliver output signals of such high amplitudes. Moreover the total power within ACU integrated spectra can be taken as reference to judge if a possible wrap around in ACU burst data may have occurred.

4.8.2 Analogue Calibration of ACU burst data :

Details of ACU sensor: see 4.7.2 (ACU Spectrum calibration)

Timing measurements performed with a PWA-D and PWA-A bread board model

Calibration process:

- Take file acu.cal (see 4.7.2)

- Calculate average gain for the 2 ACU burst frequency ranges out of acu.cal

- Results **au_burst.cal**
  (see attachment)

- timing: distance of lightning measurements = 8.9881 ms (9.0 ms taken for calibration)
  Result: **au_btime.cal** (see attachment)

4.8.3 Analogue + Digital Calibration of ACU burst data within m-pwa software:

- Calculate amplitudes both ACU frequency ranges at the ADC-input out of ACU burst telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM*6}{20}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (au.cal for RX high gain)

$s_{ACU} = s_{ADC}$ - li132rxl.cal

Result: mean voltage measured for the ACU burst frequency ranges at the sensor output in dBV_{peak} versus time (amplitude in dB relative to 1 V_{peak} versus time in seconds)

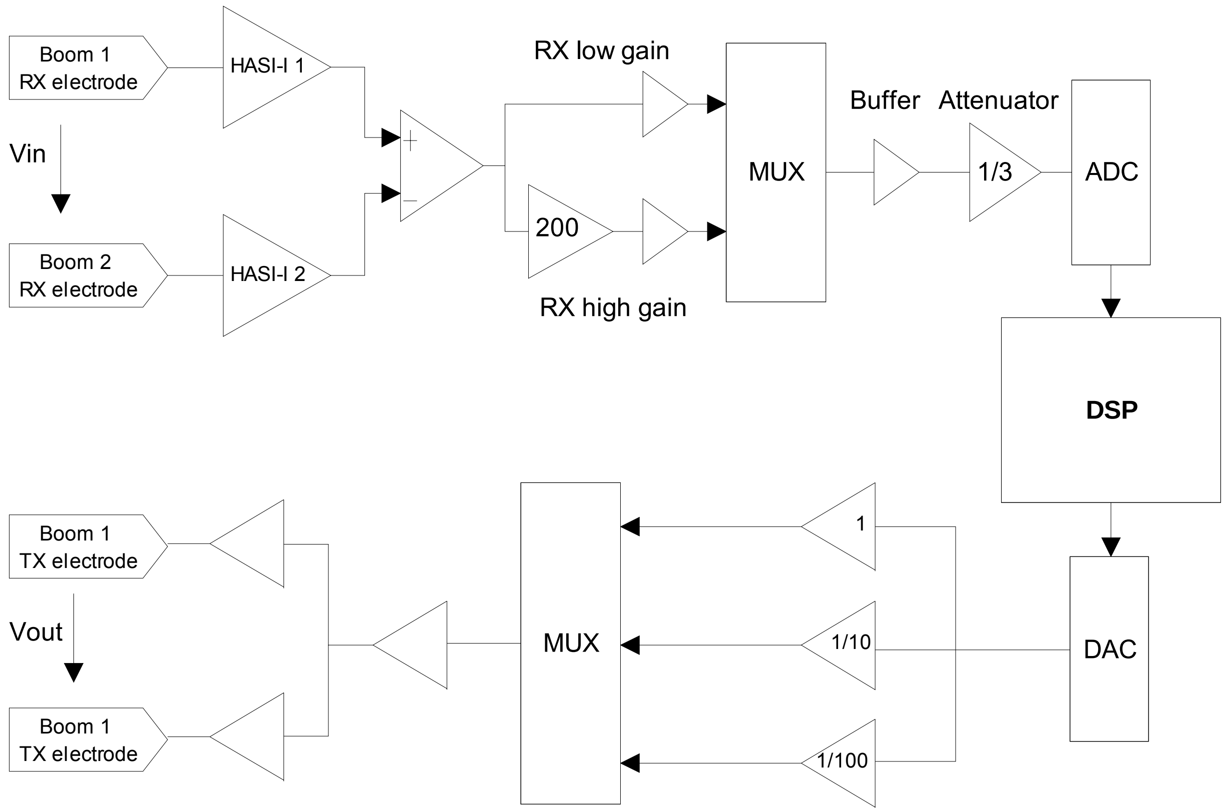
- calculate sound pressur level

$p_{ACU} = s_{ACU}$ - 20*log10(sensitivity [V/Pa]*p0[Pa])
$= s_{ACU}$ - 20*log10(0.00000289*0.00002)

Result: Sound pressure measured for the ACU burst frequency ranges by ACU sensor in dB_{SPL} versus frequency (amplitude in dB relative to p0=20µPa versus frequency in Hz)

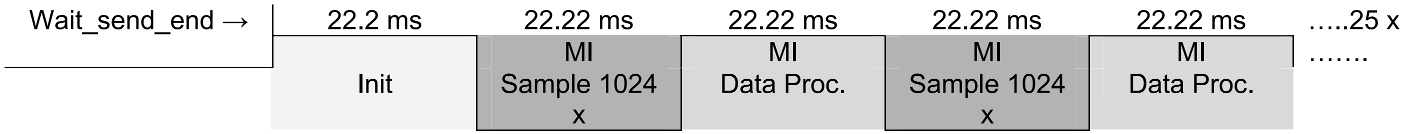
5 MI-Science Data Packet

5.1 Block diagram for MI measurement



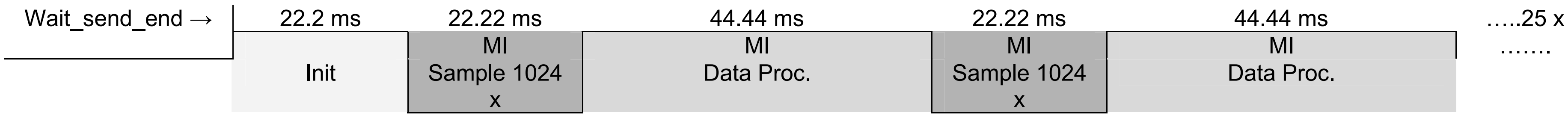
5.2 Timing of MI measurements

<u>MI timing for low amplitudes:</u>



Note: for high amplitudes, MI data processing (FFT) may take longer than 22.22 -> next MI sampling after 44.44 ms

→ <u>MI timing for high amplitudes :</u>



→ <u>MI timing for changing amplitudes :</u>

MI data proc. may take 44.44 ms or 22.22 ms, changing during the 25 measurements depending on measured amplitudes in the single spectres.

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5.3 MI spectrum

Measurement principle

- sample 25 x 1024 points with 46.08 kHz

(attention: between sampling of 1024 points and the next 1024 points gaps of 22.22ms or 44.44 ms for data processing)

- calculate 25 x 1024 point FFT -> calculate 25 power spectras
- calculate the average of the 25 power spectras
- logarithmic compression and offset
- transfer the first 204 lines of the averaged power spectrum to telemetry (including DC line)

5.3.1 Digital Data Processing:

Sampling frequency	$fs_{\max} \approx 46.08khz$		(.59)
Spectral range	DC to $\frac{205 \cdot f_{s\max}}{1024}$	0 Hz - 9.225 kHz	(.60)
Resolution	$\frac{f_{s\max}}{1024}$	45 Hz	
Telemetry Data	204 lines (line 0 - line 203), 8.0 unsigned		
Conversion to Decibel	$\frac{TM-8.22}{32} \cdot 20 = 20 \cdot \log_{10}(S)$		(.61)
Conversion to DSP-input samples	$S_{DSP} = 10^{\frac{TM-8.22}{32}}$		(.62)
Conversion to ADC input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-8.22}{32}}$		(.63)

Processing

- 25 times {take 1024 samples → scale (1/4) → calculate 1024p-FFT → calculate power spectra}
- Make sum of 25 power spectra
- Scaling (1/16)
- Calculate $\log_{10}$(x + offset value (0x570) / 256) (note: offset is used to get only positive numbers)
- Result: 512 logarithmic spectral lines (line 0 - line 511, but only 204 are transmitted)

Numerical Scaling

Software	Scaling	Computation	Format
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
FFT	512	N / 2	16.0
power spec – pre scaling	2^{-8}	ASHIFT BY –8	8.8
multiply in ADSP2100	2	used for X^2	16.16
25-times average	25	25 times sum	16.16
log pre scale	2^{-4}	ASHIFT BY –4	12.20
conversion 32.0 to 16.16	2^{-16}	log input is in 16.16 format	16.16 / 2^{20}
log output 8.8 format + offset	log () + offset	offset = 0x570 = 1392 / 28 (in 8.8 format)	8.8
log post scale	2^{-4}	ASHIFT BY –4 (converted to 4.12 format)	4.12
transfer to 82C55 (lower byte)	2^{8}	only lower 8 bits are transferred	8.0

$$TM = \left\{ \log_{10}\left[(S \cdot \frac{1}{4} \cdot 512 \cdot 2^{-8})^2 \cdot 2 \cdot 25 \cdot 2^{-4} \cdot 2^{-16} \right] + 0x570 \cdot 2 \right.$$

$$TM = 16 \cdot \left\{ \log_{10}\left[S^2 \cdot \frac{50}{2^{22}} \right] + \frac{1392}{2^8} \right\}$$

$$TM = 16 \cdot \log_{10}\left[S^2 \cdot \frac{50}{2^{22}} \right] + 87$$

$$TM = 32 \cdot \log_{10}(S) + 8.22$$

TM … value (spectral line) transferred in telemetry; S … ADSP Input sample (range: 1 to 2^{15})

range	TM (dec)	TM (hex)	DSP input (hex)	ADC-input (V)	dB
min	8.22	0x08	0x0001	137.3 µV_p	0 dB
max[1]	152.72	0x98	0x7FFF	4.5 V_p	90 dB

note: ratio TM/dB = 1.6

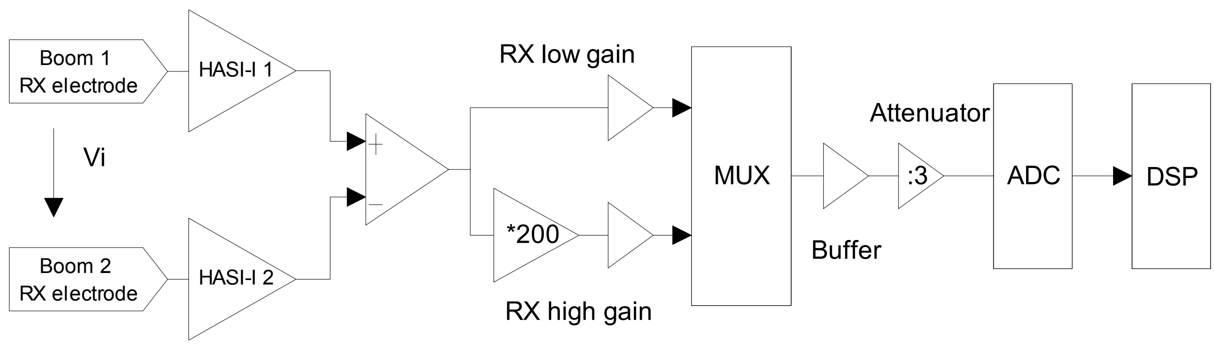
[1] This maximum number is referred to pure sine wave amplitudes. With other signals the resulting amplitude (after FFT) may be higher than the given max. value !

Signal to Noise

The calculation of S_{ADC} is based on the calculation of the power spectra. Hence the result will differ from the amplitude calculated from means of real-parts and means of imaginary parts. The reason is due to the fact that averaging of power spectra does not reduce noise levels (scalars are summed up) as strong as averaging of real parts and imaginary parts (vectors are summed up).
It may be useful to compare results of amplitude estimation from (.63) and (.73) and express the result as signal to noise ratio.

$$\frac{S}{N} = 20 \cdot \log_{10} \cdot \frac{Amp_{ADC}}{S_{ADC}} \text{ dB}$$ Signal to noise ratio

5.3.2 Analogue Calibration of integrated MI spectrum :



For analogue calibration, the following Flight Model measurements have been taken into account:

- Transfer functions from PWA FM RX electrodes to Test point on PWA-A FM (is situated between the buffer and the attenuator)
- Separate measurements of the gain of the attenuator on PWA-A FM

These measurements have been made with a Bruel Kjaer Audio Analyser, Type 2012, in June 1995 at IWF Graz.

Files: HASI\CASSINI.FM\FM_TEST\GRAZ0695.FM\ BOOM1RXL.ada
BOOM2RXL.ada
BOOM1RXH.ada
BOOM2RXH.ada

Attenuator gain: 0.34 = -9.37042165915 dB from FM-ADP, PWA-FM-DOC-010

Calibration process :

- Calculate average value from boom1 and boom2 transfer functions for receiver low gain (RXL) and receiver high gain (RXH)

- Calculate gain on the MI data frequency bins by interpolation
  (0 Hz – 9.225 kHz with 45 Hz resolution)

- Subtract attenuator gain (9.37042165915 dB)

- Results **mirxl.cal**
  mirxh.cal
  (see attachment)

5.3.3 Analogue + Digital Calibration of integrated MI spectrum data within m-pwa software:

- Calculate amplitudes at all MI frequency bins at the ADC-input out of MI telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-8.22}{32}}$$

…………amplitudes in dBVp at ADC-input

- subtract analogue calibration data (mirxl.cal for RX low gain, mirxh.cal for RX high gain)

for RXL: $s_{rxl} = s_{ADC}$ - mirxl.cal
for RXH: $s_{rxh} = s_{ADC}$ - mirxh.cal

Result: amplitude measured at the RX electrodes in dBV_{peak} versus frequency
(amplitude in dB relative to 1 V_{peak} versus frequency in Hz)

5.4 MI Amplitude

Measurement principle:

- take the 25 spectras (calculated during 5.3 (MI spectrum)
  (25 x 1024p FFT, sampling frequency = 46.08 kHz)
- at the actual TX frequency (usually 45 Hz, also higher frequencies in ground mode) calculate the sum of the 25 real parts and the sum of the 25 imaginary parts of this frequency line.
- logarithmic compression and offset
- transfer real and imaginary part to telemetry

5.4.1 Digital Data Processing:

$TM_{RE} = \mathrm{Re} \cdot \frac{25}{32} + 32768$	TM-value of real part after computation	(.66)
$TM_{IM} = \mathrm{Im} \cdot \frac{25}{32} + 32768$	TM-value of imaginary part after computation	(.67)

Physical Value:

$\mathrm{Re}_{DSP} = (TM_{RE} - 32768) \cdot \frac{32}{25}$	real part (referred to DSP input samples)	(.68)
$\mathrm{Im}_{DSP} = (TM_{IM} - 32768) \cdot \frac{32}{25}$	imaginary part (referred to DSP input samples)	(.69)

note: Equation (.68) seems to be incorrect in respect to equation (.66), but it is not ! This is due to the conversion behavior of two's complement numbers on PC's in respect to ADSP2100.

$\mathrm{Re}_{ADC} = \frac{4.5V}{2^{15}} (TM_{RE} - 32768) \cdot \frac{32}{25}$	real part (referred to ADC input samples)	(.70)
$\mathrm{Im}_{ADC} = \frac{4.5V}{2^{15}} (TM_{IM} - 32768) \cdot \frac{32}{25}$	imaginary part (referred to ADC input samples)	(.71)
$Amp_{DSP} = \sqrt{\mathrm{Re}_{DSP}^{\ 2} + \mathrm{Im}_{DSP}^{\ 2}}$	amplitude of spectral line at TX-frequency (referred to DSP input samples)	(.72)
$Amp_{ADC} = \frac{4.5V}{2^{15}} \sqrt{\mathrm{Re}_{DSP}^{\ 2} + \mathrm{Im}_{DSP}^{2}}$	amplitude of spectral line at TX-frequency (referred to ADC-input voltages)	(.73)

Processing

- 25 times {take 1024 samples → scale by 1/4 → calculate 1024p-FFT → real & imag. parts}
- Sum of 25 real parts, sum of 25 imaginary parts at TX-frequency → RE, IM

Data format

RE 16.0 unsigned (!)[2]
IM 16.0 unsigned (!)[3]

Numerical Scaling

software	scaling	computation	format
Sample input scaling	1 / 4	ASHIFT BY- 2	14.2
FFT	512	N / 2	16.0
average pre scaling	2^{-12}	ASHIFT BY –12	
25-times average	25	25 times sum	16.16
two's complement conversion	+ 0x8000	- 0x8000	16.16

[2] due to error in ADSP software, needs to be converted in EGSE software by subtracting 0x8000
[3] due to error in ADSP software, needs to be converted in EGSE software by subtracting 0x8000

5.4.2 Analogue Calibration of MI amplitude data :

Details of MI receiver analogue path: see 5.3.2 (MI Spectrum calibration)

Calibration process:

- Take file mi.cal (see 5.3.2)

- Take gain at MI transmitter frequency out of mi.cal and use it for calibration of MI amplitude data

5.4.3 Analogue + Digital Calibration of MI amplitude data within m-pwa software:

- Calculate MI amplitude at the ADC-input out of MI amplitude telemetry data (TM_{RE} and TM_{IM}) in Volts (V_{peak})

$$Amp_{ADC} = \frac{4.5V}{2^{15}} \sqrt{\left(TM_{RE} - 32768\right)^2 + \left(TM_{IM} - 32768\right)^2} \cdot \frac{32}{25}$$

..MI amplitude at ADC-input in Volts

- Divide by gain factor at TX frequency taken from analogue calibration data (calculate gain factor out of gain in dBV first)

  (mirxl.cal for RX low gain
  mirxh.cal for RX high gain)

$$Amp_{RX} = \frac{Amp_{ADC}}{10^{\frac{gain[dBV]}{20}}}$$

Result: voltage measured at MI transmitter frequency in Volts

5.5 MI Phase

Measurement principle: see MI amplitude

5.5.1 Digital Data Processing:

$\varphi = a\tan\left(\frac{\mathrm{Im}}{\mathrm{Re}}\right)$	calculation of phase shift	(.74)

Delta (constant group delay in the digital system):

Emitted TX- Frequency [Hz]	Delta [°]
45	0.3515625 * 1.5
90	0.703125 * 1.5
360	2.8125 * 1.5
1440	11.25 * 1.5
5760	45 *1.5

(see HASI-PWA-DOC026, Mutual Impedance Measurement Report)

$\varphi = a\tan\left(\frac{TM_{IM} - 32768}{TM_{RE} - 32768}\right)$ - Delta [°]	calculation of phase shift at TX-frequency (phase shift of ADC-input related to DAC-output)	(.75)

5.5.2 Analogue Calibration of MI phase data :

There is no analog calibration of MI phase available yet.

5.5.3 Analogue + Digital Calibration of MI phase data within m-pwa software:

- Calculate MI phase in [°] out of telemetry data for actual MI TX frequency (without subtraction of group delay)

$$\varphi = a\tan\left(\frac{TM_{IM} - 32768}{TM_{RE} - 32768}\right)$$ ..MI phase in [°] without considering group delay

- Make a continuous angle scale by selecting the right quadrant

if {(TM_{RE}-32767.5)<0}&{(TM_{IM}-32767.5)<0} -> φ = φ +180.0

if {(TM_{RE}-32767.5)>0}&{(TM_{IM}-32767.5)>0} -> do nothing !

if {(TM_{RE}-32767.5)>0}&{(TM_{IM}-32767.5)<0} -> φ = φ +360.0;

if {(TM_{RE}-32767.5)<0}&{TM_{IM}-32767.5)>0} -> φ = φ +180.0

- Subtract group delay

  φ = φ – delta – 90

- Correct for going from quadrant 4 to quadrant 1 (not to end up at -90°)

  If φ<0 -> φ = φ +360.0;

5.6 MI Standard Deviation

Measurement principle:

- take the 25 spectres (calculated during 5.3 (MI spectrum)
  (25 x 1024p FFT, sampling frequency = 46.08 kHz)
- take real and imaginary parts of the 25 spectres at the actual TX frequency (usually 45 Hz, also higher frequencies in ground mode)

- calculate standard deviation for the 25 real and 25 imaginary parts
- transfer SDR (standard deviation for real parts) and SDI (standard deviation for imaginary parts) to telemetry

5.6.1 Digital Data Processing:

$$S = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left[\left(\overline{x} -\right.\right.}$$

… definition of standard deviation

Processing

- 25 times {1024 samples → divide by 4 → 1024p FFT}
- Gives 25 real parts, 25 imag. parts at TX-frequency
- Calculate standard deviation for 25 real and 25 imaginary parts → SDR, SDI

$SDR = \frac{25}{32}\cdot\sqrt{2\cdot\sum_{i=1}^{25}\left[\left(\overline{re} - re_i\right)^2\right]\cdot 25}$	calculation of SDR in MI-routine	(.77)
$SDI = \frac{25}{32}\cdot\sqrt{2\cdot\sum_{i=1}^{25}\left[\left(\overline{im} - im_i\right)^2\right]\cdot 25}$	calculation of SDI in MI-routine	(.78)

with: re_i , im_i .... real and imag. part of emitted freq. in the i-th spectrum (i= 1..25)
note: factor 2 within the square root comes because of multiplication habit of ADSP-2100

Data Format

SDI	16.0 unsigned
SDR	16.0 unsigned

Numerical Scaling

software	scaling	Computation	format
Sample input scaling and FFT calculation	25 / 32	see MI-amplitude values	
multiplier stage	$\sqrt{2}$	SQRT(ADSP2100 multiply habit)	
25-times numbers	25	25 times sum	16.16
deviation scaling	$\sqrt{24}$	- 0x8000	16.16

$SDR = S_R \frac{25}{32} \cdot \sqrt{2} \cdot 25 \cdot \sqrt{24}$ $SDR = S_R \frac{25}{32} \sqrt{30000}$	Standard deviation of real part as calculated by ADSP SR … standard deviation according to (.76)	(.79)
$SDI = S_I \frac{25}{32} \cdot \sqrt{2} \cdot 25 \cdot \sqrt{24}$ $SDI = S_I \frac{25}{32} \sqrt{30000}$	Standard deviation of real part as calculated by ADSP SI … standard deviation according to (.76)	(.80)

note: SDR and SDI values need to be scaled with $\frac{1}{\sqrt{30000}}$ to be in scale with real-part and imag-part values !

Physical value

$S_{real\ ADC} = \frac{4.5V}{2^{15}} \cdot \frac{32}{25} \cdot \frac{1}{\sqrt{30000}} \cdot SDR$	conversion to ADC-input voltages	(.81)
$S_{\mathrm{Im}ag\ ADC} = \frac{4.5V}{2^{15}} \cdot \frac{32}{25} \cdot \frac{1}{\sqrt{30000}} \cdot SDI$	conversion to ADC-input voltages	(.82)

5.6.2 Analogue Calibration of MI standard deviation data :

Details of MI receiver analogue path: see 5.3.2 (MI Spectrum calibration)

Calibration process:

- Take file mi.cal (see 5.3.2)

- Take gain at MI transmitter frequency out of mi.cal and use it for calibration of MI amplitude data

5.6.3 Analogue + Digital Calibration of MI amplitude data within m-pwa software:

- Calculate MI standard deviation for real and imaginary part at the ADC-input out of MI amplitude telemetry data (SDR and SDI) in Volts (V_{peak})

$$S_{real\ ADC} = \frac{4.5V}{2^{15}} \cdot \frac{32}{25} \cdot \frac{1}{\sqrt{30000}} \cdot SDR$$

$$S_{\mathrm{Im}ag\ ADC} = \frac{4.5V}{2^{15}} \cdot \frac{32}{25} \cdot \frac{1}{\sqrt{30000}} \cdot SDI$$

.Standard Deviations at ADC-input in Volts

- Divide by gain factor at TX frequency taken from analogue calibration data (calculate gain factor out of gain in dBV first)

(mirxl.cal for RX low gain
mirxh.cal for RX high gain)

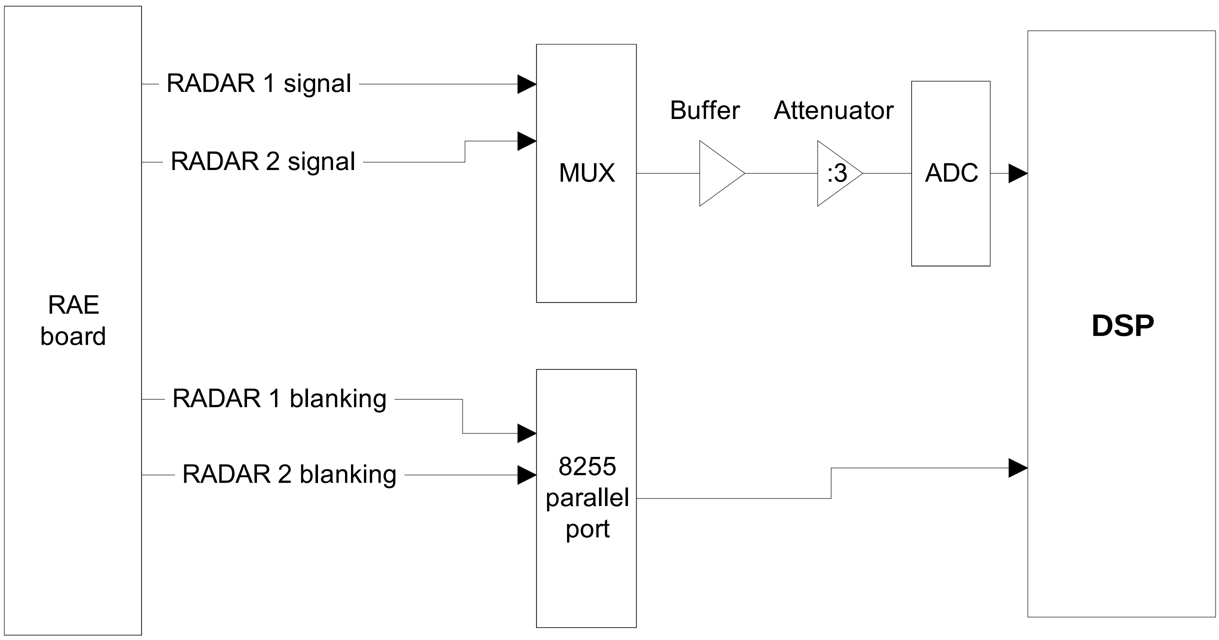
$$S_{real\ RX} = \frac{S_{real\ ADC}}{10^{\frac{gain[dBV]}{20}}}$$

$$S_{\mathrm{Im}ag\ RX} = \frac{S_{\mathrm{Im}ag\ ADC}}{10^{\frac{gain[dBV]}{20}}}$$

Result: Standard deviations of MI amplitude at MI Receiver in Volts (at MI TX frequency)

6 RAE-(RADAR) Science Data Packet

6.1 Block diagram for RAE measurements



6.2 Sequence and timing of RAE measurements

6.3 Radar Mode estimation

Look for blanking pulses (polling via digital port, count number of ADC interrupts)
IF no pulses THEN timeout → sample 104 points → put them to telemetry (in logarithmic form)
IF pulses exist THEN measure time for 2 ramps plus 2 pulses → calculate T_{estim}

IF T_{estim} > 150 THEN Radar Mode = 52 → do 128pFFT
IF T_{estim} > 80 THEN Radar Mode = 26 → do 64pFFT
IF T_{estim} > 38 THEN Radar Mode = 13 → do 32pFFT
IF T_{estim} <=38 THEN Radar Mode = 0 → 104 logarithmic time samples

6.4 Radar spectra / Time samples

6.4.1 Digital Data Processing:

Processing

RM52
- sample 128 points → scale (divide by 4) → Hamming Window → 128pFFT
- repeat 8 times (4x ramp1, 4x ramp2)
- calculate 8 power spectra
- sum up (1x integrate 4 ramp1 power spectra → 1 spectra , same for ramp2)
- Logarithm(spectra) + Offset Value (0x500)
– Result: 1 x 64p power spectrum (Line 0 - Line 63), ramp1, 4 times averaged
  1 x 64p power spectrum (Line 0 - Line 63), ramp2, 4 times averaged

RM26
- sample 64 points → scale (divide by 4) → Hamming Window → 64pFFT
- repeat 16 times (8x ramp1, 8x ramp2)
- calculate 16 power spectra
- sum up (2 x integrate 4 ramp1 power spectra → 2 spectra, same for ramp2)
- Logarithm(spectra) + Offset Value (0x500)
- Result: 2 x 32p power spectra (Line 0 - Line 31), ramp1, 4 times averaged
  2 x 32p power spectra (Line 0 - Line 31), ramp2, 4 times averaged

RM13
- sample 32 points → scale (divide by 4) → Hamming Window → 32pFFT
- repeat 32 times (16x ramp1, 16x ramp2)
- calculate 32 power spectra
- sum up (4 x integrate 4 ramp1 power spectra → 4 spectra, same for ramp2)
- Logarithm(spectra) + Offset Value (0x500)
- Result: 4 x 16p power spectra (Line 0 - Line 15), ramp1, 4 times averaged
  4 x 16p power spectra (Line 0 - Line 15), ramp2, 4 times averaged

RM 0
- sample 104 points
- Logarithmic compression + Offset Value (0x500)
- Result: 104 Time samples

Telemetry data

RM52	2 x 52p spectra (line 1 - line 52)		
	Spectral Range	fsmax / 128 to 53 * fsmax / 128	360 Hz - 19080 Hz
	Resolution	fsmax /128	≈ 360 Hz per Line
RM26	2 x 4 x 26p spectra (line 1 - line 26)		
	Spectral Range	fsmax / 64 to 27 * fsmax / 64	720 Hz - 19440 Hz
	Resolution	fsmax / 64	≈ 720 Hz per Line
RM13	2 x 4 x 13p spectra (line 1 - line 13)		
	Spectral Range	fsmax / 32 to 14 * fsmax / 32	1440 Hz - 20160 Hz
	Resolution	fsmax / 32	≈ 1440 Hz per Line
RM 0	104 time samples, logarithmic fs = 46.08 kHz		
RM –1	non valid data, timeout during measurement		

Numerical Scaling for RM52, RM26, RM13-Spectra

Software	Scaling	Computation	Format
Hamming window multiply	0.533	ADSP2100 multiply habit	16.0 x 1.15 = 16.16
Sample input scaling	1 / 4	ASHIFT BY –4	12.4
128p,64p or 32p –FFT	64, 32, 16	N / 2	16.0
power spec – pre scaling	2-5	ASHIFT BY –5	11.5
multiply in ADSP2100	2	used for X2	
4-times integration	4	4 times sum	
log – pre scale	2-1	ASHIFT BY –1	
conversion 32.0 to 16.16	2-16	log input is 16.16 format	16.16
log output 8.8 format + offset	log()+offset	offset = 0x500 = 1280 / 28 (converted in 8.8 format)	8.8
log post scale	2-4	ASHIFT BY –4 (converted to 12.4 format)	4.4
transfer to 82C55 (lower byte)	28	only lower 8 bits are Transferred	8.0 unsigned

$$TM = \left\{ \log_{10} \left[(S \cdot 0{,}533 \cdot \frac{1}{4} \cdot \frac{N}{2} \cdot 2^{-5})^2 \cdot 2 \cdot 4 \cdot 2^{-1} \cdot 2^{-16} \right] + 0x500 \cdot 2^{-} \right.$$

$$TM = 16 \cdot \log_{10} \left[S^2 \cdot \frac{0.284}{2^{22}} \cdot N^2 \right] + 80$$

$$TM = 32 \cdot \log_{10}(S) + 32 \cdot \log_{10}(N) - 34.70$$

$$N = 128 \Rightarrow TM = 32 \cdot \log_{10}(S) + 32.73$$

$$N = 64 \Rightarrow TM = 32 \cdot \log_{10}(S) + 23.09$$

$$N = 32 \Rightarrow TM = 32 \cdot \log_{10}(S) + 13.46$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{15})

range	TM RM52 N=128	TM RM26 N=64	TM RM13 N=32	DSP input	ADC-input (V)	dB
min	0x20	0x17	0x0D	0x0001	137.3 μV_p	0 dB
max[4]	0xB1	0xA7	0x9D	0x7FFF	4.5 V_p	90 dB

4

Conversion to Decibel	$\frac{TM - X}{32} \cdot 20 = 20 \cdot \log_{10}(S)$	RM52: X=32.73 RM26: X=23.09 RM13: X=13.46	(.84)
Conversion to DSP input samples	$S_{DSP} = 10^{\frac{TM-X}{32}}$		(.85)
Conversion to ADC-input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-X}{32}}$		(.86)

Numerical Scaling for RM0 - Time Samples

Software	Scaling	Computation	Format
log – pre scale	2-1	ASHIFT BY –1	
log output 8.8 format	log()		2.8
log post scale	2-1	ASHIFT BY –1	2.7
transfer to 82C55 (lower byte)	28	only lower 8 bits are Transferred	8.0 unsigned

$$TM = \log_{10}\left[(S \cdot \frac{2^8}{2})\right] \cdot 2^{-1} = 2^{-1} \cdot \log_{10}[(128 \cdot S)]$$

$$TM = 0xFF \cap (2^{-1} \cdot \log_{10}(128 \cdot S))$$

TM … value transferred in telemetry; S … Input sample (range: 1 to 2^{16})

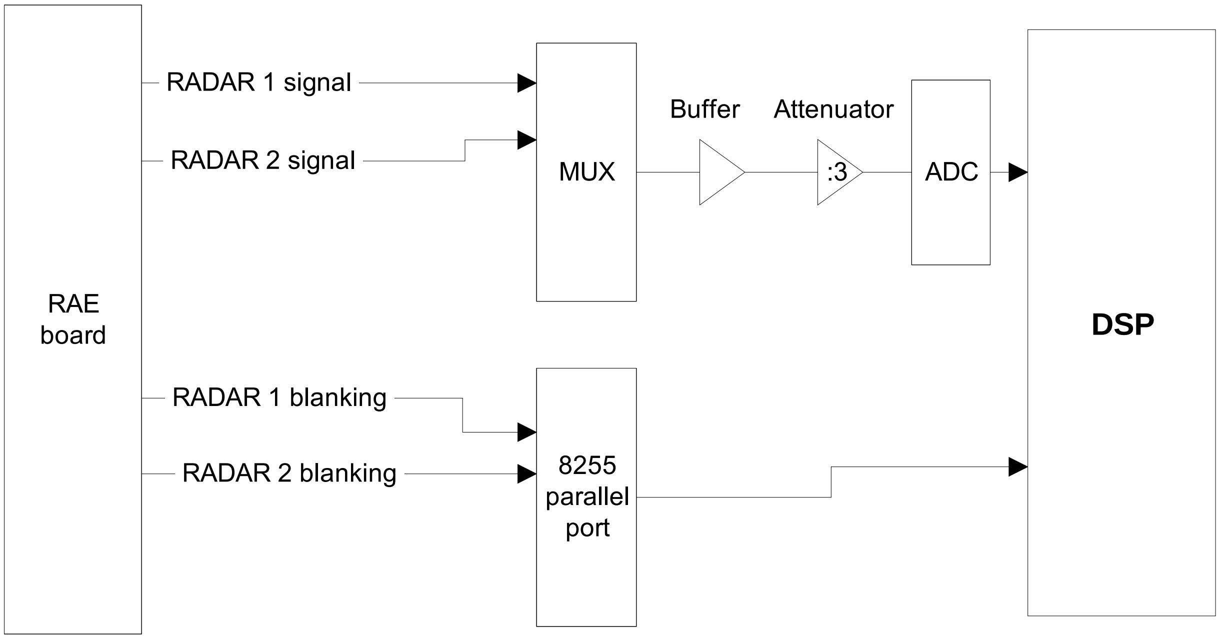
Conversion to DSP input samples	$S_{DSP} = 2 \cdot 10^{\frac{TM+X}{128}} - 32768$	
Conversion to ADC-input signals	$S_{ADC} = \frac{4.5V}{2^{15}} \cdot \left(2 \cdot 10^{\frac{TM+X}{128}} - 32768 \right)$	

with x = 512 for $0 \le TM \le 65$

x = 256 for $66 \le TM \le 255$

range	TM RM0 N=104	DSP input	ADC-input (V)
zero	0x1B	0x0000	0 V_p
max	0x41	0x7FFF	+4.5 V_p
min	0x42	0xFFFF	-4.5 V_p

6.4.2 Analogue Calibration of Radar spectrum /amplitude:



Measured attenuator gain:

FM: 0.34 = -9.37042166 dB (see FM-ADP)

Files: **RM56.cal**
RM26.cal
RM13.cal

6.4.3 Analogue + Digital Calibration of Radar spectrum within m-pwa software:

- Calculate amplitudes at all RAE frequency bins at the ADC-input out of RAE telemetry data (TM) in dBV_{peak}:

$$S_{ADC} = \frac{4.5V}{2^{15}} \cdot 10^{\frac{TM-X}{32}}$$

…with RM52: X=32.73,
RM26: X=23.09,
RM13: X=13.46

-> amplitudes in dBVp at ADC-input

- subtract analogue calibration data (attenuator gain: -9.37042166 dB)

for RXL: $s_{rae} = s_{ADC}$ – (-9.37042166 dB)

Result: voltage measured at the output of the RAE board in dBV_{peak} versus frequency (amplitude in dB relative to 1 V_{peak} versus frequency in Hz)

6.5 Radar Altitude estimation

6.5.1 Processing

RM52 Measure 4 x ramp1 time period → integrate → $T1_{avg}$
Measure 4 x ramp2 time period → integrate → $T2_{avg}$

RM26 Measure 8 x ramp1 time period → integrate → $T1_{avg}$
Measure 8 x ramp2 time period → integrate → $T2_{avg}$

RM13 Measure 16 x ramp1 time period → integrate → $T1_{avg}$
Measure 16 x ramp2 time period → integrate → $T2_{avg}$

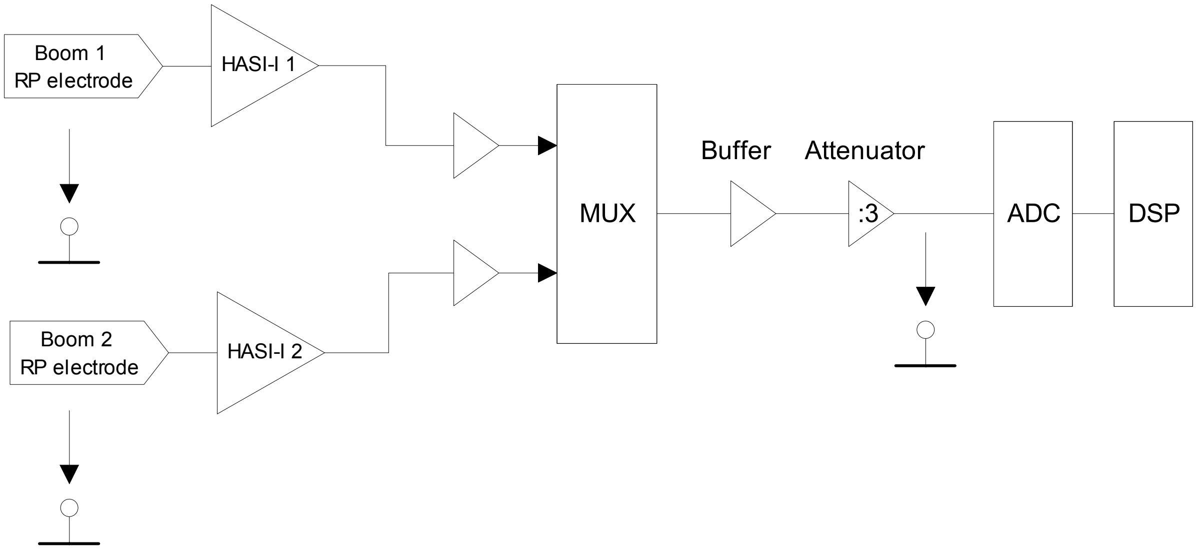
RM0 Measure 16 x ramp1 time period → integrate → $T1_{avg}$
Measure 16 x ramp2 time period → integrate → $T2_{avg}$

Note: there is no direct indication to decide which ramp is ramp1 or ramp2 . But data analysis has shown that the two ramp time periods give always a systematic deviation from T_{avg} (ramp1 has **always** smaller periods than ramps 2 or vice versa). This may be used to distinguish between the two ramps.

	Testim = (T1avg + T2avg) / N where N = 8, 16, 32, 64 for RM52,RM26,RM13,RM0	(.88)
	Altitude = $T_{estim} \cdot \frac{1000}{46080} km$	(.89)
RM52	Altitude = $\frac{T1_{avg} + T2_{avg}}{8} \cdot \frac{1000}{46080} km$	(.90)
RM26	Altitude = $\frac{T1_{avg} + T2_{avg}}{16} \cdot \frac{1000}{46080} km$	(.91)
RM13	Altitude = $\frac{T1_{avg} + T2_{avg}}{32} \cdot \frac{1000}{46080} km$	(.92)
RM0	Altitude = $\frac{T1_{avg} + T2_{avg}}{64} \cdot \frac{1000}{46080} km$	(.93)

7 Block diagram for Schumann, AC Spectrum and Lightning RP-Science Data Packet

7.1 Block diagram for RP measurement



7.2 Sequence and timing of RP measurements

Sampling relative to t0 = slot_sync of packet with slot counter no. 0

t0: Relays switched on (to +5V, -5V or GND), (t0 = Start of slot 0)
t0+500ms: take 1 sample of RP1, 1 sample of RP2
t0+1s: switch relays off
t0+1.05s: start of fast sampling period for RP1, 40 samples, Δt = 20ms,
last fast RP1 sample at t0+1.83s
t0+1.06s: start of fast sampling period for RP2, 40 samples, Δt = 20ms,
last fast RP2 sample at t0+1.84s
t0+2.00011s: start of slow sampling period, every 2s 4samples are taken
(2 x RP1, 2 x RP2) with Δt = 110us
t0+2.00011s: 1st RP1 sample,
t0+2.00022s: 2nd RP1 sample
t0+2.00033s: 1st RP2 sample
t0+2.00044s: 2nd RP2 sample
t0+4.00011s: next 4 samples
.
.
2 x 28 slow samples for RP1
2 x 28 slow samples for RP2
(last slow RP sample at t0+56.00044s)

7.3 RP data

7.3.1 Digital and Analog Data Processing:

Telemetry Data	8.0 format, unsigned integer	
Conversion to DSP input samples	$RP = (TM - 128)$	(.94)
Conversion to ADC input signals	$RP = (TM - 128) \cdot \frac{4.5V}{128}$	(.95)
Conversion to RP sensor input signals	$RP = (TM - 128) \cdot \frac{4.5V}{128} \cdot \left(-\frac{1}{0.34}\right)$	(.96)

7.3.2 Analogue Calibration of RP data :

Measured attenuator gain:

FM: 0.34 = -9.37042166 dB (see FM-ADP)

Files: **Rp_time.asc**

7.3.3 Analogue + Digital Calibration RP data within m-pwa software:

$$RP = (TM - 128) \cdot \frac{4.5V}{128} \cdot \left(-\frac{1}{0.34}\right)$$

Result: potential at RP1, RP2 electrode versus time
(potential in Volts time in seconds)

8 Appendix

8.1 Schumann Calibration Tables

SH131RXH.CAL:

frequency[Hz]	gain[dBV]
3.0000000e+000	1.1231232e+000
6.0000000e+000	1.8660239e+001
9.0000000e+000	1.9080689e+001
1.2000000e+001	1.9479211e+001
1.5000000e+001	2.0324056e+001
1.8000000e+001	2.0936742e+001
2.1000000e+001	2.1453719e+001
2.4000000e+001	2.1861730e+001
2.7000000e+001	2.2163358e+001
3.0000000e+001	2.2363422e+001
3.3000000e+001	2.2530710e+001
3.6000000e+001	2.2676570e+001
3.9000000e+001	2.2829501e+001
4.2000000e+001	2.2913598e+001
4.5000000e+001	2.2971712e+001
4.8000000e+001	2.3025847e+001
5.1000000e+001	2.3075197e+001
5.4000000e+001	2.3113044e+001
5.7000000e+001	2.3152217e+001
6.0000000e+001	2.3195261e+001
6.3000000e+001	2.3238305e+001
6.6000000e+001	2.3267990e+001
6.9000000e+001	2.3297234e+001
7.2000000e+001	2.3323652e+001
7.5000000e+001	2.3345862e+001
7.8000000e+001	2.3368071e+001
8.1000000e+001	2.3393118e+001
8.4000000e+001	2.3420758e+001
8.7000000e+001	2.3448399e+001
9.0000000e+001	2.3474467e+001
9.3000000e+001	2.3496715e+001
9.6000000e+001	2.3518964e+001

SH132RXH.CAL:

frequency[Hz]	gain [dBV]
4.5000000e+000	1.5379893e+001
1.0500000e+001	1.9080949e+001
1.6500000e+001	2.0633175e+001
2.2500000e+001	2.1642746e+001
2.8500000e+001	2.2270059e+001
3.4500000e+001	2.2602901e+001
4.0500000e+001	2.2884295e+001
4.6500000e+001	2.2998779e+001
5.2500000e+001	2.3094120e+001
5.8500000e+001	2.3173739e+001
6.4500000e+001	2.3253368e+001
7.0500000e+001	2.3311857e+001
7.6500000e+001	2.3356966e+001
8.2500000e+001	2.3406938e+001
8.8500000e+001	2.3462219e+001
9.4500000e+001	2.3507839e+001

8.2 AC Calibration Tables

AC131RXL.CAL:

f[Hz]	gain[dBV]
0.0000000e+000	-2.2547122e+001
1.8000000e+002	-2.2739329e+001
3.6000000e+002	-2.2623667e+001
5.4000000e+002	-2.2584069e+001
7.2000000e+002	-2.2575974e+001
9.0000000e+002	-2.2587158e+001
1.0800000e+003	-2.2619995e+001
1.2600000e+003	-2.2671165e+001
1.4400000e+003	-2.2730775e+001
1.6200000e+003	-2.2803215e+001
1.8000000e+003	-2.2888958e+001
1.9800000e+003	-2.2983322e+001
2.1600000e+003	-2.3088084e+001
2.3400000e+003	-2.3201169e+001
2.5200000e+003	-2.3320585e+001
2.7000000e+003	-2.3452932e+001
2.8800000e+003	-2.3589309e+001
3.0600000e+003	-2.3733429e+001
3.2400000e+003	-2.3882749e+001
3.4200000e+003	-2.4038911e+001
3.6000000e+003	-2.4197893e+001
3.7800000e+003	-2.4363845e+001
3.9600000e+003	-2.4529796e+001
4.1400000e+003	-2.4703450e+001
4.3200000e+003	-2.4878125e+001
4.5000000e+003	-2.5054480e+001
4.6800000e+003	-2.5238268e+001
4.8600000e+003	-2.5422056e+001
5.0400000e+003	-2.5606765e+001
5.2200000e+003	-2.5796452e+001
5.4000000e+003	-2.5986139e+001
5.5800000e+003	-2.6175826e+001
5.7600000e+003	-2.6369803e+001
5.9400000e+003	-2.6565144e+001
6.1200000e+003	-2.6760484e+001
6.3000000e+003	-2.6955825e+001
6.4800000e+003	-2.7153071e+001
6.6600000e+003	-2.7350424e+001
6.8400000e+003	-2.7547777e+001
7.0200000e+003	-2.7745129e+001
7.2000000e+003	-2.7943278e+001
7.3800000e+003	-2.8141820e+001
7.5600000e+003	-2.8340361e+001

7.7400000e+003	-2.8538902e+001
7.9200000e+003	-2.8737444e+001
8.1000000e+003	-2.8935804e+001
8.2800000e+003	-2.9134138e+001
8.4600000e+003	-2.9332472e+001
8.6400000e+003	-2.9530805e+001
8.8200000e+003	-2.9729139e+001
9.0000000e+003	-2.9927002e+001
9.1800000e+003	-3.0124366e+001
9.3600000e+003	-3.0321731e+001
9.5400000e+003	-3.0519096e+001
9.7200000e+003	-3.0716460e+001
9.9000000e+003	-3.0913825e+001
1.0080000e+004	-3.1109481e+001
1.0260000e+004	-3.1303000e+001
1.0440000e+004	-3.1496520e+001
1.0620000e+004	-3.1690040e+001
1.0800000e+004	-3.1883560e+001
1.0980000e+004	-3.2077080e+001
1.1160000e+004	-3.2270600e+001
1.1340000e+004	-3.2462328e+001

AC131RXH.CAL:

Frequency[Hz]	Gain[dBV]
0.0000000e+000	2.1861713e+001
1.8000000e+002	2.3690484e+001
3.6000000e+002	2.3766160e+001
5.4000000e+002	2.3803052e+001
7.2000000e+002	2.3794139e+001
9.0000000e+002	2.3713297e+001
1.0800000e+003	2.3652444e+001
1.2600000e+003	2.3542072e+001
1.4400000e+003	2.3451618e+001
1.6200000e+003	2.3293423e+001
1.8000000e+003	2.3162570e+001
1.9800000e+003	2.2969404e+001
2.1600000e+003	2.2770397e+001
2.3400000e+003	2.2549192e+001
2.5200000e+003	2.2311809e+001
2.7000000e+003	2.2088314e+001
2.8800000e+003	2.1850878e+001
3.0600000e+003	2.1586662e+001
3.2400000e+003	2.1319833e+001
3.4200000e+003	2.1049564e+001
3.6000000e+003	2.0775720e+001
3.7800000e+003	2.0493044e+001
3.9600000e+003	2.0210367e+001
4.1400000e+003	1.9878162e+001
4.3200000e+003	1.9539391e+001
4.5000000e+003	1.9207067e+001
4.6800000e+003	1.8903297e+001
4.8600000e+003	1.8599526e+001
5.0400000e+003	1.8289948e+001
5.2200000e+003	1.7949015e+001
5.4000000e+003	1.7608083e+001
5.5800000e+003	1.7267150e+001
5.7600000e+003	1.6928905e+001
5.9400000e+003	1.6591515e+001
6.1200000e+003	1.6254125e+001
6.3000000e+003	1.5916735e+001
6.4800000e+003	1.5578925e+001
6.6600000e+003	1.5241092e+001
6.8400000e+003	1.4903259e+001
7.0200000e+003	1.4565426e+001
7.2000000e+003	1.4227559e+001
7.3800000e+003	1.3889677e+001
7.5600000e+003	1.3551794e+001
7.7400000e+003	1.3213911e+001
7.9200000e+003	1.2876028e+001

8.1000000e+003	1.2544220e+001
8.2800000e+003	1.2213314e+001
8.4600000e+003	1.1882408e+001
8.6400000e+003	1.1551502e+001
8.8200000e+003	1.1220596e+001
9.0000000e+003	1.0895302e+001
9.1800000e+003	1.0575941e+001
9.3600000e+003	1.0256581e+001
9.5400000e+003	9.9372210e+000
9.7200000e+003	9.6178608e+000
9.9000000e+003	9.2985007e+000
1.0080000e+004	8.9841008e+000
1.0260000e+004	8.6759013e+000
1.0440000e+004	8.3677018e+000
1.0620000e+004	8.0595024e+000
1.0800000e+004	7.7513029e+000
1.0980000e+004	7.4431034e+000
1.1160000e+004	7.1349039e+000
1.1340000e+004	6.8303036e+000

AC132RXL.CAL:

frequency [Hz]	gain[dBV]
3.6000000e+002	-2.2623667e+001
7.2000000e+002	-2.2575974e+001
1.0800000e+003	-2.2619995e+001
1.4400000e+003	-2.2730775e+001
1.8000000e+003	-2.2888958e+001
2.1600000e+003	-2.3088084e+001
2.5200000e+003	-2.3320585e+001
2.8800000e+003	-2.3589309e+001
3.2400000e+003	-2.3882749e+001
3.6000000e+003	-2.4197893e+001
3.9600000e+003	-2.4529796e+001
4.3200000e+003	-2.4878125e+001
4.6800000e+003	-2.5238268e+001
5.0400000e+003	-2.5606765e+001
5.4000000e+003	-2.5986139e+001
5.7600000e+003	-2.6369803e+001
6.1200000e+003	-2.6760484e+001
6.4800000e+003	-2.7153071e+001
6.8400000e+003	-2.7547777e+001
7.2000000e+003	-2.7943278e+001
7.5600000e+003	-2.8340361e+001
7.9200000e+003	-2.8737444e+001
8.2800000e+003	-2.9134138e+001
8.6400000e+003	-2.9530805e+001
9.0000000e+003	-2.9927002e+001
9.3600000e+003	-3.0321731e+001
9.7200000e+003	-3.0716460e+001
1.0080000e+004	-3.1109481e+001

AC132RXH.CAL:

f[Hz]	gain[dBV]
3.6000000e+002	2.3766160e+001
7.2000000e+002	2.3794139e+001
1.0800000e+003	2.3652444e+001
1.4400000e+003	2.3451618e+001
1.8000000e+003	2.3162570e+001
2.1600000e+003	2.2770397e+001
2.5200000e+003	2.2311809e+001
2.8800000e+003	2.1850878e+001
3.2400000e+003	2.1319833e+001
3.6000000e+003	2.0775720e+001
3.9600000e+003	2.0210367e+001
4.3200000e+003	1.9539391e+001
4.6800000e+003	1.8903297e+001
5.0400000e+003	1.8289948e+001
5.4000000e+003	1.7608083e+001
5.7600000e+003	1.6928905e+001
6.1200000e+003	1.6254125e+001
6.4800000e+003	1.5578925e+001
6.8400000e+003	1.4903259e+001
7.2000000e+003	1.4227559e+001
7.5600000e+003	1.3551794e+001
7.9200000e+003	1.2876028e+001
8.2800000e+003	1.2213314e+001
8.6400000e+003	1.1551502e+001
9.0000000e+003	1.0895302e+001
9.3600000e+003	1.0256581e+001
9.7200000e+003	9.6178608e+000
1.0080000e+004	8.9841008e+000

8.3 LI (AC Burst) Calibration Tables

LI131RXL.CAL:

freq.range	gain [dBV]
1	-2.2932328e+001
2	-2.5086709e+001
3	-2.9622659e+001

LI131RXH.CAL:

freq.range	gain [dBV]
1	2.3087270e+001
2	1.9194612e+001
3	1.1451990e+001

LI132RXL.CAL:

freq.range	gain [dBV]
1	-2.3002058e+001
2	-2.5265021e+001
3	-2.9721320e+001

LI132RXH.CAL:

freq.range	gain [dBV]
1	2.2943177e+001
2	1.8879380e+001
3	1.1286295e+001

LI131_ti.CAL:

time[s]
0.0000000e+000
7.4000000e-003
1.4800000e-002
2.2200000e-002
2.9600000e-002
3.7000000e-002
4.4400000e-002
5.1800000e-002
5.9200000e-002
6.6600000e-002
7.4000000e-002
8.1400000e-002
8.8800000e-002
9.6200000e-002
1.0360000e-001
1.1100000e-001
1.1840000e-001
1.2580000e-001
1.3320000e-001
1.4060000e-001
1.4800000e-001
1.5540000e-001
1.6280000e-001
1.7020000e-001
1.7760000e-001
1.8500000e-001
1.9240000e-001
1.9980000e-001
2.0720000e-001
2.1460000e-001
2.2200000e-001
2.2940000e-001
2.3680000e-001
2.4420000e-001
2.5160000e-001
2.5900000e-001
2.6640000e-001
2.7380000e-001
2.8120000e-001
2.8860000e-001
2.9600000e-001
3.0340000e-001
3.1080000e-001
3.1820000e-001
3.2560000e-001
3.3300000e-001
3.4040000e-001
3.4780000e-001
3.5520000e-001

3.6260000e-001
3.7000000e-001
3.7740000e-001
3.8480000e-001
3.9220000e-001
3.9960000e-001
4.0700000e-001
4.1440000e-001
4.2180000e-001
4.2920000e-001
4.3660000e-001
4.4400000e-001
4.5140000e-001
4.5880000e-001
4.6620000e-001
4.7360000e-001
4.8100000e-001
4.8840000e-001
4.9580000e-001
5.0320000e-001
5.1060000e-001
5.1800000e-001
5.2540000e-001
5.3280000e-001
5.4020000e-001
5.4760000e-001
5.5500000e-001
5.6240000e-001
5.6980000e-001
5.7720000e-001
5.8460000e-001

LI132_ti.CAL:

time[s]
0.0000000e+000
9.0000000e-003
1.8000000e-002
2.7000000e-002
3.6000000e-002
4.5000000e-002
5.4000000e-002
6.3000000e-002
7.2000000e-002
8.1000000e-002
9.0000000e-002
9.9000000e-002
1.0800000e-001
1.1700000e-001
1.2600000e-001
1.3500000e-001
1.4400000e-001
1.5300000e-001
1.6200000e-001
1.7100000e-001
1.8000000e-001
1.8900000e-001
1.9800000e-001
2.0700000e-001
2.1600000e-001
2.2500000e-001
2.3400000e-001
2.4300000e-001
2.5200000e-001
2.6100000e-001
2.7000000e-001
2.7900000e-001
2.8800000e-001
2.9700000e-001
3.0600000e-001
3.1500000e-001
3.2400000e-001
3.3300000e-001
3.4200000e-001
3.5100000e-001
3.6000000e-001
3.6900000e-001
3.7800000e-001
3.8700000e-001
3.9600000e-001
4.0500000e-001
4.1400000e-001
4.2300000e-001
4.3200000e-001
4.4100000e-001

4.5000000e-001
4.5900000e-001
4.6800000e-001
4.7700000e-001
4.8600000e-001
4.9500000e-001
5.0400000e-001
5.1300000e-001
5.2200000e-001
5.3100000e-001
5.4000000e-001
5.4900000e-001
5.5800000e-001
5.6700000e-001
5.7600000e-001
5.8500000e-001
5.9400000e-001
6.0300000e-001
6.1200000e-001
6.2100000e-001
6.3000000e-001
6.3900000e-001
6.4800000e-001
6.5700000e-001
6.6600000e-001
6.7500000e-001
6.8400000e-001
6.9300000e-001
7.0200000e-001
7.1100000e-001

8.4 ACU Calibration Tables

AU.CAL:

Frequency [Hz]	gain[dBV]
2.4000000e+002	8.5555578e+001
4.8000000e+002	8.5629578e+001
7.2000000e+002	8.5629578e+001
9.6000000e+002	8.5629578e+001
1.2000000e+003	8.5629578e+001
1.4400000e+003	8.5629578e+001
1.6800000e+003	8.5568378e+001
1.9200000e+003	8.5486778e+001
2.1600000e+003	8.5390778e+001
2.4000000e+003	8.5287578e+001
2.6400000e+003	8.5184378e+001
2.8800000e+003	8.5081178e+001
3.1200000e+003	8.4981578e+001
3.3600000e+003	8.4885578e+001
3.6000000e+003	8.4789578e+001
3.8400000e+003	8.4693578e+001
4.0800000e+003	8.4589578e+001
4.3200000e+003	8.4469578e+001
4.5600000e+003	8.4349578e+001
4.8000000e+003	8.4229578e+001
5.0400000e+003	8.4109578e+001
5.2800000e+003	8.3989578e+001
5.5200000e+003	8.3869578e+001
5.7600000e+003	8.3749578e+001
6.0000000e+003	8.3629578e+001
6.2400000e+003	8.3468778e+001
6.4800000e+003	8.3307978e+001
6.7200000e+003	8.3147178e+001

AU_BURST.CAL:

sensitivity [V/Pa]
.00000289

freq.range	gain[dBV]
1	8.5574228e+001
2	8.4493103e+001

AU_BTIME.CAL:

time[s]
0.0000000e+000
9.0000000e-003
7.2000000e-002
8.1000000e-002
1.4400000e-001
1.5300000e-001
2.1600000e-001
2.2500000e-001
2.8800000e-001
2.9700000e-001
3.6000000e-001
3.6900000e-001
4.3200000e-001
4.4100000e-001
5.0400000e-001
5.1300000e-001
5.7600000e-001
5.8500000e-001
6.4800000e-001
6.5700000e-001

8.5 MI Calibration Tables

MIRXL.CAL:

frequency [Hz]	Gain[dBV]
0.0000000e+000	-2.2095484e+001
4.5000000e+001	-2.2883792e+001
9.0000000e+001	-2.2806941e+001
1.3500000e+002	-2.2767654e+001
1.8000000e+002	-2.2739329e+001
2.2500000e+002	-2.2704147e+001
2.7000000e+002	-2.2672714e+001
3.1500000e+002	-2.2634771e+001
3.6000000e+002	-2.2623667e+001
4.0500000e+002	-2.2607046e+001
4.5000000e+002	-2.2597344e+001
4.9500000e+002	-2.2590863e+001
5.4000000e+002	-2.2584069e+001
5.8500000e+002	-2.2578542e+001
6.3000000e+002	-2.2574312e+001
6.7500000e+002	-2.2575452e+001
7.2000000e+002	-2.2575974e+001
7.6500000e+002	-2.2574489e+001
8.1000000e+002	-2.2575494e+001
8.5500000e+002	-2.2581159e+001
9.0000000e+002	-2.2587158e+001
9.4500000e+002	-2.2594544e+001
9.9000000e+002	-2.2601930e+001
1.0350000e+003	-2.2610757e+001
1.0800000e+003	-2.2619995e+001
1.1250000e+003	-2.2629540e+001
1.1700000e+003	-2.2643411e+001
1.2150000e+003	-2.2657281e+001
1.2600000e+003	-2.2671165e+001
1.3050000e+003	-2.2685622e+001
1.3500000e+003	-2.2700080e+001
1.3950000e+003	-2.2714537e+001
1.4400000e+003	-2.2730775e+001
1.4850000e+003	-2.2748151e+001
1.5300000e+003	-2.2765527e+001
1.5750000e+003	-2.2782903e+001
1.6200000e+003	-2.2803215e+001
1.6650000e+003	-2.2824355e+001
1.7100000e+003	-2.2845495e+001
1.7550000e+003	-2.2866635e+001
1.8000000e+003	-2.2888958e+001
1.8450000e+003	-2.2912549e+001

1.8900000e+003	-2.2936140e+001
1.9350000e+003	-2.2959731e+001
1.9800000e+003	-2.2983322e+001
2.0250000e+003	-2.3008790e+001
2.0700000e+003	-2.3035221e+001
2.1150000e+003	-2.3061653e+001
2.1600000e+003	-2.3088084e+001
2.2050000e+003	-2.3114516e+001
2.2500000e+003	-2.3141767e+001
2.2950000e+003	-2.3171468e+001
2.3400000e+003	-2.3201169e+001
2.3850000e+003	-2.3230871e+001
2.4300000e+003	-2.3260572e+001
2.4750000e+003	-2.3290273e+001
2.5200000e+003	-2.3320585e+001
2.5650000e+003	-2.3353671e+001
2.6100000e+003	-2.3386758e+001
2.6550000e+003	-2.3419845e+001
2.7000000e+003	-2.3452932e+001
2.7450000e+003	-2.3486018e+001
2.7900000e+003	-2.3519105e+001
2.8350000e+003	-2.3553279e+001
2.8800000e+003	-2.3589309e+001
2.9250000e+003	-2.3625339e+001
2.9700000e+003	-2.3661369e+001
3.0150000e+003	-2.3697399e+001
3.0600000e+003	-2.3733429e+001
3.1050000e+003	-2.3769459e+001
3.1500000e+003	-2.3805489e+001
3.1950000e+003	-2.3843708e+001
3.2400000e+003	-2.3882749e+001
3.2850000e+003	-2.3921789e+001
3.3300000e+003	-2.3960830e+001
3.3750000e+003	-2.3999870e+001
3.4200000e+003	-2.4038911e+001
3.4650000e+003	-2.4077951e+001
3.5100000e+003	-2.4116991e+001
3.5550000e+003	-2.4156405e+001
3.6000000e+003	-2.4197893e+001
3.6450000e+003	-2.4239381e+001
3.6900000e+003	-2.4280869e+001
3.7350000e+003	-2.4322357e+001
3.7800000e+003	-2.4363845e+001
3.8250000e+003	-2.4405333e+001
3.8700000e+003	-2.4446820e+001
3.9150000e+003	-2.4488308e+001
3.9600000e+003	-2.4529796e+001
4.0050000e+003	-2.4572444e+001

4.0500000e+003	-2.4616113e+001
4.0950000e+003	-2.4659781e+001
4.1400000e+003	-2.4703450e+001
4.1850000e+003	-2.4747119e+001
4.2300000e+003	-2.4790788e+001
4.2750000e+003	-2.4834457e+001
4.3200000e+003	-2.4878125e+001
4.3650000e+003	-2.4921794e+001
4.4100000e+003	-2.4965463e+001
4.4550000e+003	-2.5009132e+001
4.5000000e+003	-2.5054480e+001
4.5450000e+003	-2.5100427e+001
4.5900000e+003	-2.5146374e+001
4.6350000e+003	-2.5192321e+001
4.6800000e+003	-2.5238268e+001
4.7250000e+003	-2.5284215e+001
4.7700000e+003	-2.5330162e+001
4.8150000e+003	-2.5376109e+001
4.8600000e+003	-2.5422056e+001
4.9050000e+003	-2.5468003e+001
4.9500000e+003	-2.5513950e+001
4.9950000e+003	-2.5559897e+001
5.0400000e+003	-2.5606765e+001
5.0850000e+003	-2.5654187e+001
5.1300000e+003	-2.5701609e+001
5.1750000e+003	-2.5749030e+001
5.2200000e+003	-2.5796452e+001
5.2650000e+003	-2.5843874e+001
5.3100000e+003	-2.5891296e+001
5.3550000e+003	-2.5938717e+001
5.4000000e+003	-2.5986139e+001
5.4450000e+003	-2.6033561e+001
5.4900000e+003	-2.6080982e+001
5.5350000e+003	-2.6128404e+001
5.5800000e+003	-2.6175826e+001
5.6250000e+003	-2.6223297e+001
5.6700000e+003	-2.6272132e+001
5.7150000e+003	-2.6320968e+001
5.7600000e+003	-2.6369803e+001
5.8050000e+003	-2.6418638e+001
5.8500000e+003	-2.6467473e+001
5.8950000e+003	-2.6516308e+001
5.9400000e+003	-2.6565144e+001
5.9850000e+003	-2.6613979e+001
6.0300000e+003	-2.6662814e+001
6.0750000e+003	-2.6711649e+001
6.1200000e+003	-2.6760484e+001
6.1650000e+003	-2.6809320e+001

6.2100000e+003	-2.6858155e+001
6.2550000e+003	-2.6906990e+001
6.3000000e+003	-2.6955825e+001
6.3450000e+003	-2.7005056e+001
6.3900000e+003	-2.7054395e+001
6.4350000e+003	-2.7103733e+001
6.4800000e+003	-2.7153071e+001
6.5250000e+003	-2.7202409e+001
6.5700000e+003	-2.7251747e+001
6.6150000e+003	-2.7301086e+001
6.6600000e+003	-2.7350424e+001
6.7050000e+003	-2.7399762e+001
6.7500000e+003	-2.7449100e+001
6.7950000e+003	-2.7498438e+001
6.8400000e+003	-2.7547777e+001
6.8850000e+003	-2.7597115e+001
6.9300000e+003	-2.7646453e+001
6.9750000e+003	-2.7695791e+001
7.0200000e+003	-2.7745129e+001
7.0650000e+003	-2.7794468e+001
7.1100000e+003	-2.7844008e+001
7.1550000e+003	-2.7893643e+001
7.2000000e+003	-2.7943278e+001
7.2450000e+003	-2.7992914e+001
7.2900000e+003	-2.8042549e+001
7.3350000e+003	-2.8092184e+001
7.3800000e+003	-2.8141820e+001
7.4250000e+003	-2.8191455e+001
7.4700000e+003	-2.8241090e+001
7.5150000e+003	-2.8290726e+001
7.5600000e+003	-2.8340361e+001
7.6050000e+003	-2.8389996e+001
7.6500000e+003	-2.8439632e+001
7.6950000e+003	-2.8489267e+001
7.7400000e+003	-2.8538902e+001
7.7850000e+003	-2.8588538e+001
7.8300000e+003	-2.8638173e+001
7.8750000e+003	-2.8687808e+001
7.9200000e+003	-2.8737444e+001
7.9650000e+003	-2.8787054e+001
8.0100000e+003	-2.8836637e+001
8.0550000e+003	-2.8886221e+001
8.1000000e+003	-2.8935804e+001
8.1450000e+003	-2.8985388e+001
8.1900000e+003	-2.9034971e+001
8.2350000e+003	-2.9084555e+001
8.2800000e+003	-2.9134138e+001
8.3250000e+003	-2.9183721e+001

8.3700000e+003	-2.9233305e+001
8.4150000e+003	-2.9282888e+001
8.4600000e+003	-2.9332472e+001
8.5050000e+003	-2.9382055e+001
8.5500000e+003	-2.9431639e+001
8.5950000e+003	-2.9481222e+001
8.6400000e+003	-2.9530805e+001
8.6850000e+003	-2.9580389e+001
8.7300000e+003	-2.9629972e+001
8.7750000e+003	-2.9679556e+001
8.8200000e+003	-2.9729139e+001
8.8650000e+003	-2.9778723e+001
8.9100000e+003	-2.9828306e+001
8.9550000e+003	-2.9877661e+001
9.0000000e+003	-2.9927002e+001
9.0450000e+003	-2.9976343e+001
9.0900000e+003	-3.0025684e+001
9.1350000e+003	-3.0075025e+001

MIRXH.CAL:

frequency [Hz]	Gain[dBV]
0.0000000e+000	2.0300166e+001
4.5000000e+001	2.2971712e+001
9.0000000e+001	2.3474467e+001
1.3500000e+002	2.3616508e+001
1.8000000e+002	2.3690484e+001
2.2500000e+002	2.3730340e+001
2.7000000e+002	2.3733957e+001
3.1500000e+002	2.3773996e+001
3.6000000e+002	2.3766160e+001
4.0500000e+002	2.3783666e+001
4.5000000e+002	2.3782497e+001
4.9500000e+002	2.3796327e+001
5.4000000e+002	2.3803052e+001
5.8500000e+002	2.3799983e+001
6.3000000e+002	2.3788375e+001
6.7500000e+002	2.3793019e+001
7.2000000e+002	2.3794139e+001
7.6500000e+002	2.3784658e+001
8.1000000e+002	2.3768380e+001
8.5500000e+002	2.3739386e+001
9.0000000e+002	2.3713297e+001
9.4500000e+002	2.3699249e+001
9.9000000e+002	2.3685200e+001
1.0350000e+003	2.3669113e+001
1.0800000e+003	2.3652444e+001
1.1250000e+003	2.3634825e+001
1.1700000e+003	2.3603813e+001
1.2150000e+003	2.3572802e+001
1.2600000e+003	2.3542072e+001
1.3050000e+003	2.3522899e+001
1.3500000e+003	2.3503725e+001
1.3950000e+003	2.3484552e+001
1.4400000e+003	2.3451618e+001
1.4850000e+003	2.3409895e+001
1.5300000e+003	2.3368171e+001
1.5750000e+003	2.3326448e+001
1.6200000e+003	2.3293423e+001
1.6650000e+003	2.3262847e+001
1.7100000e+003	2.3232272e+001
1.7550000e+003	2.3201696e+001
1.8000000e+003	2.3162570e+001
1.8450000e+003	2.3114278e+001
1.8900000e+003	2.3065987e+001
1.9350000e+003	2.3017696e+001

1.9800000e+003	2.2969404e+001
2.0250000e+003	2.2920059e+001
2.0700000e+003	2.2870172e+001
2.1150000e+003	2.2820284e+001
2.1600000e+003	2.2770397e+001
2.2050000e+003	2.2720510e+001
2.2500000e+003	2.2668211e+001
2.2950000e+003	2.2608702e+001
2.3400000e+003	2.2549192e+001
2.3850000e+003	2.2489682e+001
2.4300000e+003	2.2430173e+001
2.4750000e+003	2.2370663e+001
2.5200000e+003	2.2311809e+001
2.5650000e+003	2.2255935e+001
2.6100000e+003	2.2200061e+001
2.6550000e+003	2.2144187e+001
2.7000000e+003	2.2088314e+001
2.7450000e+003	2.2032440e+001
2.7900000e+003	2.1976566e+001
2.8350000e+003	2.1916932e+001
2.8800000e+003	2.1850878e+001
2.9250000e+003	2.1784824e+001
2.9700000e+003	2.1718770e+001
3.0150000e+003	2.1652716e+001
3.0600000e+003	2.1586662e+001
3.1050000e+003	2.1520608e+001
3.1500000e+003	2.1454554e+001
3.1950000e+003	2.1387400e+001
3.2400000e+003	2.1319833e+001
3.2850000e+003	2.1252265e+001
3.3300000e+003	2.1184698e+001
3.3750000e+003	2.1117131e+001
3.4200000e+003	2.1049564e+001
3.4650000e+003	2.0981997e+001
3.5100000e+003	2.0914430e+001
3.5550000e+003	2.0846390e+001
3.6000000e+003	2.0775720e+001
3.6450000e+003	2.0705051e+001
3.6900000e+003	2.0634382e+001
3.7350000e+003	2.0563713e+001
3.7800000e+003	2.0493044e+001
3.8250000e+003	2.0422375e+001
3.8700000e+003	2.0351705e+001
3.9150000e+003	2.0281036e+001
3.9600000e+003	2.0210367e+001
4.0050000e+003	2.0132241e+001
4.0500000e+003	2.0047548e+001
4.0950000e+003	1.9962855e+001

4.1400000e+003 1.9878162e+001
4.1850000e+003 1.9793469e+001
4.2300000e+003 1.9708776e+001
4.2750000e+003 1.9624083e+001
4.3200000e+003 1.9539391e+001
4.3650000e+003 1.9454698e+001
4.4100000e+003 1.9370005e+001
4.4550000e+003 1.9285312e+001
4.5000000e+003 1.9207067e+001
4.5450000e+003 1.9131124e+001
4.5900000e+003 1.9055182e+001
4.6350000e+003 1.8979239e+001
4.6800000e+003 1.8903297e+001
4.7250000e+003 1.8827354e+001
4.7700000e+003 1.8751411e+001
4.8150000e+003 1.8675469e+001
4.8600000e+003 1.8599526e+001
4.9050000e+003 1.8523584e+001
4.9500000e+003 1.8447641e+001
4.9950000e+003 1.8371698e+001
5.0400000e+003 1.8289948e+001
5.0850000e+003 1.8204715e+001
5.1300000e+003 1.8119482e+001
5.1750000e+003 1.8034249e+001
5.2200000e+003 1.7949015e+001
5.2650000e+003 1.7863782e+001
5.3100000e+003 1.7778549e+001
5.3550000e+003 1.7693316e+001
5.4000000e+003 1.7608083e+001
5.4450000e+003 1.7522849e+001
5.4900000e+003 1.7437616e+001
5.5350000e+003 1.7352383e+001
5.5800000e+003 1.7267150e+001
5.6250000e+003 1.7181948e+001
5.6700000e+003 1.7097601e+001
5.7150000e+003 1.7013253e+001
5.7600000e+003 1.6928905e+001
5.8050000e+003 1.6844558e+001
5.8500000e+003 1.6760210e+001
5.8950000e+003 1.6675863e+001
5.9400000e+003 1.6591515e+001
5.9850000e+003 1.6507168e+001
6.0300000e+003 1.6422820e+001
6.0750000e+003 1.6338473e+001
6.1200000e+003 1.6254125e+001
6.1650000e+003 1.6169778e+001
6.2100000e+003 1.6085430e+001
6.2550000e+003 1.6001083e+001

6.3000000e+003 1.5916735e+001
6.3450000e+003 1.5832300e+001
6.3900000e+003 1.5747842e+001
6.4350000e+003 1.5663384e+001
6.4800000e+003 1.5578925e+001
6.5250000e+003 1.5494467e+001
6.5700000e+003 1.5410009e+001
6.6150000e+003 1.5325551e+001
6.6600000e+003 1.5241092e+001
6.7050000e+003 1.5156634e+001
6.7500000e+003 1.5072176e+001
6.7950000e+003 1.4987717e+001
6.8400000e+003 1.4903259e+001
6.8850000e+003 1.4818801e+001
6.9300000e+003 1.4734342e+001
6.9750000e+003 1.4649884e+001
7.0200000e+003 1.4565426e+001
7.0650000e+003 1.4480968e+001
7.1100000e+003 1.4396501e+001
7.1550000e+003 1.4312030e+001
7.2000000e+003 1.4227559e+001
7.2450000e+003 1.4143089e+001
7.2900000e+003 1.4058618e+001
7.3350000e+003 1.3974147e+001
7.3800000e+003 1.3889677e+001
7.4250000e+003 1.3805206e+001
7.4700000e+003 1.3720735e+001
7.5150000e+003 1.3636264e+001
7.5600000e+003 1.3551794e+001
7.6050000e+003 1.3467323e+001
7.6500000e+003 1.3382852e+001
7.6950000e+003 1.3298381e+001
7.7400000e+003 1.3213911e+001
7.7850000e+003 1.3129440e+001
7.8300000e+003 1.3044969e+001
7.8750000e+003 1.2960499e+001
7.9200000e+003 1.2876028e+001
7.9650000e+003 1.2792399e+001
8.0100000e+003 1.2709673e+001
8.0550000e+003 1.2626946e+001
8.1000000e+003 1.2544220e+001
8.1450000e+003 1.2461493e+001
8.1900000e+003 1.2378767e+001
8.2350000e+003 1.2296040e+001
8.2800000e+003 1.2213314e+001
8.3250000e+003 1.2130587e+001
8.3700000e+003 1.2047861e+001
8.4150000e+003 1.1965134e+001

8.4600000e+003 1.1882408e+001
8.5050000e+003 1.1799681e+001
8.5500000e+003 1.1716955e+001
8.5950000e+003 1.1634228e+001
8.6400000e+003 1.1551502e+001
8.6850000e+003 1.1468775e+001
8.7300000e+003 1.1386049e+001
8.7750000e+003 1.1303322e+001
8.8200000e+003 1.1220596e+001
8.8650000e+003 1.1137869e+001
8.9100000e+003 1.1055143e+001
8.9550000e+003 1.0975142e+001
9.0000000e+003 1.0895302e+001
9.0450000e+003 1.0815462e+001
9.0900000e+003 1.0735621e+001
9.1350000e+003 1.0655781e+001

8.6 Radar Calibration Tables

RM52.CAL:

frequency[Hz]	gain[dBV]
3.6000000e+002	-9.3704217e+000
7.2000000e+002	-9.3704217e+000
1.0800000e+003	-9.3704217e+000
1.4400000e+003	-9.3704217e+000
1.8000000e+003	-9.3704217e+000
2.1600000e+003	-9.3704217e+000
2.5200000e+003	-9.3704217e+000
2.8800000e+003	-9.3704217e+000
3.2400000e+003	-9.3704217e+000
3.6000000e+003	-9.3704217e+000
3.9600000e+003	-9.3704217e+000
4.3200000e+003	-9.3704217e+000
4.6800000e+003	-9.3704217e+000
5.0400000e+003	-9.3704217e+000
5.4000000e+003	-9.3704217e+000
5.7600000e+003	-9.3704217e+000
6.1200000e+003	-9.3704217e+000
6.4800000e+003	-9.3704217e+000
6.8400000e+003	-9.3704217e+000
7.2000000e+003	-9.3704217e+000
7.5600000e+003	-9.3704217e+000
7.9200000e+003	-9.3704217e+000
8.2800000e+003	-9.3704217e+000
8.6400000e+003	-9.3704217e+000
9.0000000e+003	-9.3704217e+000
9.3600000e+003	-9.3704217e+000
9.7200000e+003	-9.3704217e+000
1.0080000e+004	-9.3704217e+000
1.0440000e+004	-9.3704217e+000
1.0800000e+004	-9.3704217e+000
1.1160000e+004	-9.3704217e+000
1.1520000e+004	-9.3704217e+000
1.1880000e+004	-9.3704217e+000
1.2240000e+004	-9.3704217e+000
1.2600000e+004	-9.3704217e+000
1.2960000e+004	-9.3704217e+000
1.3320000e+004	-9.3704217e+000
1.3680000e+004	-9.3704217e+000
1.4040000e+004	-9.3704217e+000
1.4400000e+004	-9.3704217e+000
1.4760000e+004	-9.3704217e+000
1.5120000e+004	-9.3704217e+000
1.5480000e+004	-9.3704217e+000

1.5840000e+004	-9.3704217e+000
1.6200000e+004	-9.3704217e+000
1.6560000e+004	-9.3704217e+000
1.6920000e+004	-9.3704217e+000
1.7280000e+004	-9.3704217e+000
1.7640000e+004	-9.3704217e+000
1.8000000e+004	-9.3704217e+000
1.8360000e+004	-9.3704217e+000
1.8720000e+004	-9.3704217e+000

RM26.CAL:

frequency[Hz]	gain[dBV]
7.2000000e+002	-9.3704217e+000
1.4400000e+003	-9.3704217e+000
2.1600000e+003	-9.3704217e+000
2.8800000e+003	-9.3704217e+000
3.6000000e+003	-9.3704217e+000
4.3200000e+003	-9.3704217e+000
5.0400000e+003	-9.3704217e+000
5.7600000e+003	-9.3704217e+000
6.4800000e+003	-9.3704217e+000
7.2000000e+003	-9.3704217e+000
7.9200000e+003	-9.3704217e+000
8.6400000e+003	-9.3704217e+000
9.3600000e+003	-9.3704217e+000
1.0080000e+004	-9.3704217e+000
1.0800000e+004	-9.3704217e+000
1.1520000e+004	-9.3704217e+000
1.2240000e+004	-9.3704217e+000
1.2960000e+004	-9.3704217e+000
1.3680000e+004	-9.3704217e+000
1.4400000e+004	-9.3704217e+000
1.5120000e+004	-9.3704217e+000
1.5840000e+004	-9.3704217e+000
1.6560000e+004	-9.3704217e+000
1.7280000e+004	-9.3704217e+000
1.8000000e+004	-9.3704217e+000
1.8720000e+004	-9.3704217e+000

RM13.CAL:

frequency[Hz]	gain[dBV]
1.4400000e+003	-9.3704217e+000
2.8800000e+003	-9.3704217e+000
4.3200000e+003	-9.3704217e+000
5.7600000e+003	-9.3704217e+000
7.2000000e+003	-9.3704217e+000
8.6400000e+003	-9.3704217e+000
1.0080000e+004	-9.3704217e+000
1.1520000e+004	-9.3704217e+000
1.2960000e+004	-9.3704217e+000
1.4400000e+004	-9.3704217e+000
1.5840000e+004	-9.3704217e+000
1.7280000e+004	-9.3704217e+000
1.8720000e+004	-9.3704217e+000

RM0.CAL:

time[s]
0.0000000e+000
2.1701389e-005
4.3402778e-005
6.5104167e-005
8.6805556e-005
1.0850694e-004
1.3020833e-004
1.5190972e-004
1.7361111e-004
1.9531250e-004
2.1701389e-004
2.3871528e-004
2.6041667e-004
2.8211806e-004
3.0381944e-004
3.2552083e-004
3.4722222e-004
3.6892361e-004
3.9062500e-004
4.1232639e-004
4.3402778e-004
4.5572917e-004
4.7743056e-004
4.9913194e-004
5.2083333e-004
5.4253472e-004

5.6423611e-004
5.8593750e-004
6.0763889e-004
6.2934028e-004
6.5104167e-004
6.7274306e-004
6.9444444e-004
7.1614583e-004
7.3784722e-004
7.5954861e-004
7.8125000e-004
8.0295139e-004
8.2465278e-004
8.4635417e-004
8.6805556e-004
8.8975694e-004
9.1145833e-004
9.3315972e-004
9.5486111e-004
9.7656250e-004
9.9826389e-004
1.0199653e-003
1.0416667e-003
1.0633681e-003
1.0850694e-003
1.1067708e-003
1.1284722e-003
1.1501736e-003
1.1718750e-003
1.1935764e-003
1.2152778e-003
1.2369792e-003
1.2586806e-003
1.2803819e-003
1.3020833e-003
1.3237847e-003
1.3454861e-003
1.3671875e-003
1.3888889e-003
1.4105903e-003
1.4322917e-003
1.4539931e-003
1.4756944e-003
1.4973958e-003
1.5190972e-003
1.5407986e-003
1.5625000e-003
1.5842014e-003

1.6059028e-003
1.6276042e-003
1.6493056e-003
1.6710069e-003
1.6927083e-003
1.7144097e-003
1.7361111e-003
1.7578125e-003
1.7795139e-003
1.8012153e-003
1.8229167e-003
1.8446181e-003
1.8663194e-003
1.8880208e-003
1.9097222e-003
1.9314236e-003
1.9531250e-003
1.9748264e-003
1.9965278e-003
2.0182292e-003
2.0399306e-003
2.0616319e-003
2.0833333e-003
2.1050347e-003
2.1267361e-003
2.1484375e-003
2.1701389e-003
2.1918403e-003
2.2135417e-003
2.2352431e-003

8.7 Relaxation Probe Calibration Tables

RP_time.asc:

RP1,RP2 timeaxis, absolute terms

T0:= switch relays on
T0 + 0.5s: voltage on rp1 and rp2 read
T0 + 1.0s: relays switched off

Sample nr.	t-RP1 [T0+ x sec.]	t-RP2 [T0+ x sec.]
0	0.5	0.5
1	1.05	1.06
2	1.07	1.08
3	1.09	1.10
4	1.11	1.12
5	1.13	1.14
6	1.15	1.16
7	1.17	1.18
8	1.19	1.20
9	1.21	1.22
10	1.23	1.24
11	1.25	1.26
12	1.27	1.28
13	1.29	1.30
14	1.31	1.32
15	1.33	1.34
16	1.35	1.36
17	1.37	1.38
18	1.39	1.40
19	1.41	1.42
20	1.43	1.44
21	1.45	1.46
22	1.47	1.48
23	1.49	1.50
24	1.51	1.52
25	1.53	1.54
26	1.55	1.56
27	1.57	1.58
28	1.59	1.60
29	1.61	1.62
30	1.63	1.64
31	1.65	1.66
32	1.67	1.68
33	1.69	1.70
34	1.71	1.72

35	1.73	1.74
36	1.75	1.76
37	1.77	1.78
38	1.79	1.80
39	1.81	1.82
40	1.83	1.84
41	2.00011	2.00033
42	2.00022	2.00044
43	4.00011	4.00033
44	4.00022	4.00044
45	6.00011	6.00033
46	6.00022	6.00044
47	8.00011	8.00033
48	8.00022	8.00044
49	10.00011	10.00033
50	10.00022	10.00044
51	12.00011	12.00033
52	12.00022	12.00044
53	14.00011	14.00033
54	14.00022	14.00044
55	16.00011	16.00033
56	16.00022	16.00044
57	18.00011	18.00033
58	18.00022	18.00044
59	20.00011	20.00033
60	20.00022	20.00044
61	22.00011	22.00033
62	22.00022	22.00044
63	24.00011	24.00033
64	24.00022	24.00044
65	26.00011	26.00033
66	26.00022	26.00044
67	28.00011	28.00033
68	28.00022	28.00044
69	30.00011	30.00033
70	30.00022	30.00044
71	32.00011	32.00033
72	32.00022	32.00044
73	34.00011	34.00033
74	34.00022	34.00044
75	36.00011	36.00033
76	36.00022	36.00044
77	38.00011	38.00033
78	38.00022	38.00044
79	40.00011	40.00033
80	40.00022	40.00044
81	42.00011	42.00033
82	42.00022	42.00044

83	44.00011	44.00033
84	44.00022	44.00044
85	46.00011	46.00033
86	46.00022	46.00044
87	48.00011	48.00033
88	48.00022	48.00044
89	50.00011	50.00033
90	50.00022	50.00044
91	52.00011	52.00033
92	52.00022	52.00044
93	54.00011	54.00033
94	54.00022	54.00044
95	56.00011	56.00033
96	56.00022	56.00044

next T0 = T0old + 64s