

Thermal Design of a Base Transceiver Station using MacroFlow

Nanqiang Zhu, Daniel Plaza and Craig R. Maitz
Lucent Technologies, Inc.
450 Clark Drive
Mt. Olive, NJ 07828
nzhu@lucent.com; dplaza@lucent.com; cmaitz@lucent.com

Abstract

The objective of the present study was to perform thermal analysis for the design of a Base Transceiver Station (BTS) outdoor frame, which consists of a PCB rack, an ATM switch unit, a RF amplifier unit, two RF filters and a rectifier. The electronic components are completely isolated from the outside ambient air. The primary objective of the analysis was to package all these units into a compact portable cabinet with effective cooling strategies for outdoor environmental conditions.

The Flow Network Modeling (FNM) technique was used for the thermal analysis from conceptual design through the final design. At the conceptual design phase, flow network models were built to examine different packaging concepts and to generate new design proposals by identifying the problem areas of the examined design concepts. A highly integrated heat exchanger/BTS frame design concept was developed after iterations of this process. At the detailed design stage, FNM analysis was used for the placement of units, for necessary air baffling and flow balancing, and for the design of the heat exchanger. The results of system-level FNM analysis were also used in the unit-level analysis using Computational Fluid Dynamic (CFD) technique.

The use of FNM technique benefits this design in its ability to provide quick system-level modeling and problem solving. A CFD analysis for the BTS frame with detail heat exchanger and heat sink models, which are critical for the design, requires tremendous modeling effort and computational time and is not feasible nor necessary at the early design stage. Use of FNM shortened the design process significantly.

Key word: base transceiver station, flow network modeling, computational fluid dynamics.

Introduction

Increasing demands for higher speed, higher capacity and smaller packaging in cellular base transceiver station (BTS) results in growth of complexity in system thermal management. The combination of high internal heat density and hostile outside environment of a outdoor BTS poses more challenges that require a thorough understanding of the system's thermal performance under all possible field conditions. In-depth thermal analysis, mostly based on the Computational Fluid Dynamics (CFD) technique, is increasingly used to guide the design engineers in the system packaging. However, in the early design stage a less sophisticated but faster thermal analysis method is in the interest of thermal design engineers when design details are not readily available and there is a need to evaluate many different possibilities.

This paper describes the thermal design of an outdoor BTS based on the thermal analysis using Flow

Network Modeling (FNM) technique. Unlike CFD-based analysis, FNM is a generalized methodology that represents a flow system as a network of components and flow paths, and predicts system-wide distribution of flow rates and temperatures based on flow and heat transfer correlations for the components used in the network model. Because of the simplification of component modeling, FNM provides a quick means of system-level modeling and problem solving. This is especially helpful early in the design cycle when a development schedule is tight and a high order of accuracy is not required. The thermal analysis for the outdoor BTS was performed by using a commercial software package MacroFlow, which is based on this FNM technique.

The Physical System

The high capacity cellular BTS being designed consists of a PCB rack with seventeen PCBs and two PCU boards, a high power radio frequency (RF) amplifier, two RF filters, an ATM switch unit, and a

rectifier. All these units, totally dissipating 1.7 kilowatts of heat, are being packed into a compact portable cabinet. The cabinet shall be designed for outdoor environment and must handle the maximum solar heat load at a maximum ambient air temperature of +52 °C and at maximum internal heat load.

To protect electronics from outdoor environment such as rain, humidity, dust and pollutants, the internal equipment must be isolated from outside ambient air. The internal heat is transferred primarily by conduction or convection to the inside surfaces of the cabinet, by conduction through the cabinet walls, and then by convection and radiation to the ambient. Attached heat exchangers are usually used to enhance heat transfer if the internal heat load is high. The same cooling method was used in the current BTS design. However, considering the internal heat load and the constraint of maximum internal and external air temperatures, the BTS would require a very large heat exchanger, which is not acceptable for the product.

Design Proposal: A very attractive design proposal is to cool the RF amplifier, which is a major contributor to the internal heat, with external air. Figure 1 shows the concept of the design proposal. The amplifier assembly is packed into a sealed box with a heat sink attached to its cover. Heat generated by the amplifier is conducted to the heat sink and the opposite surface of the box. Two blowers provide the external air through the heat sink and the other heated surface of the amplifier. The external air also flows through the outside surfaces of the cabinet walls, before into and after exiting the amplifier section, to cool the rest equipment of the BTS. A higher cooling capacity was expected for the cabinet because of the following reasons:

- The RF amplifier is cooled by directly using external air.
- Instead of natural convection, a forced convection cooling is utilized for the outside surfaces of the cabinet.
- Extended surface (fins) is used on both sides of the cabinet walls.

Another advantage of this design proposal is that it eliminates the use of an attached heat exchanger and therefore is very attractive for the portable BTS.

Conceptual Design: A thermal analysis was performed using MacroFlow to examine the proposed design. The use of MacroFlow instead of CFD tools is due to the following factors:

- Time for making design decision does not allow a CFD-based analysis

- Analysis with high order of accuracy is not needed at this design stage.

Two MacroFlow models were built: one for the external airflow path and the other one for the internal airflow through PCBs and other equipment. FNM analysis was performed to determine the airflow rate and the extended surface area of the cabinet walls required to remove the maximum internal heat and solar load at the maximum ambient air temperature. The analysis showed that the total flow impedance of the external air flow path is very high and there is no proper air moving device capable of delivering adequate air for this cooling configuration. The analysis also showed a very large pressure drop for internal airflow such that big blowers are needed.

Figure 2 shows the new design concept based on the prior design proposal and the MacroFlow analysis. A heat exchanger core was integrated into the cabinet underneath the RF amplifier. This design retains the advantages of the prior design proposal but dramatically reduces the external air flow impedance by using parallel flow configuration. Internal airflow

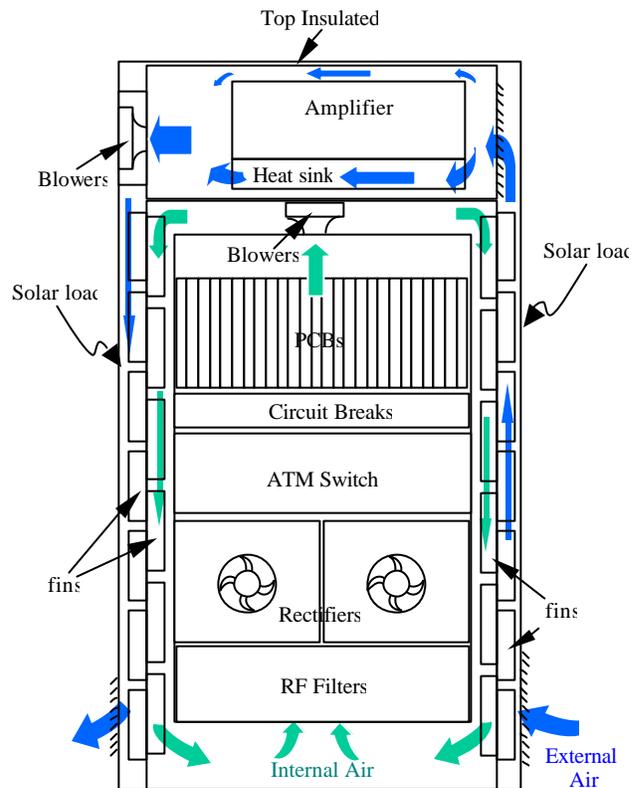


Figure 1. Schematic of the conceptual design proposal

resistance is also reduced by directing proper amount of air to different devices. The new design enhances the cooling performance of the cabinet due to the following improvements:

- Higher flow rate due to lower flow resistance
- More heat transfer surface area due to the introduction of the heat exchanger core
- Proper baffle and direction of internal cool air to devices
- Impingement of internal hot air into the heat exchanger core

The most important point is that the proposed highly integrated heat exchanger/BTS frame greatly reduces the cabinet size, compared to cabinets with attached heat exchanger. This is critical to the success of the project.

Flow Network Modeling of the BTS

Figures 3 and 4 show the flow network models of the external and the internal airflow sections, respectively. During the detailed design stage the FNM analysis was performed many to optimize the internal device placement, the heat exchanger design, the airflow baffling and balancing using perforated plates with different openings, and the fan selection, etc.

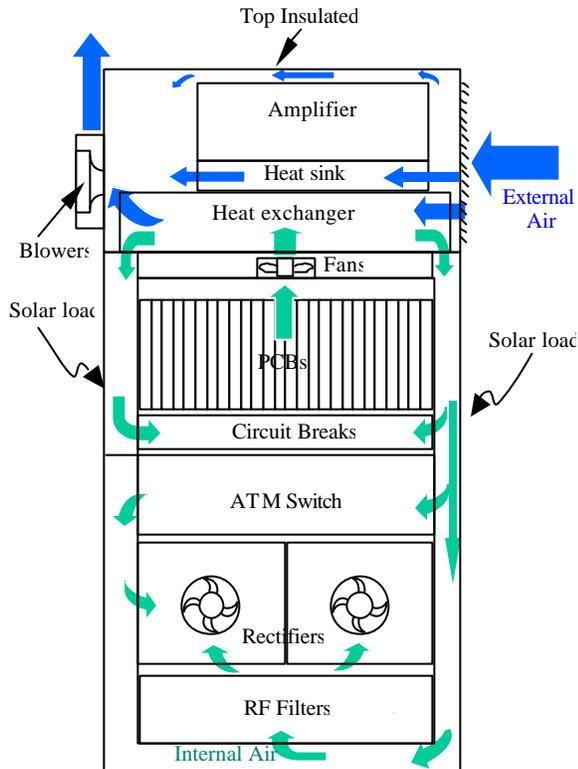


Figure 2. Schematic of the improved BTS design

Input of flow and heat transfer characteristics is required for the components used in the network models. The input of flow characteristics involves specifying the variation of pressure loss across a component as a function of flow rate. The pressure loss across screens, perforated plates and channels between PCBs was calculated using the software built-in power based correlation:

$$\Delta p = A Q^2 \quad (1)$$

where p is the pressure and Q the volumetric flow rate. The coefficient A was calculated based on correlations and data provided in [1] and [2]. The pressure losses in the ATM switch and the rectifier as a function of flow rate were obtained from vendor's data. Vendor provided fan curves were also used for the fans in the models.

Heat dissipation of the PCBs and other devices were input to corresponding components in the models. A maximum solar load, which was calculated based on Bellcore standard [3], was applied to corresponding flow channels in the models by taking the external air inlet side to be the shiny surface and the exhaust side to be in the shade. Forced convection heat transfer mode was specified in the models for all heat dissipating components and for flow channels such as heat exchanger and heat sink interchannels within which heat transfer calculation is needed. It should be noted that neglecting the effects of flow impingement in the heat exchanger core will result in an underestimate of the heat transfer capacity of the heat exchanger. Since only steady state analysis was performed, the total heat dissipation for devices in the internal airflow section was input to the heat exchanger in the external airflow model. The calculated heat transfer coefficient and average air temperature within the external airflow channel of the heat exchanger were then input to the internal airflow model as boundary conditions.

Figures 5 and 6 show volumetric flow rates through various parts of the BTS. In the external airflow section, the amplifier rear channel was properly sized based on the analysis in order to maximize the heat exchanger core. In the internal airflow section, necessary flow baffling and flow balancing were used to direct proper amount of air to different devices and to reduce the overall pressure loss for internal flow. FNM analysis was utilized for proper flow baffle and for the determination of perforation of the baffling plates. The interchannel size of the heat exchanger was also optimized using FNM analysis to balance between pressure loss and heat transfer performance.

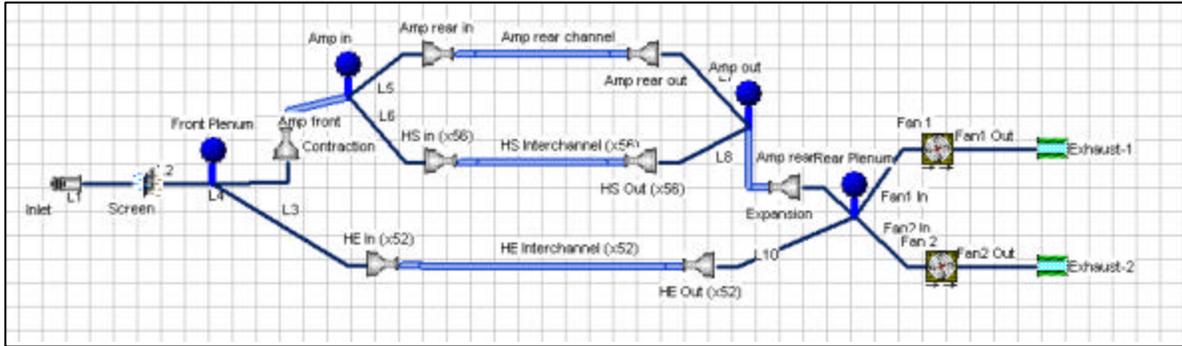


Figure 3. Flow network model of the external airflow section

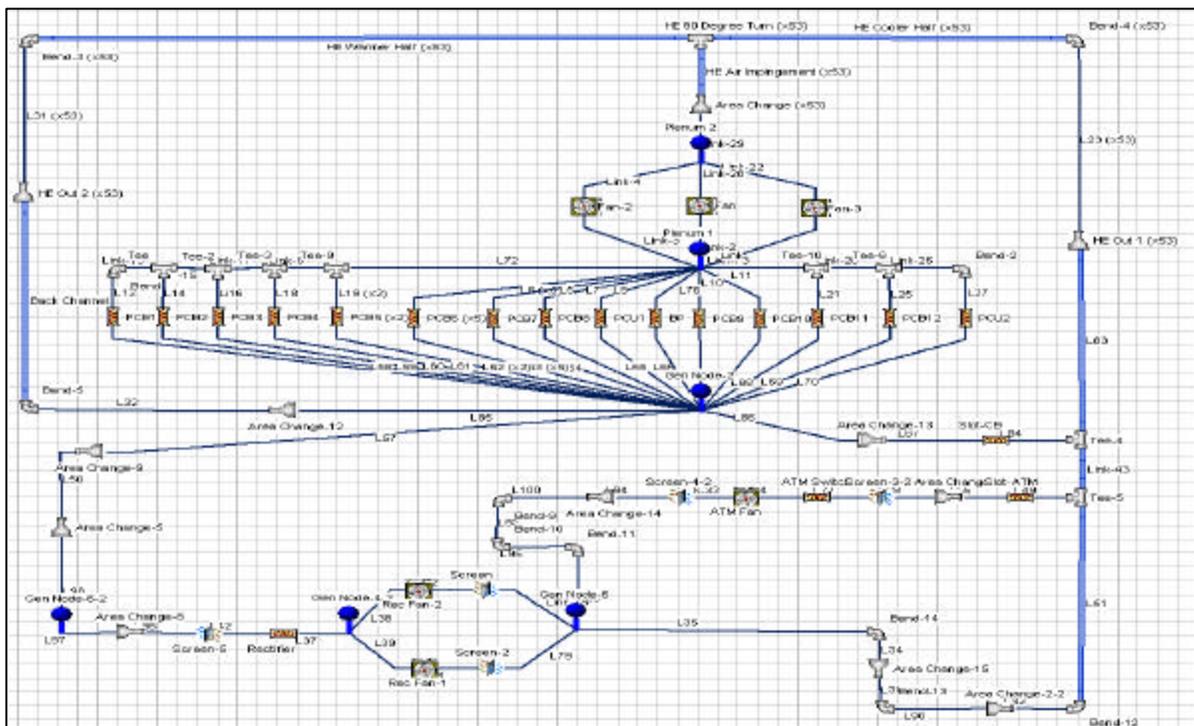


Figure 4. Flow network model of the internal airflow section

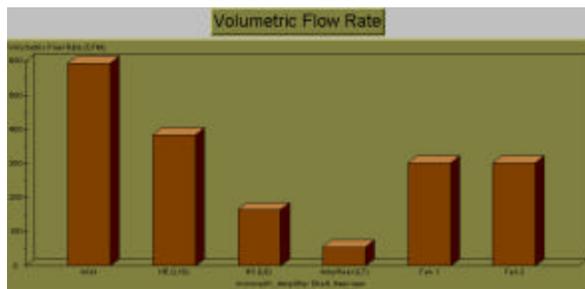


Figure 5. Volumetric flow rate through various part of the external airflow section

Figures 7 and 8 show the bulk temperature of air exiting different parts of the BTS. The wall temperatures and the PCB board temperatures were also obtained. However, accurate temperature information cannot be obtained from the FNM analysis due to the simplified representation of PCBs in the FNM models. A board level CFD-based analysis was performed to obtain detail temperature profile for PCBs, using the air flow and temperature information from the FNM analysis. The authors also tried to perform a CFD-based system level analysis with detail heat sink and heat exchanger models. However, the big difference between the

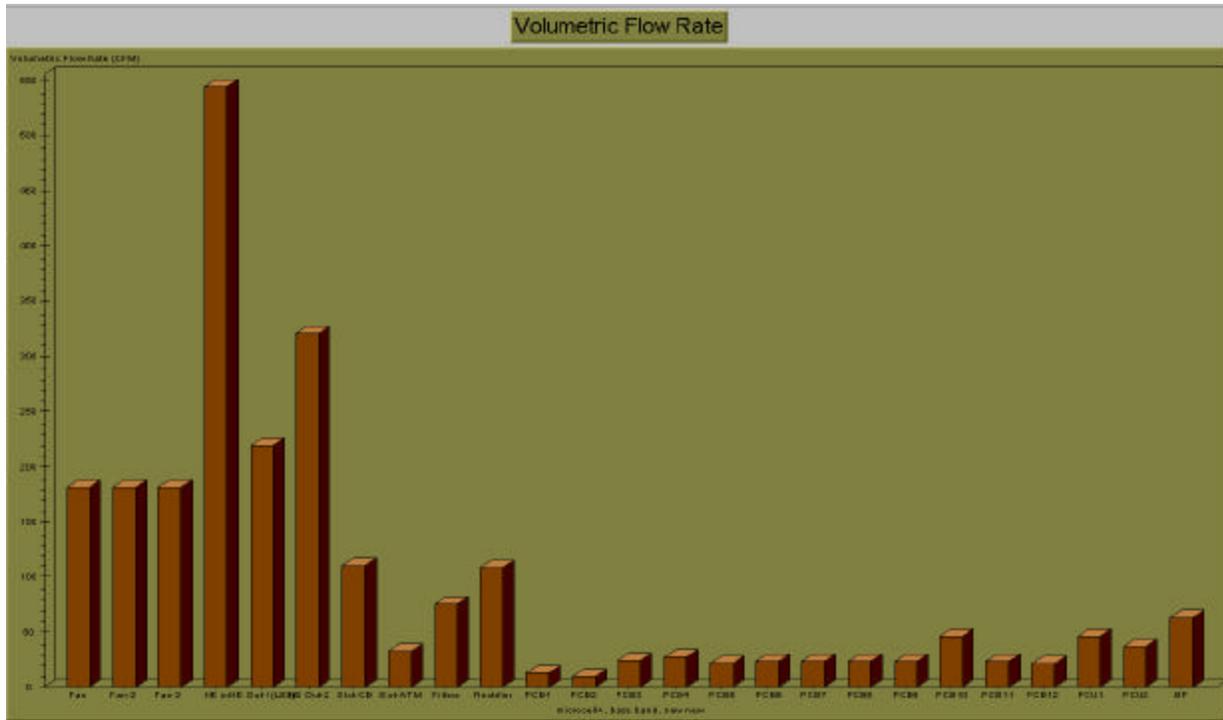


Figure 5. Volumetric flow rate through various part of the internal airflow section

cabinet size (40 inches) and the flow channel size of the heat sink and heat exchanger (0.018 inch) resulted in a huge number of grid points for the CFD model, which makes the solving of the model impossible. Compact models for the heat sinks and the heat exchanger had to be used in the CFD-based system level model. Tremendous efforts were taken to characterize these compact models.

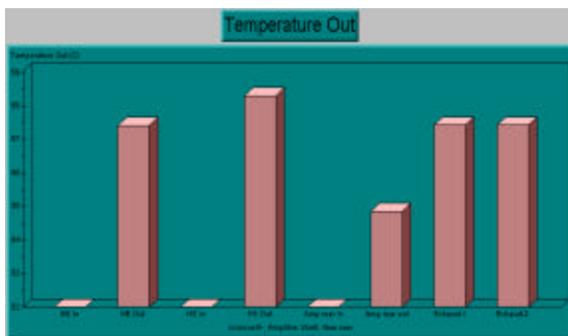


Figure 7. Bulk temperature of air exiting different parts of the external airflow section

Conclusions

This paper describes the thermal design of a high capacity portable outdoor BTS using the FNM analysis. Flow network models were built using MacroFlow and analyses were performed in both conceptual design and detailed design stages. System-wide flow and temperature distributions were obtained and used to guide the thermal design. The system level flow and temperature information from the FNM analysis was also used as boundary conditions in CFD-based board level analysis. It is found that the FNM approach provides fast and effective means to evaluate different design concepts, to stimulate engineers to think of creative ideas for design improvement, and to perform system-level design optimization. FNM approach also found to be useful where CFD tools have difficulty.

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