Team Dec14-14
Low Cost RF Power Meter

Project Plan

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Introduction

Project Statement:

Radio frequency ("RF") power measurement has its own significance to modern communication technology. Large number of systems and components are required accurate and efficient RF power detection. The reason in choosing power detection over voltage is because a waveguide setup is very difficult in measuring.

Our client, PowerFilm. Inc, needs us to build a low cost RF power meter which can successfully measure his RF source. PowerFilm. Inc is a solar cell fabrication industry, and there are hundreds of power generation machine. Our goal is to design a power meter for their measurement, however the price has to be low in order for massive production. So the ultimate mission for us is to construct a low cost RF power meter and test the product to ensure its compatibility and accuracy.

Functional Requirement:

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

Non-functional requirement:

- Cost under 100 dollars
- A plan for power measurement up to 1200W
- System robustness after assembling
- Safe and easy to use

Deliverables:

First semester:

- Wired directional coupler
- Detector simulations
- Project plan and design document

Second semester:

- PCB board
- Aluminum closure with all components

System Overview

Block Diagram:

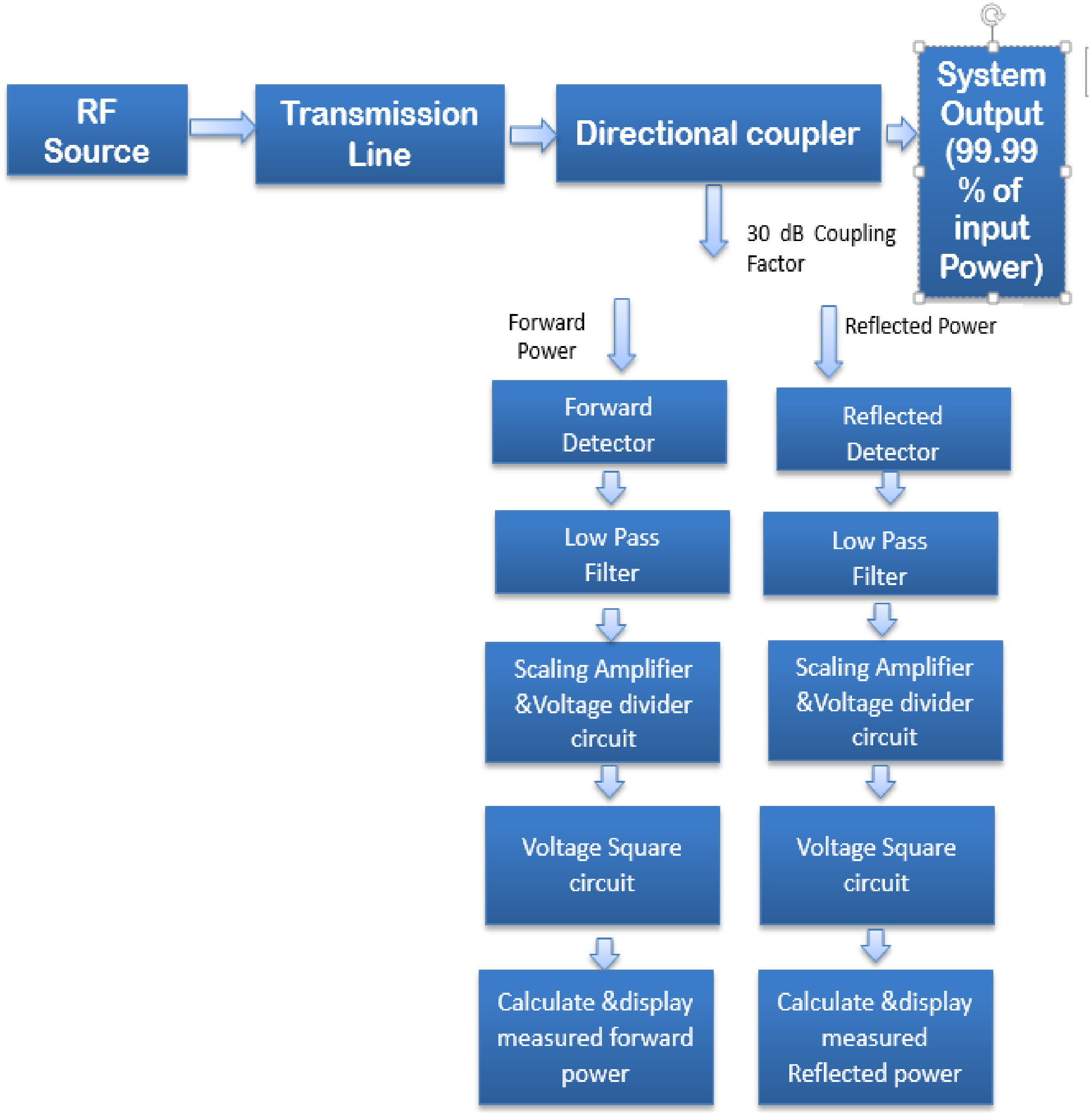

Figure 1: System Block Diagram

Transmission Line:

A transmission line is a cable which is designed to carry radio frequency. It will be used to connect generator and Antenna Tuner which is the device we are going to measure. Based on the requirements from our client: 20 to 60 dBm power range with 13 to 40MHz, maximum power 1200 W, RG-8A/U is a desired transmission line.

Directional Coupler:

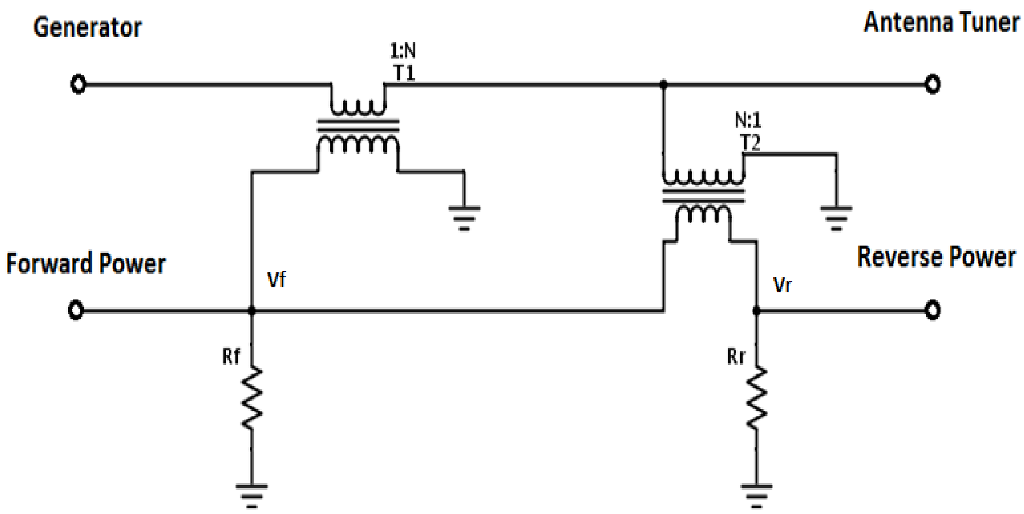

Figure 2: Directional Coupler Schematics

The directional coupler can help us to split a measurable power that can be used in another circuit (Detector). We decide to have two power range in our directional coupler. If the input is in 0.1 - 350W range, we will have a -30 dB attenuation in our directional coupler. If the input 350 - 1000W range, we plan to add another 10 dB attenuator to our output (total -40 attenuation in directional coupler).

The tandem directional coupler consists of a pair of toroidal transformers T1 and T2. R1 is standby forward power and R2 is standby reverse power. We are trying to build the directional coupler in a 4×4×2 inches closure. There are two N-type connectors connecting to input Generator and Antenna. And there are two BNC connectors connecting the output of forward power and reverse power.

Diode Detector:

Diode detector is an important element that converts the AC voltage to DC (called “rectifier”). We chose diode peak detector over thermocouple and thermistor as our sensor is because of its fast response. Although the other two sensors might result more accurate output, they also have environment sensitivity and the circuit complexity issues. HSMS-282K is a good choice of diode. It has very small inner capacitance, so the time constant is small (fast transient response).

According to diode IV characteristic curve, two operation regions can act as a rectifier, square-law region and linear region. In the square-law region, the input power is proportional to the square of the peak output. It has good sensitivity in detecting voltage, but the dynamic range is limited. Our project requires wide power range, so in this case, the linear region detector is a better option. Within the linear region, the input power is proportional to the peak output voltage (Pin = $\frac{{V_{OUT_{peak}}}^2}{2*R_{source}}$).

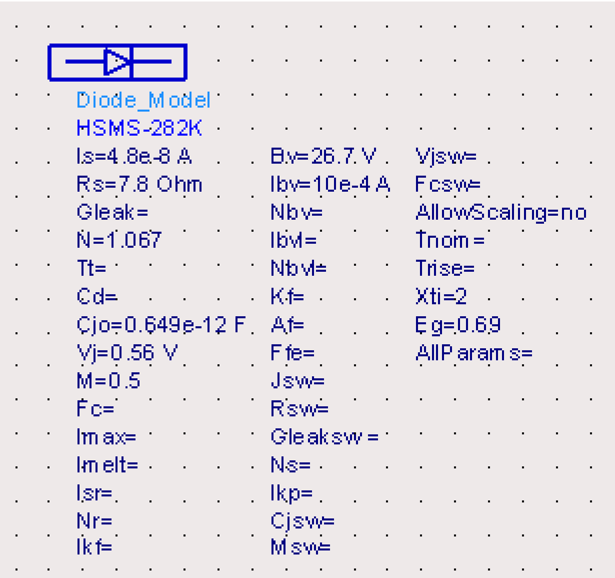

Figure 3: HSMS-282K Diode Detector Model

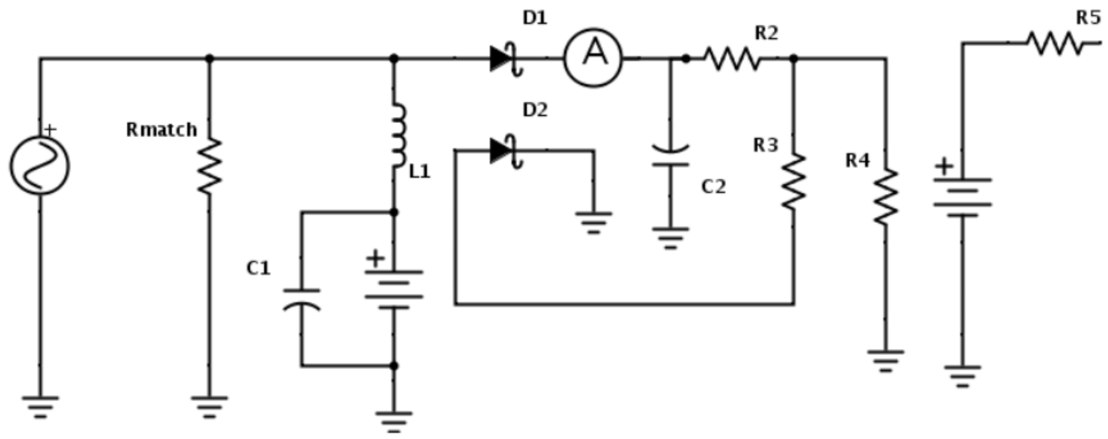

Figure 4: Diode Detector Schematics

Diode detector comprises following components:

- Matching Circuit:

  Matching circuit is to maximize the forward power transfer when load impedance is equal to complex conjugate of source impedance. In our design, source impedance is merely the resistance, so the matching component is a pure resistor which should be identical to our source resistance in theory.

- Choke Circuit:

  Choke circuit is a simple inductor. The purpose of adding this component is to block higher frequency currents. It will be used to pass the DC current and suppress any noise and RF from the circuit. However the value should be cautiously selected in case of causing self-resonant.

- Rectifier:

  Rectifier is the key of the detector. It has the ability to convert AC voltage to DC. Our diode will convert the AC voltage to its peak value known as envelope detection.

- Smoothing:

  Smoothing circuit is to use a capacitor to reduce the ripple of rectified DC voltage. The principle of smoothing is based on the charging and discharging of capacitor. As voltage increases, the capacitor charges, and as the output starts to fall, it will release its stored charge. So for a large value of capacitance will result better DC output since the capacitor will take more time in discharging, and will charge up for little voltage drop.

- Temperature Compensation:

  According to the junction resistor equation $R_j = \frac{n\frac{kT}{q}}{I_{bias}+I\_saturation}$, the resistance depends on the temperature T which makes it as a variable resistor. This is a huge value under zero biasing due to the small saturation current. So adding a load diode which is identical to the rectifier will prevent the voltage drop in the middle of the line.

- Biasing:

  As problem mentioned before, the junction resistance of diode is too large. So another way to decrease the value is to add small bias current. When reasonable bias current is injected, both diode will have less resistance, and the load voltage will depend on two fixed value resistors that will improve the linearity of the curve.

Low-Pass Filter:

The role of low-pass filter is to get more attenuations on high frequency signals. Any signals with frequency higher than cutoff frequency will be attenuated in a certain rate of amount. The operational amplifier is a good active low-pass filter.

The op-amps used in this schematics are both LMC6492, because it has ultra-low input current (200pA) which will not affect significantly to the bias current in diode detector.

The cutoff frequency is f = $\frac{1}{2\pi RC}$. So from here getting the attenuation from diode's output will know the deficiency of attenuation, and then we can figure out the desired cutoff frequency.

A voltage divider is needed at this point in order to get a positive gain in scaling amplifier (discuss in next step)

Scaling Amplifier:

As client request, the output voltage has to be within 0-5V. The traditional way is to split this voltage across the whole power range. However in this way, the error will be very large because of the wide dynamic range. The scaling amplifier uses different gains in different ranges but result 0-5V output voltage in each range. Using this approach, the output voltage will be more accurate.

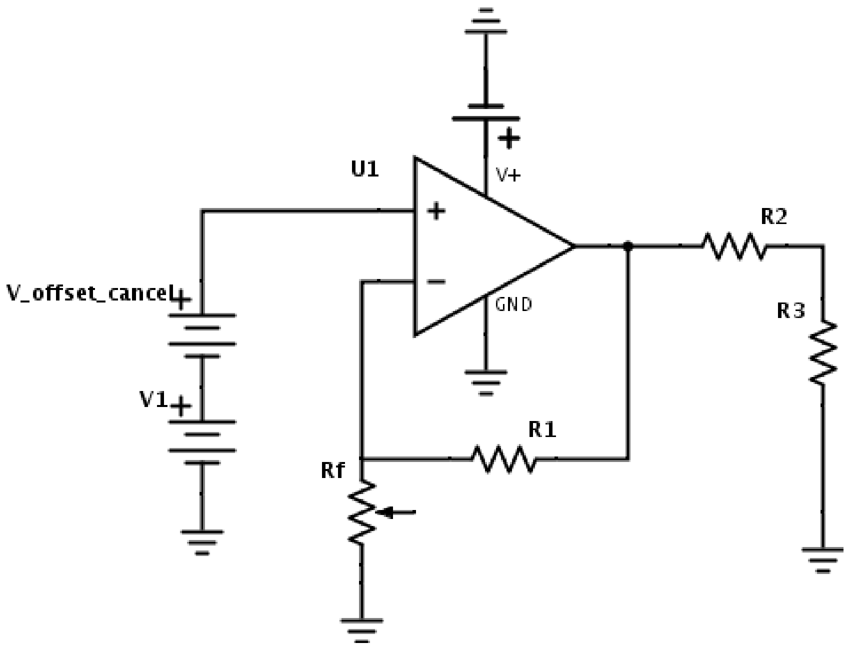

Figure 5: Scaling Amplifier Schematics

Figure 5 shows an example of one range's scaling amplifier. This is a non-inverting amplifier design to generate a positive gain. The gain is calculated by the division of 5V and the boundary input voltage. Choose the correct input and feedback resistances to get this gain value. Also the offset cancellation source is needed for small voltage level.

Square, Division, Subtraction Circuit:

All the outputs are voltage numbers, yet the client wants to know the power level instead of voltage. According to P = $\frac{{V_{OUT}}_{peak}^{\;2}}{2*R}$, the output peak voltage needs to be square and divided by 2*R. After power values has obtained from both forward and reflected port, the final output should be the difference of these two numbers.

Assembling and Test

Assembling:

The directional coupler needs to wire the toroid in calculated terms; Diode, LPF, scaling amplifier, and other calculation operation circuits need PCB design; A box to put all those components inside.

Test:

In the first semester, simulation test with all components need to be done. In the second semester, after all devices and components are assembled, we need to test our system using client's RF input source, and then fix and optimize the existing problems.

Market Survey

There are plenty of RF power meters in the market that can achieve our specifications. For example Telewave 44A is a broadband RF wattmeter which has very high accuracy and sensitivity in measuring a wide dynamic range of power. Then the question is why our client don't just buy one of this. The main reason is the cost. Those power meters in market has very good quality, but some of the product qualities actually they don't need it. Those extra qualities might be costly especially for their massive fabrication. Our design is to make a system that just suitable for our client's utilization. The price for Telewave 44A is 952 dollars per unit, even if for massive purchase, the single price has to be 700 dollars above. The cost of our single product is just under 100 dollars, so if our client needs 100 quantities, the total money saving is at least 60000 dollars.

Cost Evaluation

Cost				
Part Description	Part Number	Quantity	Price/Unit(100)	Price
Toroid	T80-6	2	$1.2	$2.4
Wire gauge	AWG #22	50feet	$0.159	$7.95
Enclosure	4*4*2 inch	1	$8.71	$8.71
Diode	HSMS282K	5	$0.598	$2.99
BNC connector	Female	2	$1.99	$3.98
PC Board	2-side Copper-Clad	1	$4.99	$4.99
Amplifier	LMC6492	7	$3.44	$24.08
N-Type Connector	PE4013	2	$7.62	$15.24
Transmission Line	RG8A/U	1feet	$2	$2

Capacitors	68C2933	5	$0.327	$1.635
Resistors	1W210	30	$0.188	$5.64
Attenuator	9033-10	1	$20.00	$20.00
Total				**$99.615**

Table 1: Cost Evaluation of Parts

Project Timeline

01/19/2014 – 01/25/2014
Met with our advisor and client to get more information about our project.
01/26/2014 – 02/01/2014
Study and research about fundamental knowledge and related design.
02/02/2014 – 02/08/2014
Review the required knowledge (materials such as EE 201, 230, 311).
02/09/2014 – 03/08/2014
Split into two groups to do directional coupler and detector (basic concept, circuit design, calculation and simulation).
03/09/2014 - 04/06/2014
To do measurement unit.
04/07/2014 – 04/30/2014
Design combination and prepare the presentation

08/25/2014-09/25/2014
Build the directional coupler and test. (Silu Feng, Yusi Xie, Yijia Huang)
Reflected simulation and PCB layout. (Xiaoshuo Li, Boyang Hu, Cong Han)
09/26/2014-10/26/2014
Optimize the directional coupler. (Silu Feng, Yusi Xie, Yijia Huang)
Build the detector circuit and test. (Xiaoshuo Li, Boyang Hu, Cong Han)
10/27/2014-11/27/2014
Design and build the voltage square and divider circuit. (Silu Feng, Yusi Xie, Yijia Huang)
Optimize the detector circuit. (Xiaoshuo Li, Boyang Hu, Cong Han)
11/28/2014-12/14/2014
Integration the whole system and test whole system. (All team member)

Potential Issues

Technical:

- Low cost
- Broad dynamic range
- Schedule delay
- Software usage
- Decision making

Personal:

- Lack of knowledge
- Lack of research experience
- Efficient communication
- Schedule delay
- Software usage
- Decision making

Conclusion

In technical aspect, it is a challenging topic to develop a RF power measurement system. This project integrates the knowledge from circuit, semiconductor, and electromagnetic areas. We need to review and learn these concepts for each component. The high technical requirement gives us a chance to use the knowledge we have known to make a real product out of the book.

In personal aspect, this project is a great opportunity to establish the personality such as leadership, cooperation, patience etc. Those qualities will follow us to the workplace in the future when we are all engineers. So it is important to communicate in an effective way as a team that will make us intelligent when we deal with more sophisticated projects.