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8/13/21

Summer 2021 Report

I. Microwave Monitoring System

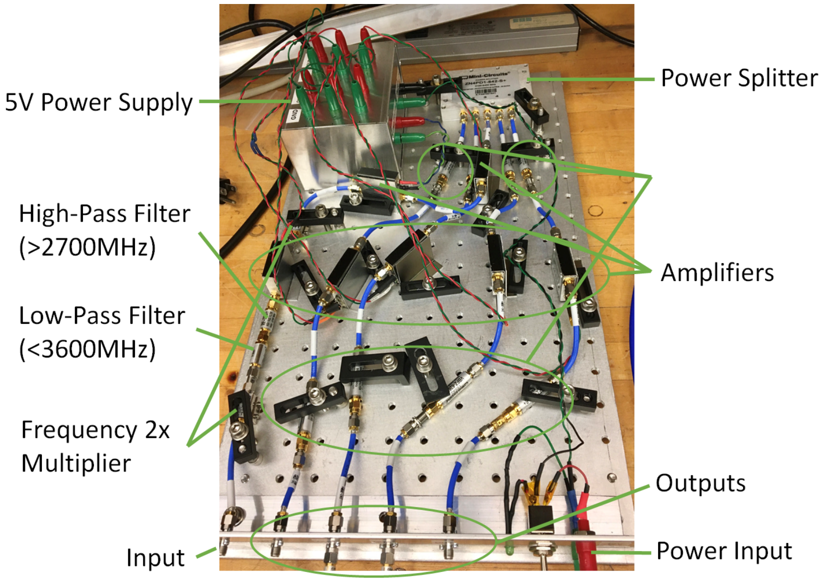

Figure 1. A labelled picture of the microwave monitoring system

Design/ Components:

- Frequency 2x Multiplier (ZX90-2-36-S+)
- Bandpass Filter (VBFZ-6260-S+)
- Amplifier (GVA-84+)
- Voltage Regulator (MC7805)
- High pass filter (VHF-2700A+)
- Low pass filter (VLF-3000+)
- Power Splitter (ZN4PD1-842-S+)

Specification:

Standard Operation:
Microwave Input: 15dBm at 1.7GHz
Microwave Output: ~11dBm at 6.8GHz
Power Supply: 12V, ~0.82A

Range of Operation for set-up as is:
Microwave Input Frequency: 1.7-1.75GHz (outputs 6.8-7GHz)
Microwave Input Power: 7-17dBm
Microwave Output Power: 8-11dBm
Power supply voltage: 7-18V

Range of Operation if start at the 2nd multiplier (do not use the first multiplier, the high pass filter, the low-pass filter or the first amplifier):
Microwave Input Frequency: 2.6-3.5GHz (outputs 5.2-7GHz)
Microwave Input Power: 7-17dBm
Microwave Output Power: 8-11dBm
Power Supply: 7-18V (at 12V, ~0.7A)

II. Investigating Phase Stability

Background Work:

This investigation of phase was conducted based on the knowledge that if two signals are sent into a mixer, the phase difference between the two corresponds to a DC offset of the output from the mixer. To check this, I sent two signals with the same frequency into the mixer and looked at the output using an oscilloscope. By changing the length of the cables going into the mixer and thus the phase difference I was able to confirm that the DC offset changed as the cables changed, likely because of the change in phase. I then used 2 sources in which I could control the phase without changing the cables and confirmed that it was due to change in the phase difference.

Final procedure:

I sent the sources that I could control the phase with the computer into the mixer with phase-stable cables and then into a multimeter with 6.5 digits. I then changed the phase of one of the sources and found the maximum and the minimum DC offset, which were 345mV and -345mV respectively. From this I got the equation for DC offset to phase difference, V (mV) = 345*cos(Δφ). Even though Δφ was not exactly the same as what the computer read, the horizontal shift of the equation is unimportant when determining how the stability of the voltage corresponds to the phase stability. I also found at what phase difference the DC offset was around 0mV, as this is where any phase instability would be most easily detected. I then recorded the DC offset measured about every 15ms for 60s on a flash drive. I then used the equation to convert the range of voltages to the range of Δφ in radians

Results:

As seen in figure 2, the DC offset has a range of about -2.6mV to about 1.9mV, which corresponds to a phase difference of about 10^{-2} radians.

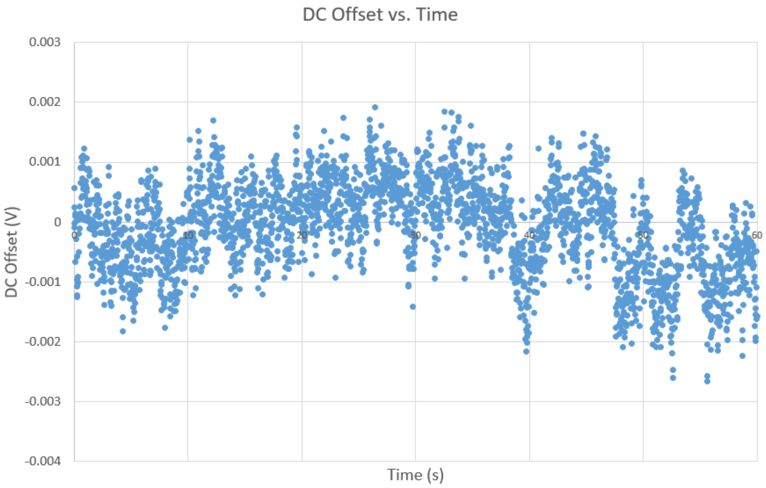

Figure 2. The raw data of the DC offset obtained from the multimeter of the output from the mixer

As shown in Figure 3, the averaged DC offset is more stable than the unaveraged data. It ranges from about -1.3mV to about 0.9mV, which corresponds to about $6 \cdot 10^{-3}$ radians.

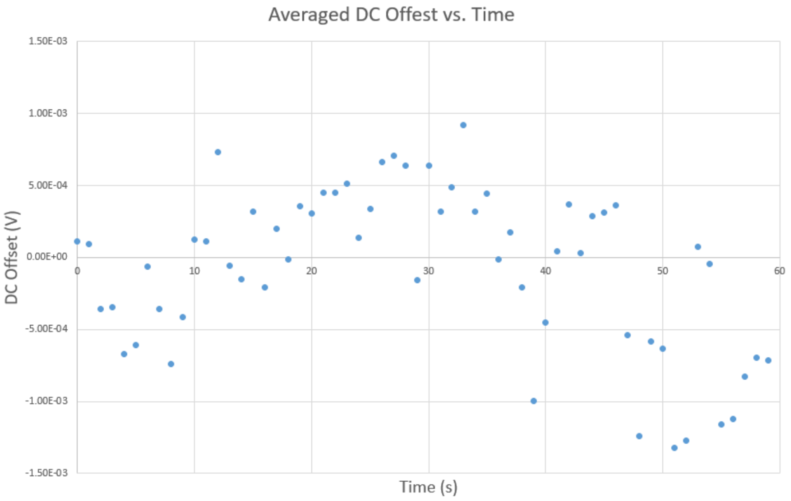

Figure 3. The data of the DC offset obtained from the multimeter of the output from the mixer averaged over each second.

Conclusion:

With the set-up used, the phase stability of sources is about $6 \cdot 10^{-3}$ radians, which is higher than the 10^{-6} radians needed. However, some of this instability could also be from instability in the signal power, as that also affects the DC offset. If it were possible this would likely not get the phase stability down to the 10^{-6} radians, it would likely improve it.

III. Connectors from the Microstrip to the Signal

Direct Coaxial Cable to the Trace

What I tried:

- Different Dielectric Materials (the conductor was always copper)
- Different inner conductor radii
- Different lengths of the pins connecting the outside of the cable to the top of the substrate
- Different lengths of the extension of the inner conductor onto the microstrip
- Different shapes of the extension of the inner conductor

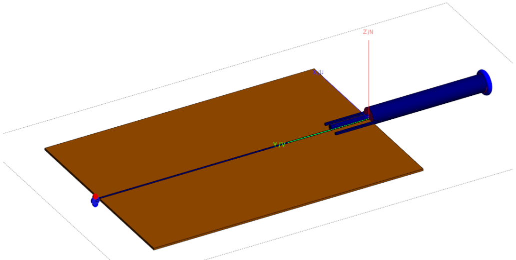

Figure 4. A model of a coaxial cable directly connecting to the microstrip

Results:

Version (Coax-Strip__)	Inner Radius (µm)	Outer Radius (µm)	Dielectric	Pin Length (mm)	Inner Conductor Extension (mm)	Reflection Coefficient Range	Impedance Range (Ω)	Frequency Range (GHz)
1.1	27	47.1	Polyethylene	0.2	-	0.05 - 0.21	38.3 - 63.8	1-10
2	27	47.1	Polyethylene	-	-	0.04 - 0.19	44 - 67	1-10
3	27	47.1	Polyethylene	0.2	0.1	0.04 - 0.15	45.5 - 61.3	1-10
4	27	47.1	Polyethylene	0.2	0.1 (tapered)	0.04 - 0.18	45.2 - 61.1	1-10
5[1]	27	47.1	Polyethylene	0.2	0.1	0.19 - 0.97	20 - 148	1-10
6[2]	27	47.1	Polyethylene	0.2	0.1	0.03 - 0.16	46 - 63.8	1-10
7	10.8	50	Kapton	0.2	0.1	0.009 - 0.058	45.2 - 53.4	1-10
8	10.27	50	Kapton	0.2	0.1	0.03 - 0.1	45.1 - 55.8	1-10
9	27	125	Kapton	0.2	0.1	0.01 - 0.18	46 - 67.4	1-10
10	10.8	50	Kapton	0.1	0.1	0.01 - 0.054	47.6 - 53.3	1-10
11	10.8	50	Kapton	0.1	0.075	0.01 - 0.054	46.5 - 53.1	1-10
12	10.8	50	Kapton	0.3	0.075	0.06 - 0.058	45.8 - 52.4	1-10
13[3]	39.35	127	PTFE	0.1	0.1	0.01 - 0.056	47.7 - 54.8	1-10
13all	39.35	127	PTFE	0.1	0.1	0.01 - 0.122	43.4 - 58	1-20

14	39.35	127	PTFE	1	1	0.014 - 0.13	43.8 - 64	1-20
14.1	39.35	127	PTFE	0.8	0.8	0.004 - 0.11	44.2 - 61.6	1-20
14.2	39.35	127	PTFE	1	0.5	0.011 - 0.09	43.9 - 57.9	1-20
15[4]	63.5	216	PTFE	1	1	0.016 - 0.34	35.4 - 70	1-20
15.1	63.5	216	PTFE	1	0.5	0.01 - 0.23	41.5 - 62.3	1-20
15.2	63.5	216	PTFE	1	1 (tapered)	0.01 - 0.36	25 - 64.5	1-20
15.3	63.5	216	PTFE	1.3	1	0.01-0.48	20-89.3	1-20
15.4	63.5	216	PTFE	1.2	1	0.015 - 0.45	25.6 - 88	1-20
15.5	63.5	216	PTFE	0.8	1	0.013 - 0.24	43.2 - 73.9	1-20
15.7	63,5	216	PTFE	0.1	0.1	0.008 - 0.195	36.4 - 60.2	1-20
16	25	80.7	PTFE	0.1	0.1	0.009 - 0.12	48.2 - 62.9	1-20
17	15.5	50	PTFE	0.1	0.1	0.02 - 0.27	50.8 - 87	1-20

[1] Outer conductor of the cable not connected to the ground plane

[2] Via from the microstrip to the ground plane under the conductor extension

[3] Simulating the UT-013 cable from microstock (the smallest cable, but connect be bought connectorized)

[4] Simulating the UT-020 cable from microstock (the 2nd smallest cable, but can be bought connectorized)

Final thoughts for this method:

Overall, I found that the best simulation I ran was when the inner conductor was about the same size as the microstrip (model 16). However, the slightly larger cable (model 13) ran almost as well, while the slightly smaller cable (model 17) ran much worse, with reflection coefficients about twice as high. Therefore, it seems that it is better for the inner conductor of the cable to be slightly larger than the microstrip trace, as opposed to slightly smaller. The even larger cable (model 15.7) also ran better than the smallest model.

When creating the models, I found that the most important thing to remember is to connect the outer conductor of the coaxial cable to the ground plane of the microstrip. In addition, the inner conductor needs to be in contact with the microstrip trace. I also found that, at least with my placement and shape of the pins (the things attaching the outer conductor to the top of the microstrip substrate), the smaller the pins the better. However, there should be more simulations ran testing different size pins and placement of the pins (ie. placing farther apart) in order to better understand the best way to attach the coaxial cable to the microstrip.

The main difficulties with this method is that the best two simulations (16 and 17) are difficult to either obtain, as 17 is not a commercially available cable, or is difficult to connect to a source, as 16 is not available with connectors.

Tapered Coaxial Connector

What I tried:

- Different taper lengths/ the extremity of the taper
- Different shapes of the taper
- Different sizes for the large and small sides of the connector

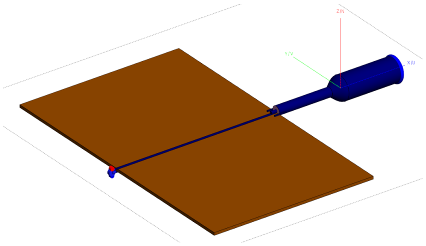

Figure 5. The model of the tapered connector attached to the microstrip, specifically version Taper-12microptfeall

Results:

Just the Tapered Connector:

Version (Taper-___)	Big End Radii Outer: Inner (µm)	Small End Radii Outer: Inner (µm)	Taper Shape and Length (mm)	Straight cable length (mm)	Reflection Coefficient Range	Impedance Range (Ω)	Frequency Range (GHz)
8	157.4 : 39.4	43.2 : 10.8	5 (Conical)	2.5	0.01 - 0.095	44.8 - 50.8	1-10
8all	157.4 : 39.4	43.2 : 10.8	5 (Conical)	2.5	0.004 - 0.094	43 - 59	1-20
8.1	165.3 : 39.4	45.4 : 10.8	5 (Conical)	2.5	0.015 - 0.05	49.3 - 55	1-10
8.2	169.2 : 39.4	46.4 : 10.8	5 (Conical)	2.5	0.018 - 0.068	49.8 - 56.8	1-10
8.3	161.3 : 39.4	44.3 : 10.8	5 (Conical)	2.5	0.011 - 0.047	49.5 - 53.5	1-10
8.3all	161.3 : 39.4	44.3 : 10.8	5 (Conical)	2.5	0.006 - 0.097	44.4 - 59.8	1-20
8.4	159.4 : 39.4	43.7 : 10.8	5 (Conical)	2.5	0.01 - 0.094	44.8 - 50.9	1-10
8.5	160.4 : 39.4	44 : 10.8	5 (Conical)	2.5	0.01 - 0.045	49.2 - 53.1	1-10
8.6	160.2 : 39.4	43.9 : 10.8	5 (Conical)	2.5	0.01 - 0.047	49.5 - 53.1	1-10
8.7	153.5 : 39.4	42.1 : 10.8	5 (Conical)	2.5	0.015 - 0.091	44.2 - 50.7	1-10
8.7all	153.5 : 39.4	42.1 : 10.8	5 (Conical)	2.5	0.01 - 0.1	42 - 58	1-20
8.7allshort	153.5 : 39.4	42.1 : 10.8	5 (Conical)	1	0.008 - 0.112	42.3 - 60.3	1-20
8.7all-st	153.5 : 39.4	42.1 : 10.8	4 (Conical)	2.5	0.924 - 0.975	10 - 660	1-20
8.7all-3.5	153.5 : 39.4	42.1 : 10.8	3.5 (Conical)	2.5	0.006 - 0.168	47.7 - 70.1	1-20
8.7all-lt	153.5 : 39.4	42.1 : 10.8	10 (Conical)	2.5	0.001 - 0.156	45 - 68.2	1-20
8.7all-7	153.5 : 39.4	42.1 : 10.8	7 (Conical)	2.5	0.005 - 0.16	45.3 - 68.8	1-20

8.7all-7.5	153.5 : 39.4	42.1 : 10.8	7.5 (Conical)	2.5	0.018 - 0.16	36.5 - 53	1-20
8.8	182.9 : 39.4	50.2 : 10.8	5 (Conical)	2.5	0.034-0.112	50.5 - 62.3	1-10
8.8all	182.9 : 39.4	50.2 : 10.8	5 (Conical)	2.5	0.01 - 0.12	50.7 - 63.5	1-20
8.9	159.8 : 39.4	43.8 : 10.8	5 (Conical)	2.5	0.01 - 0.047	49.4 - 52.9	1-10
8.9all	159.8 : 39.4	43.8 : 10.8	5 (Conical)	2.5	0.005 - 0.097	44 - 59	1-20
8.10	160.5 : 39.4	44.1 : 10.8	5 (Conical)	2.5	0.01 - 0.047	49.5 - 53.1	1-10
8.11	149.5 : 39.4	41 : 10.8	5 (Conical)	2.5	0.01 - 0.13	39.3 - 57.2	1-10
8.12	182.2 : 39.4	50 : 10.8	5 (Conical)	2.5	0.02 - 0.13	51.3 - 65	1-10
8.12all	182.2 : 39.4	50 : 10.8	5 (Conical)	2.5	0.01 - 0.12	43.8 - 59.4	1-20
8.12all-short	182.2 : 39.4	50 : 10.8	5 (Conical)	1	0.01 - 0.122	43.2 - 59.3	1-20
9	294 : 63.5	50 : 10.8	1.331 (Curved)	2	0.007 - 0.12	50.5- 57.5	1-10
10	294 : 63.5	50 : 10.8	0.421 (Curved)	2	0.004 - 0.077	50.3 - 55.5	1-10
11	294 : 63.5	50 : 10.8	0.294 (Curved)	2	0.004 - 0.073	50.3 - 55.2	1-10
11all	294 : 63.5	50 : 10.8	0.294 (Curved)	2	0.004 - 0.193	47.4 - 55.2	1-20
12	285.8 : 63.5	48.6 : 10.8	0.294 (Curved)	2	0.003- 0.07	50.3 - 53.9	1-10
12all	285.8 : 63.5	48.6 : 10.8	0.294 (Curved)	2	0.003 - 0.193	46 - 53.8	1-20

Tapered Connector to Microstrip:

Version (Taper-__)	Dielectric	Big End Radii Outer: Inner (µm)	Small End Radii Outer: Inner (µm)	Reflection Coefficient Range	Impedance Range (Ω)	Frequency Range (GHz)
12micro	Kapton	285.8 : 63.5	49.6 : 10.8	0.01 - 0.056	50.9 - 53.6	1-10
12microall	Kapton	285.8 : 63.5	49.6 : 10.8	0.01 - 0.28	39.5 - 59	1-20
12microptfe	PTFE	216 : 63.5	85 : 25	0.01 - 0.037	50.8 - 53.6	1-10
12microptfeall	PTFE	216 : 63.5	85 : 25	0.01 - 0.24	50.8 - 65.4	1-20

(Note: all the tapered connectors have a 0.294 mm curved taper, a 1mm cable on each side, and 0.1mm long pins and conductor extension)

Final thoughts:

Overall, the curved taper seems to be a better choice than the straight, conical taper, as the curved taper allows for a more extreme change in size of the cable over a shorter distance compared to the conical taper. However, I have not found a place that would be able to machine both the metal and dielectric components of the connector, both at the size and while still being vacuum compatible. I have also not fully figured out how to connect the tapered connector to a cable.

When I connected the tapered connector to the microstrip in version Taper-12microptfeall, which goes from the size of the UT-020 cable from microstock to the inner conductor being about the size of the microstrip trace, it performed about the same as just the UT-020 cable attached to the microstrip (Coax-Strip15.7). Thus, I wonder if it is worth it to go through the trouble of manufacturing it when it does not seem to currently perform better than a commercially available cable. However, more simulations should be run adjusting the connection of the tapered connector to the microstrip before it is written off, just as more simulations need to be done for connecting the plain coaxial cables to the microstrip.

Upside-Down CPW to Microstrip

What I tried:

- Different amounts of overlap
- Different transitions from just the CPW to the overlapping region
- Different placements of the ground plane connections

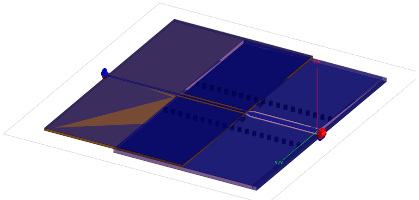

Figure 6. A model of the upside-down CPW to the microstrip (CPW-Micro3ground)

Results:

Version (CPW-Micro__)	CPW trace (µm)	CPW gap (µm)	Ground-plane connection	Reflection Coefficient Range	Impedance Range (Ω)	Frequency Range (GHz)	Comments
3	48	25	None	0.02 - 0.28	46.8-49.6	1-10	
3all	48	25	None	0.02 - 0.54	46.8-125	1-20	
3ground	48	25	Yes - 0.4mm apart	0.025 - 0.28	45 - 59	1-10	
3ground2	48	25	Yes - 0.8mm apart	0.026 - 0.27	41-55.4	1-10	Little difference from 3ground
4	48	1/ 25	None	0.006 - 0.191	34.2 - 51.8	1-10	1µm gap when not overlapping, 25µm when intersecting
5	48	1/25	None	0.007 - 0.181	35 - 51.2	1-10	Same as 4, but the gap transition is tapered instead of abrupt
5ground	48	1/25	Yes - 0.8mm apart	0.007 - 0.181	35 - 54.8	1-10	Abrupt increase in reflection
6	48	26	None	0.02 - 0.28	47.3 - 49.6	1-10	
7	48	30	None	0.014 - 0.29	49.1 - 51.9	1-10	
8	48	1/25	None	0.006 - 0.19	34.3 - 51.2	1-10	Same as 8 but a shorter transition
9	48	1/25	None	0.03 - 0.19	34.2 - 58	1-10	Same as 5, but the CPW is 3mm wide instead of 5mm
10	48	30	None	0.02 - 0.29	48-51.1	1-10	Same as 7, but the CPW is 3mm wide overall of 5mm

10all	48	30	None	0.02 - 0.58	48-135	1-20	
11	48	20	None	0.038 - 0.28	42.5 - 53	1-10	
11all	48	20	None	0.038 - 0.56	42.5 - 123	1-20	
12	48	30	None	0.027 - 0.25	42.5-50	1-10	Same as 10, but with 2mm overlap instead of 1.5mm
12all	48	30	None	0.027 - 0.53	42.5-111	1-20	
12ground	48	30	Yes - 0.8mm apart	0.015 - 0.25	40-81	1-10	
14	150/50	50	Yes - 0.8mm apart	0.007 - 0.18	36.2 - 50.4	1-10	CPW trace 150µm when not overlapping, then tapers to 50µm as it overlaps the microstrip
14.1	150/50	50	Yes - 0.8mm apart	0.007 - 0.17	36.3-50.2	1-10	Same as 14 but no connection between the 2 CPW ground planes on the microstrip side
14.3	150/50	50	Yes - 0.8mm apart	0.007 - 0.17	36.8 - 50.4	1-10	Same as 14.1, but not vias during the overlapping section

(Note: all the simulated CPWs have vias)

Final thoughts:

Overall, none of the simulations I ran seem like viable options for a connection to the atom chip. All of the reflection coefficients seem too high, especially considering they were all modelled with short CPWs and microstrips (on the millimeter scale). In addition, most of the models seem difficult if not impossible to manufacture due to the small size of both the traces and the gaps of the CPW. Lastly, I have not been able to explain the sudden jump in reflection around 6GHz that all the models have when the ground planes of the CPW and the microstrip are attached, as it persists with various modifications to the substrates and ground plane connections. Therefore, unless there are modifications that I am unaware of, I do not think this method of connection needs to be explored further as other methods seem more promising.

CPW to Microstrip (not upside down)

What I tried:

- Different lengths of the CPW

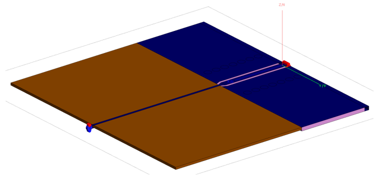

Figure 7. The model of the CPW directly transitioning to the microstrip

Results:

Version (CPW-Micro __)	Large Trace: Gap (µm)	Small Trace: Gap (µm)	CPW Length (mm)	Substrate	Reflection Coefficient Range	Impedance Range (Ω)	Frequency Range (GHz)
14.2	150 : 50	50 : 50	1.5	3mil Kapton	0.014 - 0.034	50.7 - 53.3	1-10
14.2all	150 : 50	50 : 50	1.5	3mil Kapton	0.014 - 0.146	48.5 - 64.9	1-20
14.2.1	150 : 50	50 : 50	10	3mil Kapton	0.017 - 0.028	48.3-52.6	1-10

Final thoughts:

Although few trials have been done, so far the results for this seem promising, as it has one of the lowest reflections from 1-20 GHz of any of the simulations for the connectors that I have run. Since it is in early stages, there is a lot of testing to be done. This includes changing the connection of the ground planes (how many connections, etc.), increasing the length of both the CPW and the microstrip, and potentially looking at different substrates besides kapton for the CPW. The reason to look at different substrates is because kapton at the thicknesses available only allows for a small range of microstrip traces with feasible gap widths while maintaining 50Ω. However, even though the 50µm trace and 50µm gap has an impedance greater than 50Ω, I think because it is such a small section of the CPW it does not seem to cause too much reflection so the kapton might be fine as a substrate.

Overall Connector Conclusion:

Currently, the CPW to the microstrip transition seems the most promising, but it is also in the early stages of testing, so more simulations and research into different substrates needs to be done, as previously mentioned. The coaxial cable connection to the microstrip is also showing some decent results, whether it is just the plain cable to the microstrip or the tapered connector. Thus, I believe it warrants further research into the best connection from a coaxial cable/ connector to the microstrip, especially related to the pin size and placement, as previously stated. The upside-down CPW to microstrip looks the least promising, as at high frequencies (up to 20GHz), the reflection coefficient goes up to about 0.5 for any model I have tried. I have tried numerous ways to reduce the reflection with limited success , so it does not seem useful to continue down this path.