Updating NMR Probe Electronics in the Muon g-2 Experiment

Audrey Kvam

University of Washington

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CONTENTS

Background

A particle's magnetic moment $\boldsymbol{\mu}$ is related to its spin $\mathbf{S}$ by

$$\boldsymbol{\mu} = g\mu_B\mathbf{S}, \qquad \mu_B = \frac{e\hbar}{2m}$$

For point-like fermions, $g \approx 2$ when radiative corrections are taken into account. The deviation from 2 is called the *anomalous magnetic moment*, and is defined as

$$a = \frac{1}{2}(g-2).$$

Standard Model Theoretical Prediction

$$a^{\text{SM}} = a^{\text{QED}} + a^{\text{EW}} + a^{\text{Hadron}}$$

- QED
- Hadronic
- EW

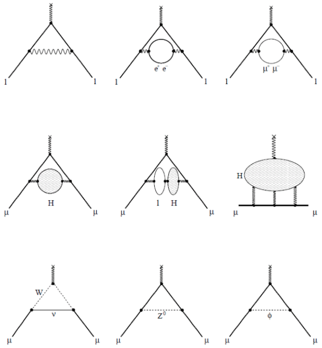
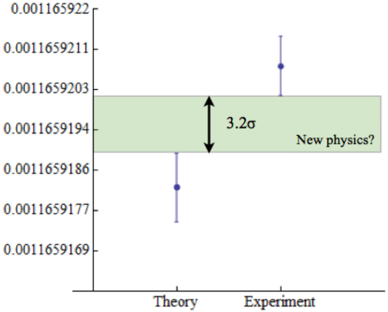


Figure: Radiative corrections to muon g-factor [1].



High precision measurements of the magnetic anomaly compared to similarly precise theoretical predictions provide a stringent test of the completeness of the Standard Model.

g-2 at Fermilab

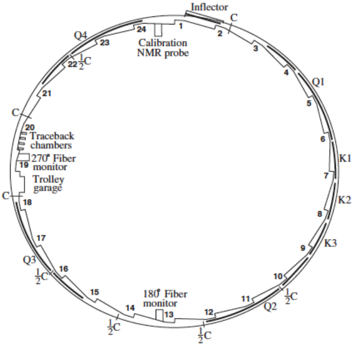
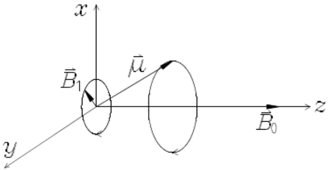


Figure: Storage ring used in g-2 at Brookhaven National Laboratory [3].

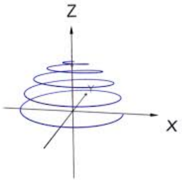
$$\omega_a = \omega_s - \omega_c = -a_\mu \frac{qB}{m}$$

$$a_\mu = \frac{\omega_a/\omega_p}{\mu_\mu/\mu_p - \omega_a/\omega_p}$$

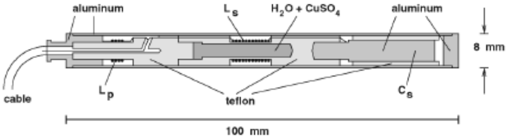
Pulsed NMR



Introduce second, oscillating magnetic field in x-y plane [6].



Relaxation of magnetic field [5].



Schematic of NMR probe [1].

The end goal is to measure the returning free induction decay (FID) signal, from which you can extract ω_p.

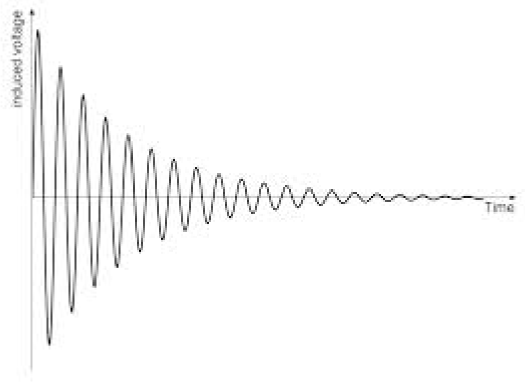


Figure: Shape of ideal FID [4].

Example FID - exponential decay modulated by sine wave.

NMR Probe Circuit Diagram

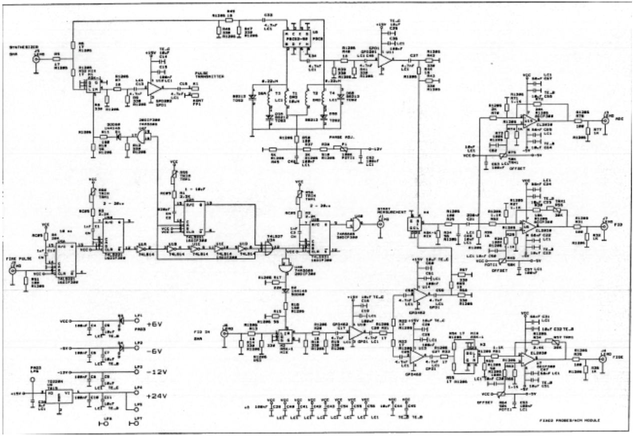
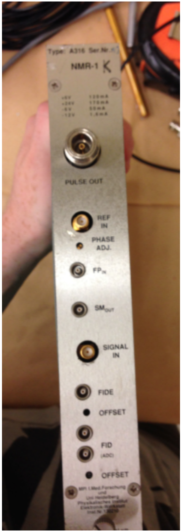
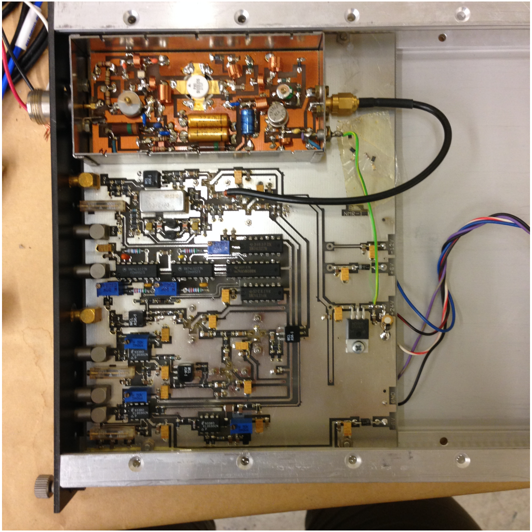
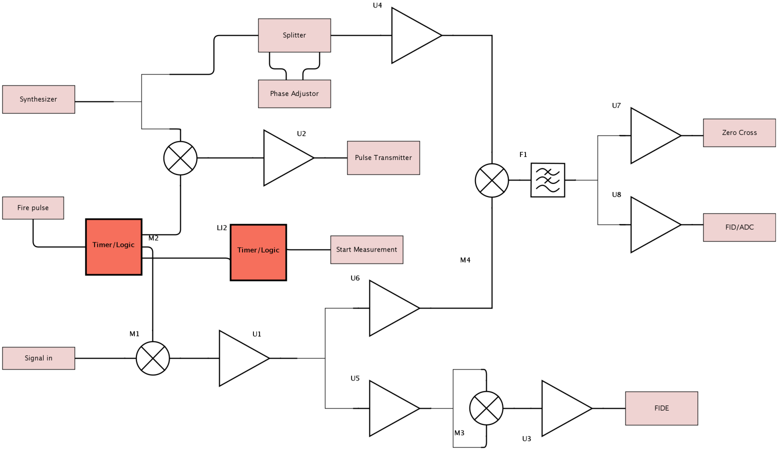
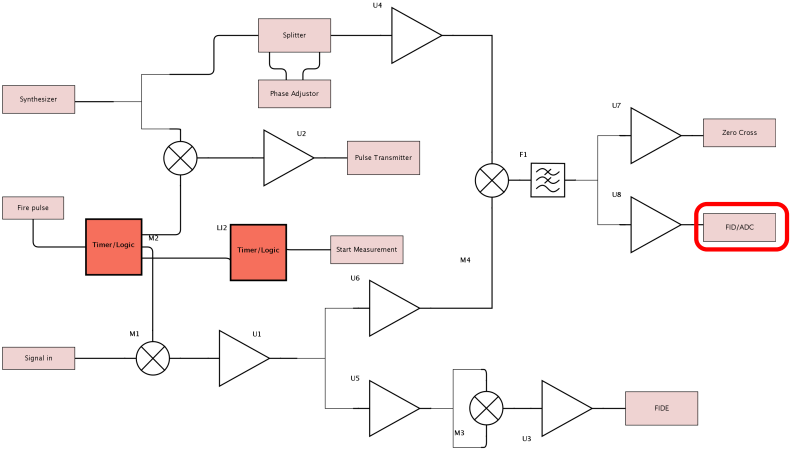


Figure: Schematic of NMR probe circuit [2].


NMR-1
PULSE OUT
REF IN
PHASE ADJ.
SIGNAL IN
FIDE
OFFSET
FID
OFFSET




U4
Splitter
Phase Adjustor
Synthesizer
U2
Pulse Transmitter
U7
Zero Cross
F1
U8
FID/ADC
Fire pulse
Timer/Logic
M2
LI2
Timer/Logic
Start Measurement
M4
U6
M1
U1
Signal in
U5
M3
U3
FIDE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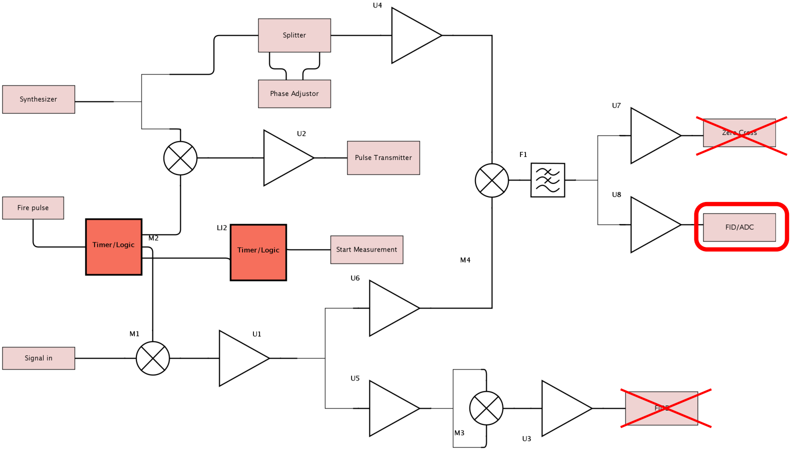
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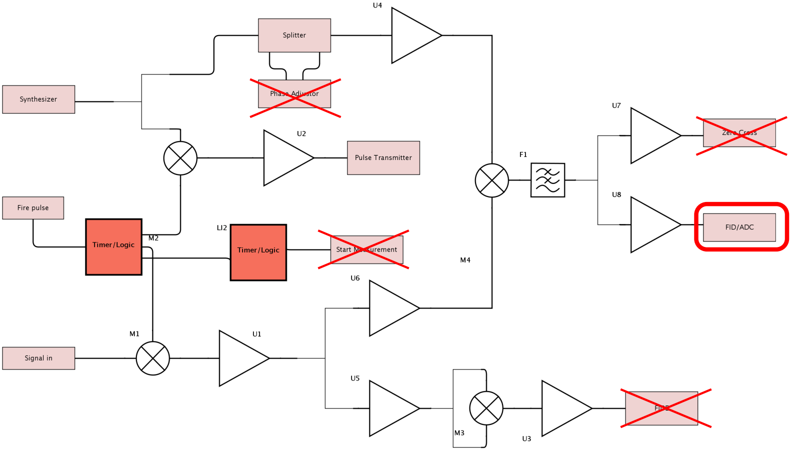
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Timer/Logic
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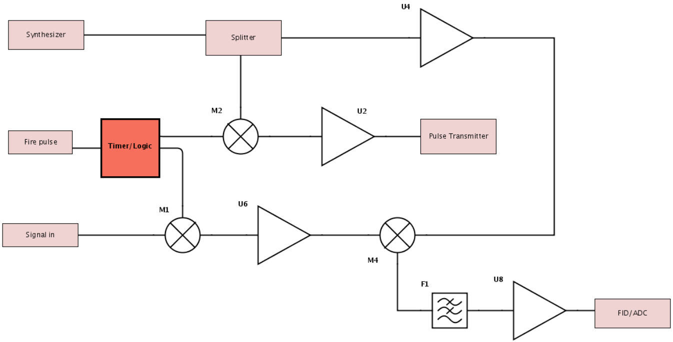
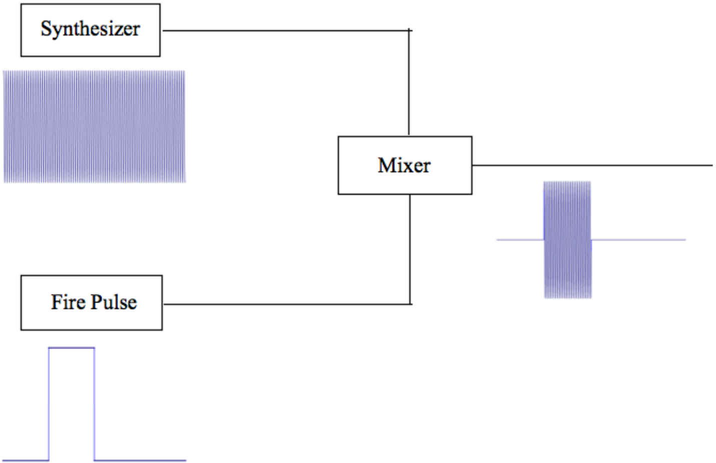
U6
M1
U1
Signal in
U5
M3
U3
FID

New Schematic



Transmitted Signal



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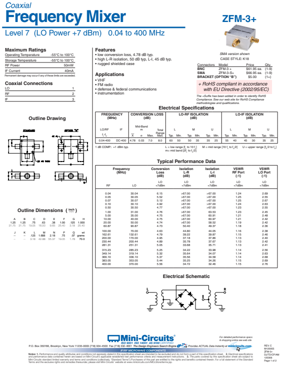

Coaxial

Frequency Mixer

Level 7 (LO Power +7 dBm) 0.04 to 400 MHz

ZFM-3+

SMA version shown

CASE STYLE: K18

Connectors	Model	Price	Qty.
BNC	ZFM-3+	$61.95 ea.	(1-9)
SMA	ZFM-3-S+	$66.95 ea.	(1-9)
BRACKET (OPTION "B")		$5.00	(1+)

+ RoHS compliant in accordance with EU Directive (2002/95/EC)

The +Suffix has been added in order to identify RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications.

Maximum Ratings

Operating Temperature	-55°C to 100°C
Storage Temperature	-55°C to 100°C
RF Power	50mW
IF Current	40mA

Permanent damage may occur if any of these limits are exceeded.

Coaxial Connections

LO	1
RF	2
IF	3

Features

- low conversion loss, 4.78 dB typ.
- high L-R isolation, 50 dB typ, L-I, 45 dB typ.
- rugged shielded case

Applications

- VHF
- FM radio
- defense & federal communications
- instrumentation

Electrical Specifications

FREQUENCY (MHz) LO/RF f_L-f_U	FREQUENCY (MHz) IF	CONVERSION LOSS (dB) Mid-Band m $\overline{X}$	CONVERSION LOSS (dB) Mid-Band m σ	CONVERSION LOSS (dB) Max.	Total Range Max.	LO-RF ISOLATION (dB) L Typ.	L Min.	M Typ.	M Min.	U Typ.	U Min.	LO-IF ISOLATION (dB) L Typ.	L Min.	M Typ.	M Min.	U Typ.	U Min.
0.04-400	DC-400	4.78	0.03	7.0	8.0	60	50	50	35	35	25	55	40	45	30	35	25

1 dB COMP.: +1 dBm typ.

L = low range [f_L to 10 f_L] M = mid range [10 f_L to f_U/2] U = upper range [f_U/2 to f_U]
m= mid band [2f_L to f_U/2]

Outline Drawing

STANDARD OPTION "B"

Outline Dimensions (inch / mm)

A	B	C	D	E	F	G	H
1.25	1.25	.75	.63	.38	1.00	.125	1.000
31.75	31.75	19.05	16.00	9.65	25.40	3.18	25.40

J	K	L	M	N	P	Q	wt
--	--	.125	1.688	2.18	.75	.07	grams
--	--	3.18	42.88	55.37	19.05	1.78	70.0

Typical Performance Data

Frequency (MHz) RF	Frequency (MHz) LO	Conversion Loss (dB) LO +7dBm	Isolation L-R (dB) LO +7dBm	Isolation L-I (dB) LO +7dBm	VSWR RF Port (:1) LO +7dBm	VSWR LO Port (:1) LO +7dBm
0.04	30.04	6.15	>67.00	>67.00	1.24	2.69
0.05	30.05	5.52	>67.00	>67.00	1.25	2.55
0.07	30.07	5.12	>67.00	>67.00	1.25	2.67
0.10	30.10	4.92	>67.00	>67.00	1.24	2.63
0.50	30.50	4.77	>67.00	>67.00	1.23	2.55
1.00	31.00	4.76	>67.00	63.53	1.23	2.45
5.00	35.00	4.75	>67.00	60.91	1.21	2.48
10.00	40.00	4.75	>67.00	60.97	1.21	2.42
20.00	50.00	4.74	>67.00	58.52	1.19	2.42
60.87	90.87	4.73	50.40	49.37	1.18	2.36
100.00	70.00	4.63	44.80	44.05	1.16	2.38
162.61	132.61	4.79	39.22	39.87	1.15	2.46
200.00	170.00	4.95	37.18	37.86	1.13	2.40
230.44	200.44	4.89	35.78	37.67	1.13	2.42
281.31	251.31	5.05	33.68	35.71	1.13	2.41
315.23	285.23	5.25	34.22	33.98	1.14	2.56
349.14	319.14	5.32	35.64	34.07	1.14	2.63
366.10	336.10	5.37	35.56	34.58	1.14	2.68
383.05	353.05	5.44	35.25	34.26	1.15	2.69
400.00	370.00	5.56	34.72	32.46	1.15	2.76

Electrical Schematic

L I R

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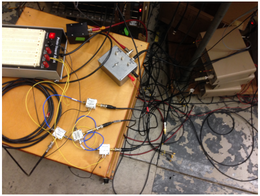
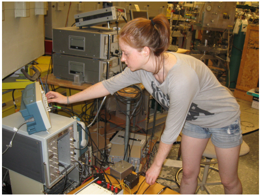
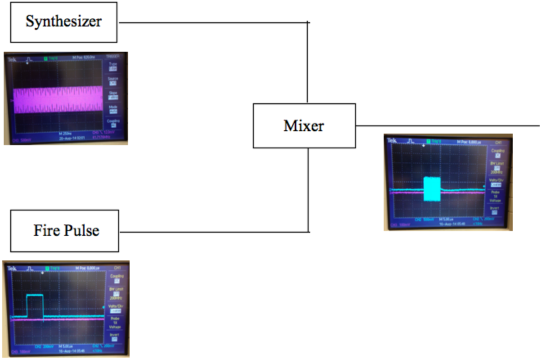
Figure: From [7].

Workspace

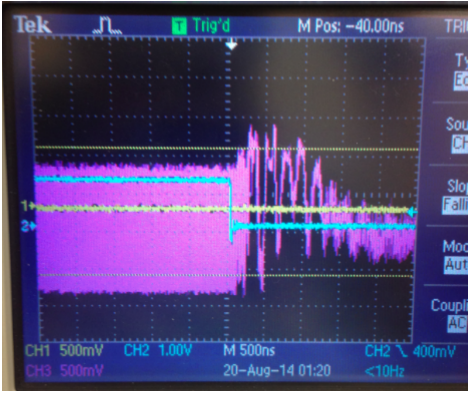




Seeing Signals

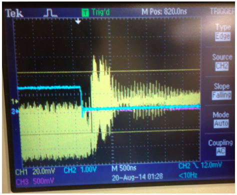


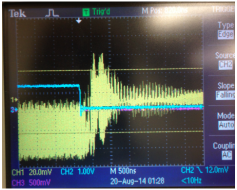
Returning Signal

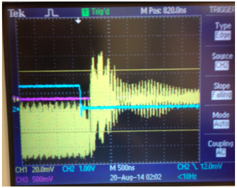


Mix with synthesizer to get FID...

Success

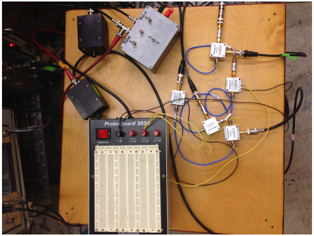


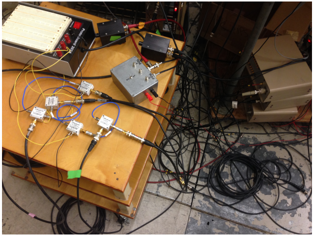




FIDs! With tweaking (adjusting current etc), can look nicer than these.

Final Circuit





Making the Circuit Better

- Continue to work with g-2
- Make baseboard for circuit
- Make compatible for experiment
- Additional possibilities
  - Control length of $\frac{\pi}{2}$ pulse
  - Add sequencing of pulses
  - Disentangle relaxation times T_1 and T_2 from spin-echo

Acknowledgments

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