RF Leakage Detector System

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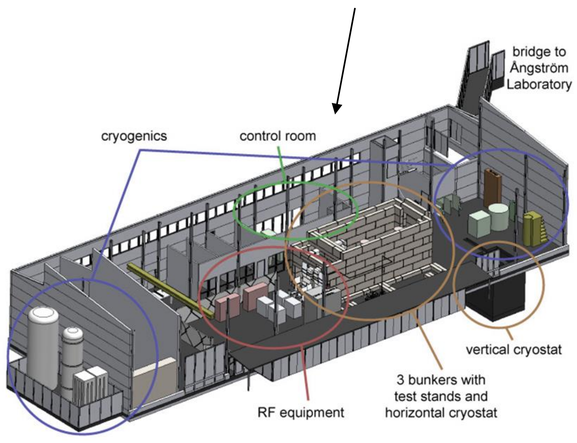
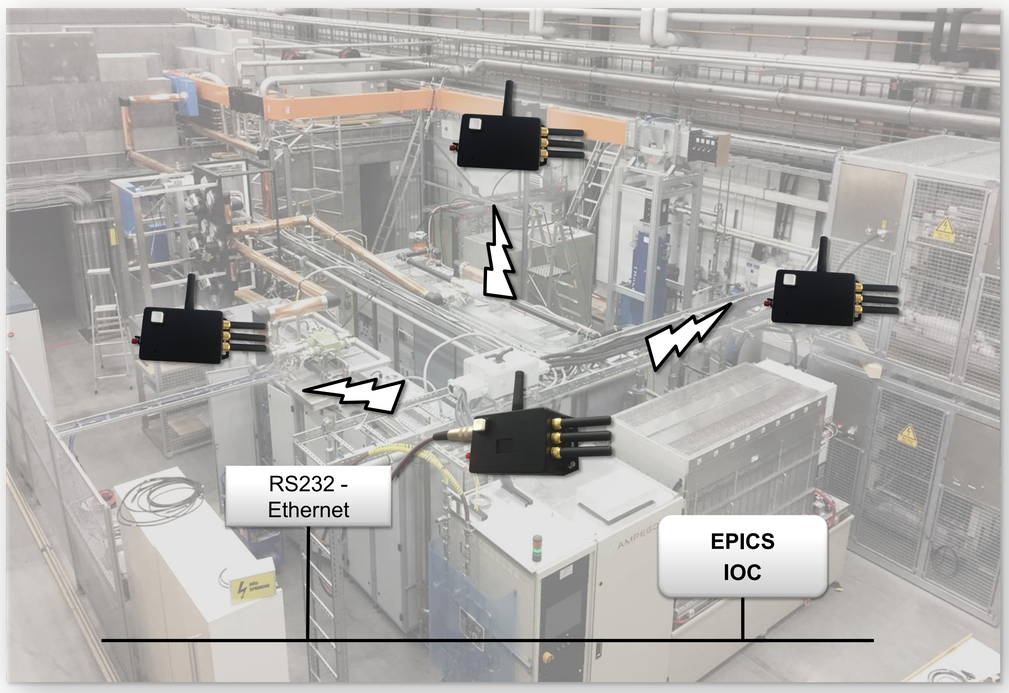
FREIA Laboratory in Uppsala, Sweden, supports development of accelerator technology and instrumentation.
Superconducting RF cavity tests are planned at 352, 400, and 704 MHz using pulsed RF sources up to about 1 MW.
Problem: Monitor the electromagnetic field in the experimental hall for personal safety.

Goals for an RF leakage detector system:
- Low cost
- Small footprint -> 60x100x40 mm
- Easy installation -> Wireless readout
- Low power consumption <-> Battery operation
- Integration with EPICS

Features:
- Physically identical multiple nodes
- One configured as master, the others as slaves
- OLED Display
- Acoustic Alarm Signal
- RS232 & USB Interface to Master
- Master controlled by EPICS StreamDevice using RS232 to Ethernet MOXA NPort 5610 server



Main parameters:
- 3 independent RF measurement channels per node
- Frequency span: 100 kHz to 1 GHz, unfiltered
- Filtered: E.g. 334 to 360 MHz, independent channels
- Dynamic Range: -20 to +14 dBm
- Sample Rate: up to 2 kHz (adjustable)
- Direct Shottky based detectors
- Pulsed signal operation, minimum 0.5 ms (adjustable)
- Power: 3xAAA, USB or 24V External
- Average power (Slave) : 123 to 515 µA
- 0.3 to 1.1 year battery life (Slave)
- Wireless Link at 868 MHz ISM band
- Range: 100m (Realistic Estimate)
- Data Rate: 0.01 to 10 Hz (adjustable)



Bill of Material (BOM) – Single Component Purchase (in €)

Components			
Lumped Elements			3,85
Regulator	REG71050DDCT		1,567
	SWS001		1,256
Op-Amp	L78L05ABUTR		0,235
µC	PIC24F16KA102-I/ML		2,493
LDO 24V	MCP6001UT-I/OT		0,284
Crystal	QC32		1,669
Transceiver	MRF89XAT-I/MQ		2,051
FTDI	FT230XS		1,951
RS232	ST3232BDR		0,631
RFM (3 pcs)	LTC5507ES6PBF		10,254
SMA Connector (4 pcs)	SMA JACK R/A 50 OHM PCB		6,68
RFM	LTC5507ES6PBF		3,418
USB Connector	MINI-USB-32005-201		1,085
		Sub Total:	34,006

Other				
Display	SSD1306-OLED White	Ebay		5,0
Casing		Farnell		4,62
Antenna		Farnell		2,635
PCB (Per piece if order total 10 boards)		Cogra		23,5
			Sub Total:	35,755

One of the objectives:
keep the cost low.

Estimated prototype cost:
~70 € per piece

Battery life estimation and optimization

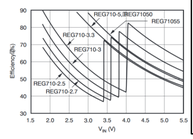
Power Consumption

V-Regulator: REG710-3.3
I_Q = 65µA
Efficiency: assume moderate 70%

RS232
Off in slave mode (hardwired)
I_Q = 0 mA

USB
Off (self-powered)
I_Q = 0 mA

Display
Normally Off (hardwired)
I_Q = 0 mA



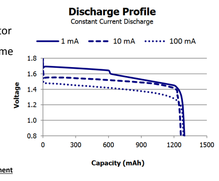
Total Power Consumption

Sampling rate: 2000 kHz (0.5ms pulses min)
$I_{Tot,3\ Detectors}$ = 65+(48.6+243+68)/0.7 = 579 µA
$I_{Tot,1\ Detector}$ = 65+(48.6+91+24)/0.7 = 299 µA

Sampling rate: 1000 kHz (1.0ms pulses min)
$I_{Tot,3\ Detectors}$ = 65+(48.6+129+35)/0.7 = 369 µA
$I_{Tot,1\ Detector}$ = 65+(48.6+53+13)/0.7 = 228 µA

Sampling rate: 500 Hz (2.0 ms pulses min)
TX freq: 0.2 Hz
$I_{Tot,3\ Detectors}$ = 65+(19.2+129+35)/0.7 = 327 µA
$I_{Tot,1\ Detector}$ = 65+(19.2+53+13)/0.7 = 187 µA

Life-Span Improvements
- Using a LDO instead of a switched regulator gives about 70 % efficiency running of same 3xAAA stack
- Microchip MCP1700 has similar sized footprint (SOT-23) and 1/3 price
- Quiescent Current of MCP1700 ~1.6 µA



Transceiver: MRF89XA
Running: 200 kbps, 1Hz TX, 20 Byte Packages
Package overhead 12 Byte
RX for 200 ms every 60 seconds
TX time = (20*8)/200e3 = 0.8 ms
TX start-up time = 1.5 ms

I_{TX} = 16 mA
$I_{TX,Average}$ = 16*2.3e-3=36.8 µA

$I_{Q,Sleep}$ = 0.1 µA

I_{RX} = 3.5 mA
$I_{RX,Average}$ = 3.5e-3*3.3e-3 = 11.7 µA

$I_{TRX,Total}$ = 36.8 + 0.1 + 11.7 = 48.6 µA

Micro-Controller: Microchip 16-bit 24F16KA102
Running: 4 MIPS (internal RC)
ADC sample time: ~40 µs
Sampling 3 channels at 2 kHz
Total sampling time = 40*3*2000 = 240 ms

I_Q = 950 µA
I_{Sleep} = 15 µA

$I_{Q,Avg,\ 3\ Detectors}$ = 950 * 120e-3 = 228 µA
$I_{Q,Avg,\ 1\ Detector}$ = 950 * 120e-3 = 76 µA

$I_{Tot,3\ Detectors}$ = 228+15 = 243 µA
$I_{Tot,1\ Detector}$ = 76+15 = 91 µA

RF-Detector : LTC5507
Off (self-powered)
Sampling rate: 2000 kHz
Sampling time: 20 µs
I_Q = 550 µA
$I_{Q,\ Sleep}$ = 2 µA
$I_{Q,Avg,\ 3\ Detectors}$ = 550*20e-6*3*2e3 = 66 µA
$I_{Q,Avg,\ 1\ Detector}$ = 550*20e-6*2e3 = 22 µA

$I_{Tot,3\ Detectors}$ = 66+2 = 68 µA
$I_{Tot,1\ Detector}$ = 22+2 = 24 µA

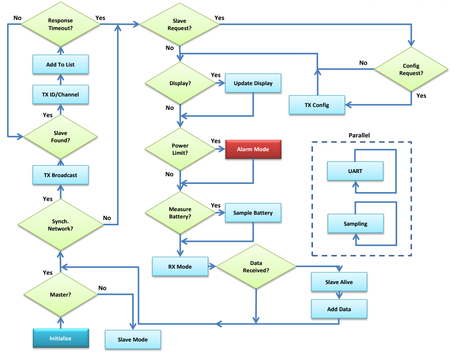
Improvement of 1.6 µA quiescent current

	Improvement
Sampling Rate: 2000 kHz (0.5ms Pulses Min)	
$I_{Tot,3\ Detectors}$ = 1.6 +(48.6+243+68)/0.7 = 515 µA	11%
$I_{Tot,1\ Detector}$ = 1.6 +(48.6+91+24)/0.7 = 235 µA	21%
Sampling Rate: 1000 kHz (1.0ms Pulses Min)	
$I_{Tot,3\ Detectors}$ = 1.6 +(48.6+129+35)/0.7 = 305 µA	17%
$I_{Tot,1\ Detector}$ = 1.6 +(48.6+53+13)/0.7 = 165 µA	28%
Sampling Rate: 500 Hz (2.0 ms Pulses Min)	
TX Freq: 0.2 Hz	
$I_{Tot,3\ Detectors}$ = 1.6+(19.2+129+35)/0.7 = 263 µA	19%
$I_{Tot,1\ Detector}$ = 1.6 +(19.2+53+13)/0.7 = 123 µA	34%

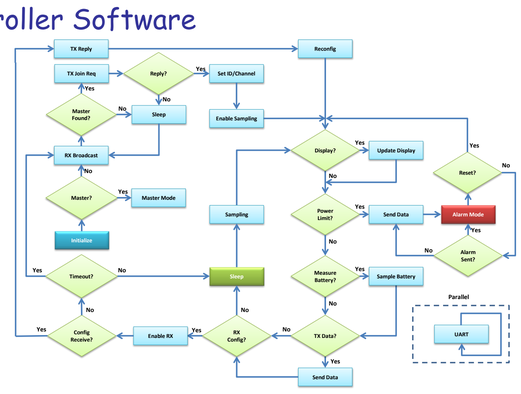
New Estimated Lifespan (Slave): 0.3 to 1.1 year

Estimated Lifespan (Slave): 0.27 to 0.8 year

Micro-controller Software

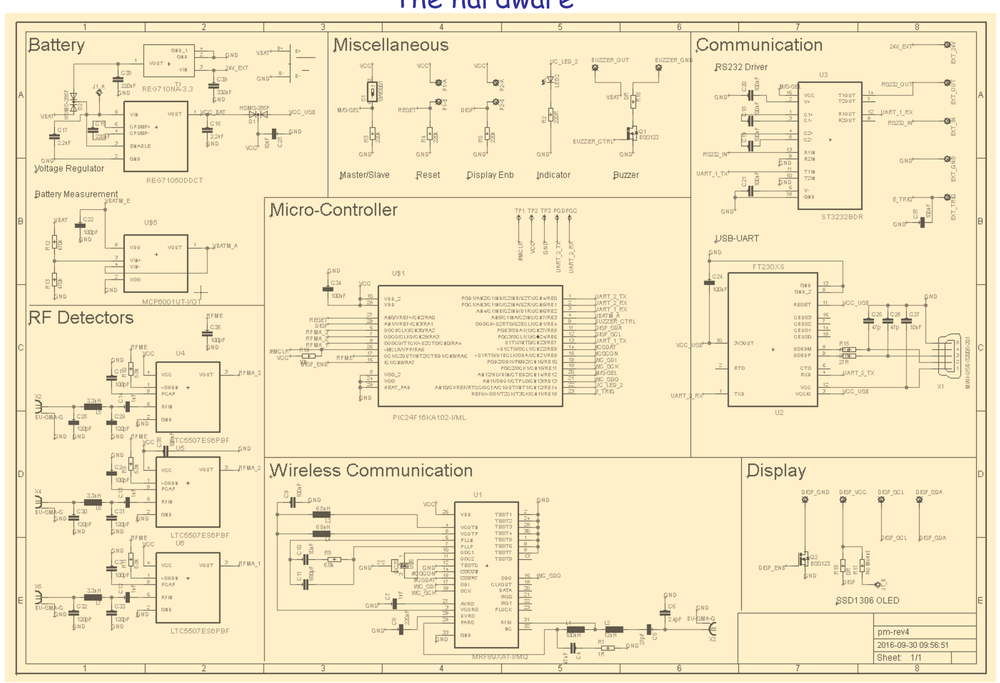


Program flow-diagram: master mode

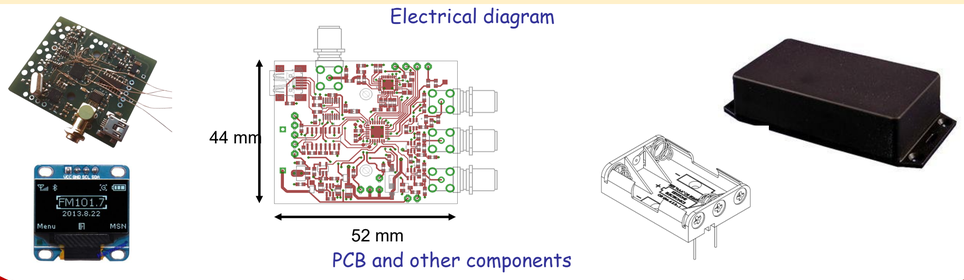


Program flow-diagram: slave mode

The hardware

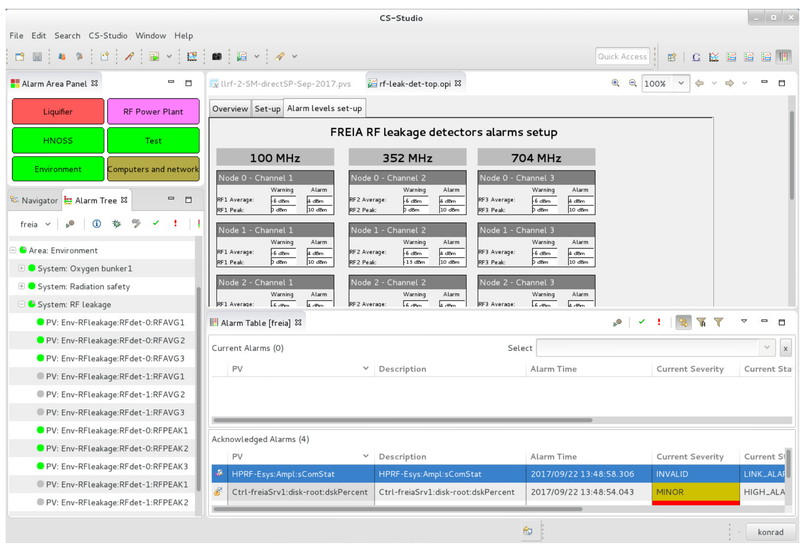


Electrical diagram

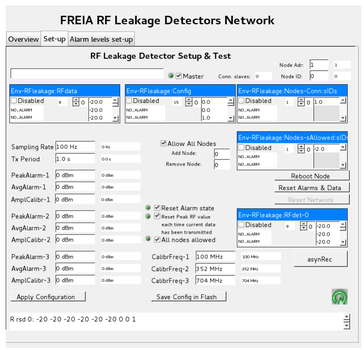


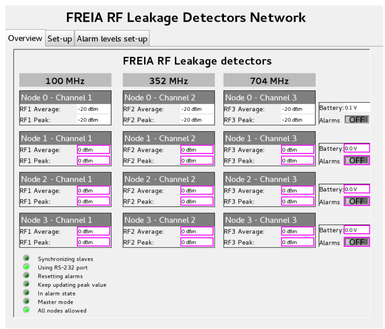
PCB and other components

Integration with Epics



Control System Studio - Alarms





Control System Studio - OPI screens

```
Terminator = LF;
ExtraInput=Ignore;
getId {
    out "R nid";
    in "R nid %d";
        @init { out "R nid"; in "R nid %d"; }
}
setId {
    out "W nid %d";
    in "W nid %d";
        @init { getId; }
}
getConfBuf {
    out "R \$1";
    in "R \$1 %d";
        @init { out "R \$1"; in "R \$1 %d"; }
}
setConfBuf {
    out "W \$1 %d";
    in "W \$1 %d";
        @init { getConfBuf; }
}
getCalibrFreq {
    out "R sf\$1";
    in "R sf\$1 %d";
        @init { out "R sf\$1"; in "R sf\$1 %d"; }
}
setCalibrFreq {
    out "W sf\$1 %d";
    in "W sf\$1 %d";
        @init { getCalibrFreq; }
}
setAllowAllNodes {
    out "W aan %d";
    in "W aan %d";
  @init { getAan; }
}
getConnNodes { separator = " ";
    out "R rci";
    in "R rci %d";
        @init { out "R rci"; in "R rci %d"; }
}
getAllowedNodes { separator = " ";
    out "R ani";
    in "R ani %d";
        @init { out "R ani"; in "R ani %d"; }
}
getRFdata { separator = " ";
    out "R rsd \$1";
    in "R rsd \$1: %d";
}
## Write Only commands
applyConfigBuf {
   out "W acs";
   in "W acs";
}
reset {
   out "W rst";
   in "W rst";
}
…
```

StreamDevice Protocol file (excerpt)

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