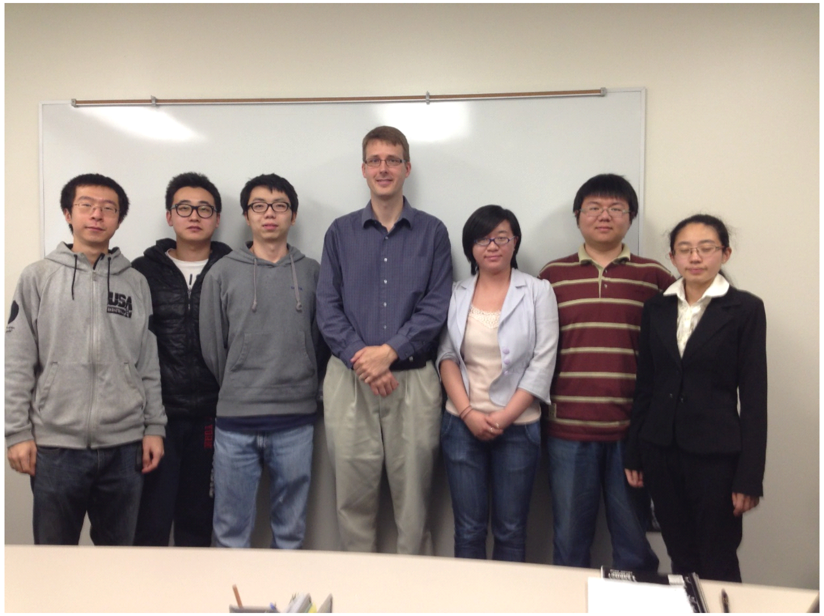
DEC14-14
Low Cost RF Power Meter

Client- PowerFilm,Inc

Adviser- Prof. Nathan Neihart

Team



Boyang Hu, Cong Han,
Xiaoshuo Li, Silu Feng,
Yijia Huang, Yusi Xie

Requirement

Functional Requirement:

- RF pickup
- Capable of measuring forward and reflected power
- Capable of measuring pure sinusoidal RF input
- Capable of measuring pulse modulated sinusoidal RF input with 50% duty cycle
- Power range: 100-250W
- Frequency level: 13.5MHz and 40Mhz
- Output voltage within 5V
- AC attenuation up to 60dB
- Be able to connect to RF transmission line using Type N connector
- Total error within 10%

Non-functional requirement:

- **Low Cost (<$100)**
- A plan for power measurement up to 1200W
- Safe and easy to use

Market Survey

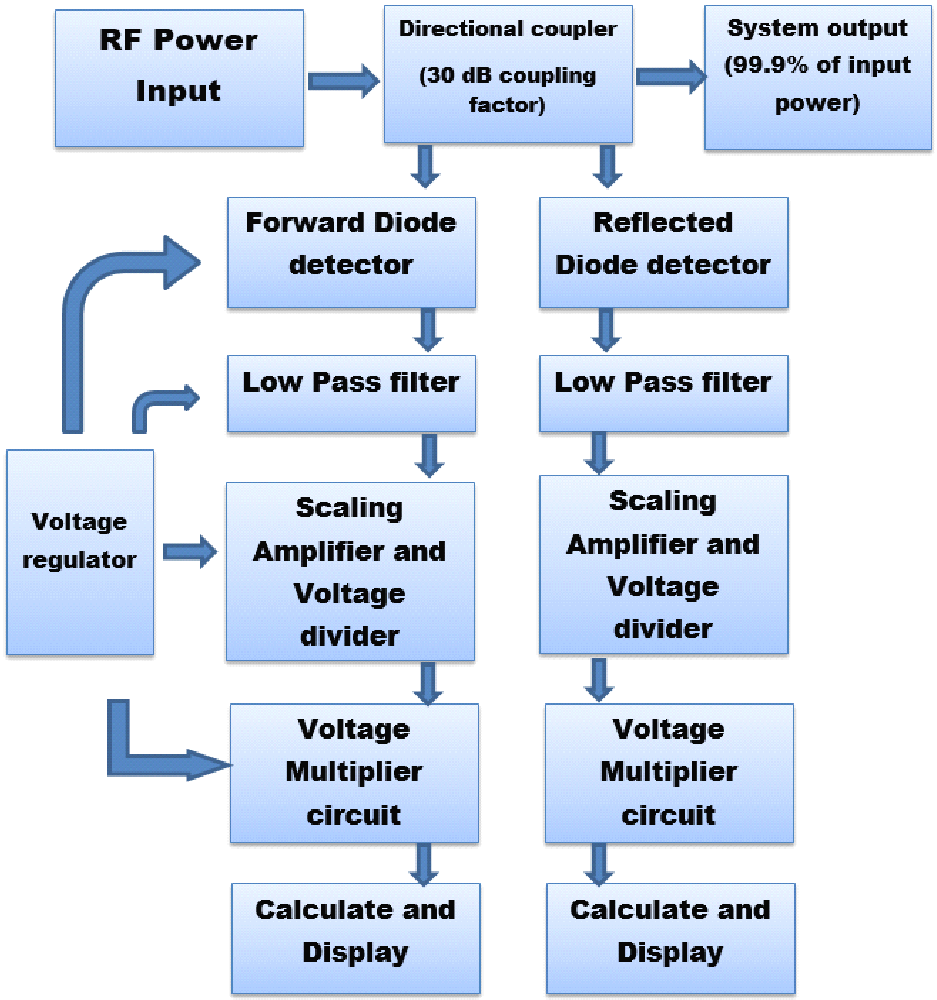
Agilent Technologies

$2051

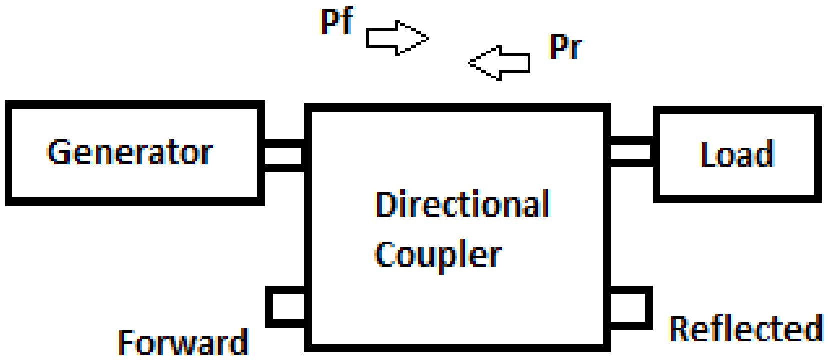
Bird
Technologies
4304A

$714.95

Block Diagram
& project schedule

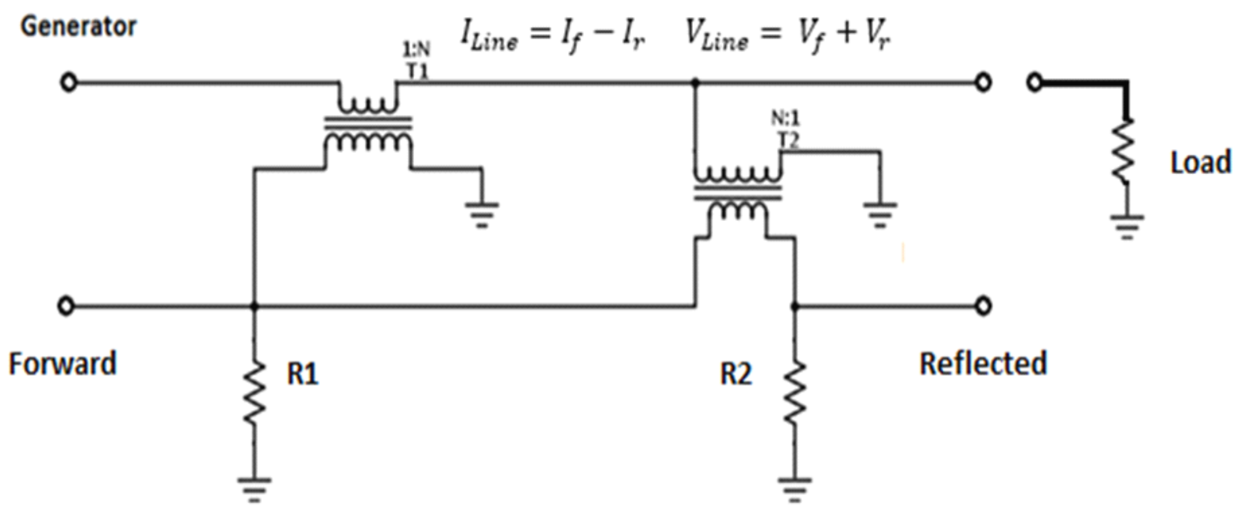


Directional Coupler



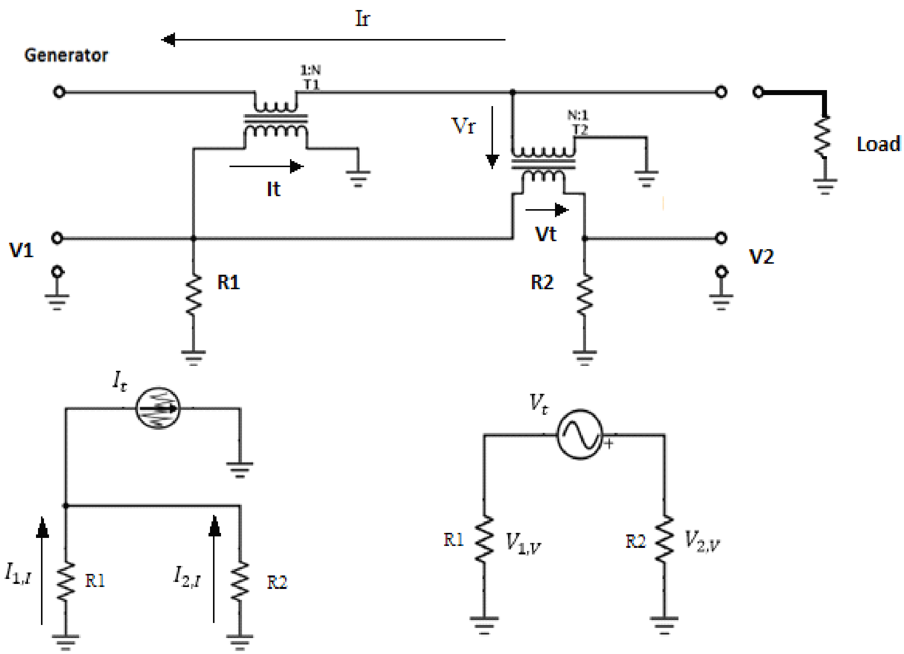
Directional coupler block diagram

Directional Coupler



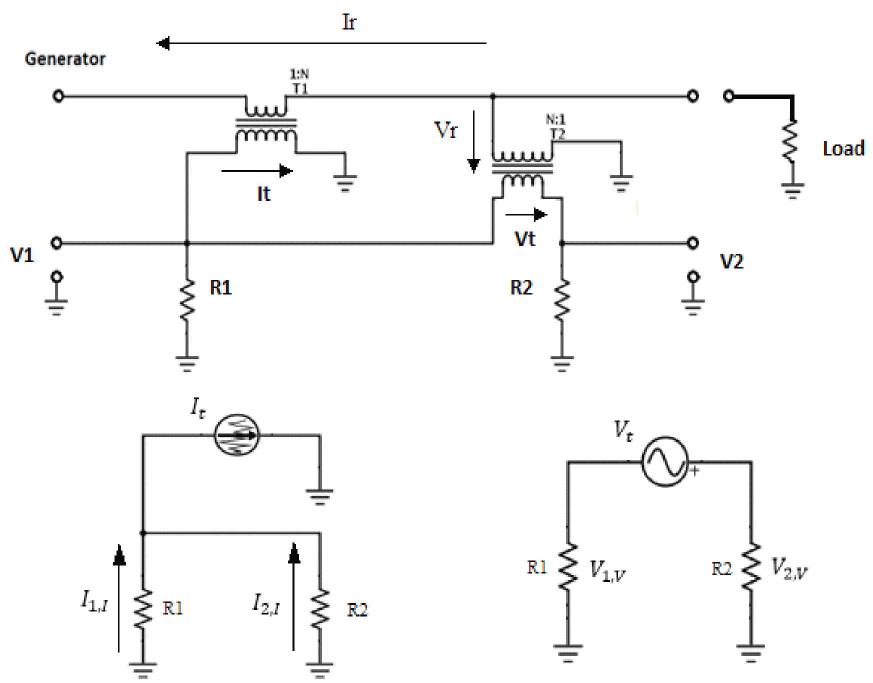
Tandem Directional Coupler

Directional Coupler with Forward Wave



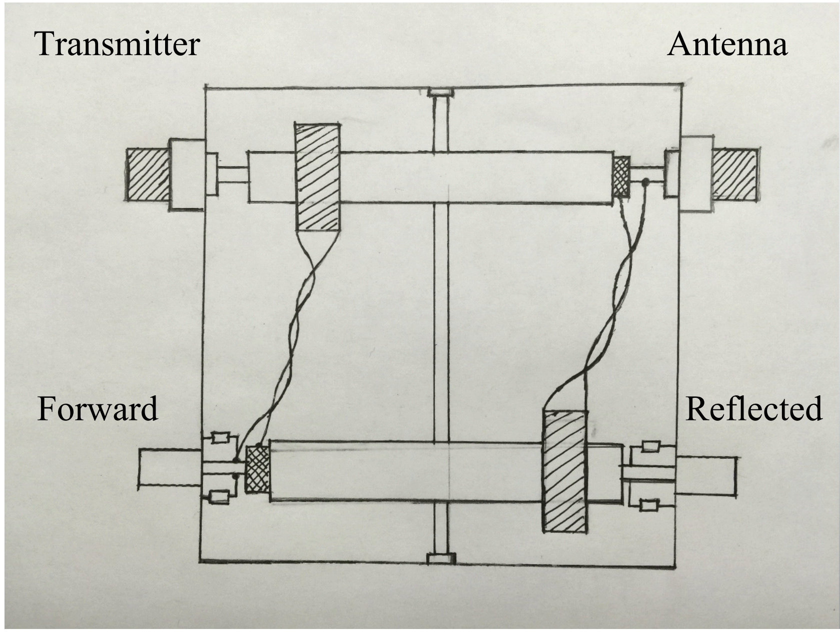
transmission line

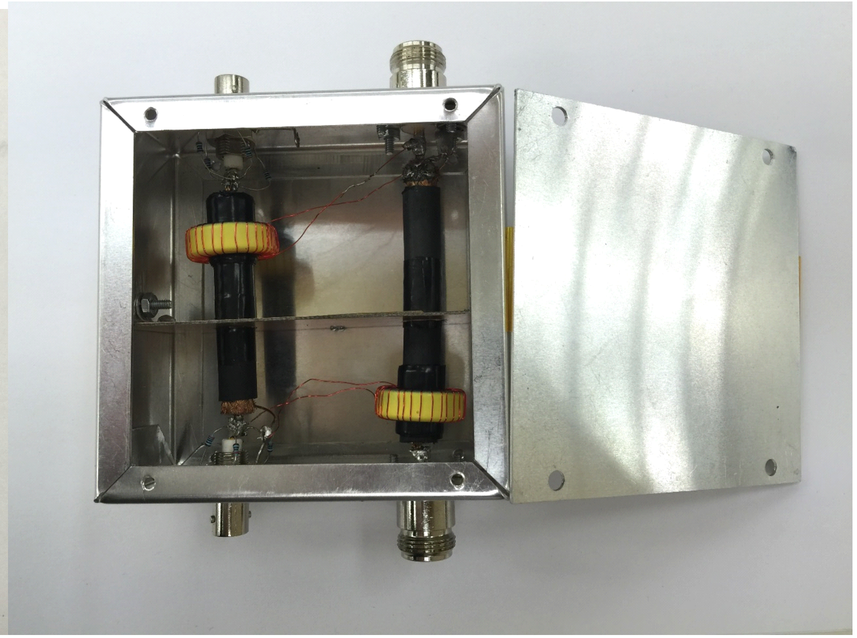
Directional Coupler with Reflected Wave



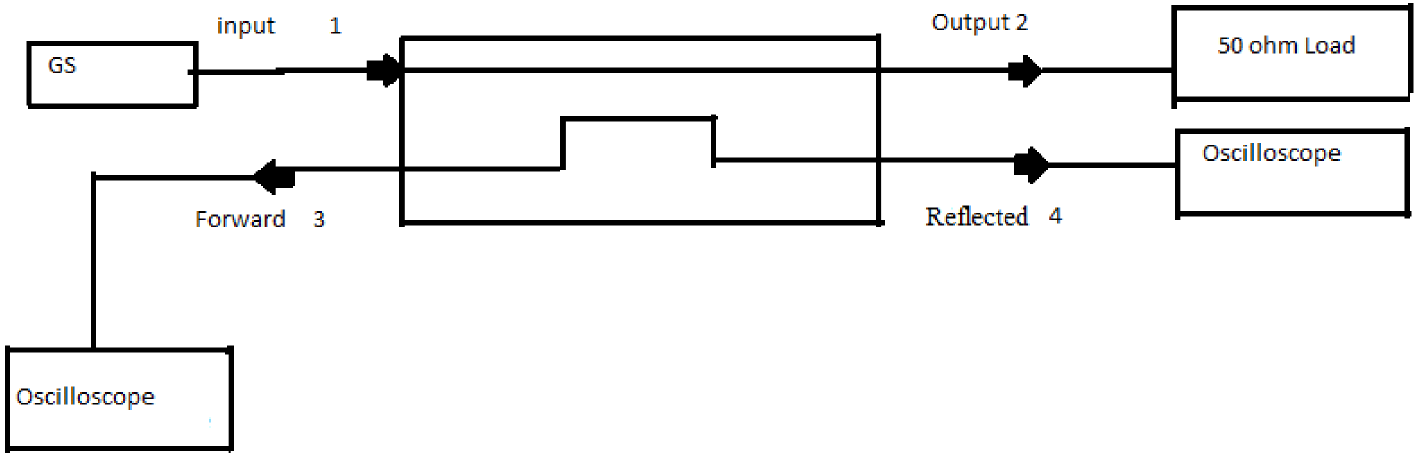
Directional Coupler

Schematic for build the directional coupler





How to test (coupling factor)



Coupling Factor (13.5 MHZ)

Frequency (MHz)	Input Power(Forward)	Input Power(Reflected)	Forward voltage(Vf pk-pk)	Reflected Voltage(Vf pk-pk)	Coupling Factor	Directivity
13.5	20.1	0.2	2.98	1.08	29.56823521	8.815850172
13.5	30.5	0.3	3.5	1.32	29.98223742	8.469882263
13.5	39.9	0.5	3.98	1.4	30.03266743	9.075100728
13.5	49.9	0.6	4.4	1.64	30.13255184	8.572176569
13.5	59.9	0.7	5	1.76	29.81546805	9.06914673
13.5	69.8	0.8	5.32	1.96	29.94092149	8.673111219
13.5	79.8	1	5.76	2	29.83217916	9.187849755
13.5	90.3	1.1	6.12	2.2	29.84244897	8.886574826

Quantiles

100.0%	maximum	30.1326
99.5%		30.1326
97.5%		30.1326
90.0%		30.1326
75.0%	quartile	30.0201
50.0%	median	29.8917
25.0%	quartile	29.8196
10.0%		29.5682
2.5%		29.5682
0.5%		29.5682
0.0%	minimum	29.5682

Summary Statistics

Mean	29.893339
Std Dev	0.1710843
Std Err Mean	0.0604874
Upper 95% Mean	30.036369
Lower 95% Mean	29.750309
N	8

Error: 0.35%

Coupling Factor = 29.717+0.00194 *input power(W)

Coupling Factor (40MHz)

Frequency (MHz)	Input Power(Forward	Input Power(Reflected)	Forward Voltage(Vf pk-pk)	Reflected Voltage(Vf pk-pk)	Power ratio	Coupling Factor
40	19.2	0	3.12	1.68	788.9546351	28.97052303
40	29	0	3.76	1.92	820.5070167	29.14082299
40	38.8	0	4.32	2.24	831.6186557	29.19924223
40	48.6	0	4.88	2.32	816.3128191	29.11856617
40	58.4	0	5.28	2.64	837.9247016	29.23204993
40	68.2	0	5.68	2.88	845.5663559	29.27147695
40	78.1	0	6.28	2.88	792.1213842	28.98791738
40	87.9	0	6.48	3.12	837.3342478	29.22898855

Quantiles

100.0%	maximum	29.2715
99.5%		29.2715
97.5%		29.2715
90.0%		29.2715
75.0%	quartile	29.2313
50.0%	median	29.17
25.0%	quartile	29.0206
10.0%		28.9705
2.5%		28.9705
0.5%		28.9705
0.0%	minimum	28.9705

Summary Statistics

Mean	29.143698
Std Dev	0.1130046
Std Err Mean	0.0399531
Upper 95% Mean	29.238173
Lower 95% Mean	29.049224
N	8

Error: 2.85%

Coupling Factor = 29.054654+0.0016636 *Input Power

Directivity, Isolation & Coupling Factor

Directivity means power level difference between the forward port and reflected port.

Isolation means power level difference between input port and reflected port. It also related to directivity.

The relation of isolation, coupling factor, and directivity:

Isolation (dB) =Coupling Factor (dB) +Directivity (dB)

Our result:

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-1.649e-7	3.585e-7	-0.46	0.6649
Coupling facotr	1	1.108e-8	9e+7	<.0001*
Directivity	1	7.329e-9	1.4e+8	<.0001*

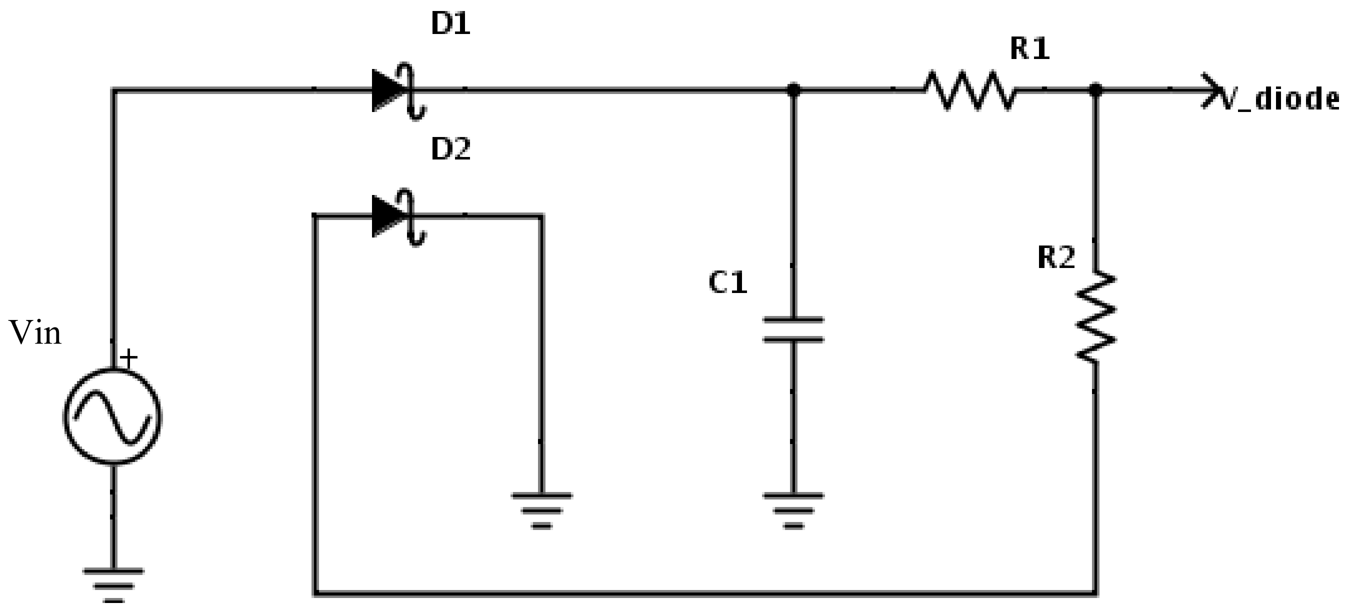
Predict Isolation =-1.649*+1*Coupling Factor+1*Directivity

Challenge

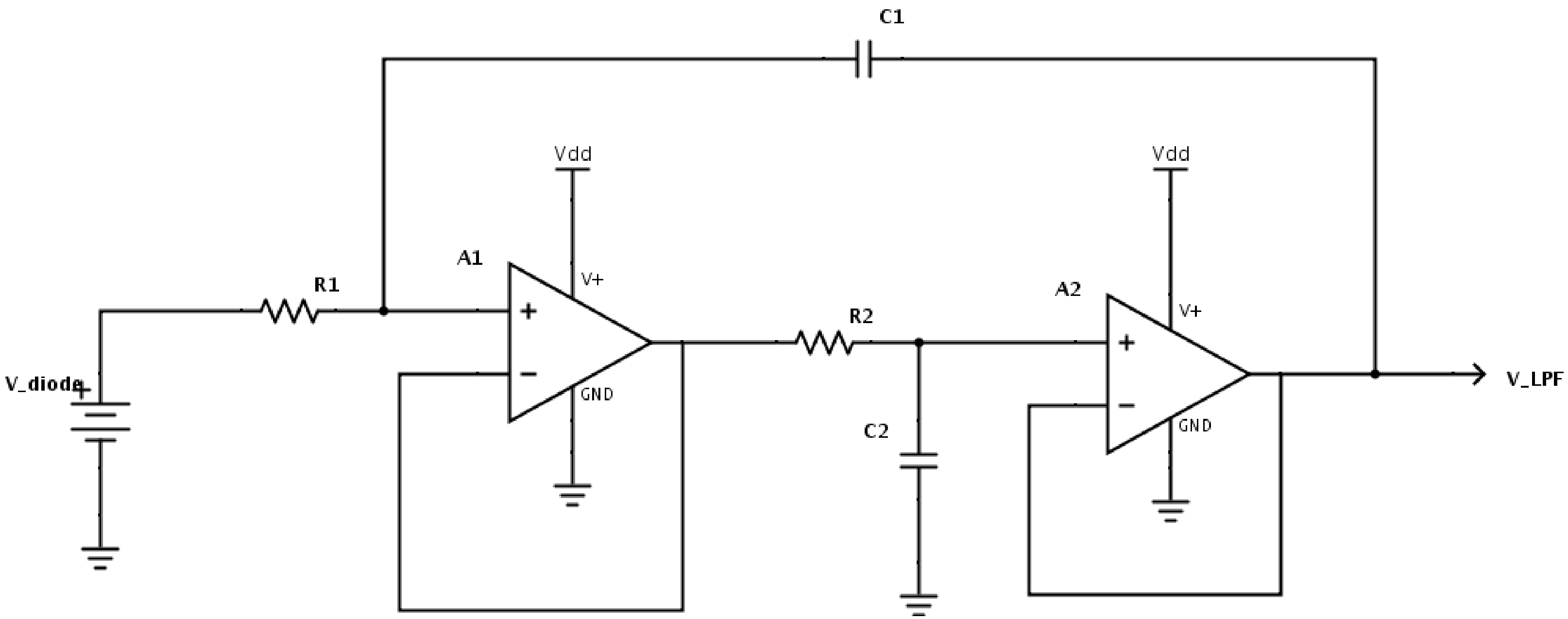
- Test plan
- Equipment's limit
- Soldering issue
- Toroid direction
- Reflected voltage not ideal
- Organize the components into the box

Detection Device

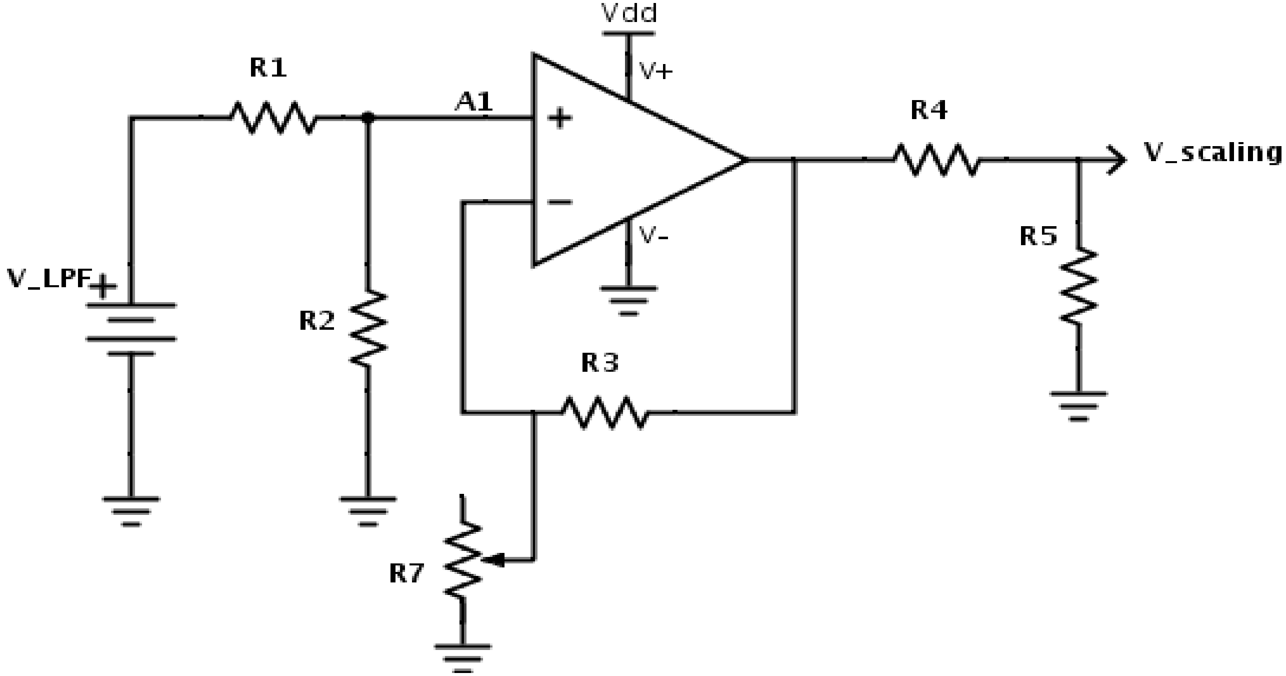
Diode Schematics



Low-pass Filter



Scaling Amplifier



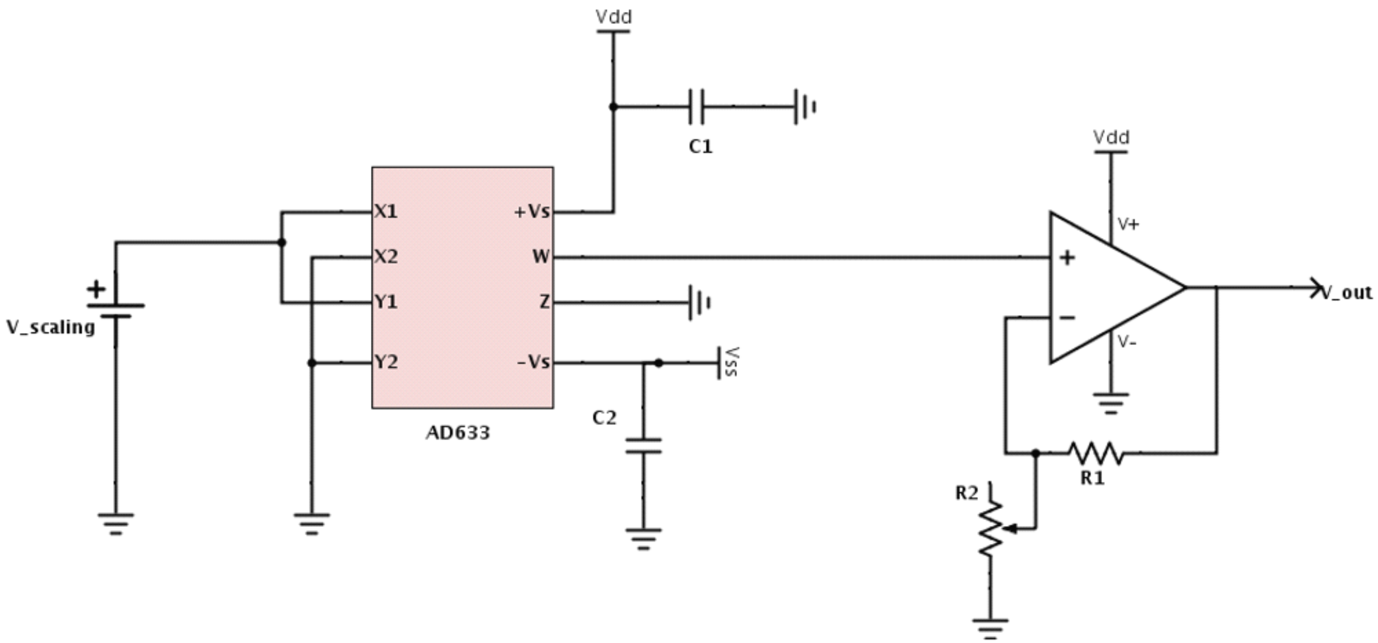
Pulse Modulated Sine Wave

Power(w)	Vout(v)	Vin(v)	Gain(v/v)	Feedback Resistance(kΩ)
50	7.071	0.3536	20	5.3
100	7.071	0.5	14.142	7.6
200	7.071	0.707	10	11.1
350	7.071	0.9354	7.559	15.2
500	7.071	1.118	6.325	18.8
1000	7.071	1.581	4.472	28.8

Pure Sine Input

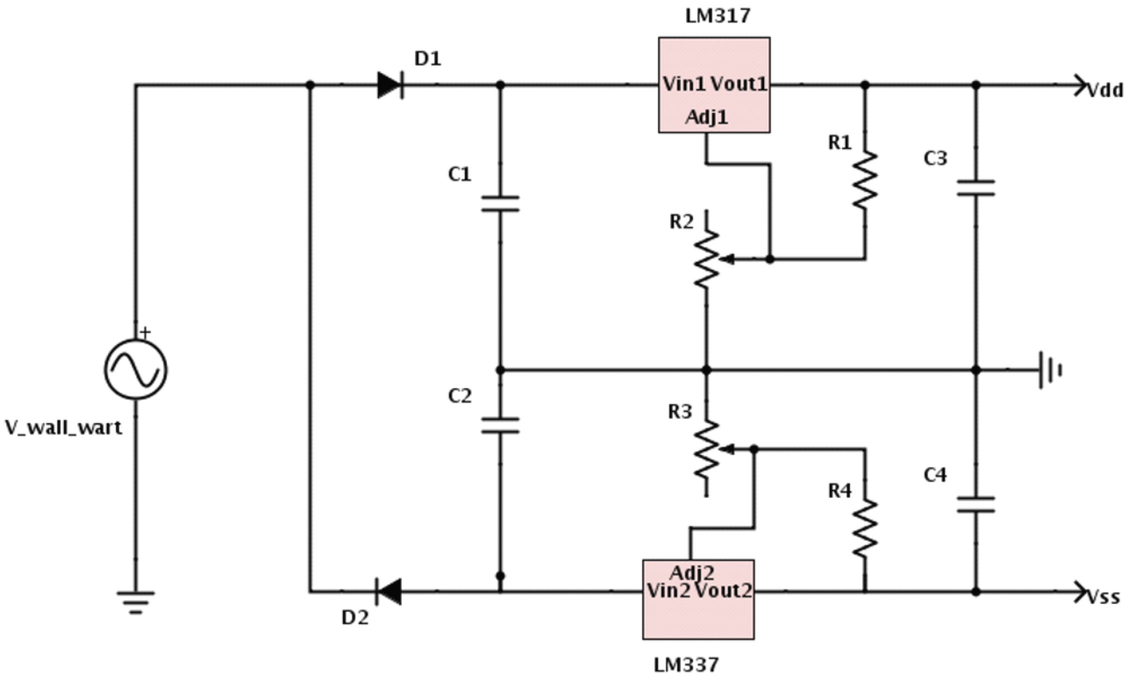
Power(w)	Vout(v)	Vin(v)	Gain(v/v)	Feedback Resistance(kΩ)
50	7.071	0.707	10	11.1
100	7.071	1	7.071	16.5
200	7.071	1.414	5	25
350	7.071	1.871	3.78	36
500	7.071	2.236	3.162	46.2
1000	7.071	3.162	2.236	81

Multiplier

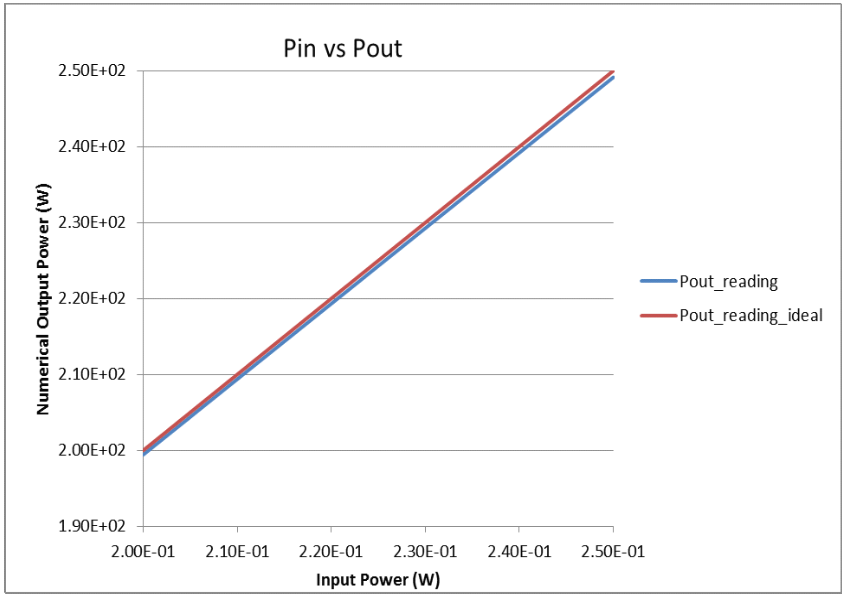


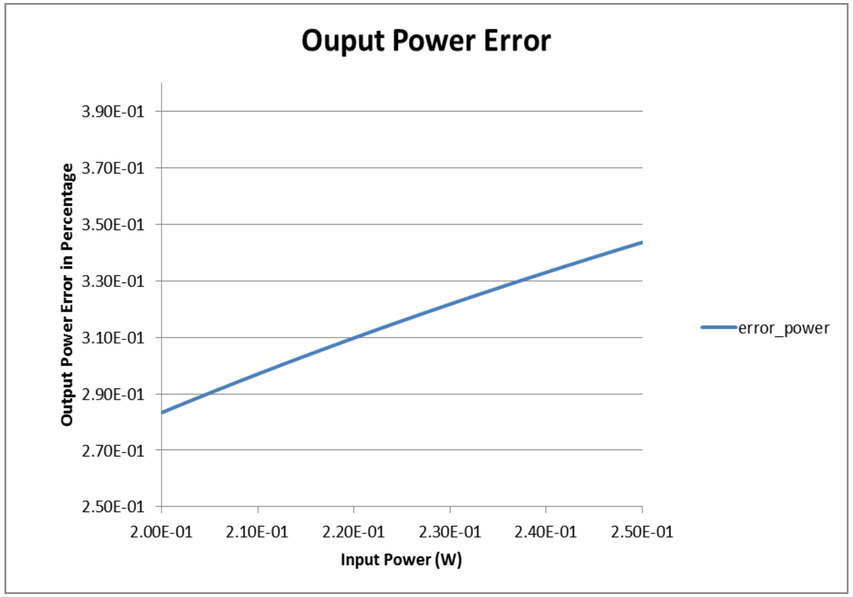
Vdd
C1
Vdd
X1
X2
Y1
Y2
+Vs
W
Z
-Vs
V+
V-
V_out
V_scaling
Vss
AD633
C2
R1
R2

Regulator


LM317
D1
Vin1 Vout1
Adj1
Vdd
R1
C3
C1
R2
+
V_wall_wart
C2
R3
R4
C4
Adj2
Vin2 Vout2
Vss
D2
LM337

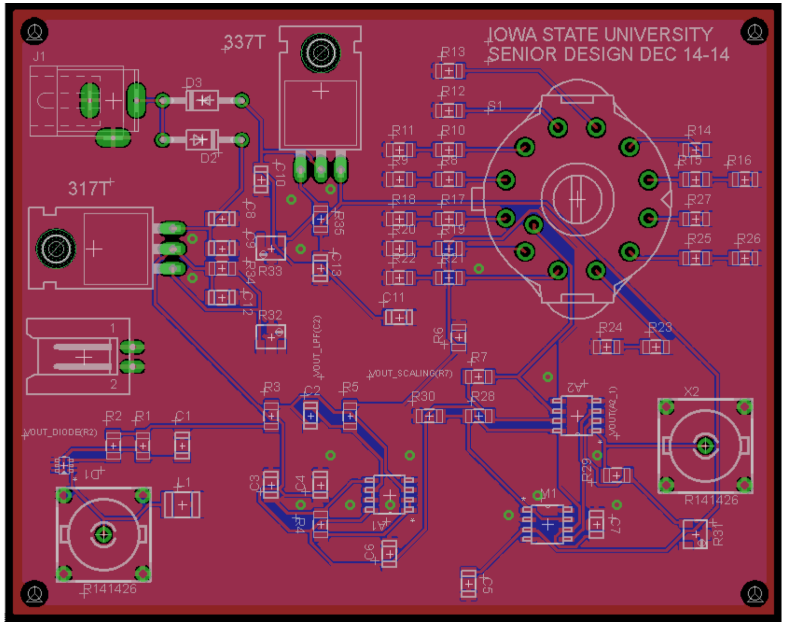
Simulation Example

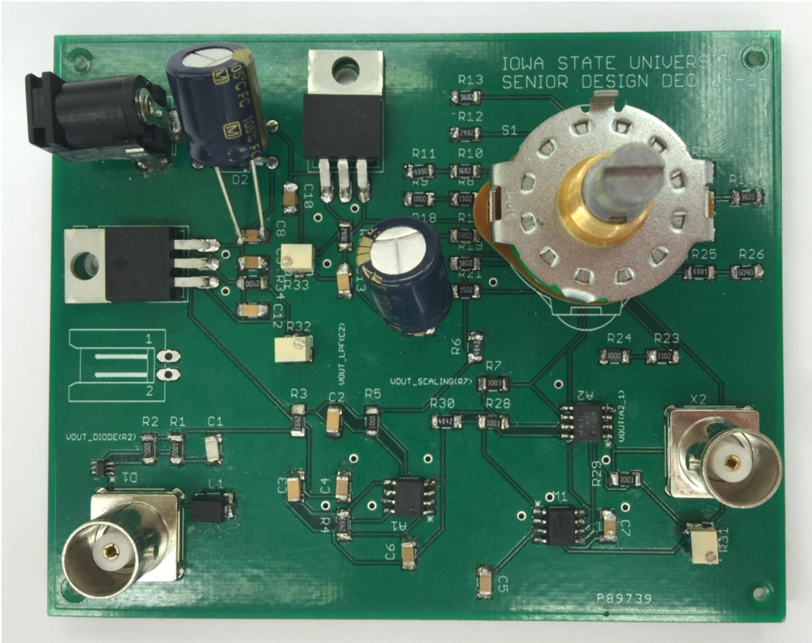




Input Power Range (after the directional coupler) : 0.2W to 0.25W

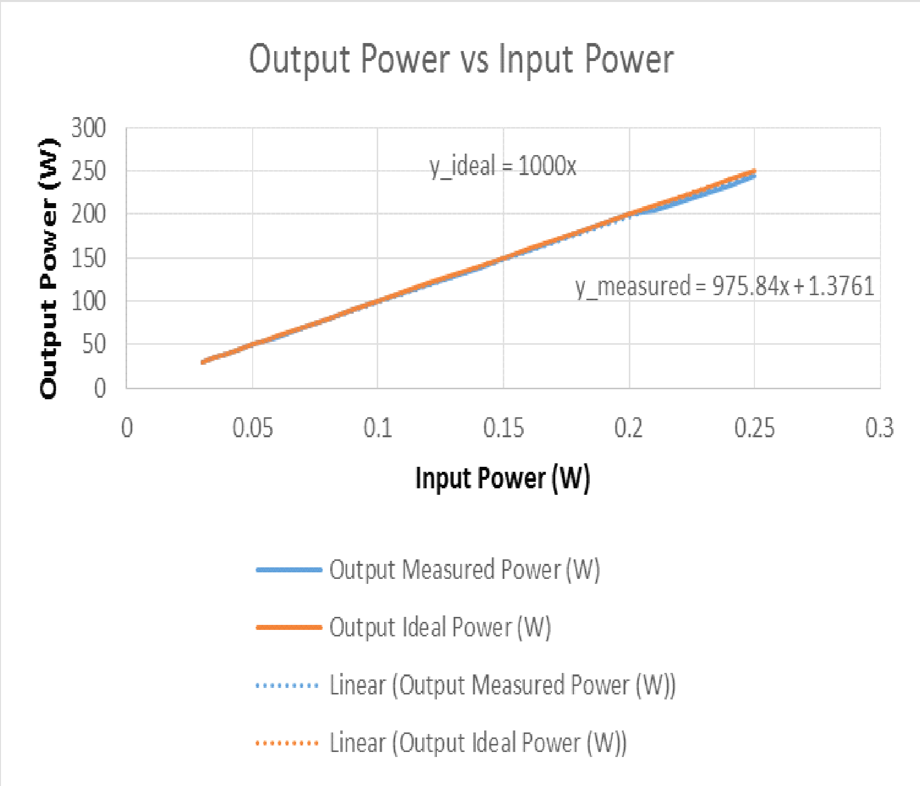
PCB Board

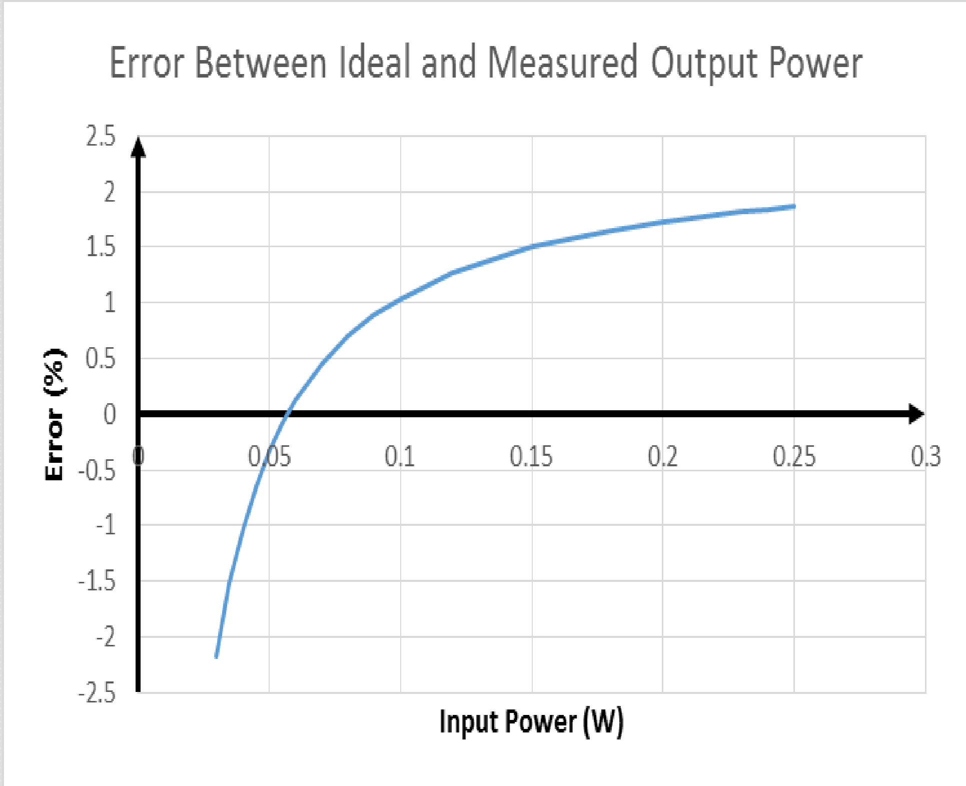

IOWA STATE UNIVERSITY
SENIOR DESIGN DEC 14-14
337T
317T


P89739

Test Result Out Of Detection Device

Input power (W)	Output Power (W)
0.03	29.6
0.035	34.8
0.04	40
0.045	45.2
0.05	50.5
0.055	53.6
0.06	58.8
0.07	69
0.08	79.6
0.09	90
0.1	100.4
0.12	118.4
0.14	138.8
0.15	149.2
0.16	159.6
0.18	180.4
0.2	200.8
0.21	204.4
0.22	214.2
0.23	224
0.24	233.8
0.25	243.6


Output Power vs Input Power
Output Power (W)
300
250
200
150
100
50
0
0
0.05
0.1
0.15
0.2
0.25
0.3
y_ideal = 1000x
y_measured = 975.84x + 1.3761
Input Power (W)
Output Measured Power (W)
Output Ideal Power (W)
Linear (Output Measured Power (W))
Linear (Output Ideal Power (W))


Error Between Ideal and Measured Output Power
Error (%)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
0
0.05
0.1
0.15
0.2
0.25
0.3
Input Power (W)

Challenge

- Transient simulation takes long time to run
- Unable to precisely measure reflected power
- Components selection (e.g. various package models)
- PCB layout manual routing
- Lack of soldering experience

Overall Test

Test Video

https://www.youtube.com/watch?v=DLEVDW_ndfo

All voltage unit is Volts, all power unit is Watts.

Eventually, the equation derived to a power in terms of voltage is:

Pout = (Vout/5)*Pmax_in_scale_range,

The example in our video shows when input power = 80.1 W,

The output voltage = 3.99V

The output power = (3.99/5)*100=79.8 W

Error = (80-79.8)/80*100 = 0.25%

Cost

Part Description:	Quantity	Price/100Units ($)	Total Price ($)
Toroid	2	1.2	2.4
Wire Gauge	50 feet	0.159	7.95
Enclosure	1	8.71	8.71
Transmission Line	1 feet	2	2
Resistor	32	0.007	0.224
Trimmer Resistor	4	1.64	6.56
220pF capacitor	1	0.073	0.073
4700pF capacitor	2	0.248	0.496
0.1uF capacitor	8	0.082	0.656
1uF capacitor	2	0.081	0.162
100uH inductor	1	0.121	0.121
HSMS-282K diode	1	0.417	0.417
LMC6492 amplifier	2	1.42	2.84
AD633 multiplier	1	4.95	4.95
LM317 regulator	1	0.26	0.26
LM337 regulator	1	0.786	0.786
BNC connector	2	2.1	4.2
Rotary switch	1	5.27	5.27
AC to AC adapter	1	8.3	8.3
Barrel connector	1	0.3162	0.3162
Pin connector	1	0.09427	0.09427
PCB board	1	30	30
Total:			**86.79**

Question?

Thank You!