ReconfigurableAntennawithMatchingNetwork
Final Project Report

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Abstract:

With the constant changing of technology, frequency reconfigurable antennas are an important innovation to the RF world. The new device limits the physical space used by eliminating the need for multiple antennas. This is especially vital in mobile devices such as cell phones that receive multiple frequency bands like cellular tower reception, Wi-Fi, and GPS. The other alternative to frequency reconfigurable antennas is a wideband antenna; however, wideband antennas receive large frequency ranges introducing noise to the system. Frequency reconfigurable antennas narrow the bandwidth to specific frequencies, typically reducing the amount of noise for the signal.

A side-goal of the project is to incorporate the use of micro electromechanical switches (MEMS) to control the resonant frequency of the antenna. MEMS are relatively new devices that are biased via Gate-Source voltages. The benefits of using MEMS over RF transistors are the very small package size, high isolation loss, and low insertion loss. The goal of this project is to create a frequency reconfigurable antenna system to switch between two commercially available GPS frequency channels.

Acknowledgements:

- We would like to thank to Dr. Prasad N. Shastry for guiding our senior project group through the entire research and development process.
- The fabrication process was possible thanks to Robert Modica at Micro-Circuits, Inc.
- Likewise, a special thanks to Endotronix and Validus Technologies for letting our team use their facilities to wire bond our MEMS.

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Chapter 1: Introduction

The goal of this project is to develop an antenna that has the capability of changing its resonant frequency and match the received signal to 50Ω. The two frequencies chosen to switch between are both commercially available GPS signals that occur at 1.227GHz and 1.575GHz. The system will have two varying sized patches, with lengths $\frac{1}{2}\lambda_{desired}$. These patches will be use various switches in order to create a minimalist system (refer to Figure 1-1)

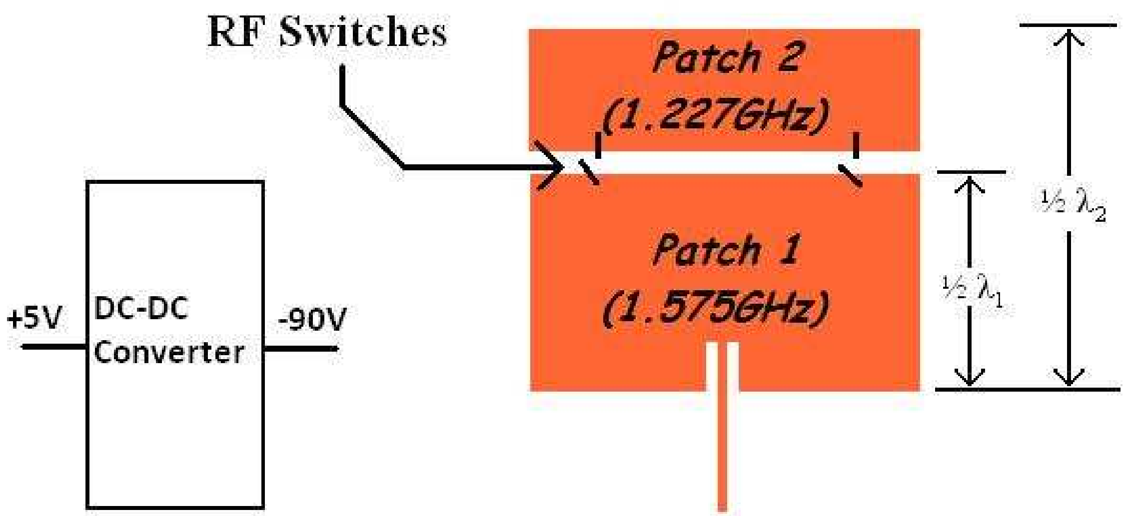


Figure 5-1: Basic design of the reconfigurable antenna for two GPS frequencies using Linear Polarization and inset feed matching.

Chapter 2: Literature Review

The combinations of antenna types, antenna design, switching devices, and impedance matching networks are nearly endless. Through research of various reconfigurable antennas, the goal is to narrow the choices by creating an antenna system that is simple yet effective.

Detailed Description:

Reconfigurable antennas present a new option for antenna capability and technology in wireless devices. They require less space and increase functionality of an antenna system. Reconfigurable antennas are a single system that accesses multiple frequencies through various switches, patch antennas and patch networks. This eliminates the need for multiple antennas or wideband antennas. Multiple antennas take up more space, as they require an antenna for each use, and are always on. Wideband antennas, due to their inherent wide-bandwidth, receive more noise at a specific frequency than a single patch antenna. The reconfigurable antenna is an alternative solution to these possible antenna options that we seek to design and analyze its performance.

The premise of the design is simple. The longer the resonant length of the patch antenna the lower the resonant frequency becomes. The width of the patch antenna controls the impedance of the patch antenna. If we have two nearby patch antennas with small RF switches (RMSW201 MEMS) in between them, biasing the switches will connect the patches together, thus changing the frequency being received. The same switching system can be used to match the impedance of the antenna by adjusting the lengths in the double stub impedance matching network. Therefore, we can use identical RF switches in interconnecting the patch antennas and to also interconnect an impedance matching network stub. The biasing signals of the patch antenna switches and impedance matching network switches can use the same signal to alter the frequency being received by the reconfigurable antenna. This switching will be done through a +5V to -90V DC-DC Converter to bias the RMSW201 MEMS Switch.

MEMS Operation:

The operation of MEM switches is relatively simple. Like a MOSFET, there are gate, drain, and source terminals. There is a cantilever beam connected to the source and floats above the gate and drain (refer to Figure 6-1). When a biasing voltage (gate-source voltage of +/- 90VDC) is applied to the gate, the difference in voltage creates an attraction that pulls the cantilever beam down to the drain causing a source to drain connection. In other words, when the switch is biased, patch 1 is connected to patch 2.

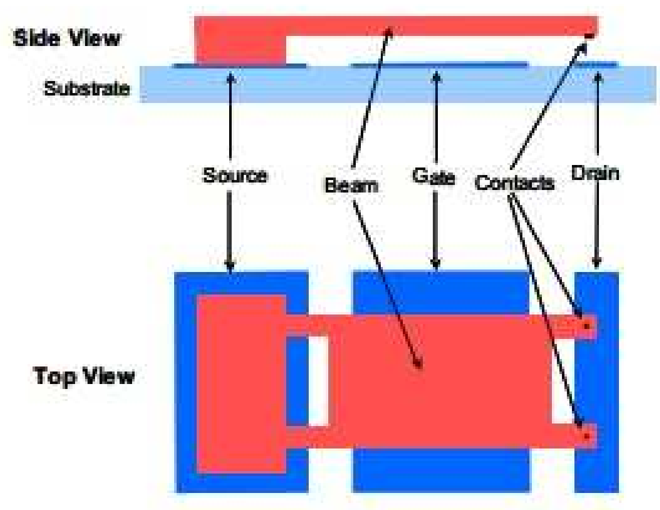


Figure 6-1: RMSW201 MEMS Cantilever beam diagram. A gate to source voltage of +/- 90VDC brings the cantilever beam down to contact the drain.

In order to use MEMS for our application, we must insure that the DC voltage of the source and drain are 0VDC while minimizing interference with any RF voltages. This will give a stable gate to source voltage for the switch. This can be done by adding in large resistors or inductors from the source and drain (Patch 1 and Patch 2) to DC ground. According to the MEMS' manufacturer RadantMEMS, a resistance of 40kΩ to 100kΩ is suggested for the source and drain (refer to Figure 7-1). 100kΩ will be used to minimize the effects on the RF signals present in the antenna.

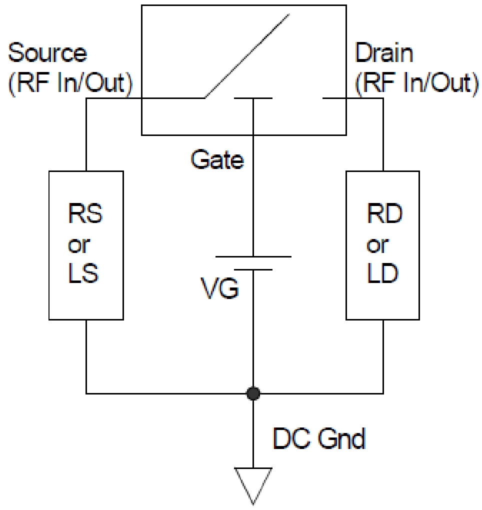


Figure 7-1: RMSW201 MEMS suggested load resistors or inductor placement to stabilize the DC voltages of the source and drain to 0VDC.

Patch Antenna Design:

Our patch antenna was designed based upon an ideal rectangular patch antenna. Initially two rectangular patches were designed, one for each desired frequency. The width for each was held constant but calculated based upon 1.575 Ghz and the RO3010, by use of the following equation: $W = c/(2f_o*\sqrt{((\varepsilon_r+1)/2)})$. The width that was calculated was 40.25 mm, this width was used to maintain proper impedance matching. Next length for each patch was determined through the following equation: $L = c/(2f_o*\sqrt{(\varepsilon_r)}) - 2\Delta L$ where ΔL is defined:

$\Delta L = 0.412h*[(\varepsilon_{eff} + 0.3)(W/h + 0.264)]/[(\varepsilon_{eff} - 0.258)(W/h + 0.8)]$.

From these equations are Lengths were determined to be $L_{1.575} = 29.27$ mm & $L_{1.227} = 37.72$ mm. After these calculations were made both antennas were designed in ADS and simulated to check for proper resonance and adjust the measurements to ensure proper resonance.

After the two rectangular patch antennas were created initial implementation of a singular reconfigurable antenna began. The design allowed for the initial patch to maintain 40.25mm width and an adjusted length of 29.98mm with a gap of roughly 3mm for MEMS implementation and a secondary patch that was tuned to the size of 1mm in length with a width of 40.25 mm. This took several iterations to ensure the proper values of each patch to maintain proper resonance. To properly simulate both patches we assumed a simple wire connection between the two patches for 1.227Ghz and an open gap for 1.575Ghz, as seen on the next page.

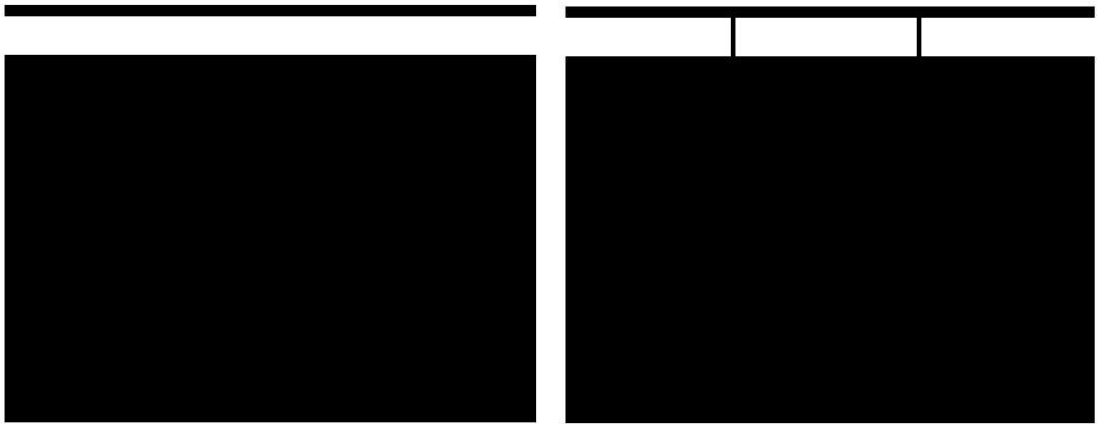


Figure 8-1: Patch Antenna design for simulation before Inset feed: 1.575 (left) 1.227 (right)

Inset Feed Design:

For finalized patch antenna design we needed to implement a matching network that would allow for a match to a 50Ω microstrip line. To do this we determined it would be best to use inset feed matching. For inset feed matching a microstrip line is inserted into a small slit into the middle of the rectangular patch, the size of the slit and location of the feed point determine the impedance that is matched.

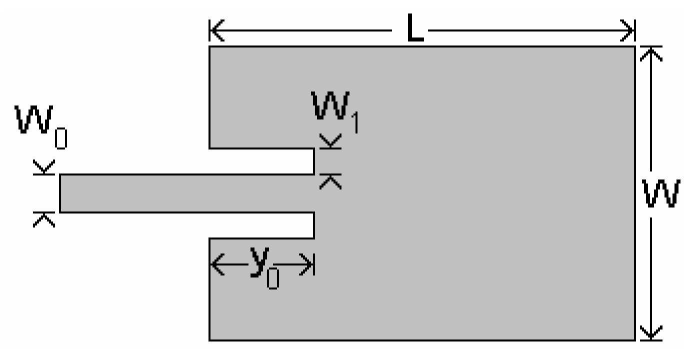


Figure 8-2: Rectangular Patch Antenna with Inset Feed line

(courtesy http://taslimi.ws/cv_files/Project_wa.pdf)

For inset feed matching the following values needed to be determined: Thickness of the mircostrip feed line (W_o), the inset feed width (W_1), and the inset feed length (y_0). To properly match our impedance to 50Ω the Z_{in} also had to be determined at the feed point, which was determined from our rectangular patch simulation (can be found in the simulations section). Based upon our W_o of 0.6mm for a 50Ω line this was then used as the W_1 value as well. Lastly, to determine y_0 the following equation was used:

$y_0 = [\cos^{-1}(Z_0/Z_{in})]^2 * (L/\pi)$

This gave us a y_0 of 10.2mm. After tuning and adjustments the finalized patch with inset feed was designed and can be seen below:

Chapter 2 Conclusions:
In order to keep this design simple, the reconfigurable antenna will be designed using a linear microstrip patch antenna. The preferred switching method will be MEMS switches due to accuracy and small package size compared to pin diodes and transistors. If this design can proven, further research can be done to increase efficiency and/or add in circular polarization.

Chapter 3: Design, Specifications, and Requirements

After thorough research, specifications must be set to insure that the proposed reconfigurable antenna design will be effective enough to complete the desired application. To prove that this design works, two commercially available GPS frequencies will be used as the application.

High Level System Block Diagram:

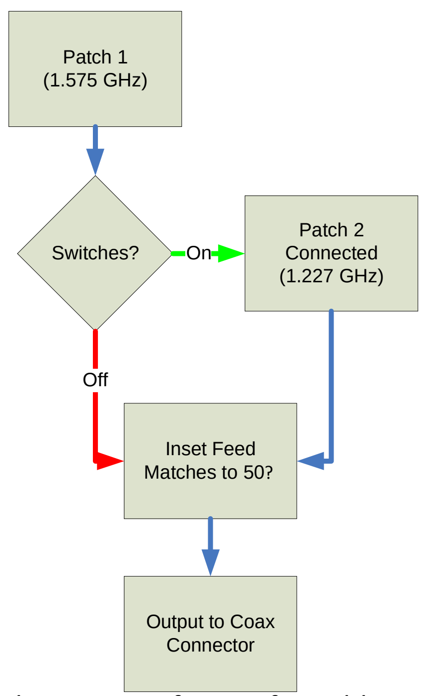


Figure 9-1: High Level System Block Diagram of Reconfigurable Antenna with Inset Feed Matching.

If the 1.575GHz GPS signal is desired, then the switches will be off, holding the patch antenna at the smaller length and thus higher resonant frequency. If the 1.227 GHz is desired, the switches will be turned on thus closing the connections between the patch antennas, this will adjust the length of both the antenna to resonant at 1.227 GHz. The operation of the reconfigurable antenna is illustrated in Figure 2-1.

Polarization:
The GPS frequencies that we will be receiving are transmitted using right-hand circular polarization according to http://www.fcc.gov. However, to meet project deadlines we will be simplifying our patch antenna design to consist of linear polarization. This means we will use square or rectangular patches without any modifications for polarization (truncated corners, slots, etc.). If we prove the linear polarization design to be possible, it will open up possibilities for future projects to add in right hand circular polarization.

Switching Technology:
We needed to determine which method of switching will not only be the most plausible but the best for our system. A small switch size is desired to limit the gap size between patch antennas. It is also very important that the RF switches have low insertion loss and high isolation in addition to operation at RF frequencies. Our goal was to implement RF MEMS switches, to meet the project objective. The drawbacks are high cost and high biasing Gate-Source Voltages. We are going to try to implement RadantMEMS RMSW201 MEMS Switches in our patch antenna. Its specifications are:

- DC to 20 GHz Operation
- 0.3dB Insertion Loss @ 2GHz
- 35dB Isolation Loss @ 2GHz
- 1.9mm x 1.85mm package size
- +/- 90V Gate-Source Voltage
- Gold Plating on Micro Strip Board required for wire bonding

Switching Control System:
To bias the MEMS Switches, we need to apply a +/- 90V to the Gate-Source of the switches. For the patch antenna system, the switches will either be all on or all off. We will be using only 2 MEMS Switches for the antenna system between the 2 patches. Since we are using inset feed matching, no MEMS switches will be required for the impedance matching.

Functional Requirements and

Specifications: Antenna System:

- The first patch antenna shall have a center resonant frequency of 1.575GHz, impedance of 50 ohms, and Linear Polarization.
- The connected patch antennas shall have a combined center resonant frequency of 1.227GHz, impedance of 50 ohms, and Linear Polarization.
- The patch antenna area shall be kept small without sacrificing too much performance.

Switching System:

- The switch package size shall be less than or equal to 2.0mm (for length) to ensure close proximity of patch antennas.
- The switches shall have a Low Insertion Loss (<0.7dB @ 2GHz).
- The switches shall have a High Isolation loss (>15dB @2GHz)
- The switches shall operate at least within 1 to 2 GHz frequency range.
- The switches shall have a fast switching speed (<10us).

Substrate:

- The substrate shall have a high dielectric constant, ε_r (~10).
- The substrate shall have as small of thickness as possible without sacrificing durability (> 10mils).
- The substrate shall minimize the bandwidth around the resonant frequencies to reject noise of outside frequencies while meeting the minimum bandwidth required for GPS.
    - 1.575 GHz Bandwidth is 1.563 GHz to 1.587 GHz
    - 1.227 GHz Bandwidth is 1.215 GHz to 1.239 GHz
- The microstrip board shall be gold plated in the areas where wire bonding is required for the MEMS switches.

Equipment List (For 1 Reconfigurable Antenna):

From RadantMEMS:

- 2 RMSW201 MEMS Switches
- 1 +/-90 V DC-DC Converter

From Rogers Corporation:

- RO3010 12”x18” High Frequency Laminate

Chapter 3 Conclusions:

With the design criteria and specifications in place, the physical design and simulations of the reconfigurable patch antenna can begin.

Chapter 4: Schematics and Layouts

This project had 3 separate circuits or layouts designed and fabricated. First off was an evaluation board of the RMSW201 MEMS switch to determine S-Parameters, but more importantly the effects of the ground pad on the bottom side of the MEMS switch. The second circuit constructed was the +/-90V DC-DC converter that controls the biasing of the MEMS switches. This schematic was obtained through RadantMEMS' datasheet for the PCB version of the DC-DC converter, but it was built on a breadboard in lab. The final layout is the actual patch antenna system with inset feed matching. All three of these layouts combine to create the final project.

RMSW201 MEMS Evaluation Board:

The evaluation board is designed for a Roger's Corporation RO3010 25mil substrate, the same substrate the antenna system uses. Its purpose is to determine the effects of the ground pad on the received signal. In order to do this, three separate orientations are used for the switch (refer to Figure 13-1). First is a 2.0mmX2.0mm landing pad with vias to the ground layer of the substrate. Conductive epoxy is used between the landing pad and the MEMS' ground pad to create a solid connection to the board both mechanically and electrically. The worry is that this ground pad will interfere with the RF signal crossing the source and drain of the switch. Possible alternatives to this are included in the two other orientations on the evaluation board. One option is a floating ground pad for the MEMS switch. It is the same as the previously mentioned orientation, but there are no vias to the ground plane of the substrate. Conductive epoxy will still be used. The final alternative option is to sand off the ground pad of the MEMS switch. The switch is then attached to the evaluation board with nonconductive double-sided thermal tape. No landing pad will be present on evaluation board. This will minimize the amount of copper that can potentially interfere with the received signals.

On the evaluation board, the transmission lines are 23.45mils wide to create a 50Ω line. A 50Ω calibration line is at the top of the board to be used when connected to the spectrum analyzer. Coax connectors are added to each port with a landing pattern specific for the Emerson 142-0701-841 connector. 8 total coax connectors are used on the evaluation board. Also, each source and drain line has a 100kΩ surface mount resistor (1.6mmX0.8mm) to the ground plane through a via hole. A 200milX200mil pad is connected to the gate of each switch to allow a wire to be soldered to the pad. This will be connected to the DC-DC converter allowing the switches to be biased when needed. The transmission line width here is arbitrary since the signal is DC and the switch draws no current.

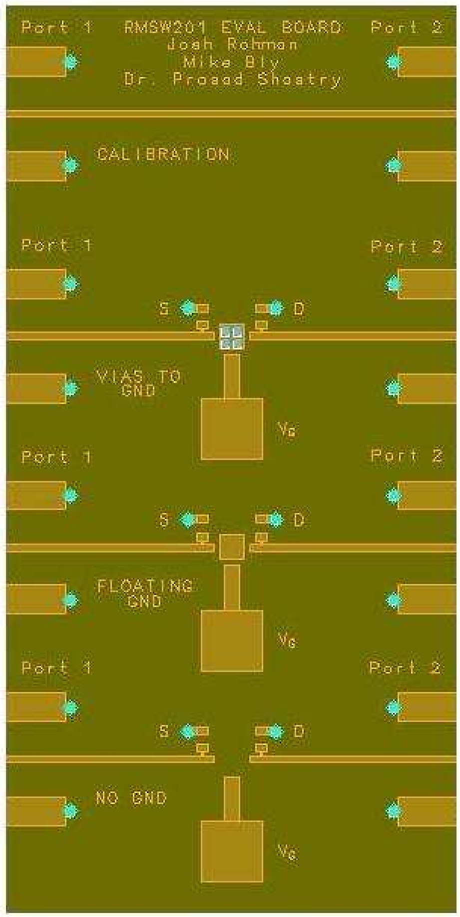


Figure 13-1: Fabricated Layout of the RMSW201 MEMS Evaluation Board.

DC-DC Converter:

The RMSW201 MEMS switch requires a gate to source biasing voltage of +/-90VDC to connect the source and drain. In order to do this, we recreated the +5V to -90V DC-DC converter available from RadantMEMS on a breadboard (refer to Figure 14-1 for schematic). The voltage output of MAX774 is determined by the ratio of the feedback resistors (R2/R1) = (Vout/Vref) where Vref is 1.5V. The value of R2 is determined by R2 = (Vout/10uA); in other words, the value of R2 is 9.1MΩ. For this DC-DC converter, R1 is 150kΩ and R2 is 9.1MΩ creating an output voltage of -91V. When the p-channel MOSFET is on, the energy is stored in the inductor L1. When the voltage across the inductor L1 exceeds 210mV, an internal voltage comparator indirectly measures the current going through the MOSFET and shuts off the MOSFET. This discharges the inductor energy to ground causing the capacitor C4 to charge to -90V. If the voltage of the drain falls below 4.8VDC, then the process repeats to maintain the -90VDC output.

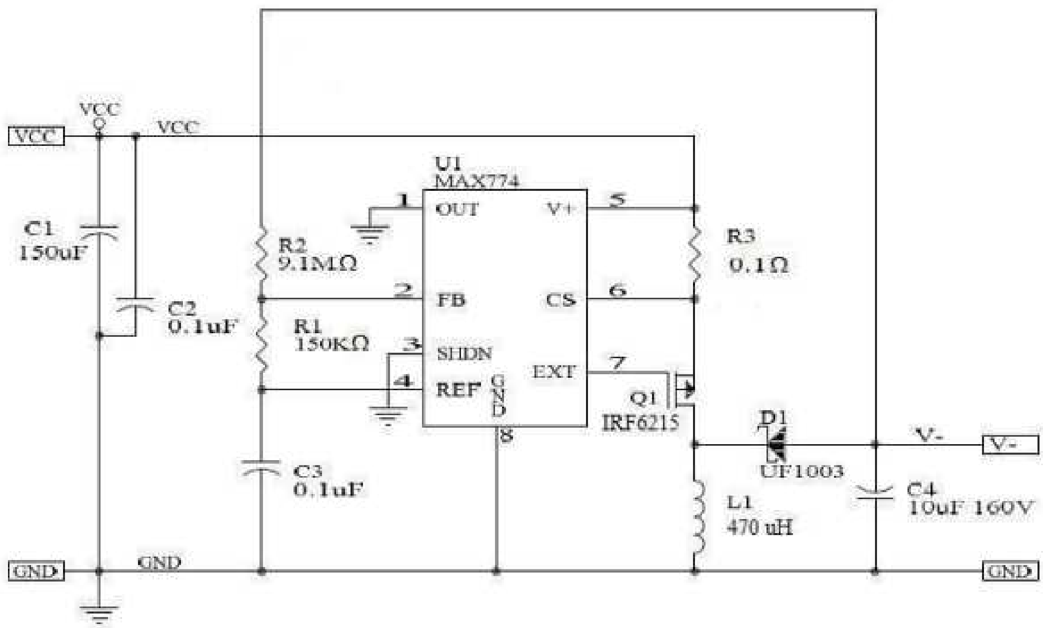


Figure 1: MAX774 DC-to-DC Converter Schematic

Figure 14-1: Schematic of RMSW201 MEMS +5V to -90V DC-DC Converter.

Patch Antenna System with Inset Feed Matching:

The finalized patch antenna will contain both patches to ensure proper frequency configurability. Along with these patches various components will be added for testing, switching, and implementation purposes. The patch and inset feed microstrip line are of the same dimensions as discussed in chapter 3, however the feed line was extended to allow for the addition of a single port coaxial connector. Similarly, to ground pads were added at this same port for proper coax connections. Secondly the additions of two small ground pads were added to the right of each patch length to allow for the addition of a RF resistor for each patch. These resistors will eliminate any noise and excess current flow at lower frequencies to prevent any errors with our GPS frequencies. Lastly a feed line was added to supply the gate portion of the MEMS switches with -90V_{DC}. The feed lines are commonly connected to a single pad at the top of the antenna where the DC to DC converter output will be attached. At the opposite end of the gate feed lines is a small gate pad to allow for proper wire bonding to the MEMS device. Also there will be two antenna types manufactured, both shown on the following page. One will contain two 2x2mm landing pads for the MEMS switches (located between the gap and next to the feed lines), the other will not contain these pads.

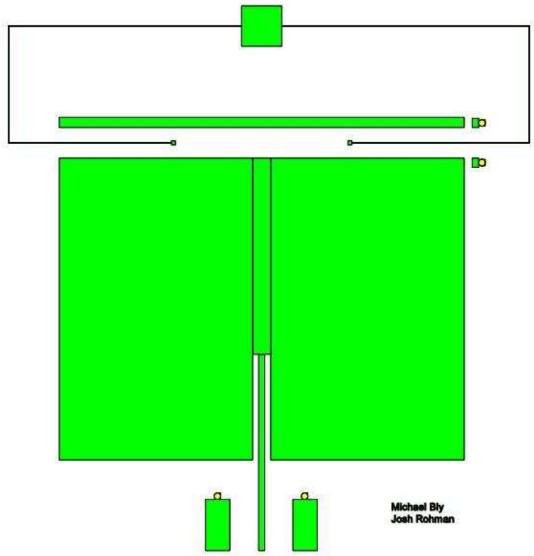


Figure 15-1: Finalized Layout of the Frequency Reconfigurable Microstrip Patch Antenna Without Landing Pads.

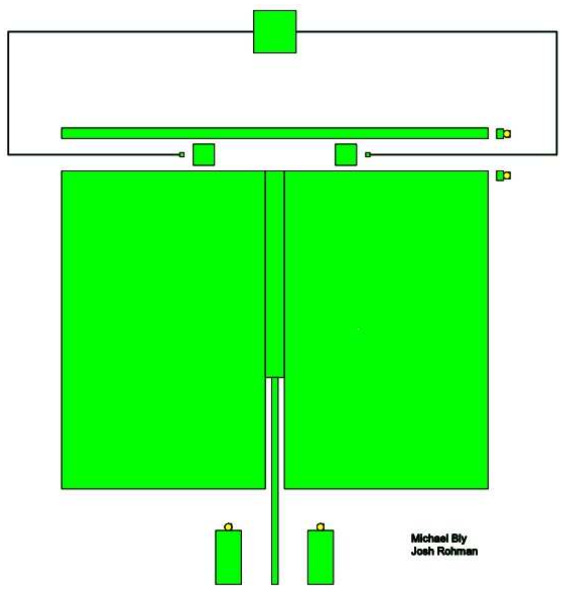


Figure 15-2: Finalized Layout of the Frequency Reconfigurable Microstrip Patch Antenna With Landing Pads.

Chapter 4 Conclusions:

The next step is to simulate and tune the results of the patch antenna system layout until the desired results are achieved. The DC-DC converter will be tested and built on a breadboard while the MEMS evaluation board is simple enough to skip simulations and go to fabrication.

Chapter 5: Simulation Results

In this chapter you will find the simulation results for the discussed layouts in chapter 3. These simulations were done through ADS Momentum with the patch antenna dimensions as described. Various simulations were done to better tune and adjust patch L, W, and inset feed matching; these results represent our final simulations both before and after inset feed implementation. Note: Some dimensions (length and width) were adjusted after addition of inset feed line.

1.575GHz (without inset feed matching)

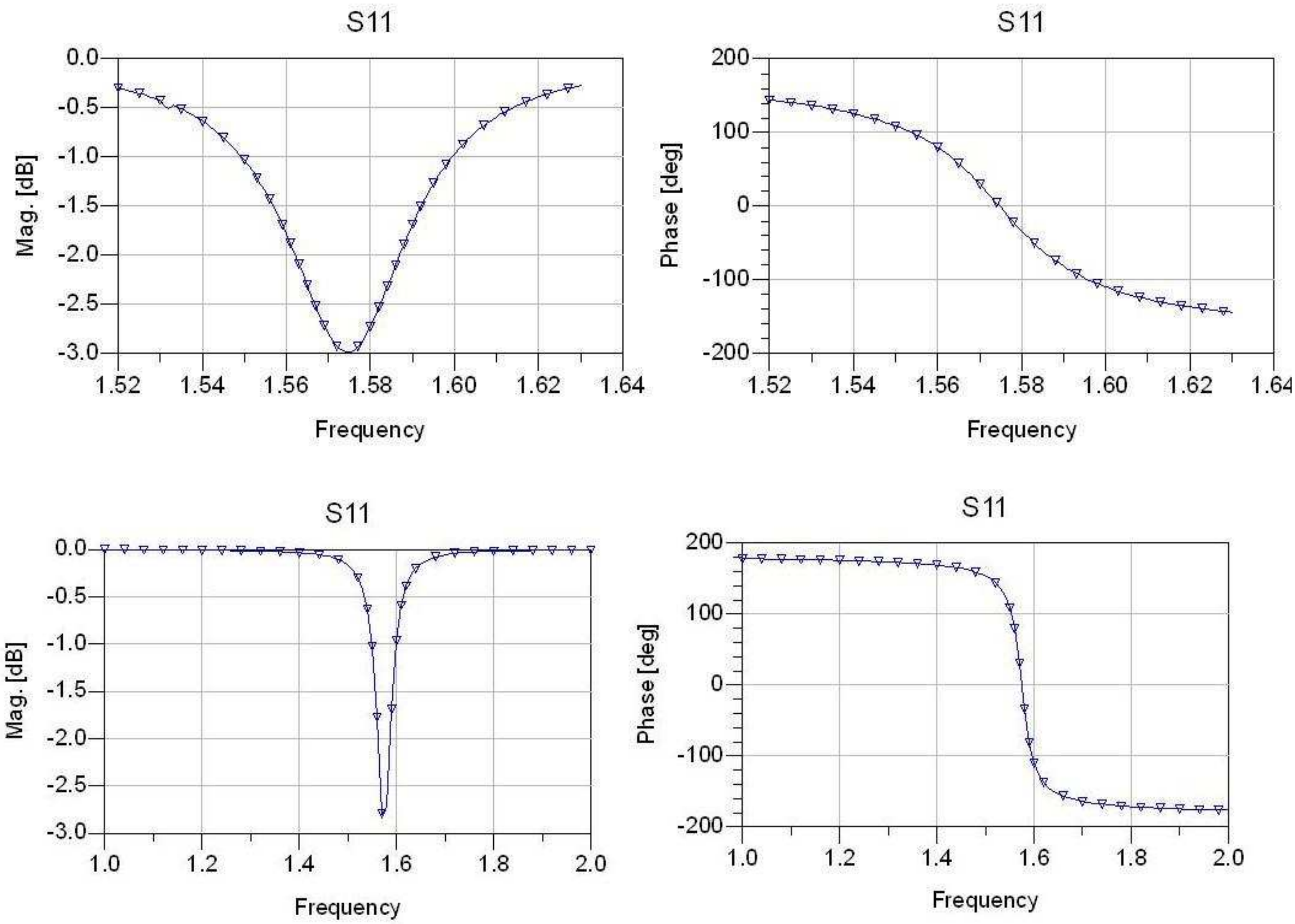


Figure 16-1: Simulation results for 1.575 Ghz patch without inset feed match

freq	var("S")	Z
1.520 GHz	0.966 / 143.965	16.285 / 86.678
1.523 GHz	0.964 / 142.352	17.070 / 86.526
1.525 GHz	0.960 / 140.600	17.931 / 86.359
1.528 GHz	0.957 / 138.697	18.877 / 86.175
1.530 GHz	0.953 / 136.584	19.941 / 85.969
1.533 GHz	0.945 / 134.274	21.128 / 85.488
1.535 GHz	0.943 / 131.723	22.453 / 85.480
1.538 GHz	0.937 / 128.911	23.950 / 85.188
1.540 GHz	0.930 / 125.740	25.680 / 84.851
1.543 GHz	0.921 / 122.201	27.670 / 84.462
1.545 GHz	0.912 / 118.240	29.978 / 84.011
1.548 GHz	0.901 / 113.777	32.694 / 83.479
1.550 GHz	0.888 / 108.661	35.978 / 82.835
1.553 GHz	0.873 / 102.822	39.984 / 82.048
1.555 GHz	0.856 / 96.278	44.860 / 81.087
1.558 GHz	0.836 / 88.468	51.333 / 79.808
1.560 GHz	0.815 / 79.652	59.727 / 78.140
1.563 GHz	0.791 / 69.455	71.366 / 75.814
1.565 GHz	0.767 / 57.826	88.278 / 72.380
1.567 GHz	0.744 / 44.721	114.681 / 66.898
1.570 GHz	0.725 / 29.981	160.507 / 56.731
1.573 GHz	0.712 / 14.297	238.610 / 35.547
1.575 GHz	0.709 / -1.961	292.113 / -5.573
1.577 GHz	0.716 / -18.503	215.267 / -42.965
1.580 GHz	0.731 / -34.059	145.698 / -60.335
1.583 GHz	0.752 / -48.291	106.565 / -68.820
1.585 GHz	0.776 / -61.101	83.067 / -73.657
1.587 GHz	0.800 / -72.148	68.069 / -76.689
1.590 GHz	0.824 / -82.136	57.233 / -78.850
1.593 GHz	0.845 / -90.617	49.472 / -80.390

Figure 17-1: Data set, simulation results for 1.575 Ghz patch without inset feed match

1.227 GHz (without inset feed matching)

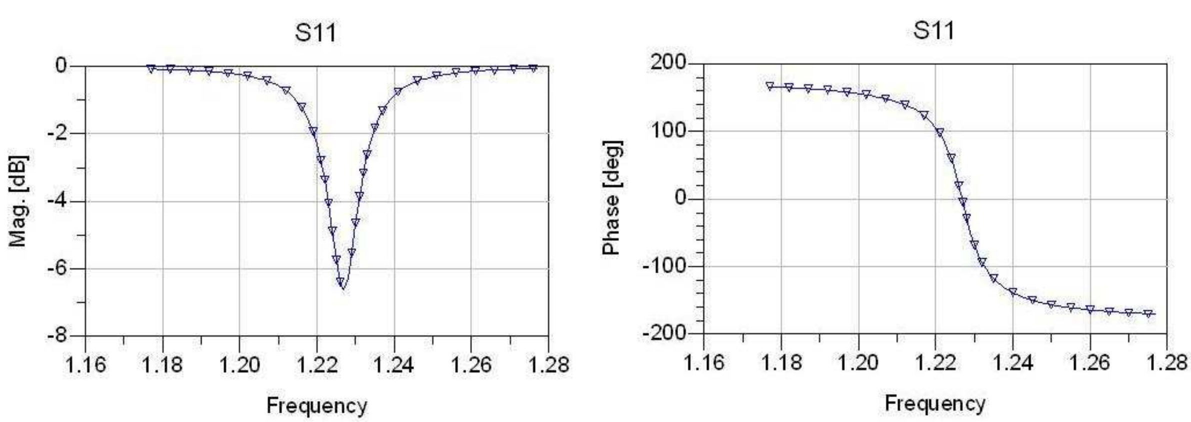
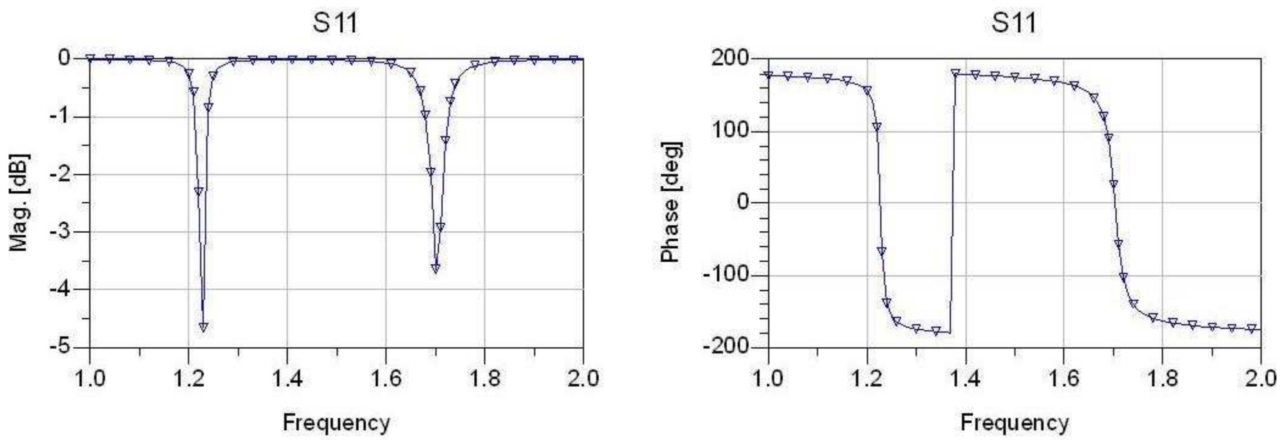


Figure 17-2: Simulation results for 1.227 Ghz patch without inset feed match



freq	S(1,1)	Z
1.187 GHz	0.986 / 163.011	7.476 / 87.308
1.189 GHz	0.985 / 162.207	7.836 / 87.167
1.191 GHz	0.983 / 161.323	8.233 / 87.010
1.193 GHz	0.982 / 160.340	8.676 / 86.835
1.195 GHz	0.979 / 159.241	9.173 / 86.636
1.197 GHz	0.977 / 158.010	9.732 / 86.412
1.199 GHz	0.974 / 156.604	10.374 / 86.154
1.201 GHz	0.970 / 154.984	11.118 / 85.853
1.203 GHz	0.965 / 153.136	11.974 / 85.505
1.205 GHz	0.959 / 150.963	12.990 / 85.090
1.207 GHz	0.952 / 148.391	14.207 / 84.591
1.209 GHz	0.942 / 145.304	15.691 / 83.980
1.211 GHz	0.929 / 141.531	17.542 / 83.214
1.213 GHz	0.911 / 136.837	19.911 / 82.229
1.215 GHz	0.886 / 130.847	23.056 / 80.914
1.217 GHz	0.851 / 122.953	27.445 / 79.066
1.219 GHz	0.800 / 112.305	33.896 / 76.321
1.221 GHz	0.726 / 97.321	44.268 / 71.825
1.223 GHz	0.626 / 75.426	62.953 / 63.371
1.225 GHz	0.517 / 41.779	101.292 / 43.196
1.227 GHz	0.467 / -5.005	136.638 / -5.948
1.229 GHz	0.529 / -50.434	89.805 / -48.585
1.231 GHz	0.641 / -82.474	56.352 / -65.149
1.233 GHz	0.740 / -103.612	39.768 / -72.517
1.235 GHz	0.811 / -118.060	30.399 / -76.540
1.237 GHz	0.860 / -128.384	24.455 / -79.053
1.239 GHz	0.893 / -136.031	20.375 / -80.761
1.241 GHz	0.917 / -141.888	17.404 / -81.996
1.243 GHz	0.934 / -146.491	15.149 / -82.927
1.245 GHz	0.946 / -150.196	13.377 / -83.653

Figure 18-1: Simulation results (and data set) for 1.227 Ghz patch without inset feed match

1.575 GHz (with inset feed matching)

1.562 GHz	0.833 / -54.300	96.092 / -77.212
1.563 GHz	0.812 / -56.510	91.485 / -75.852
1.564 GHz	0.787 / -58.953	86.753 / -74.240
1.565 GHz	0.758 / -61.672	81.886 / -72.302
1.566 GHz	0.723 / -64.701	76.909 / -69.950
1.567 GHz	0.682 / -68.077	71.855 / -67.060
1.568 GHz	0.632 / -71.836	66.786 / -63.463
1.569 GHz	0.574 / -76.003	61.804 / -58.936
1.570 GHz	0.505 / -80.581	57.080 / -53.191
1.571 GHz	0.424 / -85.524	52.890 / -45.894
1.572 GHz	0.332 / -90.679	49.647 / -36.750
1.573 GHz	0.230 / -95.551	47.932 / -25.773
1.574 GHz	0.119 / -98.004	48.389 / -13.473
1.575 GHz	0.018 / -30.720	51.560 / -1.046
1.576 GHz	0.115 / 51.082	57.710 / 10.267
1.577 GHz	0.226 / 48.869	66.835 / 19.693
1.578 GHz	0.328 / 44.028	78.825 / 27.090
1.579 GHz	0.421 / 38.889	93.640 / 32.679
1.580 GHz	0.501 / 33.942	111.417 / 36.788
1.581 GHz	0.572 / 29.291	132.769 / 39.730
1.582 GHz	0.630 / 25.180	157.108 / 41.592
1.583 GHz	0.679 / 21.413	186.144 / 42.633
1.584 GHz	0.721 / 18.028	220.434 / 42.884
1.585 GHz	0.756 / 14.992	261.180 / 42.360
1.586 GHz	0.785 / 12.263	309.994 / 41.017
1.587 GHz	0.810 / 9.813	368.664 / 38.751
1.588 GHz	0.831 / 7.599	439.660 / 35.378
1.589 GHz	0.849 / 5.597	524.868 / 30.644
1.590 GHz	0.864 / 3.780	624.801 / 24.217
1.591 GHz	0.877 / 2.122	735.689 / 15.745
1.592 GHz	0.889 / 0.606	844.267 / 5.102
1.593 GHz	0.898 / -0.788	927.219 / -7.301
1.594 GHz	0.907 / -2.072	961.987 / -20.305
1.595 GHz	0.915 / -3.259	945.232 / -32.462
1.596 GHz	0.921 / -4.361	893.821 / -42.806
1.597 GHz	0.927 / -5.388	828.399 / -51.121
1.598 GHz	0.932 / -6.345	762.754 / -57.617
1.599 GHz	0.937 / -7.242	702.783 / -62.689

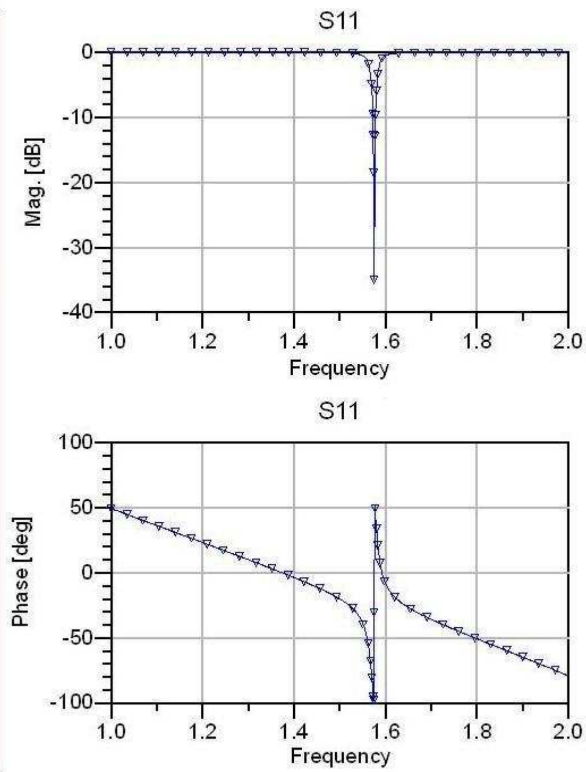


Figure 19-1: Simulation & data set for 1.575 Ghz with inset feed matching

1.227 GHz (with inset feed matching)

1.213 GHz	0.955 / 5.611	922.798 / 64.681
1.214 GHz	0.949 / 4.332	1.087E3 / 55.244
1.215 GHz	0.942 / 2.887	1.277E3 / 40.031
1.216 GHz	0.933 / 1.240	1.377E3 / 17.318
1.217 GHz	0.922 / -0.656	1.219E3 / -8.003
1.218 GHz	0.908 / -2.865	918.926 / -27.288
1.219 GHz	0.889 / -5.471	662.072 / -39.086
1.220 GHz	0.865 / -8.587	479.974 / -45.802
1.221 GHz	0.833 / -12.369	352.864 / -49.315
1.222 GHz	0.788 / -17.030	261.720 / -50.568
1.223 GHz	0.725 / -22.849	194.327 / -49.873
1.224 GHz	0.636 / -30.188	143.278 / -47.053
1.225 GHz	0.511 / -39.478	104.200 / -41.350
1.226 GHz	0.342 / -51.209	74.934 / -31.145
1.227 GHz	0.132 / -67.528	55.225 / -13.927
1.228 GHz	0.100 / 112.509	46.334 / 10.600
1.229 GHz	0.316 / 94.300	47.892 / 34.975
1.230 GHz	0.492 / 82.084	55.790 / 52.154
1.231 GHz	0.624 / 72.362	66.109 / 62.856
1.232 GHz	0.718 / 64.745	76.760 / 69.514
1.233 GHz	0.784 / 58.681	87.156 / 73.936
1.234 GHz	0.831 / 53.816	97.038 / 77.013
1.235 GHz	0.865 / 49.913	106.220 / 79.215
1.236 GHz	0.890 / 46.687	114.850 / 80.872
1.237 GHz	0.909 / 43.999	122.922 / 82.144
1.238 GHz	0.923 / 41.725	130.495 / 83.145
1.239 GHz	0.934 / 39.777	137.617 / 83.948
1.240 GHz	0.943 / 38.089	144.338 / 84.601
1.241 GHz	0.951 / 36.611	150.702 / 85.142
1.242 GHz	0.956 / 35.304	156.747 / 85.593
1.243 GHz	0.961 / 34.138	162.508 / 85.975
1.244 GHz	0.965 / 33.086	168.037 / 86.301
1.245 GHz	0.969 / 32.142	173.298 / 86.579
1.246 GHz	0.972 / 31.277	178.379 / 86.821
1.247 GHz	0.974 / 30.485	183.278 / 87.032
1.248 GHz	0.976 / 29.755	188.016 / 87.217
1.249 GHz	0.978 / 29.079	192.608 / 87.379
1.250 GHz	0.980 / 28.450	197.071 / 87.523

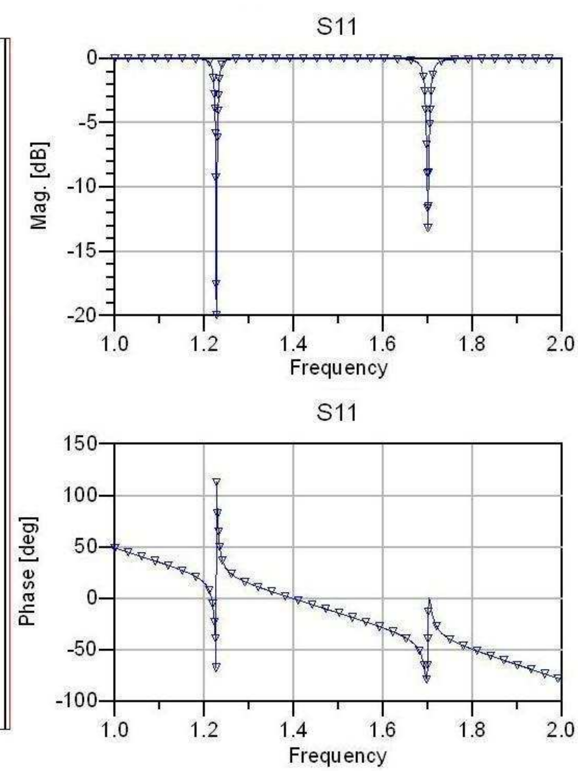


Figure 19-2: Simulation & data set for 1.227 Ghz with inset feed matching

Chapter 6: Test Results and Simulation Comparison

As the end of the semester came about at the same time as our fabrication, the procedure to demonstrate our project changed. We wanted to demonstrate our two resonant frequencies and DC-DC Converter. In order to do this, one antenna system remained unchanged to resonate at 1.575 GHz. Another antenna system was modified by soldering 2 wires between the patches to represent a closed MEMS switch (1.227 GHz).

DC-DC Converter Results:

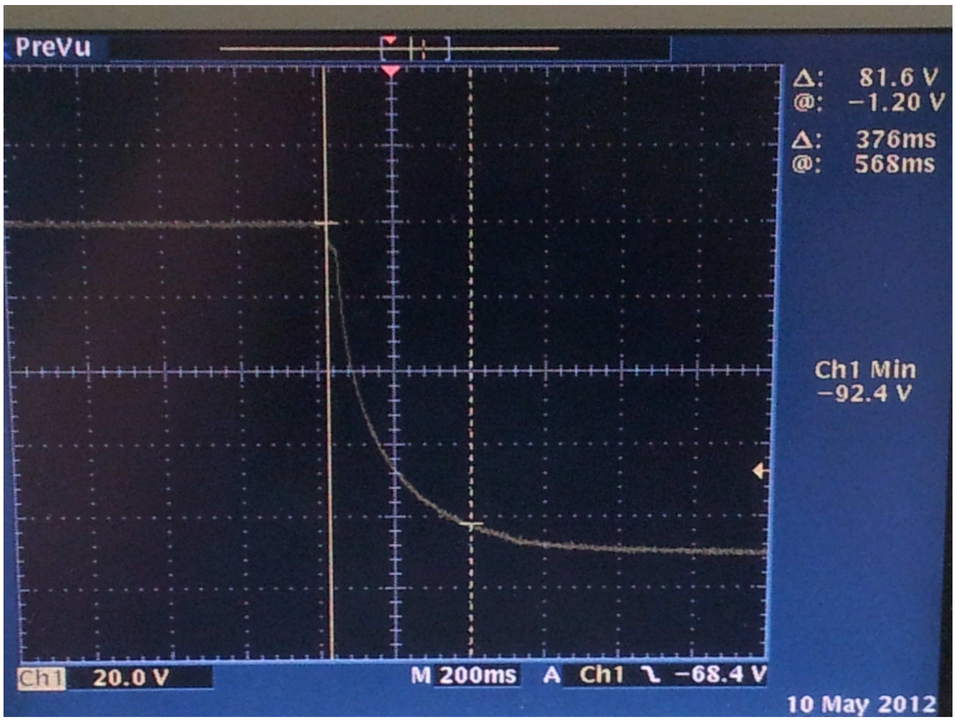


Figure 20-1: Oscilloscope plot of the DC-DC Converter switching from 0V (Ground) to -90V (when Vin is +5V).

The DC-DC inverting boost converter successfully switches between 0V and ~-92V pending the Vin voltage.

1.575 GHz Results:

The results for our 1.575 GHz patch antenna was obtained via spectrum analyzer to find the S11 parameters of the antenna. These results can be compared to our simulated data. The antenna used is shown in Figure 21-1. The results are shown in Figure 21-2. The actual resonant frequency is shown in blue (1.515 GHz) while the target resonant frequency is shown in red (1.575 GHz). The resonant frequency is 60 MHz lower than the target frequency. The dB at the resonant frequency is about -10dB, which is not as strong of a signal as the simulation data due to the inset feed being set up to match 1.575 GHz.

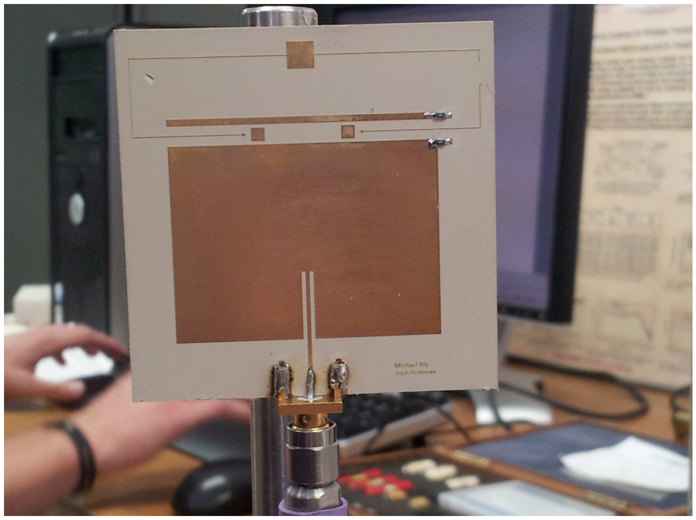
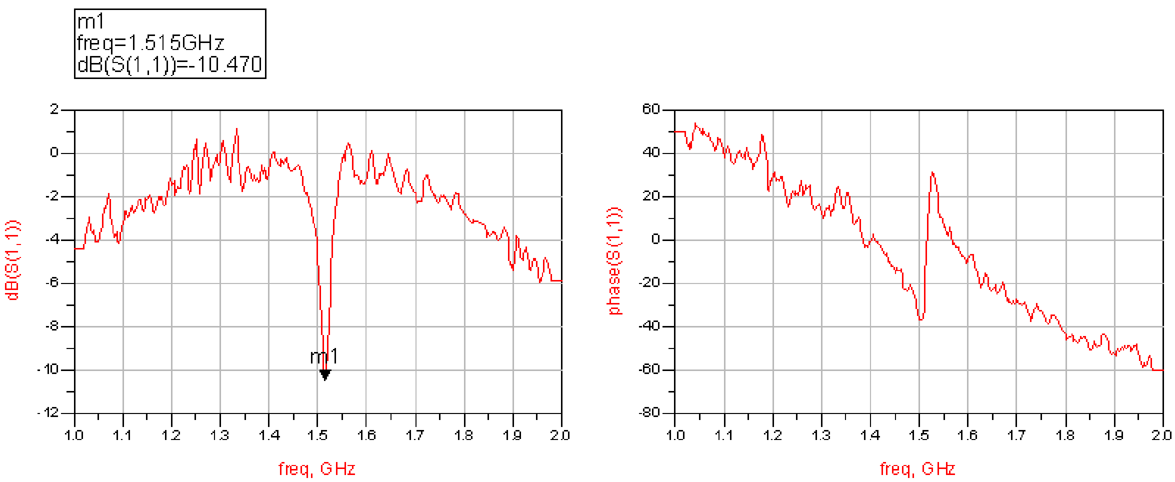


Figure 21-1: 1.575 GHz antenna system used to obtain Test Results.



freq	Z(1,1)	S(1,1)
1.510 GHz	92.014 / -22.454	0.356 / -30.498
1.513 GHz	94.337 / -12.284	0.325 / -17.413
1.515 GHz	92.389 / -3.851	0.300 / -5.870
1.518 GHz	95.635 / 3.882	0.315 / 5.564
1.520 GHz	97.707 / 15.432	0.350 / 20.252
1.523 GHz	107.468 / 23.176	0.417 / 25.050
1.525 GHz	113.941 / 29.920	0.470 / 28.465
1.528 GHz	120.757 / 38.091	0.534 / 31.657
1.530 GHz	138.362 / 45.632	0.618 / 30.721
1.533 GHz	162.687 / 49.932	0.685 / 27.450
1.535 GHz	183.935 / 52.555	0.728 / 24.989
1.538 GHz	228.459 / 54.926	0.783 / 20.619
1.540 GHz	301.056 / 49.536	0.808 / 14.568
1.543 GHz	415.832 / 51.220	0.861 / 10.770
1.545 GHz	460.186 / 56.293	0.887 / 10.367
1.548 GHz	533.346 / 67.218	0.930 / 9.893
1.550 GHz	928.629 / 72.569	0.968 / 5.883
1.553 GHz	1.023E3 / 83.426	0.989 / 5.562
1.555 GHz	866.581 / 70.994	0.963 / 6.247
1.558 GHz	1.541E3 / 100.7...	1.012 / 3.653
1.560 GHz	2.315E3 / 130.7...	1.029 / 1.875
1.563 GHz	827.648 / 114.9...	1.052 / 6.275
1.565 GHz	1.479E3 / 133.6...	1.048 / 2.802
1.567 GHz	3.071E3 / -105....	1.009 / -1.800
1.570 GHz	2.012E3 / -52.8...	0.970 / -2.271
1.573 GHz	1.793E3 / -29.9...	0.953 / -1.594
1.575 GHz	745.085 / -24.0...	0.885 / -3.145
1.577 GHz	760.278 / -25.4...	0.888 / -3.250
1.580 GHz	793.091 / -26.3...	0.893 / -3.214

Figure 21-2: 1.575 GHz Test Results.

1.227 GHz Results:

In order to simulate closed MEMS switches, two wires were soldered across the location where the MEMS switches would be placed. These connections changed the resonant frequency.

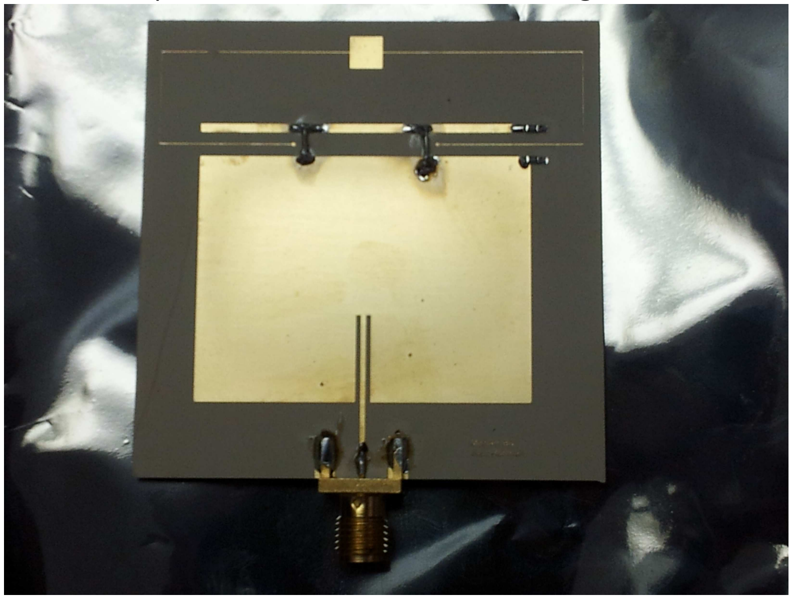
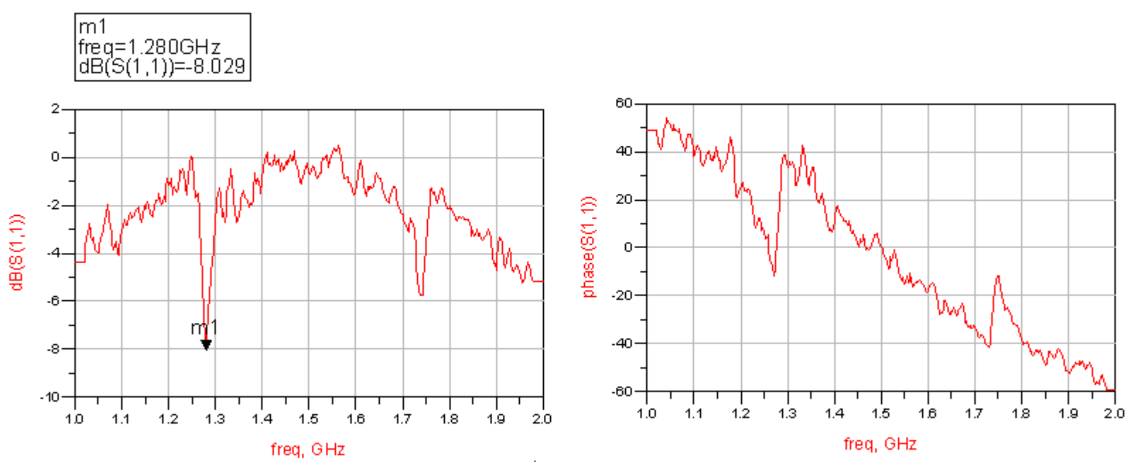


Figure 22-1: 1.227 GHz antenna system using 2 wires to simulate closed MEMS switches.



freq	Z(1,1)	S(1,1)
1.222 GHz	272.197 / 74.0...	0.907 / 20.084
1.225 GHz	349.519 / 76.6...	0.937 / 15.868
1.228 GHz	435.368 / 70.6...	0.928 / 12.387
1.230 GHz	543.150 / 71.6...	0.944 / 9.994
1.232 GHz	615.873 / 64.4...	0.933 / 8.386
1.235 GHz	446.336 / 50.1...	0.867 / 9.883
1.238 GHz	353.746 / 49.6...	0.834 / 12.395
1.240 GHz	373.890 / 53.4...	0.854 / 12.341
1.242 GHz	527.976 / 58.6...	0.907 / 9.274
1.245 GHz	767.484 / 76.9...	0.971 / 7.266
1.248 GHz	703.605 / 91.7...	1.004 / 8.126
1.250 GHz	903.412 / 87.1...	0.994 / 6.328
1.252 GHz	1.656E3 / 89.7...	1.000 / 3.458
1.255 GHz	687.093 / 31.6...	0.883 / 4.390
1.258 GHz	469.875 / 25.3...	0.825 / 5.265
1.260 GHz	559.383 / -4.602	0.836 / -0.828
1.263 GHz	512.422 / -24.9...	0.838 / -4.752
1.265 GHz	355.890 / -21.2...	0.769 / -5.926
1.268 GHz	279.932 / -22.2...	0.717 / -7.945
1.270 GHz	206.981 / -23.3...	0.640 / -11.477
1.273 GHz	166.647 / -14.1...	0.551 / -9.187
1.275 GHz	137.813 / -4.960	0.469 / -4.133
1.278 GHz	121.700 / 2.391	0.418 / 2.362
1.280 GHz	113.406 / 9.591	0.397 / 10.335
1.283 GHz	114.108 / 19.0...	0.424 / 19.535
1.285 GHz	116.326 / 29.7...	0.476 / 27.612

Figure 22-2: 1.227 GHz Test Results

From the results, 1.280 GHz is the actual resonant frequency while 1.227 GHz is the target frequency. Again, the resonant frequency is about 50 to 60 MHz off, but this time it is a higher than the target frequency. The dB of the resonant frequency is about -8dB, which is not as strong as expected due to the inset feed being set up for 1.227 GHz.

Chapter 7: Conclusion

Testing with MEMS switches will follow, but at the moment the antenna system behaves almost as intended beyond the resonant frequency locations. However, a larger bandwidth could have fixed these problems. This could be done with a thicker substrate or lower dielectric constant. Determining the cause of the change in resonant frequency will come with later testing.

Recommendations:

The design behind the reconfigurable patch antenna has many possibilities for future work. First off, circular polarization can be added by truncated corners, slots, etc. It was dropped from the project due to time constraints and complexity it presented. Some preliminary work was done to show it was feasible, but the goal was to produce a working frequency reconfigurable antenna by the end of the semester.

In addition, a single stub or double stub impedance matching network could be used instead of inset feed matching. While not entirely necessary, at different application frequencies these impedance matching networks will give more accurate matching for each resonant frequency. The downfall of these matching networks compared to inset feed matching is the complexity and physical size added into the project.

For final fabrication and design of the patch antenna, due to variances between simulations and tests, it is suggested that multiple designs are made of the antenna. For these designs some patches should be made to resonant slightly higher than desired, some at desired, and some below desired during simulations. These, when fabricated, will help determine the final dimensions to be used for final product fabrication and thus will help eliminate any variances, like the ~60Mhz differences we noticed.

Lastly, newer MEMS switches with smaller package sizes and/or lower biasing voltages can be picked for the antenna system. With the RMSW201, removing the ground plane with sandpaper is not a practical design choice. Also, a third MEMS switch could be added to improve connectivity between patches.

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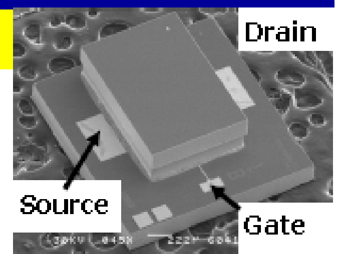
Appendix:

SPST, High-Isolation, RF-MEMS Switch DC to 20 GHz

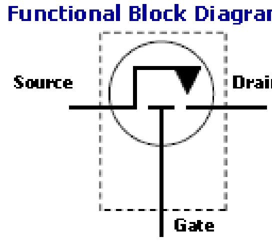


RMSW201™

Features

- High Isolation (20 dB typical @ 10 GHz)
- Low Insertion Loss (<0.5 dB typical @ 10 GHz)
- Near Zero Harmonic Distortion
- No Quiescent Power Dissipation
- Long Life (typical lifetime >100 billion cycles @ 27 dBm, >1 billion cycles @ 30 dBm)
- Hermetically sealed die designed for die-attach and wire-bond to board. Please contact us for other packaging options.

Functional Block Diagram



Description

The RMSW201™ is a Single Pole Single Throw (SPST) Reflective RF Switch utilizing Radant's break-through MEMS technology that delivers high linearity, high isolation and low insertion loss in a chip-scale package configuration.

This device is ideally suited for use in many applications such as RF and microwave multi-throw switching, radar beam steering antennas, phase shifters, RF test instrumentation, ATE, cellular, and broadband wireless access.

Typical Device Specifications

Insertion Loss DC 2 GHz 10 GHz 18 GHz	 < 4 Ω < 0.30 dB < 0.45 dB < 0.60 dB	**Lifecycle** Cold-switched, 27 dBm Cold-switched, 30 dBm Cold-switched, 33 dBm Hot-switched, -20 dBm Hot-switched, -10 dBm Hot-switched, 20 dBm	 > 10^{11} cycles > 10^{9} cycles > 10^{3} cycles > 10^{11} cycles > 10^{9} cycles > 10^{3} cycles
Isolation DC 2 GHz 10 GHz 18 GHz	 > 1 GΩ > 35 dB > 21 dB > 18 dB	**Control** Gate-Source Voltage (on) Gate-Source Voltage (off) Control Power, steady-state Control Power, 1 KHz cycle rate	 +/- 90 V 0 V < 1 nW < 2 µW
Return Loss 2 GHz 10 GHz 18 GHz	 < -27 dB < -22 dB < -20 dB	**Switching speed** On Off	 < 10 µs < 2 µs
Input IP3 (Two-tone inputs 900 MHz and 901 MHz up to +5 dBm)	> 65 dBm	**Operating temperature** Maximum Minimum	 85 °C -40 °C
		Storage temperature Maximum Minimum	 150 °C -55 °C

Notes:
1. All RF measurements were made in a 50 Ω system.
2. Measurements include bond-wires from die to test-board.

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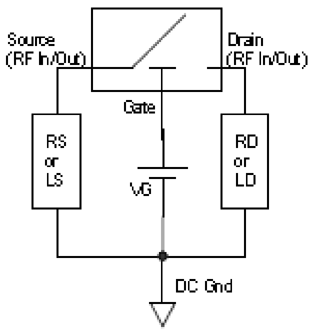
SPST, High Isolation, RF-MEMS Switch, DC to 20 GHz RMSW201™

Absolute Maximum Ratings

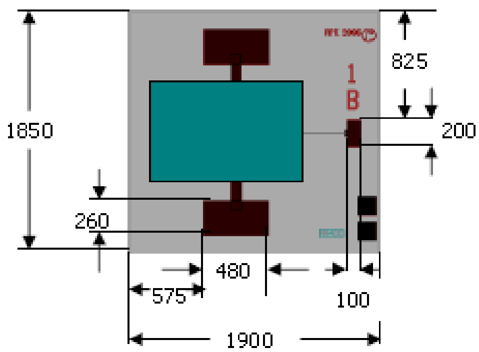
Maximum Temperature (10 seconds) (120 seconds)	 290 °C 250 °C
Maximum Voltage, Gate-Source	+/- 110 V
Maximum Voltage, Drain-Source	+/- 100 V

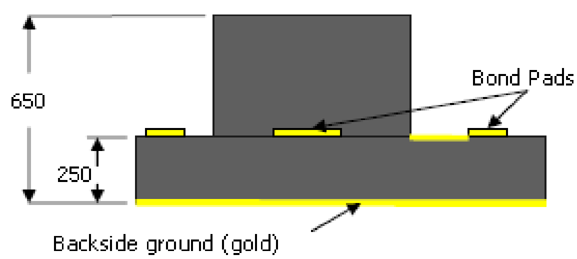
Recommended Application



1. Resistors RS and RD (40 KΩ-100 KΩ) or inductors LS and LD should be used to provide a path to DC Ground from Source and Drain.
2. VG may be of either polarity.
3. VG rise-time should be at least 10 µs for optimal lifetime.
4. Please refer to "Application Note for Test and Handling of SPST RF-MEMS Switches" for more information. Contact us for driver solutions.

Nominal Device Dimensions





Dimensions are in micrometers.
Please contact us for a footprint in .gds or .dxf format.

Static sensitivity

This device has an ESD (HBM) sensitivity of 100 V. Use proper ESD precautions when handling. Please refer to "Application Note for Test and Handling of SPST RF-MEMS Switches" for more information.

Die Assembly

The gold backside-metallization on the die is designed to be mounted with electrically conductive silver epoxy, or with a lower temperature solder which does not consume gold. Bond pads on the die are made of gold. Ball-bonds should be utilized to attach gold or Aluminum 1 mil wires. Please refer to "Application Note for Test and Handling of SPST RF-MEMS Switches" for more information.

APPLICATION NOTE FOR TEST & HANDLING OF SPST RF-MEMS SWITCHES

GENERAL DESCRIPTION

RMI's RMSWXXX™ RF-MEMS switches are electrostatically actuated cantilever beams connected in a three terminal configuration. Functionality is analogous to a field effect transistor (FET), with the terminals labeled Source, Gate, and Drain (Figure 1).

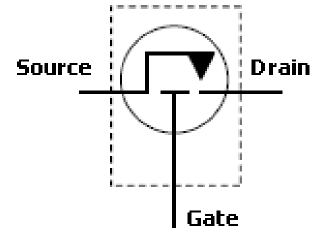


Figure 1 – Functional block diagram of SPST switch

In the simplified model of a representative switch in Figure 2, a DC actuation voltage is applied between the Gate and the Source terminals, creating an electrostatic force that, in turn, pulls the free end of the beam into contact with the Drain. When the voltage is removed, the beam acts as a spring, generating sufficient restoring force to open the connection between source and drain, breaking the circuit. In multi-throw switches, each throw is an independently actuated cantilever beam.

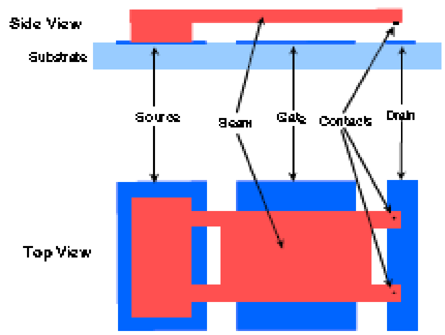


Figure 2 – Simplified representation of a switch

SWITCH ACTUATION

The gate to source actuation voltage is insensitive to polarity, i.e. the gate may be driven either positive or negative with respect to the source. The recommended actuation voltage is +/- 90 V.

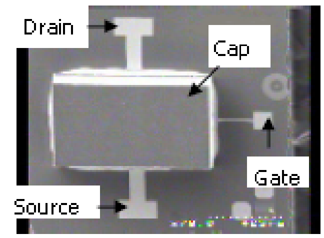


Figure 3 – SEM image of a RMSW100™ SPST Switch

Since these are three terminal devices, V_{GS}, the bias voltage applied to the gate to actuate the switch, must be made relative to the source. If the voltage amplitude of the signal passing through the switch is not small (V_S>5V) compared to V_{GS}, the gate voltage V_G will have to be varied accordingly to keep V_{GS} constant.

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RECOMMENDED APPLICATION

Parasitic capacitances in the test system will cause capacitive coupling of the actuation signal to the Drain and Source terminals. In order to minimize hot-switching caused by the coupled signals, a resistor RS (40 kΩ-100 kΩ) or inductor LS should be used to provide a path to DC ground from each Source pad. Similarly, a resistor RD (40 kΩ-100 kΩ) or inductor LD should be used to provide a path to DC Ground from the Drain pad, as is shown in Figure 4.

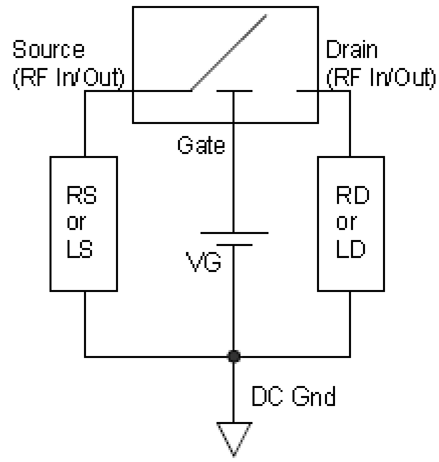

Figure 4 — Recommended switch connections to minimize hot switching caused by coupled signals

DIE ASSEMBLY

As seen in Figure 5, the gold backside-metallization on the die is designed to be mounted with electrically conductive silver epoxy. Radant MEMS recommends Chemtronics TDS CW2460 conductive epoxy, which can be cured at 100°C for 15 minutes. Ball-bonds should be utilized to attach 0.001” diameter wires (as many as three 0.001” diameter wires may be used side by side) to the bond pads. Die should be handled with vacuum pickups or with plastic tweezers.

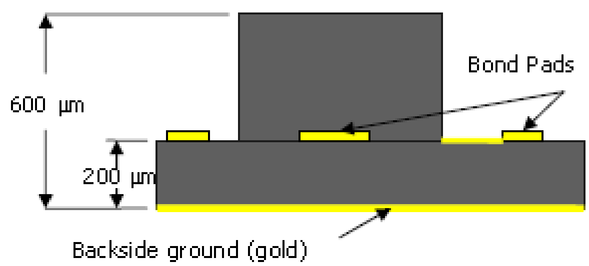

Figure 5 — A Radant MEMS switch in profile

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ESD AND TEST PRECAUTIONS

RMI's RF-MEMS switches have been fabricated without any ESD protection. Because of their extremely small size, low on-resistance, and minimal parasitic capacitance, the devices have a ESD sensitivity of 100 V (Human Body Model) . Stored charge inadvertently conducted through the switches can result in immediate permanent damage to the devices.

All handling precautions for ESD-sensitive devices should be observed, including working only on static-dissipative surfaces, wearing wrist-straps or other ESD control devices, storing unused devices in conductive foam, etc.

Care should also be taken connecting signals to these units under test:

a. Avoid connecting "live" signal sources. Ensure that outputs are switched off (preferably grounded) before connecting to devices under test. Ensure that all instrumentation shares a common chassis ground.
b. Avoid running measurement instruments (e.g. DMM's, etc.) in auto range modes. Some instruments can generate large transient compliance voltages when switching ranges.
c. Use the highest practical range (i.e. lowest resolution) for resistance measurements. This will minimize compliance voltages.
d. Where practical, avoid using coaxial cable for DC connections. A coaxial cable has inherent capacitance that stores energy stored that can be inadvertently discharged through a device under test.

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COLD SWITCHING

To maximize switch lifetime and ensure the best contact resistance stability, Radant MEMS switches should be cold switched, where no signal is present between the drain and source pads as the switch opens or closes. Doing this prevents additional energy dissipation at the contacts during switching events.

Parasitic capacitances in the test system will cause capacitive coupling of transitions in the gate bias signal to the drain and source terminals. To minimize hot-switching caused by the coupled signals:

- **the test system must provide a resistive path (100 kΩ or less) from the drain and source terminals to ground;**
- **the bias applied to turn the switch on should have a minimum rise time (from 0 to the final value, V_{GS}) of 10 µs.**

Contact bounce will occur immediately after the switch closes (the duration of the bounce depends on the rise time of the gate bias signal). In order to avoid hot switching during contact bounce, **the switch signal (voltage between drain and source) should be applied no earlier than 5 µs after the final bias voltage, V_{GS}, is reached.**

Finally, the switch signal should be removed no later than 1 µs before the gate bias signal is turned off.

The above timing recommendations are illustrated in Figure 6.

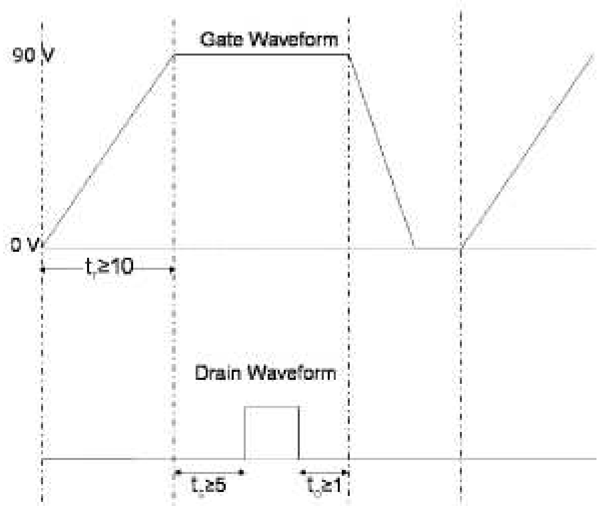

Figure 6 — Timing recommendations for cold switching

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APPLICATION NOTE FOR MAX774 DC-TO-DC CONVERTER

Description

This application note documents a DC-to-DC converter that can be used to actuate Radant MEMS switches. As seen in Figure 1, the converter, based around the Maxim IC MAX774, takes a +5 VDC input and converts it to a -90 VDC output. Users may find this DC-to-DC converter is suitable for applications where 90 VDC is not available for switch actuation.

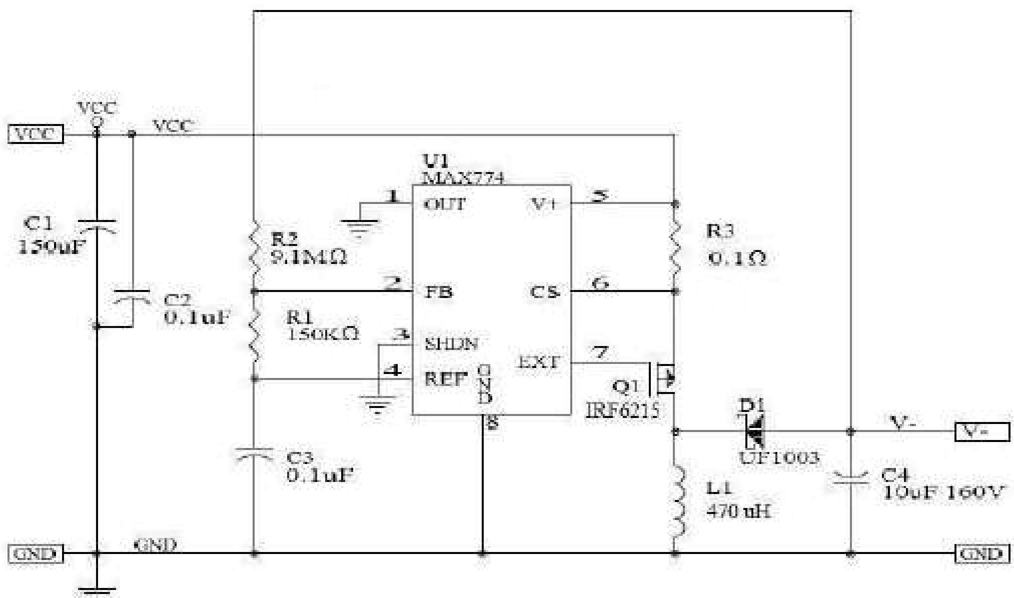

Figure 1: MAX774 DC-to-DC Converter Schematic

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Bill of Materials

Item	Ref. Des.	Description	Part Number	Manufacturer	Quantity	Package
1	U_1	Adjustable DC-to-DC controller	MAX774CSA	Maxim IC	1	SMD8A
2	Q_1	P-Channel MOSFET, 150V, 13A	IRF6215LPBF	International Rectifier	1	TO-262
3	D_1	Ultra-fast rectifier diode, 1A	UF1003-T	Diodes, Inc.	1	DO-41
4	R_1	150 kΩ, 0.25W resistor	N/A	Generic	1	1206
5	R_2	9.1 MΩ, 0.25W resistor	N/A	Generic	1	1206
6	R_3	0.1Ω, 1W, 5% current sense resistor	RW150BAR100JE	Ohmite	1	2512
7	C_1	150 µF, 10V, 100mΩ ESR tantalum capacitor	495-1531-1	Kemet	1	2917
8	C_2, C_3	0.1 µF, 50V, polyethylene capacitor	PCF1148CT	Panasonic ECG	2	1913
9	C_4	10 µF, 160V, aluminum electrolytic capacitor	AEB106V10	Cornell Dubilier Electronics	1	6767P
10	L_1	470 µH, 580 mA, 690 mΩ shielded inductor	ELL-CTV471M	Panasonic Electronic Components	1	12 mm W X 12 mm L X 4.2 mm T

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Theory of Operation

The basic design of the DC-to-DC converter is based on a switching inverting regulator. The MAX774 switches a p-channel MOSFET (Q_1) on and off, which, in turn, controls the output voltage of the DC-to-DC converter.

Initially, the MOSFET is on, allowing current to flow into the inductor (L_1) at an ever-increasing rate. As more current flows into the inductor, the voltage across it correspondingly increases, and more and more energy is stored in the inductor. When the voltage across the inductor exceeds 210 mV, the IC's internal voltage comparator, which indirectly monitors the current passing through the MOSFET, signals the IC to turn off the MOSFET. When this happens, the inductor discharges its stored energy in the form of electrical current to ground, thereby charging the output capacitor (C_4) and causing a negative voltage to develop across it. When the voltage at the drain terminal falls below 4.8 VDC, the MOSFET is turned on again, and the process repeats until the output voltage is regulated.

The desired output voltage is set using a voltage divider connected to the MAX774's feedback pin. The ratio of this divider is determined by the equation

$$\frac{R_2}{R_1} = \frac{V_{out}}{V_{ref}}$$

Where V_{ref} is equal to 1.5 VDC, V_{out} is the desired output voltage, and

$$R_2 = \frac{V_{out}}{10\ \mu A}.$$

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Data Sheet

RO3000® Series Circuit Materials

RO3003™, RO3006™ and RO3010™
High Frequency Laminates

RO3000® high frequency circuit materials are ceramic-filled PTFE composites intended for use in commercial microwave and RF applications. This family of products was designed to offer exceptional electrical and mechanical stability at competitive prices.

RO3000 series laminates are circuit materials with mechanical properties that are consistent regardless of the dielectric constant selected. This allows the designer to develop multi-layer board designs that use different dielectric constant materials for individual layers, without encountering warpage or reliability problems.

The dielectric constant versus temperature of RO3000 series materials is very stable (Charts 1 and 2). These materials exhibit a coefficient of thermal expansion (CTE) in the X and Y axis of 17 ppm/°C. This expansion coefficient is matched to that of copper, which allows the material to exhibit excellent dimensional stability, with typical etch shrinkage (after etch and bake) of less than 0.5 mils per inch. The Z-axis CTE is 24 ppm/°C, which provides exceptional plated through-hole reliability, even in severe thermal environments.

RO3000 series laminates can be fabricated into printed circuit boards using standard PTFE circuit board processing techniques, with minor modifications as described in the application note "Fabrication Guidelines for RO3000 Series High Frequency Circuit Materials."

RO3000 laminates are manufactured under an ISO 9002 certified system.

Features and Benefits:

Low dielectric loss (RO3003™ laminates)
- Laminates can be used in applications up to 77 GHz.

Excellent mechanical properties versus temperature
- Reliable stripline and multi-layer board constructions.

Uniform mechanical properties for a range of dielectric constants
- Ideal for multi-layer board designs with a range of dielectric constants
- Suitable for use with epoxy glass multi-layer board hybrid designs

Stable dielectric constant versus temperature and frequency (RO3003 laminates)
- Ideal for band pass filters, microstrip patch antennas, and voltage controlled oscillators.

Low in-plane expansion coefficient (match to copper)
- Allows for more reliable surface mounted assemblies
- Ideal for applications sensitive to temperature change
- Excellent dimensional stability

Volume manufacturing process
- Economical laminate pricing

Some Typical Applications:
- Automotive radar applications
- Global positioning satellite antennas
- Cellular telecommunications systems - power amplifiers and antennas
- Patch antenna for wireless communications
- Direct broadcast satellites
- Datalink on cable systems
- Remote meter readers
- Power backplanes

Advanced Circuit Materials Division
100 S. Roosevelt Avenue, Chandler, AZ 85226
Tel: 480-961-1382 Fax: 480-961-4533 www.rogerscorp.com

Chart 1: RO3003 Laminate Dielectric Constant vs. Temperature

The data in Chart 1 demonstrates the excellent stability of dielectric constant over temperature for RO3003 laminates, including the elimination of the step change in dielectric constant, which occurs near room temperature with PTFE glass materials.

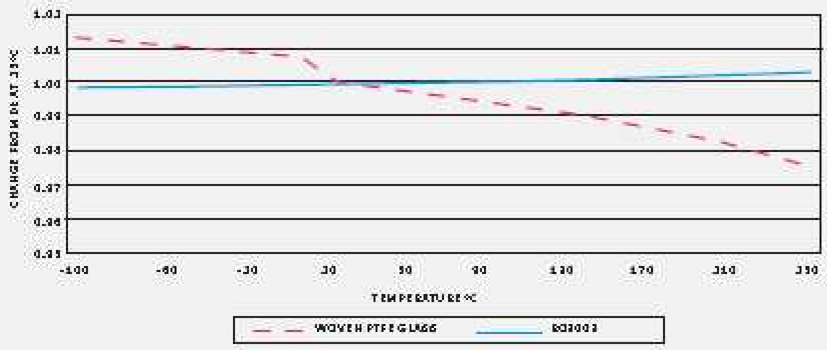


Chart 2: RO3006 and RO3010 Laminate Dielectric Constant vs. Temperature

The data in Chart 2 shows the change in dielectric constant vs. temperature for RO3006™ and RO3010™ laminates. These materials exhibit significant improvement in temperature stability of dielectric constant when compared to other high dielectric constant PTFE laminates.

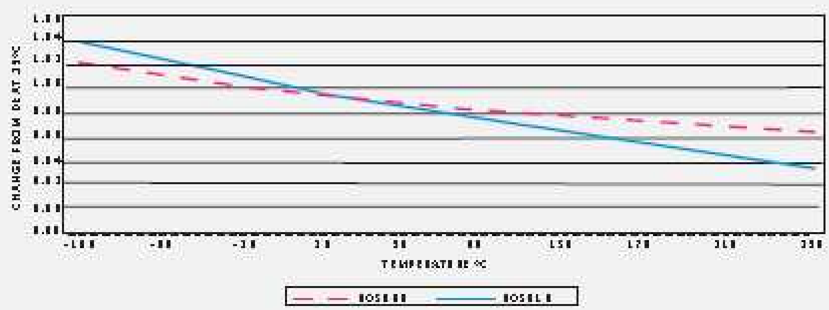
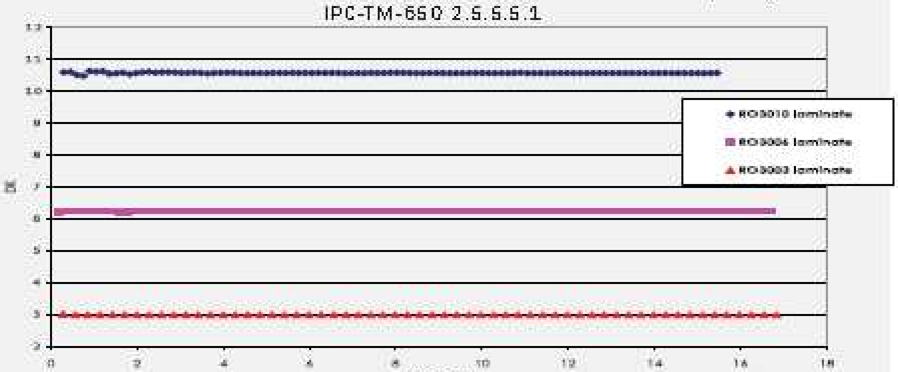


Chart 3: RO3000 Series Laminates Dielectric Constant vs. Frequency
IPC-TM-650 2.5.5.5.1

Chart 3 demonstrates the stability of dielectric constant for RO3000 series products over frequency. This stability simplifies the design of broadband components as well as allowing the materials to be used in a wide range of applications over a very broad range of frequencies.



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Data Sheet

Property	Typical Value(1)			Direction	Unit	Condition	Test Method
	RO3003	RO3006	RO3010				
Dielectric Constant, ε_r Process	3.00 ± 0.04	6.15 ± 0.15	10.2 ± 0.30	Z	-	10 GHz 23°C	IPC-TM-650 2.5.5.5 Clamped Stripline
(2) Dielectric Constant, ε_r Design	3.00	6.50	11.20	Z	-	8 GHz - 40 GHz	Differential Phase Length Method
Dissipation Factor, tan δ	0.0013	0.0020	0.0022	Z	-	10 GHz 23°C	IPC-TM-650 2.5.5.5
Thermal Coefficient of ε_r	13	-160	-280	Z	ppm/°C	10 GHz 0-100°C	IPC-TM-650 2.5.5.5
Dimensional Stability	0.01	0.5	0.5	X,Y	mm/m	COND A	ASTM D257
Volume Resistivity	10^7	10^5	10^5		MΩ•cm	COND A	IPC 2.5.17.1
Surface Resistivity	10^7	10^5	10^5		MΩ	COND A	IPC 2.5.17.1
Tensile Modulus	900	2068	1500	X, Y	MPa	23°C	ASTM D638
Water Absorption	<0.1	<0.1	<0.1	-	%	D24/23	IPC-TM-650 2.6.2.1
Specific Heat	0.9	0.86	0.8		J/g/K		Calculated
Thermal Conductivity	0.50	0.79	0.95	-	W/m/K	80°C	ASTM C518
Coefficient of Thermal Expansion	17 16 25	17 17 24	13 11 16	X Y Z	ppm/°C	-55 to 288°C	ASTM D3386-94
Td	500	500	500		°C TGA		ASTM D3850
Density	2.1	2.6	2.8		gm/cm³		
Copper Peel Strength	12.7	7.1	9.4		lb/in	1 oz. EDC After Solder Float	IPC-TM-2.4.8
Flammability	V-0	V-0	V-0				UL 94
Lead Free Process Compatible	YES	YES	YES				

RoHS Compliant

NOTES:

(1) Typical values are a representation of an average value for the population of the property. For specification values contact Rogers Corporation.

(2) The design Dk is an average number from several different tested lots of material and on the most common thickness/s. If more detailed information is required, please contact Rogers Corporation or refer to Rogers' technical papers in the Roger Technology Support Hub available at http://www.rogerscorp.com/acm/technology.

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Data Sheet

Standard Thickness	Standard Panel Size	Standard Copper Cladding
RO3003: 0.005" (0.13mm) 0.010" (0.25mm) 0.020" (0.50mm) 0.030" (0.75mm) 0.060" (1.52mm) RO3006/RO3010: 0.005" (0.13mm) 0.010" (0.25mm) 0.025" (0.64mm) 0.050" (1.28mm)	RO3003/RO3006/RO3010: 12" X 18" (305 X 457mm) 24" X 18" (610 X 457mm)	½ oz. (17µm) electrodeposited copper foil (.5ED/.5ED) 1 oz. (35µm) electrodeposited copper foil (1ED/1ED) 2 oz. (70µm) electrodeposited copper foil (2ED/2ED) Other claddings may be available. Contact customer service.

The information in this data sheet is intended to assist you in designing with Rogers' circuit material laminates. It is not intended to and does not create any warranties express or implied, including any warranty of merchantability or fitness for a particular purpose or that the results shown on this data sheet will be achieved by a user for a particular purpose. The user should determine the suitability of Rogers' circuit material laminates for each application.

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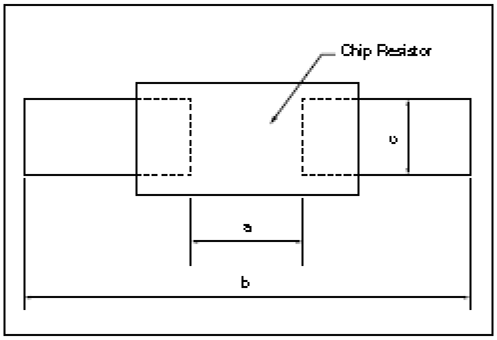
Revised 11/2011, 0952-1111-CC Publication #92-130 REV2

■ Recommended Land Pattern

● An example of a land pattern for the Rectangular Type is shown below.

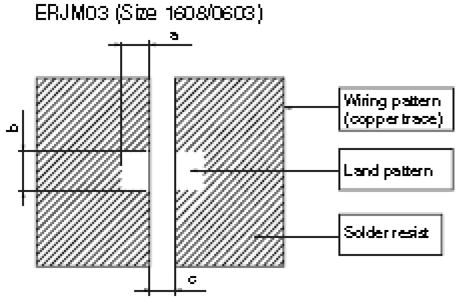


Size mm/inch	Dimensions (mm)		
	a	b	c
0402/01005	0.15 to 0.20	0.5 to 0.7	0.20 to 0.25
0603/0201	0.3 to 0.4	0.8 to 0.9	0.25 to 0.35
1005/0402	0.5 to 0.6	1.4 to 1.6	0.4 to 0.6
1005*/0402 (ERJ2BW)	0.52	1.4 to 1.6	0.4 to 0.6
1608/0603	0.7 to 0.9	2.0 to 2.2	0.8 to 1.0
1608*/0603 (ERJ3BW)	0.46	2.5 to 2.7	0.9 to 1.1
2012/0805	1.0 to 1.4	3.2 to 3.8	0.9 to 1.4
2012*/0805 (ERJ6BW)	0.9	3.2 to 3.8	1.1 to 1.4
3216/1206	2.0 to 2.4	4.4 to 5.0	1.2 to 1.8
3216*/1206 (ERJ8BW)	1.2	4.4 to 5.0	1.3 to 1.8
3225/1210	2.0 to 2.4	4.4 to 5.0	1.8 to 2.8
4532/1812	3.3 to 3.7	5.7 to 6.5	2.3 to 3.5
5025/2010	3.6 to 4.0	6.2 to 7.0	1.8 to 2.8
6432/2512	5.0 to 5.4	7.6 to 8.6	2.3 to 3.5
6432/2512 (ERJL1W)	3.6 to 4.0	7.6 to 8.6	2.3 to 3.5

* High power (double sided resistive elements structure) type

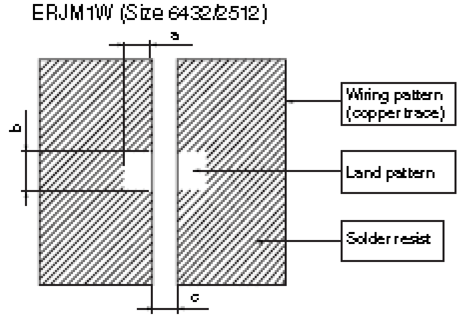
● An example of a land pattern for Low Resistance Value Chip Resistors is shown below.

ERJM03 (Size 1608/0603)



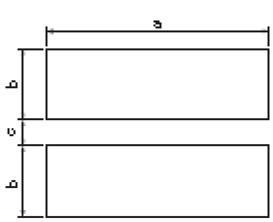
Type	Dimensions (mm)		
	a	b	c
ERJM03N	0.65	0.8	0.7

ERJM1W (Size 6432/2512)



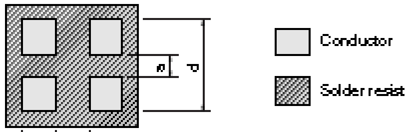
Type	Dimensions (mm)		
	a	b	c
ERJM1WS	2.1	3.4	4.2
ERJM1WT	3.1	3.4	2.2

● An example of a land pattern for High Power Chip Resistors / Wide Terminal Type is shown below.

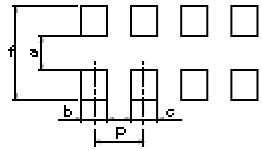


Type	Dimensions (mm)		
	a	b	c
ERJA1	6.4	1.70	0.60
ERJB1	5.0	1.30	0.70
ERJB2	3.2	0.95	0.60
ERJB3	2.0	0.85	0.50

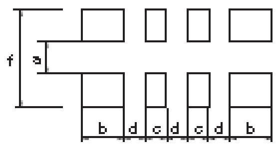
● An example of a land pattern for Chip Resistor Array and Chip Attenuator is shown below.



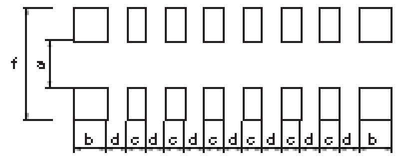
Type	Dimensions (mm) a	b	c	d
EXB14V EXB14A	0.30	0.30	0.30	0.80 to 0.90
EXB24V EXB24A	0.5	0.35 to 0.40	0.30	1.4 to 1.5



Type	Dimensions (mm) a	b	c	f	P
EXB18V	0.20 to 0.30	0.15 to 0.20	0.15 to 0.20	0.80 to 0.90	0.40
EXBV4V,V8V	0.7 to 0.9	0.4 to 0.45	0.4 to 0.45	2 to 2.4	0.80
EXB34V,38V	0.7 to 0.9	0.4 to 0.5	0.4 to 0.5	2.2 to 2.6	0.80
EXBS8V	1 to 1.2	0.5 to 0.75	0.5 to 0.75	3.2 to 3.8	1.27

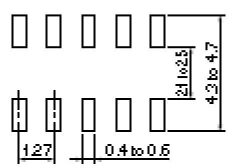
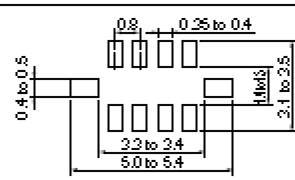
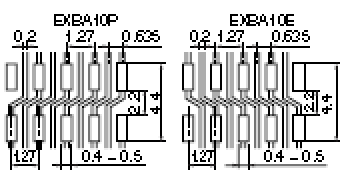
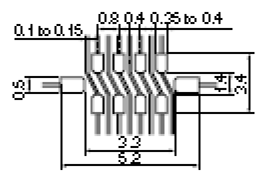
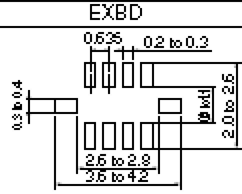
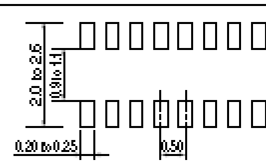


Type	Dimensions (mm) a	b	c	d	f
EXB28V	0.40	0.525	0.25	0.25	1.40
EXBN8V	0.45 to 0.50	0.35 to 0.38	0.25	0.25	1.40 to 2.00



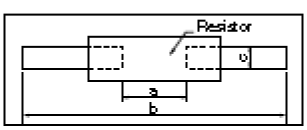
Type	Dimensions (mm) a	b	c	d	f
EXB2HV	1.00	0.425	0.25	0.25	2.00

● An example of a land pattern for Chip Resistor Networks is shown below.

	EXBA	EXBE
For popular pattern	Pitch 1.27 mm 	Pitch 0.8 mm 
For high density pattern*	Pitch 0.635 mm Through-hole less 	Pitch 0.4 mm Through-hole less 
	EXBD	**EXBQ**
For popular pattern	Pitch 0.635 mm 	Pitch 0.5 mm 

* When designing high density land patterns, examine the reliability of isolation among the lines and adopt the chip resistor networks.

● An example of a land pattern for Fixed Metal (Oxide) Film Resistors (SMD) is shown below.

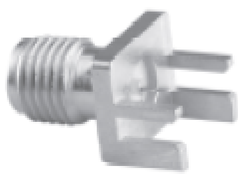


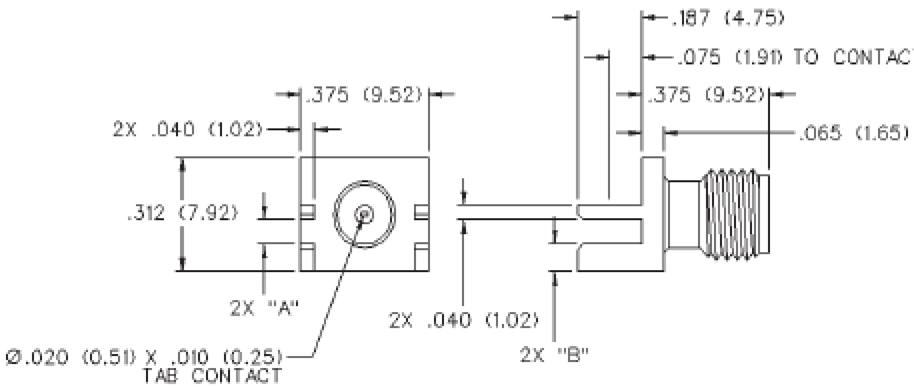
Type	Dimensions (mm) a	b	c
ERG(X)1H	3.5 to 4.0	14.5 to 15.0	2.8 to 3.3
ERG(X)2H	4.0 to 4.5	17.0 to 17.5	3.1 to 3.6

EMERSON
Network Power

SMA 50 Ohm
End Launch Jack Receptacle -
Tab Contact

INCHES (MILLIMETERS)
CUSTOMER DRAWINGS AVAILABLE UPON REQUEST





VSWR & FREQ. RANGE	BOARD THICKNESS	GOLD PLATED	NICKEL PLATED	"A"	"B"
VSWR: N/A 0-18 GHz	.042 (1.07)	142-0701-841	142-0701-846	.048 (1.22)	.103 (2.62)

SMA - 50 Ohm Connectors

Specifications

INCHES (MILLIMETERS)
CUSTOMER DRAWINGS AVAILABLE UPON REQUEST

ELECTRICAL RATINGS

Impedance: 50 ohms

Frequency Range:
- Dummy loads .... 0-2 GHz
- Flexible cable connectors .... 0-12.4 GHz
- Uncabled receptacles, RA semi-rigid and adapters .... 0-18.0 GHz
- Straight semi-rigid cable connectors and field replaceable connectors .... 0-26.5 GHz

VSWR: (f= GHz)

	Straight Cabled Connectors	Right Angle Cabled Connectors
RG-178 cable	1.20 + .025f	1.20 + .03f
RG-316, LMR-100 cable	1.15 + .02f	1.15 + .03f
RG-58, LMR-195 cable	1.15 + .01f	1.15 + .02f
RG-142 cable	1.15 + .01f	1.15 + .02f
LMR-200, LMR-240 cable	1.10 + .03f	1.10 + .06f
.086 semi-rigid	1.07 + .008f	1.18 + .015f
.141 semi-rigid (w/contact)	1.05 + .008f	1.15 + .015f
.141 semi-rigid (w/o contact)	1.035 + .005f	

Jack-bulkhead jack adapter and plug-plug adapter .... 1.05 + .01f
Jack-jack adapter and plug-jack adapter .... 1.05 + .005f
Uncabled receptacles, dummy loads .... N/A
Field replaceable (*see page 59*) .... N/A

Working Voltage: (Vrms maximum)†

Connectors for Cable Type	Sea Level	70 K Feet
RG-178	170	45
RG-316; LMR-100, 195, 200	250	65
RG-58, RG-142, LMR-240, .086 semi-rigid, uncabled receptacles, .141 semi-rigid w/o contact	335	85
.141 semi-rigid with contact and adapters	500	125
Dummy loads		N/A

Dielectric Withstanding Voltage: (VRMS minimum at sea level)†
- Connectors for RG-178 500
- Connectors for RG-316; LMR-100, 195, 200 750
- Connectors for RG-58, RG-142, LMR-240, .086 semi-rigid, field replaceable, uncabled receptacles 1000
- Connectors for .141 semi-rigid with contact and adapters 1500
- Connectors for .141 semi-rigid w/o contact, dummy loads .... N/A

Corona Level: (Volts minimum at 70,000 feet)†
- Connectors for RG-178 125
- Connectors for RG-316; LMR-100, 195, 200 190
- Connectors for RG-58, RG-142, LMR-240, 086 semi-rigid, uncabled receptacles, .141 semi-rigid w/o contact 250
- Connectors for .141 semi-rigid with contact and adapters 375

Dummy loads .... N/A

Insertion Loss: (dB maximum)
- Straight flexible cable connectors and adapters .... $0.06\sqrt{f\,(\text{GHz})}$, tested at 6 GHz
- Right angle flexible cable connectors .... $0.15\sqrt{f\,(\text{GHz})}$, tested at 6 GHz
- Straight semi-rigid cable connectors with contact .... $0.03\sqrt{f\,(\text{GHz})}$, tested at 10 GHz
- Right angle semi-rigid cable connectors .... $0.05\sqrt{f\,(\text{GHz})}$, tested at 10 GHz
- Straight semi-rigid cable connectors w/o contact .... $0.03\sqrt{f\,(\text{GHz})}$, tested at 16 GHz
- Straight low loss flexible cable connectors .... $0.06\sqrt{f\,(\text{GHz})}$, tested at 1 GHz
- Right Angle low loss flexible cable connectors .... $0.15\sqrt{f\,(\text{GHz})}$, tested at 1 GHz
- Uncabled receptacles, field replaceable, dummy loads .... N/A

Insulation Resistance: 5000 megohms minimum

Contact Resistance: (milliohms maximum)	Initial	After Environmental
Center contact (straight cabled connectors and uncabled receptacles)	3.0*	4.0*
Center contact (right angle cabled connectors and adapters)	4.0	6.0
Field replaceable connectors	6.0	8.0
Outer contact (all connectors)	2.0	N/A
Braid to body (gold plated connectors)	0.5	N/A
Braid to body (nickel plated connectors)	5.0	N/A

*N/A where the cable center conductor is used as a contact

RF Leakage: (dB minimum, tested at 2.5 GHz)
- Flexible cable connectors, adapters and .141 semi-rigid connectors w/o contact .... -60 dB
- Field replaceable w/o EMI gasket .... -70 dB
- .086 semi-rigid connectors and .141 semi-rigid connectors with contact, and field replaceable with EMI Gasket .... -90 dB
- Two-way adapters .... -90 dB
- Uncabled receptacles, dummy loads .... N/A

RF High Potential Withstanding Voltage: (Vrms minimum, tested at 4 and 7 MHz)†
- Connectors for RG-178 335
- Connectors for RG-316; LMR-100, 195, 200 500
- Connectors for RG-58, RG-142, LMR-240, .086 semi-rigid, .141 semi-rigid cable w/o contact, uncabled receptacles 670
- Connectors for .141 semi-rigid with contact and adapters 1000

Power Rating (Dummy Load): 0.5 watt @ + 25°C, derated to 0.25 watt @ +125°C

MECHANICAL RATINGS

Engagement Design: MIL-C-39012, Series SMA
Engagement/Disengagement Force: 2 inch-pounds maximum
Mating Torque: 7 to 10 inch-pounds
Bulkhead Mounting Nut Torque: 15 inch-pounds
Coupling Proof Torque: 15 inch-pounds minimum
Coupling Nut Retention: 60 pounds minimum
Contact Retention:
- 6 lbs. minimum axial force (captivated contacts)
- 4 inch-ounce minimum torque (uncabled receptacles)

Cable Retention:	Axial Force*(lbs)	Torque (in-oz)
Connectors for RG-178	10	N/A
Connectors for RG-316, LMR-100	20	N/A
Connectors for LMR-195, 200	30	N/A
Connectors for RG-58, LMR-240	40	N/A
Connectors for RG-142	45	N/A
Connectors for .086 semi-rigid	30	16
Connectors for .141 semi-rigid	60	55

*Or cable breaking strength whichever is less.

Durability: 500 cycles minimum
100 cycles minimum for .141 semi-rigid connectors w/o contact

ENVIRONMENTAL RATINGS (Meets or exceed the applicable paragraph of MIL-C-39012)

Temperature Range: - 65°C to + 165°C
Thermal Shock: MIL-STD-202, Method 107, Condition B
Corrosion: MIL-STD-202, Method 101, Condition B
Shock: MIL-STD-202, Method 213, Condition I
Vibration: MIL-STD-202, Method 204, Condition D
Moisture Resistance: MIL-STD-202, Method 106

†Avoid user injury due to misapplication. See safety advisory definitions inside front cover.

SMA - 50 Ohm Connectors

Specifications

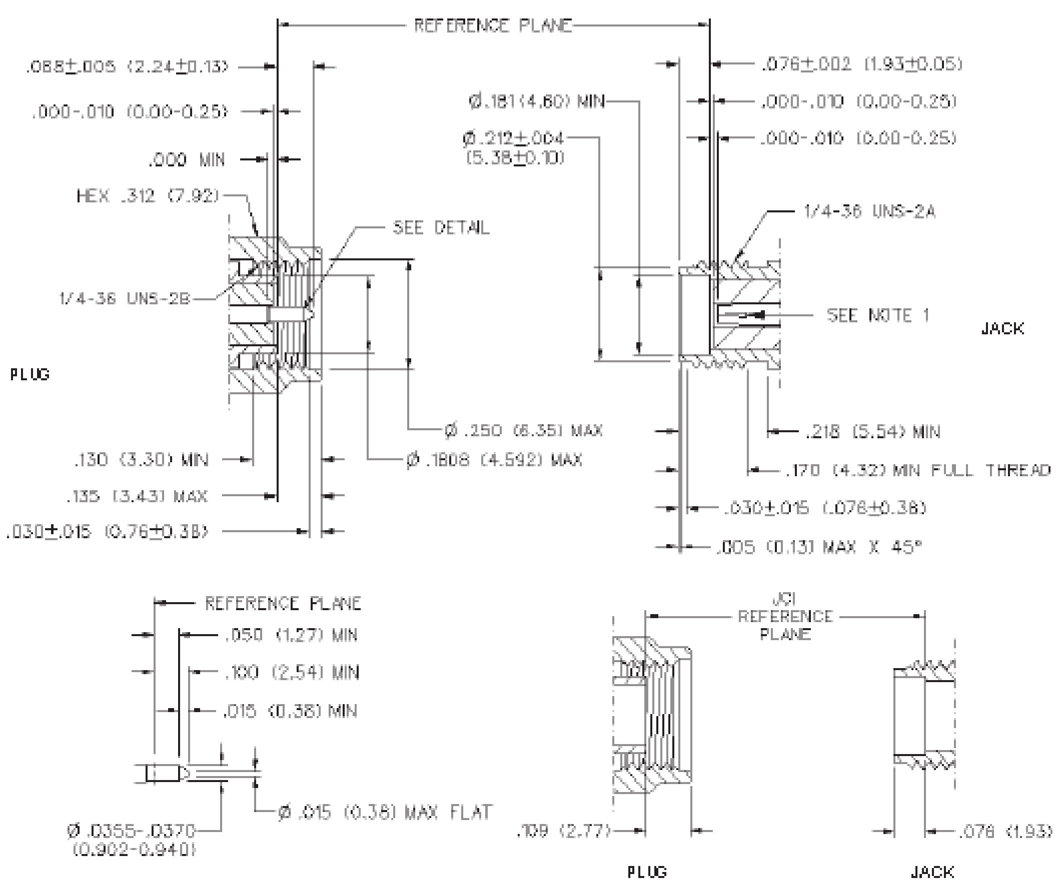
INCHES (MILLIMETERS)
CUSTOMER DRAWINGS AVAILABLE UPON REQUEST

MATERIAL SPECIFICATIONS

Bodies: Brass per QQ-B-626, gold plated* per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290
Contacts: Male - brass per QQ-B-626, gold plated per MIL-G-45204 .00003" min.
Female - beryllium copper per QQ-C-530, gold plated per MIL-G-45204 .00003" min.
Nut Retention Spring: Beryllium copper per QQ-C-533. Unplated
Insulators: PTFE fluorocarbon per ASTM D 1710 and ASTM D 1457 or Tefzel per ASTM D 3159 or PFA 340 per ASTM
Expansion Caps: Brass per QQ-B-613, gold plated per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290
Crimp Sleeves: Copper per WW-T-799 or brass per QQ-B-613, gold plated per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290
Mounting Hardware: Brass per QQ-B-626 or QQ-B-613, gold plated per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290
Seal Rings: Silicone rubber per ZZ-R-765
EMI Gaskets: Conductive silicone rubber per MIL-G-83528, Type M

* All gold plated parts include a .00005" min. nickel underplate barrier layer.

Mating Engagement for SMA Series per MIL-C-39012



NOTES
1. ID OF CONTACT TO MEET VSWR, CONTACT RESISTANCE AND INSERTION WITHDRAWAL FORCES WHEN MATED WITH DIA .0355-.0370 MALE PIN.

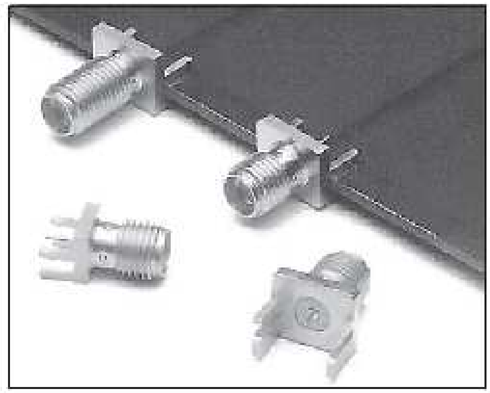
SMA - 50 Ohm Connectors

End Launch Connectors - A Johnson Components™ Original

EMERSON. Network Power

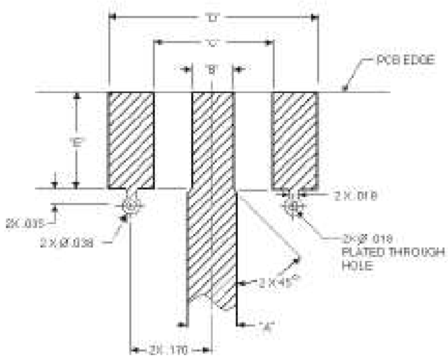
INCHES (MILLIMETERS)
CUSTOMER DRAWINGS AVAILABLE UPON REQUEST

The **End Launch** connector is attached to the circuit board by inserting the board edge between the legs and soldering the legs and center conductor to pads on the board. For optimum high frequency performance, the connector to circuit board transition must be adjusted for low VSWR. To compensate for the transition from coax to microstrip, trace widths "A" and "B" must be adjusted based on circuit board thickness. When properly adjusted, this technique yields a low VSWR over a wide bandwidth.



The tabulated dimensions "A", "B", "C", "D", and "E" were determined experimentally to achieve low VSWR (typically less than 1.5 up to 18 GHz). The circuit board used for these tests was double-sided FR 4 with 1 oz. copper on both sides. The copper was left on the bottom of the board to create a ground plane for the 50 Ohm microstrip structure. While not all inclusive, these dimensions are given as reference information for selected **SMA End Launch** connectors. Further adjustments may be necessary depending upon the application. All dimensions are in inches.

Tabulated Dimensions "A", "B", "C" and "D" are symmetrical about the center line



Part Number	Base Width	Board Thick	"A"	"B"	"C"	"D"	"E"
142-0701-801/806	.375	.062	.103	.090	.250	.440	.200
142-0701-851/861	.375	.062	.103	.090	.250	.440	.200
142-0701-871/876	.375	.062	.103	.090	.250	.440	.200
142-0711-821/826	.250	.062	.103	.070	.170	.380	.165
142-0711-871/876	.375	.047	.083	.075	.250	.440	.200
142-0711-881/886	.375	.047	.083	.075	.250	.440	.200
142-0701-881/886	.375	.031	.050	.045	.250	.440	.200

Surface Mount Versions Available!

SMA End Launch Specifications

ELECTRICAL RATINGS
Impedance: 50 Ohms
Frequency Range: 0-18 GHz
VSWR: Dependent upon application
Working Voltage (VRMS max.): 335 @ Sea Level, 85 @ 70K Feet
Dielectric Withstanding Voltage (VRMS min. at sea level): 1000
Corona Level (Volts min. at 70,000 feet): 250
Insulation Resistance: 5000 megohms min
Contact Resistance (milliohms max.): 3.0 initial, 4.0 after environmental
RF High Potential Withstanding Voltage (VRMS min. tested at 4 and 7 MHz): 670

MECHANICAL RATINGS
Engagement Design: MIL-C-39012, Series SMA
Engagement/Disengagement Force: 2 inch-pounds max.
Mating Torque: 7 to 10 inch-pounds
Coupling Proof Torque: 15 inch-pounds min.
Coupling Nut Retention: 60 pounds min.
Contact Retention Force: 6 lbs min. axial force, 4 inch-ounce min. torque
Durability: 500 cycles min.

ENVIRONMENTAL RATINGS:
(Meets or exceeds the applicable paragraph of MIL-C-39012)
Temperature Range: -65°to + 165°C
Thermal Shock: MIL-STD-202, Method 107, Condition B
Corrosion: MIL-STD-202, Method 101, Condition B
Shock: MIL-STD-303, Method 213, Condition I
Vibration: MIL-STD-202, Method 204, Condition D
Moisture Resistance: MIL-STD-202, Method 106

MATERIAL SPECIFICATIONS
Bodies: Brass per QQ-B-626, gold plated* per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290
Contacts: Male - brass per QQ-B-626, gold plated per MIL-G-45204 .00003" min.
Female - beryllium copper per QQ-C-530, gold plated per MIL-G-45204 .00003" min.
Nut Retention Spring: Beryllium copper per QQ-C-533. Unplated
Insulators: PTFE fluorocarbon per ASTM D 1710 and ASTM D 1457
Mounting Hardware: Brass per QQ-B-626 or QQ-B-613, gold plated per MIL-G-45204 .00001" min. or nickel plated per QQ-N-290

*All gold plated parts include a .00005" min. nickel underplate barrier layer.