Low SWaP Aircraft Icing Risk Detection

The US Navy is funding aircraft icing risk detection and avoidance development by First RF. Under subcontract, Radiometrics (RDX) demonstrated remote icing risk detection feasibility using ground-based observations with its G-band microwave profiler (MP-G) product. RHS Consulting, also under subcontract, installed and operated an airborne MP-G and demonstrated in-flight icing risk detection feasibility. This document outlines development plans for a low size, weight and power (SWaP), improved performance icing risk detector, and for additional airborne testing.

MP-Series Radiometers

RDX has manufactured hundreds of MP-Series radiometer products over the past two decades which are currently in worldwide operation. Feasibility of ground and aircraft based icing risk detection was demonstrated with an existing MP-G *mailbox* radiometer (Figure 1-9).

Figure 1. MP-KV (22-58 GHz) microwave profiler product.

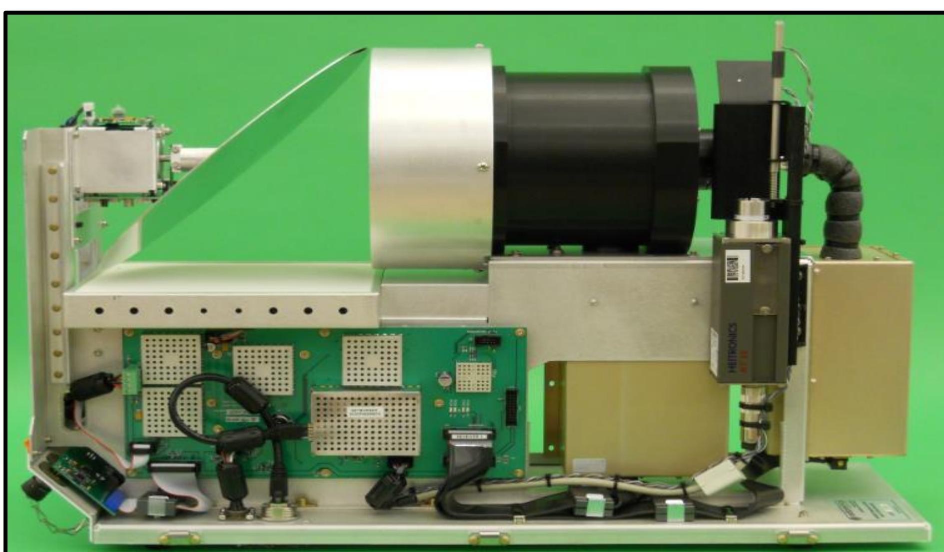


Figure 2. MP-KV internal assembly.

An MP-KV (51-59 GHz) microwave downconverter module is shown in Figure 3.

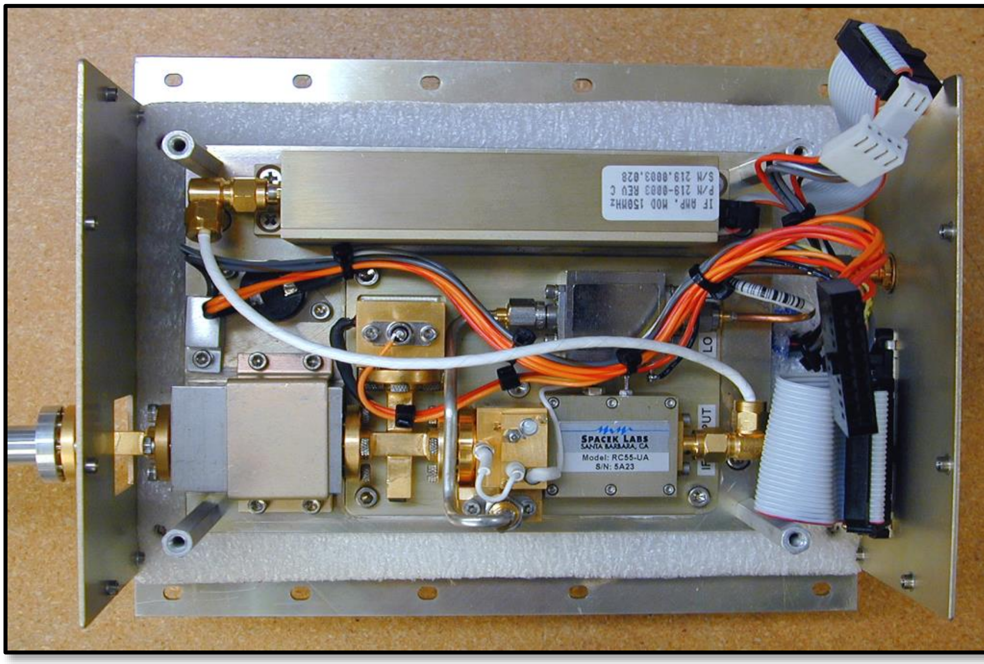


Figure 3. MP-Series 51-59 GHz microwave downconverter module.

MP-G (170-183 GHz) internal components are shown in Figure 4.

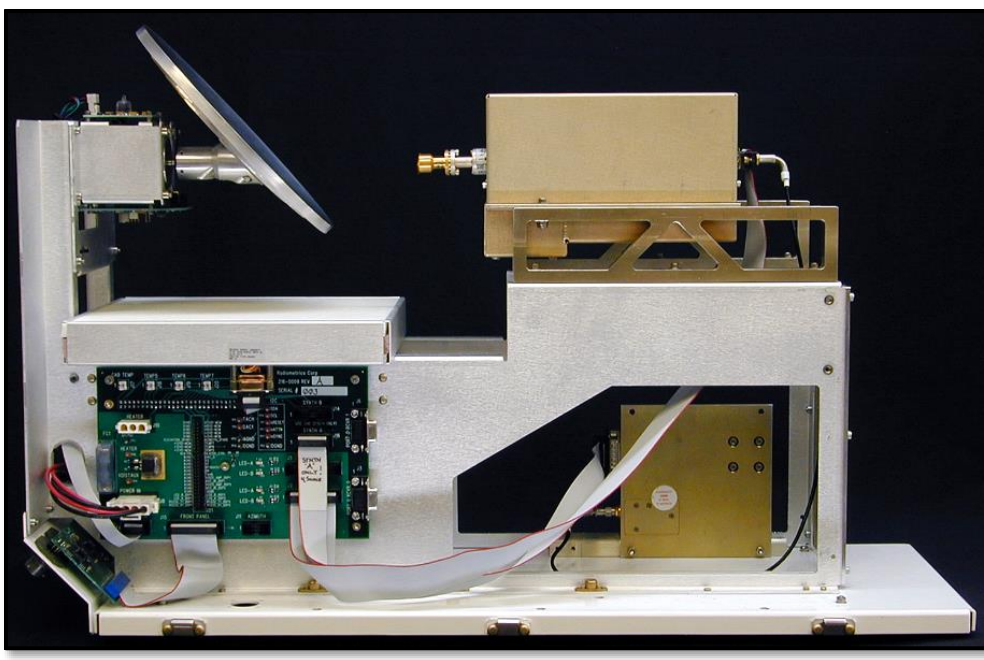


Figure 4. MP-G 170-183 GHz assembled internal components.

The MP-G radiometer block diagram is shown in Figure 5, and the MP-G downconverter module is shown in Figure 6.

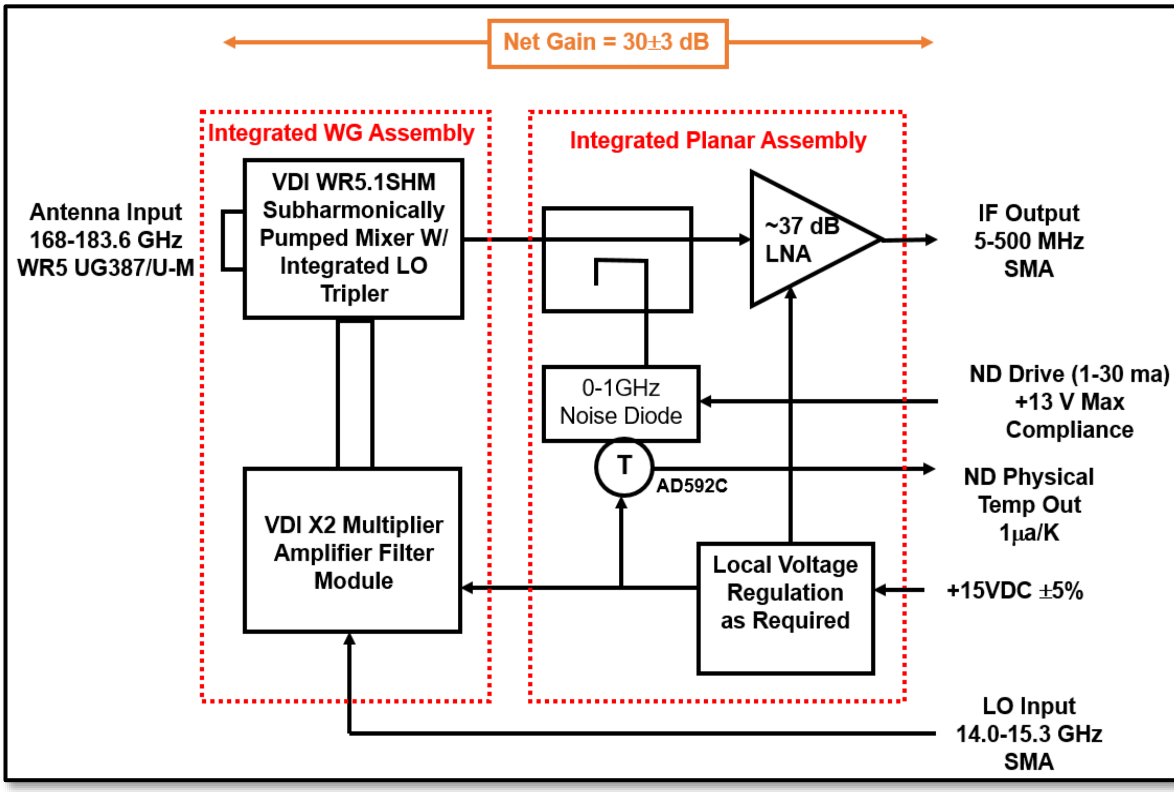


Figure 5. MP-G downconverter module block diagram.

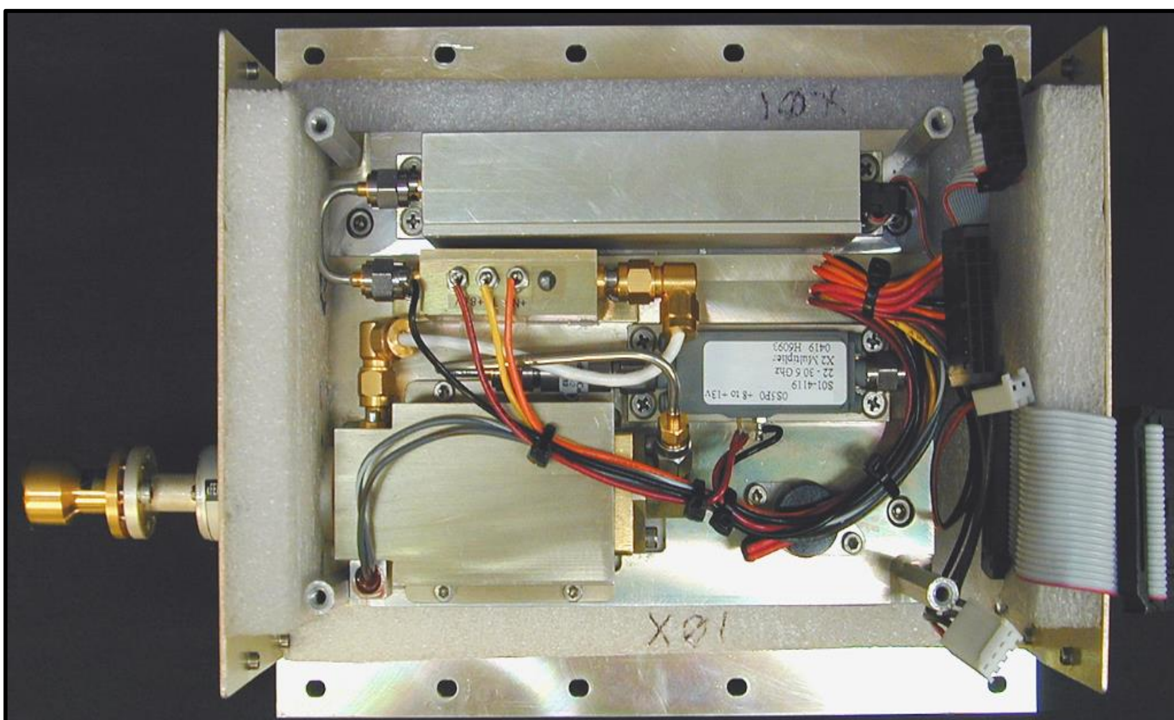


Figure 6. MP-G downconverter module assembly.

The MP-G antenna, antenna isolator, downconverter enclosure, LO multiplier, IF module, RF deck assembly is shown in Figure 7.

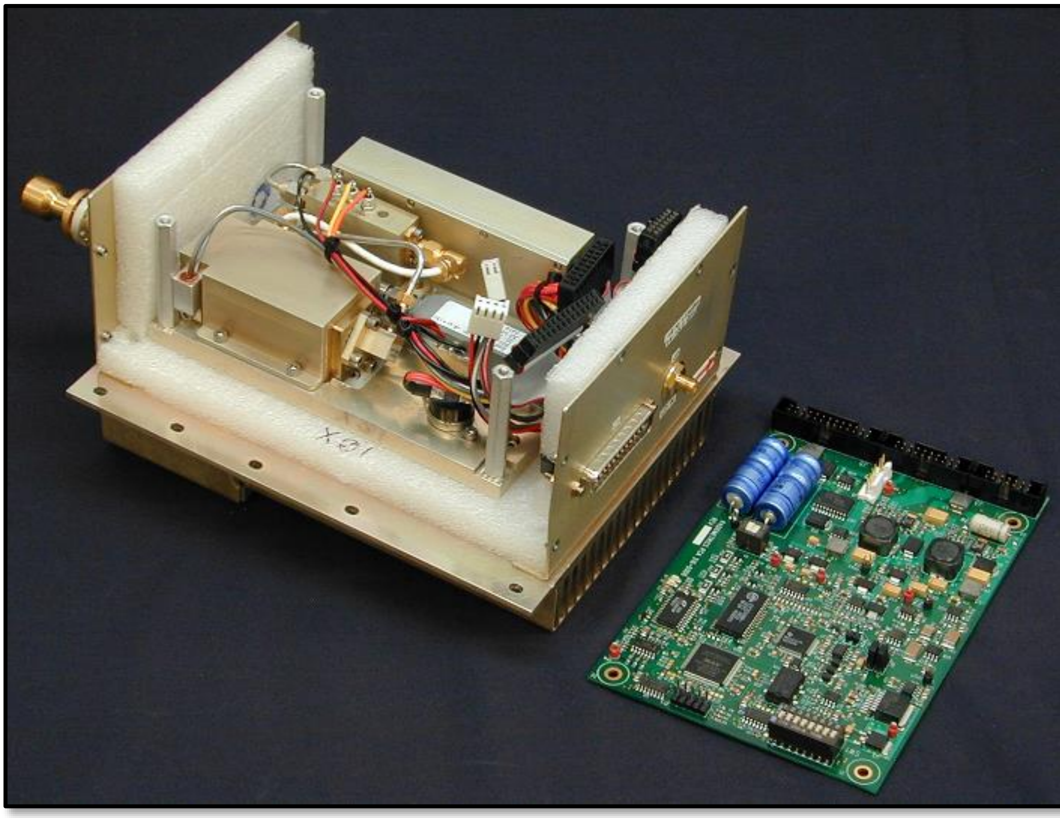


Figure 7. MP-G antenna, downconverter module and Baseband Processor.

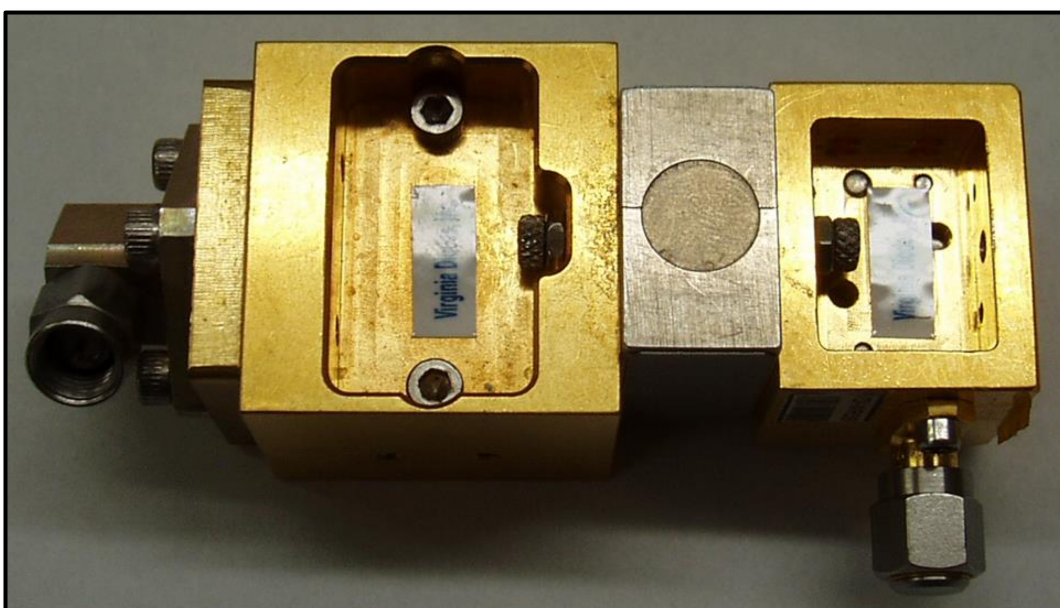


Figure 8. MP-G local oscillator input, multiplier, isolator, mixer and IF output.

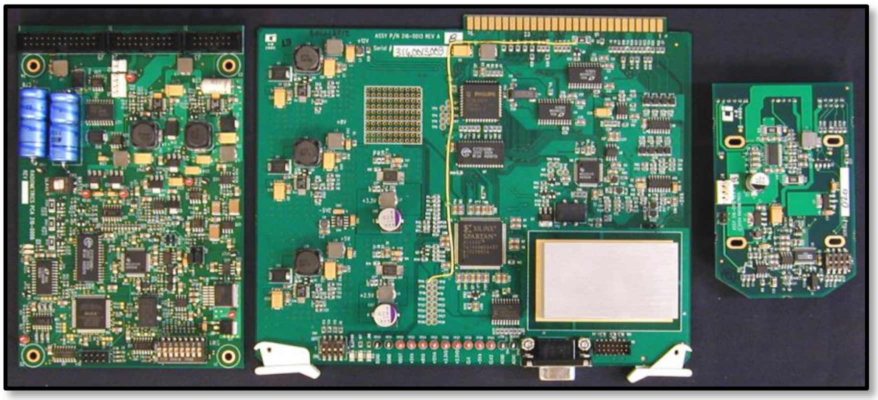


Figure 9. MP-G Baseband Processor, Master Control Module and Motor Control Board.

PR-Series Radiometers

In this section we describe a prototype G-band radiometer in a compact PR-Series configuration (Figures 10-17). The PR-G *breadbox* radiometer reduces size by 14X, weight by 3.6X and power by 4X, compared to the MP-G radiometer (Table 1). The PR-G also includes parallel (vs. MP-G serial) frequency channel observation capability and no moving parts, both of which are advantageous features for reliable and accurate airborne icing hazard detection.

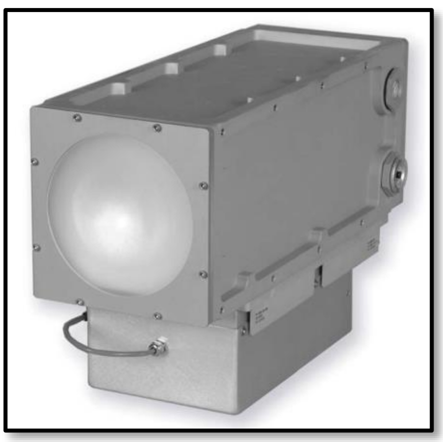


Figure 10. PR-Series radiometer.

Table 1. MP and PR series radiometers.

	Size (in)	Weight (lb)	Max Power (W)
MP	34 x 21 x 12	64	400
PR	17 x 6 x 6	18	100
MP/PR	14	3.6	4

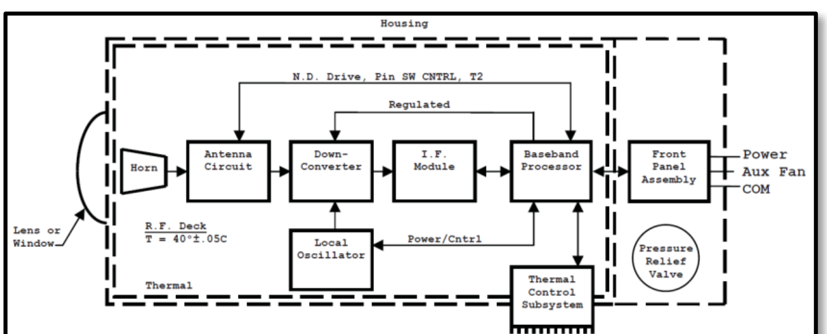


Figure 11. PR-Series block diagram.

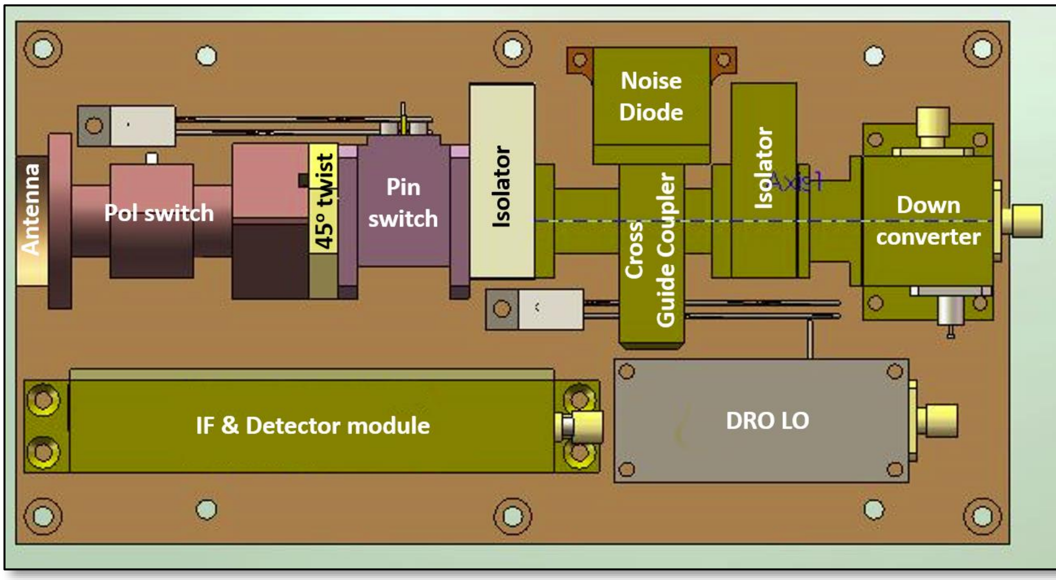


Figure 12. PR-Series dual polarization radiometer block diagram.

The PR-8900 radiometer product characterized in Figure 12 provides reliable, accurate dual polarization 89 GHz

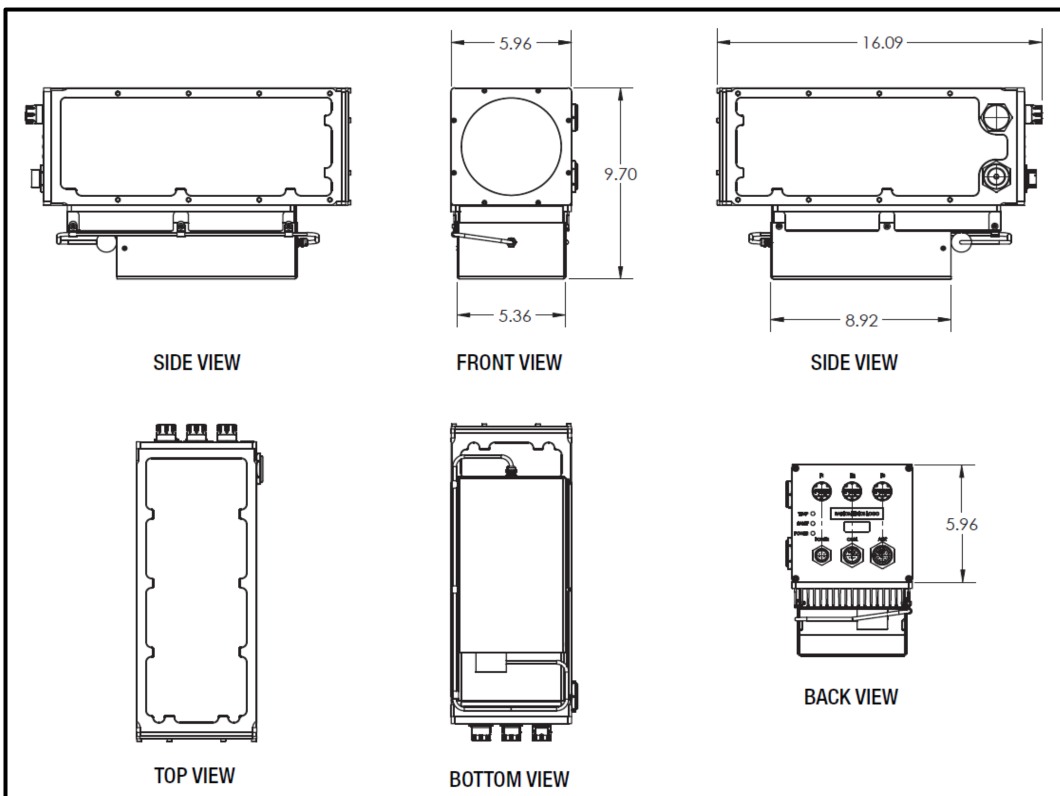


Figure 13. PR-Series radiometer cabinet.

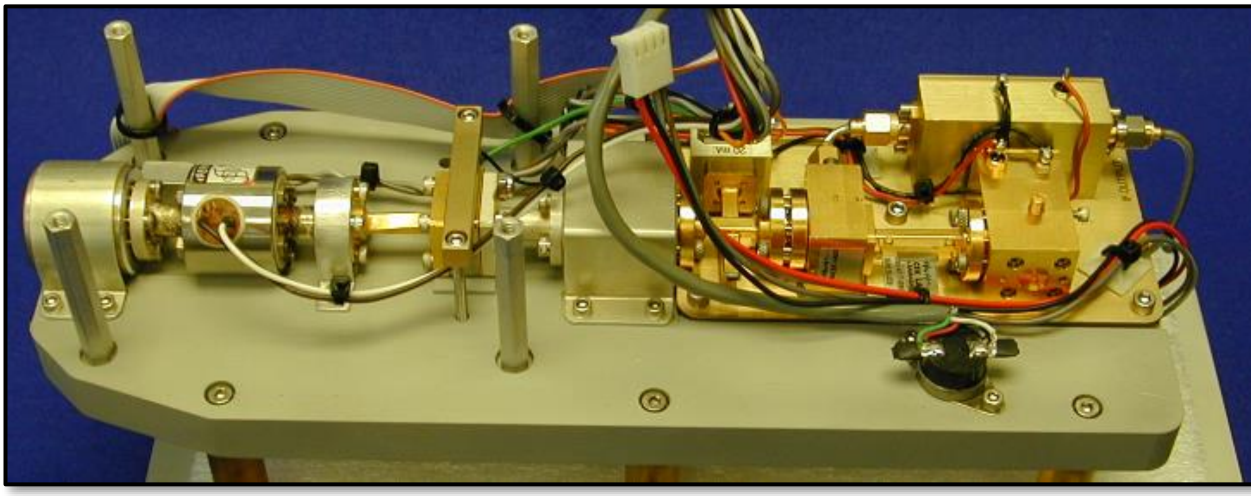


Figure 14. PR-Series 89 GHz dual-polarization radiometer.

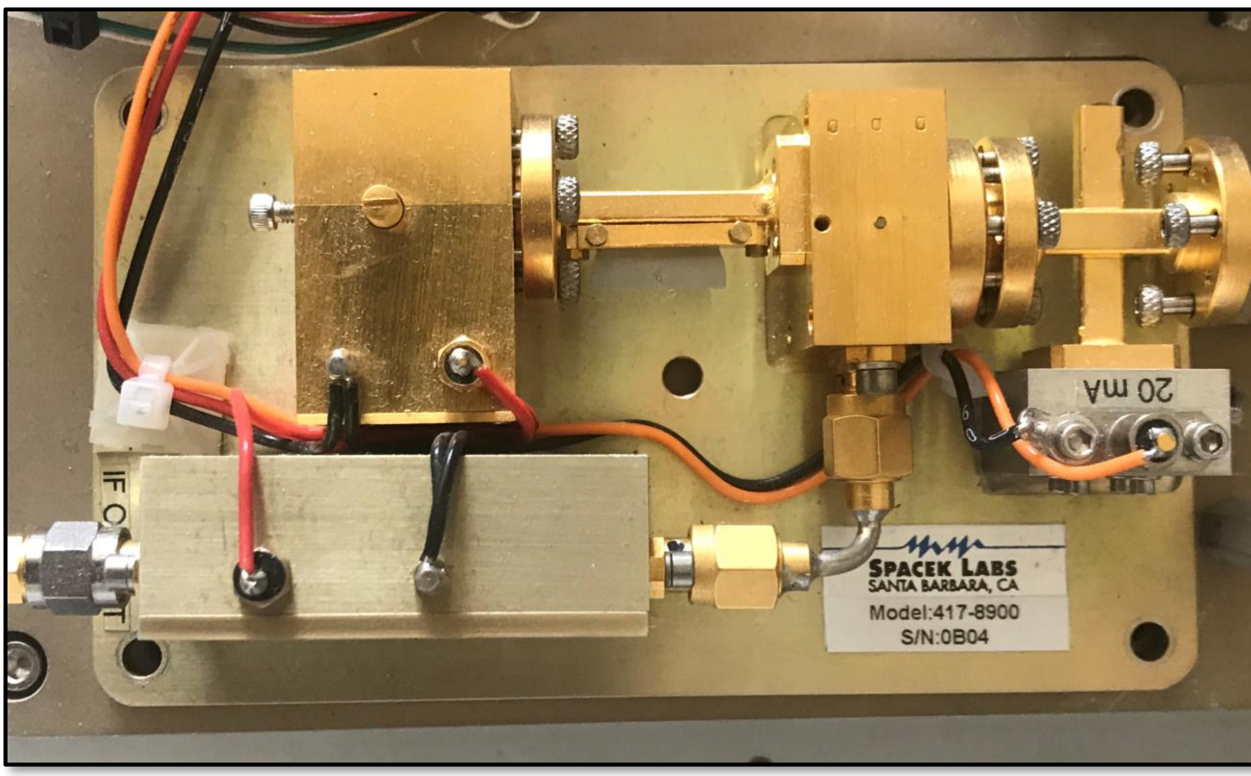
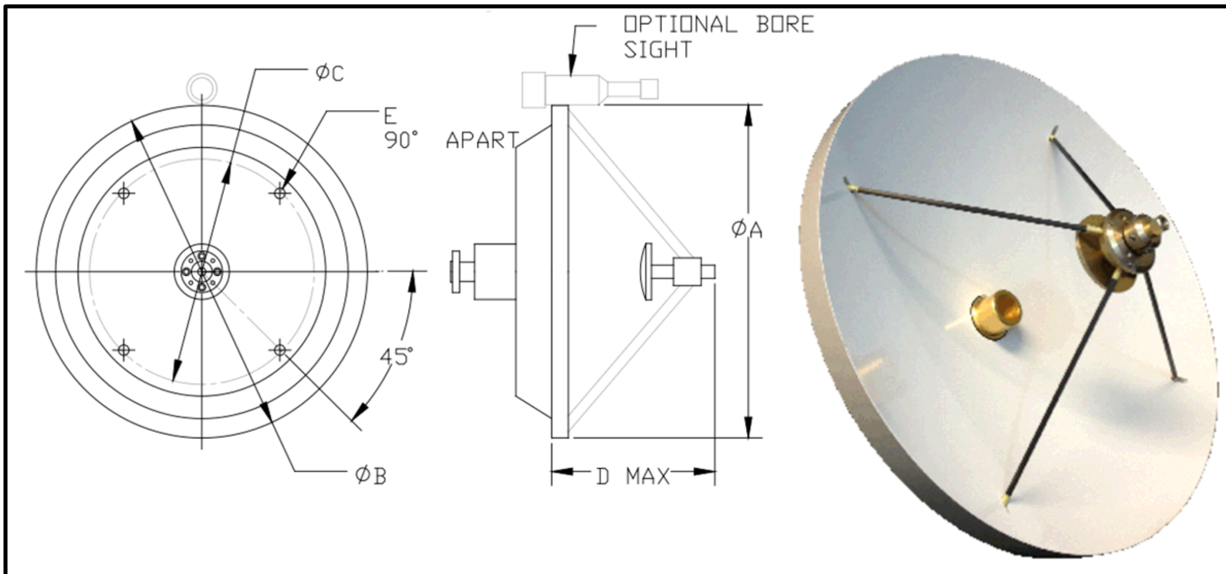


Figure 15. PR-Series downconverter and IF module.

PR-G Antenna

The PR-G prototype will include a 6” diameter Cassegrain antenna available as COTS products from several vendors. Future production costs could be reduced using a corrugated feed horn and offset paraboloid antenna. First RF will be responsible for antenna design and testing.



MECHANICAL SPECIFICATIONS

A Reflector Diameter (in/mm)	6.0/152	10.0/254	12.0/305	18.0/457	24.0/610	36.0/914	48.0/1219
B Housing Diameter (in/mm)	6.0/152	10.0/254	12.0/305	18.8/478	24.8/630	36.8/935	49.2/1250
C (in/mm)	4.0/102	7.0/178	10.0/254	10.0/254	16.5/419	24.0/610	36.0/914
D (in/mm)	3.6/91	5.1/130	5.4/137	6.9/175	7.8/198	9.5/241	14/356
E (in/mm)	.190-24UNC.	.375-16UNC.	.375-16UNC.	.375-16UNC.	.375-16UNC.	.375-16UNC.	.500-13UNC.

Figure 16. Cassegrain reflector antenna.

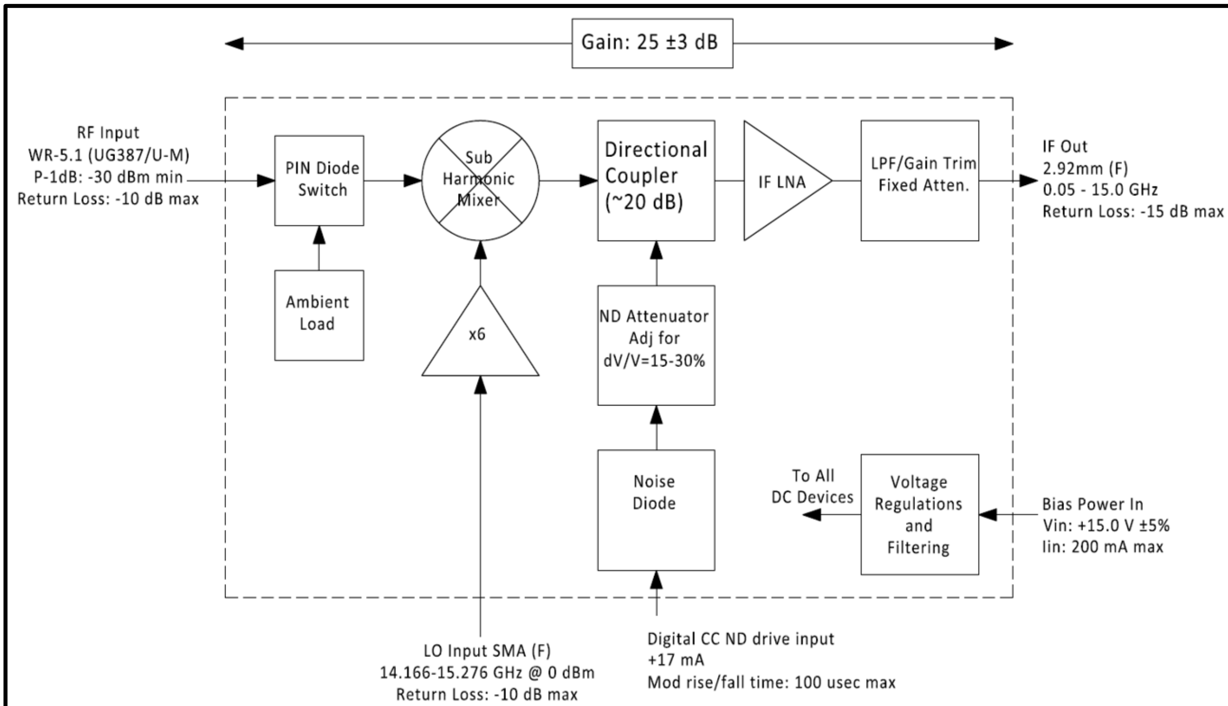


Figure 17. Preliminary PR-G block diagram.

A conceptual prototype radiometer diagram including the antenna, microwave downconverter, IF splitter and two-stage IF downconverter is shown in Figure 18.

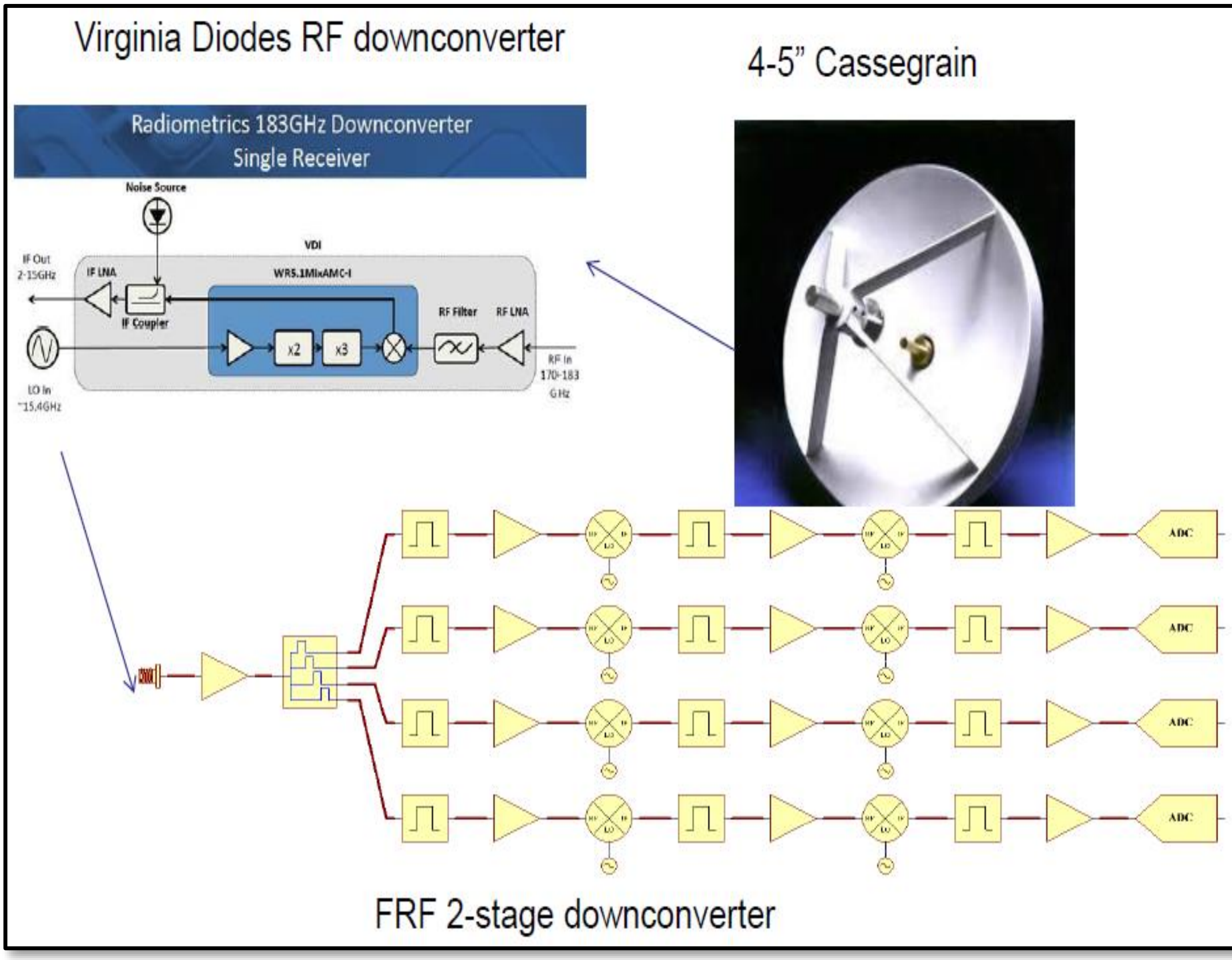


Figure 18. Antenna, microwave downconverter, IF splitter-downconverter components.

An ambient temperature load and switch, and appropriately placed isolators should be included in the preliminary microwave downconverter diagram shown in Figure 17, and in the conceptual diagram in Figure 18.

Cross-Polarization Lidar

The US Navy funds Innovative Dynamics Inc. (IDI) development and testing of lidar systems for aircraft icing risk identification. Sigma Space Corporation (SSC) is working under IDI subcontract to integrate the SSC MiniMPL aerosol lidar product with the RHS airborne MP-G cloud microphysics and supercooled liquid water sensing system. In-situ liquid and cloud particle imaging sensors, forward and side looking video cameras, and forward looking radar are included in the RHS airborne sensor suite. The MiniMPL lidar will provide accurate range to cloud and cloud microphysics information for calibration and validation of the RHS airborne MP-G ranging and cloud liquid observation system.

Forward-Looking Observations

Forward-looking airborne observations are essential for operational icing detection and avoidance system development and implementation. However, additional airborne side-looking MP-G and lidar and in-situ observations are needed for to develop and validate icing detection and avoidance methods and algorithms. The following section describes an FAA-certified equipment canister that is ideal for forward looking airborne PR-G observations.

PMS Canister

The PMS Canister is an FAA-certified enclosure for aircraft wing-mounted atmospheric measurement systems. An aerodynamic teardrop-shaped cast aluminum mount secures a hollow aluminum cylinder with 1/2“wall thickness to the underside of an aircraft wing, as shown in Figure 19. Cylinder length can extend to 24”and diameter to 12”.

Figure 19. Wing mount PMS canisters (5 left, 1 right).

A PR-G radiometer can be secured inside a 9” diameter PMS Canister outfitted with a hemispherical polyethylene radome for forward-looking PR-G observations.

Additional Side-Looking Observations

Side-looking horizontal, upward and downward MP-3 observations were used to demonstrate the feasibility of icing risk identification in orographic clouds. Additional side-looking MP-G observations in maritime icing conditions can be used to further validate and refine icing risk identification algorithms. A side-looking lidar can be added for ranging validation and cloud particle identification. The lidar can view through an existing aircraft side window, simplifying FAA certification.

Multiple icing hazard events are commonly encountered west of the California coast during the winter months. For perspective, radiosonde profiles from Vandenburg AFB on the south-central California coast during January and February 2017 are shown in Figure 20. Freezing temperatures prevailed at 15,000 ft and above during this period, with multiple RH over ice (RH/i) >100%

occurrences indicating supercooled liquid water and associated aircraft icing hazard with 12-36 hour duration.

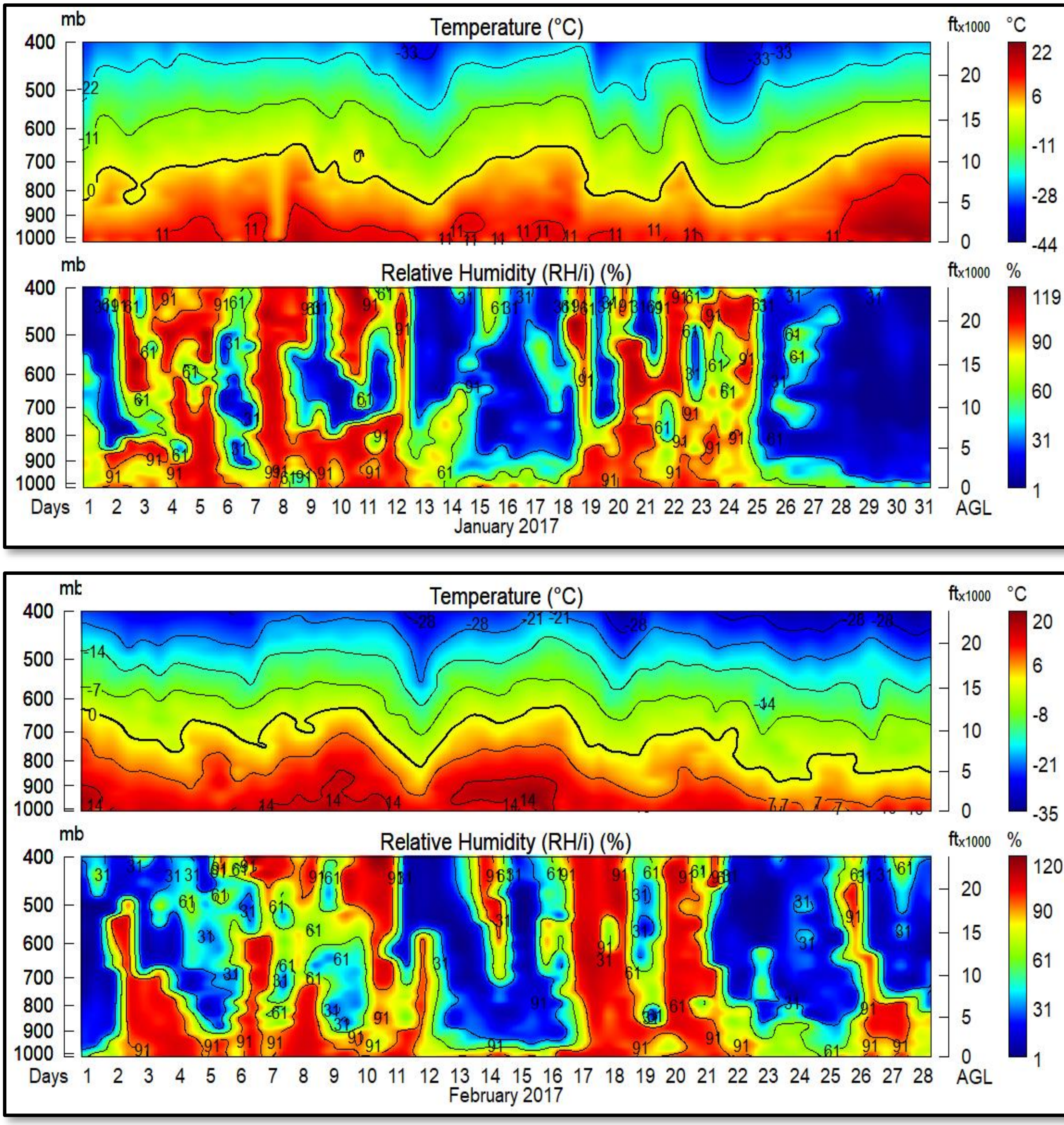


Figure 20. Vandenburg radiosonde soundings during January and February 2017.

RHS runs a high resolution numerical weather model including liquid water over California, extending at hundreds of miles west of the California coast. Based on numerous extended flights associated with weather modification operations in marine layer supercooled liquid conditions in this region during winter months, RHS confirms the accuracy of its supercooled liquid model.

Side-looking MP-3 and lidar flight observations of maritime supercooled liquid during 2018 winter months would be valuable for development and validation of marine layer aircraft icing risk detection and avoidance methods and algorithms.

Time and Cost

A preliminary time-cost outline for PR-G design, procurement, assembly, test, and flight measurements during maritime aircraft icing conditions is shown in Figure 21.

		2017 aug	sep	oct	nov	dec	2018 jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	2019 jan	feb	Cost $
1	PR-G	Design (tbd)		Procure (tbd)						Assemble (tbd)					Test (tbd)				Flight: forward-looking		
	Downconverter																				20,000
	Pin switch																				1,750
	Isolators																				tbd
	RF deck & Peltier																				950
	IF, splitter, noise diode																				tbd
	Low noise IF amp																				1,400
	Detectors																				tbd
	Antenna																				4,000
	Baseband Processor																				1,500
	Master Control Module																				5,000
	Cabinet, connectors																				tbd
	Control Computer																				2,000
	Firmware, software																				tbd
2	PMS Canister																				
	Housing, Pylon Wing Mount, PR-G Mount, Wiring and Interface									tbd		tbd		tbd			tbd		Flight: forward-looking		tbd
3	Aerosol Lidar (MiniMPL)																				
	Aircraft mount	tbd	tbd		tbd	Flight: side-looking															tbd
	FAA Certification																				tbd
4	Data Acquisition System																				
	Pitch, roll, yaw, xyz, data integration	tbd		tbd	tbd	Flight: side-looking															tbd

Figure 21. Preliminary time-cost summary.

Three prototype PR-G radiometers are required including one for flight testing and one each engineering test units for First RF and RDX. Estimated cost for most PR-G components are in lots of five, which typically are equivalent to one-off pricing in lots of three.