Design, Realization & Experimental validation of Active Array Antenna Unit for Arudhra Radar

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Abstract:

Arudhra radar is a medium power ground based 4D radar with fully active array Dual Transmit and Receive module (DTRM/DRM) based antenna.The units like DTRM's, DRM's, Array Group Receiver (AGR) and Power Supply(PS)arehoused inside antenna cabin at their respective pitchesas per electrical antenna design. The total heat dissipation of electronic unit is 65 kW. A cold plate is designed to meet the thermal and structural requirement of antenna electronic units. Liquid cooling approach adopted to maintain the temperature of electronics units mounted over the cold plate.In addition Close loop chilled air cooling approach also adopted to maintain working temperature of AGR's inside antenna cabin. This paper describes a detailed study of thermal management of antenna electronic units. The study has been validated through experimentation.

Key Words:Cold Plate, DTRM, DRM, PS, AGR ,65kW

I. INTRODUCTION

The arudhra antenna is a medium power ground based 4D radar with fully active array Dual Transmit and Receive module (DTRM/DRM) based antenna. The antenna assembly is mounted on the rotary platform of pedestal assembly.

Antenna electronic units like DTRM's, DRM's and Power Supply Modules, DBF and AGR's are dissipating heatof 65 kW and are housed inside antenna cabin at their respective pitches. A cold plate design is carried out, which provides mounting as well as thermal cooling to these members. DTRM's, DRM's and Power Supply Units are mounted on either side of the cold plates in vertical orientation and is fixed with the wedge lock. The coolant is circulated inside the cold plate through cavities for cooling the units. AGR’s and DBF are mounted inside the antenna cabin and dissipating heat of 5kW together, are cooled by the chilled air . Heat Exchanger(HE) along with fan are mounted top of antenna cabin supplies chilled air .

The structure of cold plate is extruded and then machined. The machined structure passes through burst test for testing of leakage at weld joints and surface planarity. There are 45 cold plate vertically mounted on cabin and 3 of them are looped to form such 15 loops. Each loop is to be maintained for the same flow rate . The possibility of chilled air and liquid cooling for the complete antenna was explored.Liquid cooling is adopted for DTRMs/DRMs and Power Supply units, because these units are closely mounted, high localized heat load and there was no sufficient space available for air circulation. In case of AGR and DBF, the heat load is less and space availability is sufficient for circulation of air. Therefore the forced convection chilled air cooling method is adopted to maintain the required temperature.

The paper describes the design and realization aspects of antenna based on CFD and Thermal analysis. Further the result obtained was validated through experimental results.

II.ANTENNA UNITDESIGN REQUIREMENTS

Requirements:

- Casing temperature of DTRM to be less than 45^0C.
- DTRM temperature difference is less than 10^0C
- Equal flow rate through all the 45 cold plate
- Maximum temperature at heat sink of AGR is 75 ^{0}C.

Constraints:

- Antenna cabin dimension along depth and height
- Cold plate thickness between DTRM's

III.DESIGN, REALIZATION AND VALIDATION OF COLD PLATE

The mechanical structure of antenna cabin have 45 numbers of cold plate. Line Replaceable Unit (LRUs) and radiating patch antenna are mounted over cold plate. The detailed mechanical configuration is shown in Figure 1,2,3 &4.

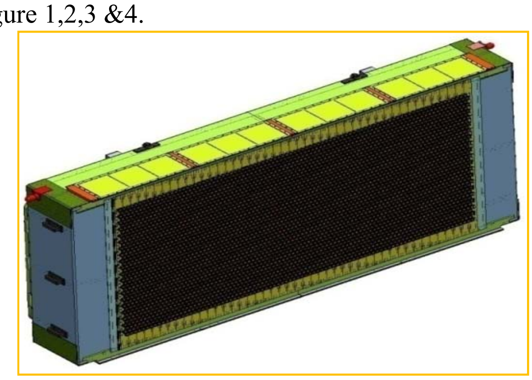


Figure 1 antenna cabin radiating side

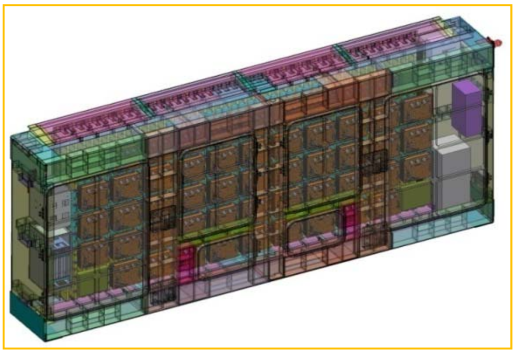


Figure 2 antenna cabin radiating side

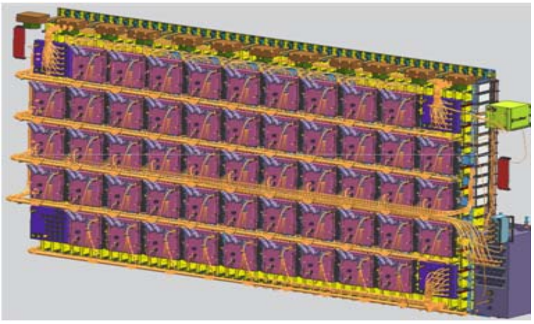


Figure 3   cable routing

The overall dimension of antenna cabin is 5.6m x0.85 m x 2.6m and weight is 7000 kg along with electronics.

The mechanical configuration of antenna cabin is shown in Figure 4

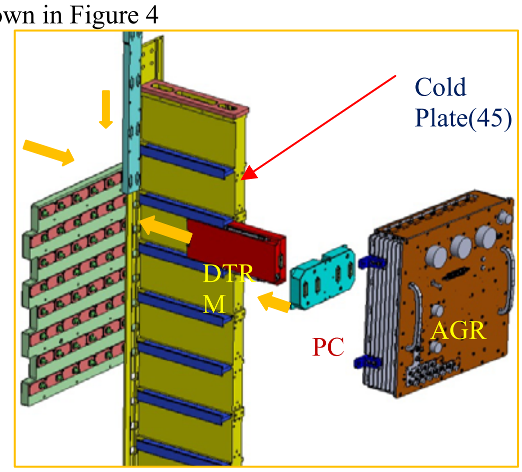


Figure 4   mechanical configuration

Cold plate of dimension (2.1m x 0.992m x 0.23m) is a mechanical structure designed to support the antenna electronic modules and an structural member of cabin. In addition, the cold plate acts as a heat sink. A cavity in terms of flow channel is finalized based on the localized heat load distribution of DTRMs/DRMs and Power supply module. To make the heat transfer more effective fins are provided in the flow channel and the coolant (water to ethylene glycol(50:50)) is circulated through channels. In addition to flow channels, other channels are made for weight reduction as shown in Figure 5,6.

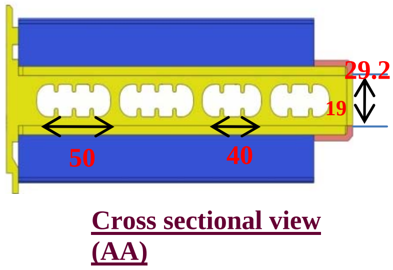


Figure 5 cold plate cross section

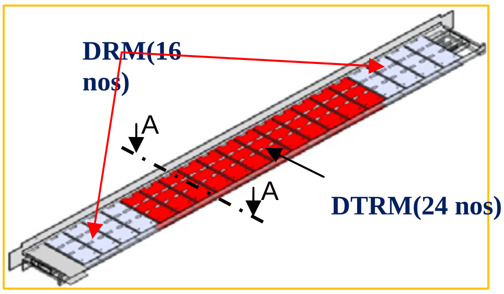


Figure 6 Isometric view of cold plate

The cold plate is made in a loop of 3, based on various iteration in CFD analysis as shown in Figure 7,8,&9 . Three different modes of entry and exit are iterated. The entry and exit from the center in a loop of 3 cold plate meets the requirement.

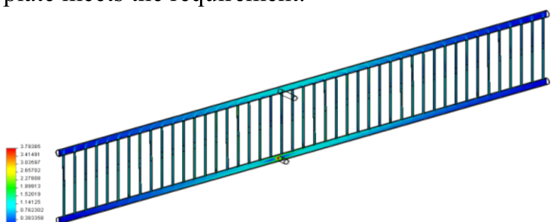


Figure 7Velocity plot - 45 cold plate

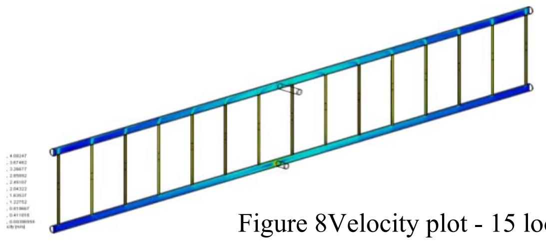


Figure 8Velocity plot - 15 loops of cold plate

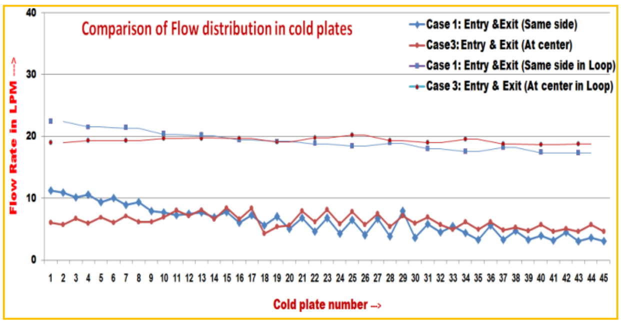


Figure 9comparison of flow

The result from flow distribution shows clearly for uniform flow distribution to each cold plate.It is required to loop 3 cold plate in series as shown in Figure10.

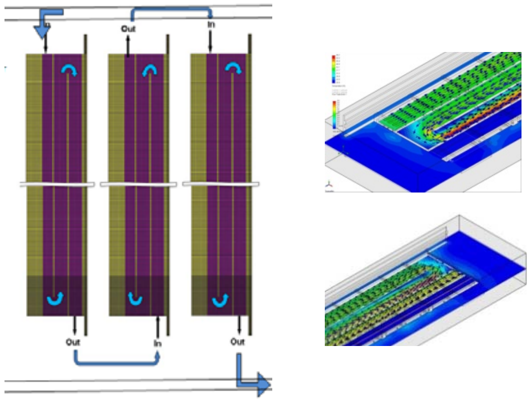


Figure 10 flow in a loop of 3

The temperature plot shows that maximum temperature difference between DTRMs is 8.80c and maximum casing temperature of DTRM is 380c.Hence the design considering of triple pass flow over a loop is meeting the requirement. It is shown in Figure 11.

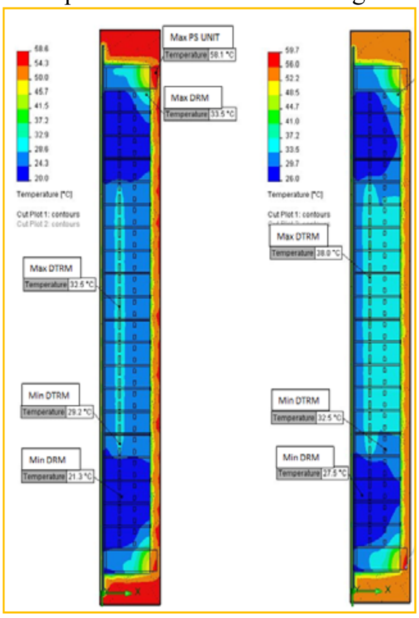


Figure 11 Temperature plot of 1st cold and 3rd cold plate

IV.EXPERIMENTAL VALIDATION OF COLD PLATE IN A LOOP

Burst test was carried out to test the leakage at the welding and surface planarity. In this process pressurized nitrogen at 14 bar is filled inside cavity and later deepen in the water tub as shown in Figure 12. Further die penetration test carried out to test the leakage and gauge instrument used to check the planarity. The electronic unit assembly sequence as shown in figure 13 clearly justifies the surface planarity, as the units are blind mated.

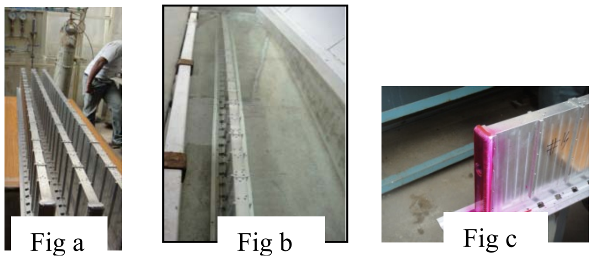


Figure 12 Burst test

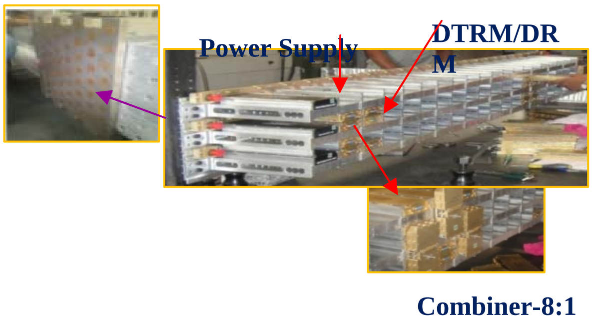


Figure 13 assembly of LRUs with cold plate

The heat pads of capacity 100w i.e. equivalent to DTRM is made and mounted over the cold plate and tested experimentally. RTD is used to measure the temperature is shown in the Figure 14. The results wereapproximatelymeeting with the analysis result.

Figure 13 Thermal test of one loop of cold plate

Results		Experiment	Fluent
Sensor No.	3-9F	31.9	30.1
	3-9B	30.2	29.3
	3-10F	30.4	30.1
	3-10B	30.2	29.3
	3-11F	30.3	30.1
	3-11B	30.2	29.3
	3-12F	30.3	30.1
	3-12B	30	29.3
	3-13F	30.6	30.1
	3-13B	31.4	29.3
	3-14F	30.2	30.1
	3-14B	30.4	29.3
	3-15F	30.4	30.1
	3-15B	30.2	29.3
	3-16F	28.2	28.6
	3-16B	28	28.0
	3-17F	27.9	28.6
	3-17B	27.9	28.0
	3-18F	30.4	30.5
	3-18B	31.9	31.6

Figure 14 3rd cold plate temperature measurement comparison

V.FLOW ANALYSIS OF ANTENNA CABIN

The air cooling is done using heat exchanger along with fan(HE/fan). Liquid to Air Heat exchanger are used. In this type of cooling, fan forces the hot air through the heat exchanger and delivers the cold air to the hot components. The HE/fan assembly is located at the top of the antenna cabin for better circulation of the air. The cold & heavy air from the heat exchanger falls down and the hot & light air rises up. This hot air comes in the contact with heat exchanger at the top and becomes cold & heavy which throws down by fan. This cycle continues to maintain the AGR temperature.

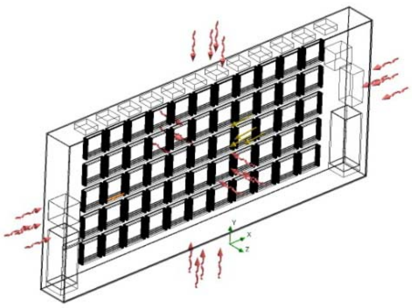


Figure 15 CFD model of antenna cabin

The boundary conditions are

- Air flow rate : 500 cfm
- Ambient Temperature: 55 ^{0}C
- Atmospheric Pressure: 1.013 bar
- Diameter of fan: 180 mm
- Solar heat load : 750 W
- Solar heat load calculation :

To minimize the solar heat, the antenna is painted with solar reflective paint(Metkon) and PU foams is fixed to walls inside of antenna cabin. This will able to reflect 90 - 95 % of solar radiation.

As per JSS 55555 Solar heat radiation intensity is 1200 W/m2.

Assuming α = 0.3 & At a time Max 3 faces of antenna exposed to sun.

Total area of antenna exposed to sun = 20 m2

Therefore, the total solar load on antenna = 10 % of (1200*20*0.3) = 720 W

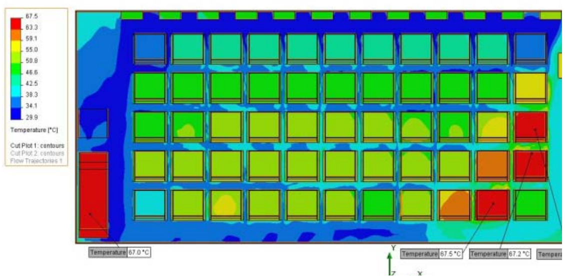


Figure 16 Temperature plot of antenna cabin

The maximum temperature at heat sink, where FPGA cards are mounted is 67.5 °C.

VI. EXPERIMENTAL VALIDATION OF AGR CASING TEMPERATURE

The temperature sensor located at various places over the AGR using thermocouples. The measurement was taken after every 15 min for a period of 2 hours. It is shown in Figure17.

T1: Temperature on the top of DBF(Left side of AGR array)

T2: Temperature on the AGR No:038 of the left middle of AGR array

T3: Temperature on the AGR No:042 of the left bottom of AGR array

T4: Temperature on the AGR No: 037 of the left top of AGR array

T5: Temperature on the AGR No: 034 of the middle bottom of AGR array

T6: Temperature on the AGR No: 015 of the right bottom of the AGR array

T7: Temperature on the AGR No: 047 of the right center of the AGR array

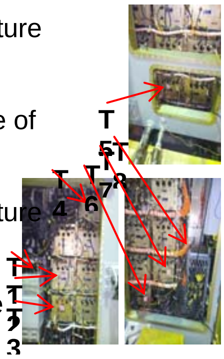
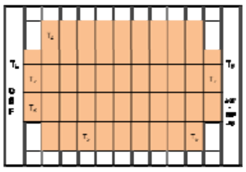


Figure a: Temp. Monitor at critical location



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T4: Temperature on the AGR No: 037 of the left top of AGR array

T5: Temperature on the AGR No: 034 of the middle bottom of AGR array

T6: Temperature on the AGR No: 015 of the right bottom of the AGR array

T7: Temperature on the AGR No: 047 of the right center of the AGR array

T8: Temperature on the top of power supply (Right side of AGR array)

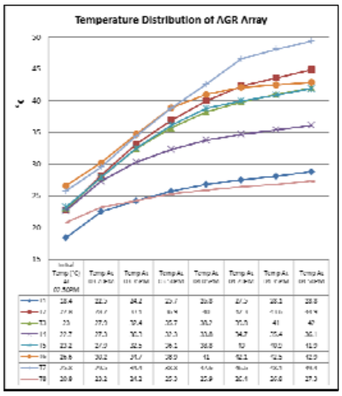

Figure b: Temp. measurement plot

Figure 17 Temperature measurement of AGRs

The antenna is integrated with pedestal and trials are being conducted.

VII. CONCLUSION

The maximum temperature at interface of DRMs & DTRMs is 38^{0}C at a flow rate of 20 lpm. In addition, Contact resistance gives an additional 3^{0}C rise in temperature. Therefore Max casing temperature of DTRM is 38^{0}C +3^{0}C = 41^{0}C, which is less than the permissible temperature limit i.e. 45^{0}C. Hence it is acceptable.Maximum temperature at the interface of PS1 &PS2 is 58.1 ^{0}C& 58.5 ^{0}C respectively. Which is within the acceptable limit i.e. 60^{0}C.? Hence it is acceptable.Temperature rise of the coolant for a loop of three cold plate is 9^{0}C which is within the allowable limit. Coolant flow rate in a loop is 20 lpm. Pressure drop across one cold plate is 0.2 bars. The maximum temperatures at heat sink of AGR, where FPGA cards are mounted is 67.5 °C. This temperature is well within the allowable temperature i.e. 75 °C. Hence it is acceptable for the given flow rate. Since the flow requirement in this configuration is high. It is decided to use 12 numbers of Heat Exchanger/Fan assemblies, each one will flow air at a speed of 500 CFM.

The antenna cabin meeting the structural and thermal requirement has been ~~designed~~ and realised successfully and validated through experimentation. Since validation and characterization have been done for antenna cold plate and structure, same building blocks can be used for similar system using modular approach.The antenna is now integrated with pedestal assembly and under field trials.

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