Development of Ethernet Switch for Industrial Use

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[Summary] We have developed the new NA2000 Series Ethernet switch for industrial use meeting the environmental durability and reliability requirements of various environments for social infrastructure systems now converting to optical networks, such as road, river, etc., installations as the successor to our high reliability compact EC2060 series. To ensure reduce equipment failures, as well as better noise and energy performance, we have eliminated the cooling fan used previously and have adopted a fanless design by increasing heat loss from the case surfaces. Additionally, the vent-free case suppresses ingress of corrosive gases helping ensure long service life. Lastly, the wide guaranteed operation range of –20° to +60°C supports use in regions with extreme climate temperature conditions and outdoors.

1 Introduction

Ethernet is one technology standard for computer networks dating from the 1960s. It is used widely by office and household LANs due to its ease-of-use and has become deeply integrated into everyday life. However, Ethernet has yet to find widespread usage in factory automation (FA) and process automation (PA) industrial applications. The industrial usage environment, such as humidity, dust, active gases, etc., is more severe than the office environment and conventional Ethernet equipment is thought unable to withstand these conditions.

More recently, manufacturers in various businesses are looking to improve process efficiency, while cutting costs and improving productivity and there is an increasing trend towards introduction of Ethernet technology into industrial plants, etc. In these circumstances, there is a rising need for Ethernet equipment supporting industrial use.

Anritsu Networks has used its long experience in developing IP network devices to develop the new NA2000 Series of Ethernet switches for industrial use (Figure 1).
This article introduces some of the technologies and features used by the NA2000 Series.

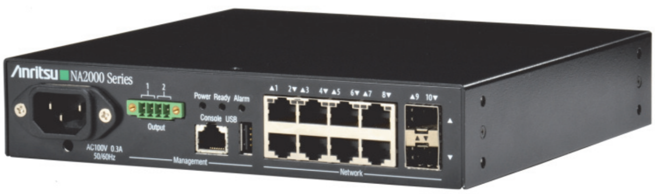


Figure 1 External View of NA2000 Series
(210W × 42H × 200D mm)

2 Development Concept

We discuss the following points in designing the NA2000 Series for a wide variety of environments, including applications at road, river, industrial plant, city water and sewage, airport, harbor, etc., sites.

2.1 Fanless and Vent-free Design

The earlier EC2060 Series included a cooling fan but these types of motor-driven parts run the risk of failure due to age-related wear and tear as well as adhesion of fine dust particles. Avoiding this risk through periodic maintenance and parts exchange causes system downtime, lowering productivity of users. Additionally, the presence of cooling vents runs the risk of faults due to short-circuits caused by ingress of moisture, etc. Moreover, fine dust entering through vents sticks to the electronic parts and absorbs moisture, causing corrosion at parts and boards.

By using a fanless and vent-free design, the NA2000 Series eliminates the need for periodic maintenance and parts exchange as well as suppresses ingress of dust and moisture. thereby controlling corrosion of electronic parts and increasing reliability.

2.2 Wide Guaranteed Operating Temperature Range

The guaranteed operating temperature range for general purpose OA Ethernet switches is 0° to +40°C. The NA2000 Series has a guaranteed operating range of –20° to +60°C to support operation in a wide range of environments, such as in industrial plants and outside in exposed cabinets.

2.3 Corrosion-proof

The main corrosive gases having an impact on communications equipment are hydrogen sulfide (H_2S), chlorine (Cl_2), sulfur dioxide (SO_2), and oxides of nitrogen (NO_X). Hydrogen sulfide in particular causes corrosion of silver and copper used widely in electronic products, while chlorine attacks many metals, especially steel. The newly developed NA2000 Series has been designed to resist corrosion from hydrogen sulfide and chlorine, making it suitable for installation in factories and facilities such as city water and sewage processing plants where levels of these gases are relatively high.

2.4 Universal Design

To facilitate improved on-site maintenance, all interfaces are on the front panel of the NA2000 Series and each is marked with a high-contrast, easy-to-read large label. The unit can be used in either the vertical or horizontal position to make best use of limited installation spaces in racks, Enclosure boxes, etc.

2.5 High-Speed Topology Changing Switching at Transmission Path Fault

To ensure real-time communications required by industrial plants, the NA2000 Series uses a communications protocol supporting quick recovery at a communications fault.

3 Design Points

3.1 Calorimetry Test

3.1.1 Implementing Fanless and Vent-free Case

To implement a fanless and vent-free case, it is essential that the heat loss from the case surfaces is larger than the maximum heat generation of the switch. Heat loss from the case surfaces by convection and radiation must satisfy the following relationship.

total heat loss from case surfaces > maximum heat generation of switch where, total heat loss from case surfaces = heat loss by convection + heat loss by radiation

(1) Thermal Design Conditions

[1] Case external dimensions

To increase heat loss from the case surface, it is better if the surface area is as large as possible, but network equipment must be installed in limited spaces, so it needs to be as small as possible. To use space efficiently, we designed the NA2000 series with a width of 210 mm and a height of 42 mm enabling two units to be installed parallel and horizontally in a 19-inch 1U rack (44.5 mm). For easy installation in commercially available outside cases, the depth has also been restricted to a compact 200 mm.

[2] External air temperature

To assure a guaranteed operating temperature range of –20° to +60°C, we used an external temperature of +60°C as the upper limit in the thermal design.

[3] Switch surface temperature

The IEC60950-1 (Version 2) standard governing surface temperature limits the maximum temperature of external metal parts with easy-to-see warning labels to 90°C. We set a 10% stricter margin than the standard and set 80°C as the maximum surface temperature.

[4] Case thermal emissivity

The thermal emissivity of the surface of a material ranges between 0 and 1, depending on the material itself as well as its color and finish. The thermal emissivity of aluminum is listed in Table 1.

Table 1 Aluminum Surface Thermal Emissivity[1)]

Material	Surface Condition	Emissivity	
		Typical value	Range
Aluminum	Polished	0.05	0.04 to 0.06
	Black alumite	0.95	0.94 to 0.96
	Alumite processes	0.8	0.7 to 0.9

The thermal emissivity of the case was examined based on Table 1, and the thermal emissivity of a black painted and unpainted aluminum surface is as follows:

・Case thermal emissivity (unpainted): 0.05

・Case thermal emissivity (black painted): 0.85

[5] Positioning

The case can be oriented either vertically or horizontally.

[6] Maximum heat generation

The total maximum heat generation of the parts used in the NA2000 series is 20 W.

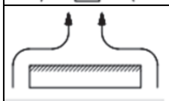
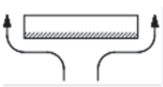
(2) Calculation of Heat Loss by Convection

The total heat loss by convection from the case surface was calculated using the following equation. The calculation assumes no difference in temperature for all the surfaces and horizontal orientation[1].

> heat loss due to convection [W]
> = coefficient of heat transfer [W/(m^2・K)] × surface area [m^2] × temperature difference [K]
> coefficient of heat transfer [W/(m^2・K)]
> = 2.51 × form factor × (temperature difference/characteristic length)$^{0.25}$

The total heat loss by convection of this switch design is about 10 W. Table 2 lists the form factors and characteristic lengths used in the above calculation.

Table 2 Change in Form Factor and Characteristic Length with Shape and Positioning[1]

Shape and Design Conditions		Form Factor	Characteristic Length
	Flat plate placed perpendicularly	0.56	Height
	Flat plate placed horizontally (hot top surface)	0.52	(Vertical × Horizontal × 2) / (Vertical + Horizontal)
	Flat plate placed horizontally (hot bottom surface)	0.26	

(3) Calculation of Heat Loss by Radiation

The total heat loss by radiation from the case surface was calculated using the following equation. The calculation assumes no difference in temperature for all the surfaces. It also assumes the worst horizontal orientation[1].

> Heat loss due to radiation [W]
> = 5.67 × 10^8 × thermal emissivity × surface area × (Absolute temperature of highest temperature surface^4 – Absolute temperature of lowest temperature surface^4)

The total heat loss by radiation of this switch design is about 18 W and the total by convection plus radiation is about 28 W. Considering 20% variation in the case surface temperature, we set the total heat loss from the case surface at about 22 W. This result is larger than the 20 W of heat generation by the switch, making it possible to implement a fanless and vent-free case design. Table 2 also clarifies that the heat loss is better in the vertical orientation than vertical.

3.1.2 Structural Design

(1) Case Thermal Structure

To implement a fanless and vent-free structure with a guaranteed operating range of –20° to +60°C, it is necessary for heat generated inside the case to be transferred efficiently outside the case. Consequently, we used a method for transferring heat from hot parts on the printed circuit board via a heat conduction plate to the case surface. The parts and heat conduction plate are in close contact using a heat conduction sheet to lower the thermal contact resistance at the touching surfaces. The thermal conduction is found using the following fundamental equation[1].

> $\Delta T = W \times (\theta_1+\theta_2+\theta_3 \cdots)$
> ΔT [°C]: Temperature difference between two points
> W [W]: Heat generated by parts
> θ [°C/W]: Thermal resistance of each of two parts

Using this equation, we arranged the hot electrical parts so that the thermal resistance did not exceed 80% of the maximum junction upper limit temperature. The back side of the printed circuit board was also designed to be in contact with the lower case surface. Using this structural design not only avoided deformation of the printed circuit board due to pressure from the heat conduction plate but also transfers heat from the circuit board efficiently to outside the case using a sandwich structure. The thermal conduction sheet has a high thermal conductivity and the thermal resistance is also kept low by using the thinnest possible sheet. Additionally, the thermal conduction sheet uses the smallest possible amount of siloxane causing poor contact at the mating services. Figure 1 shows an image of the thermal design using the heat conduction plate and Figure 3 shows the internal structure of the switch. Heat conducting grease is another material with lower contact thermal resistance than the sheet but we decided to use a heat conducting sheet rather than grease from the viewpoint of workability and long-term reliability. Table 3 compares the contact thermal resistance of the heat conducting sheet and grease.

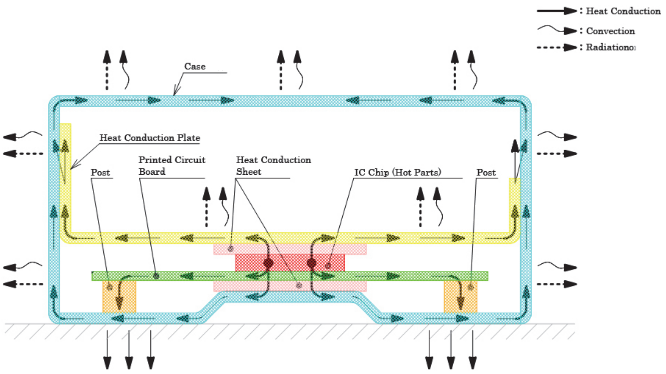


Figure 2 Thermal Image of Switch

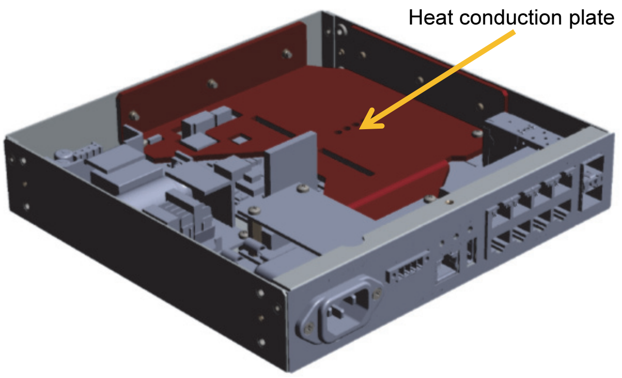


Figure 3 Switch Internal Structure

Table 3 Comparison of Contact Thermal Resistance Values[2)]

Contact Thermal Resistance Materials	Contact Thermal Resistance Model [K•cm^2/W]
Heat Conducting Grease	0.2 to 1
Heat Conducting Sheet	1 to 3

(2) Parts Layout on PCB

To transfer heat efficiently to the heat conducting plate from the heat generating parts on the printed circuit board via the heat conduction plate, we reduced the distance between the hot parts and the plate enabling use of the thinnest possible heat conduction sheet. As a result, electrical parts between the printed circuit board and heat conduction plate were chosen so that their heights did not exceed the height of the hot LSI, keeping the contact distance plate the heat conduction plate and printed circuit board as narrow as possible. Electrical parts with higher heights than the hot LSI were mounted outside the heat conduction plate area.

(3) Using High-Purity Aluminum

Normally, lightweight and strong aluminum alloys are used for case materials of communications equipment, but such materials have relatively low thermal conductivity. Copper is the best material in terms of thermal conductivity, but it is disadvantageous in terms of cost and weight. In addition, it is relatively easily corroded by active gases such as hydrogen sulfide. After investigation, it was decided to use high-purity aluminum from the aspects of cost and performance. High-purity aluminum is softer than structural aluminum, which is more resistant to deformation caused by external force, but has better thermal conductivity. Table 4 compares the thermal conductivity of these different materials.

Table 4 Comparison of Thermal Conductivity[1)]

Material	Thermal Conductivity 25°C [W/(m•K)]
Copper	370
High-purity Aluminum	238
Structural Aluminum	225
Steel	53

(4) Color Coating

To increase the heat loss by thermal radiation, the case is painted black. A perfect black body has a theoretical thermal emissivity of one and painting the case black the thermal radiation efficiency.

3.2 Corrosion Resistance

Copper traces on printed circuit boards and silver materials used in electronic parts are susceptible to corrosion caused by water (H_2O) and hydrogen sulfide (H_2S) in the air resulting in the formation of corrosive chemical compounds such as cuprous oxide (Cu_2O), copper sulfide (Cu_2S) and silver sulfide. Long exposure to these corrosive materials either shortens the life of electronic parts and wiring patterns, or causes open circuits resulting in equipment failure, so cases are built to resist these corrosive gases. By eliminating fans and vents, the design greatly reduces the amount of corrosive gases entering the case and the printed circuit board also uses a resin coating to prevent humidity and gases coming into contact and reacting with copper and silver on the board.

3.3 Universal Design

On-site maintenance work efficiency is increased by mounting all interfaces on the front panel. Using a black coating is good from the heat radiation perspective but also provides good contrast with the large white Myriad Pro Condensed font used for the interface labels to increase readability and usability. Figure 4 shows the front panel with each of the labelled interfaces.

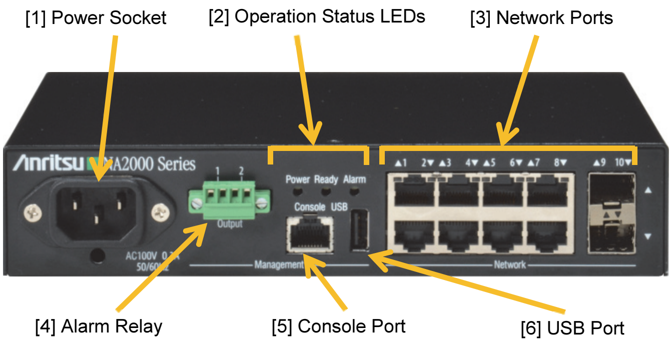


Figure 4 NA2000 Series Front Panel

3.4 Interface Specifications

The specifications for each Interface shown in Figure 4 are listed below:

[1] Power Input Connector:
Power input for 100 Vac, 24 Vdc or 48 Vdc (Figure 4 shows the 100 Vac system.)

[2] Operating Status LEDs:
Power LED (green), Ready LED (green), Alarm LED (red) indicating equipment status, fault and power supply through combination of lit, off and flashing conditions

[3] Network Ports:
Communications interfaces with switching functions for input and output of data traffic; standard RJ-45 ports support 10BASE-T, 100BASE-TX, and 1000BASE-T standards; SFP ports support 1000BASE-X and 100BASE-FX standards. Additionally, supports preventive maintenance by status monitoring such as optical input/output levels of SFP modules and fast fault isolation at network faults

[4] Alarm Relay:
Outputs alarm signals such as temperature abnormality and hardware faults

[5] Console Port:
Connected to personal computer using console cable to confirm switch settings and hardware status using command interface

[6] USB Port:
Supports external downloading of stored configurations and program files to USB memory for equipment exchange and firmware version upgrades without external personal computer

3.5 High-speed Topology Changing Switching

The NS2000 also includes Anritsu's unique advanced quick re-configuration high-speed ring control protocol (AQR++) for switching the communications path within an average of 50 ms (30 ms best) at network transmission faults, assuring high network reliability and usability. Figure 5 shows an image of topology changing switching at a transmission fault.

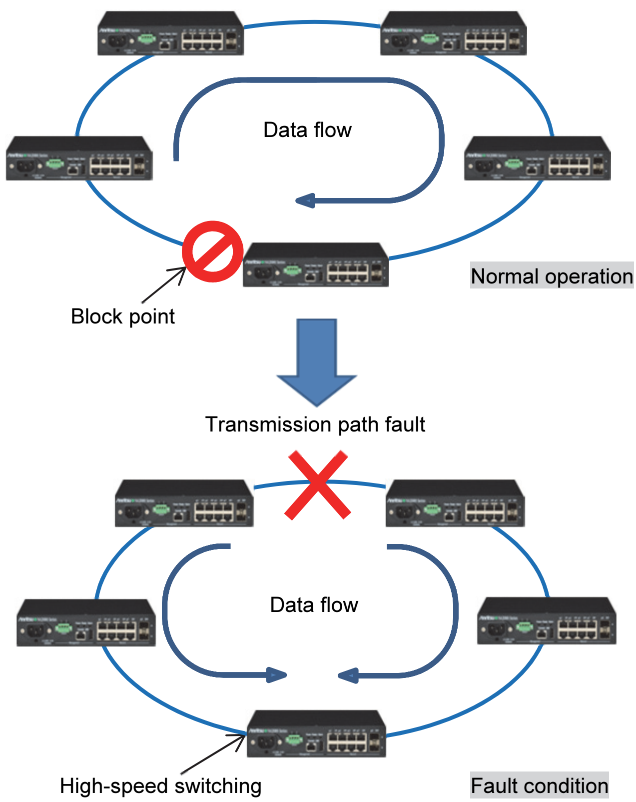


Figure 5 Topology Changing Switching Image

4 Test Results

4.1 Temperature Increase Test

Testing of the actual NA2000 Series equipment showed a case surface temperature of 71°C at an external air temperature of 60°C, demonstrating a temperature increase of 11°C. Although the equipment power consumption design specification was estimated at 20 W, the actual measured value was about 15 W. Reflecting this result back into the design calculations gave about 6 W of heat loss by convection and 10 W by radiation from the case surface and confirming a close agreement between the calculated and test results.

4.2 Mixed Gas (2) Test

An evaluation test of resistance to active gases was performed using a mixture of hydrogen sulfide and chlorine at concentrations of 20 ppm and 1 ppm, respectively, at a temperature of 40°C and a relative humidity of 90%. The test environment was chosen using high gas concentrations to cause accelerated corrosion in a shorter time period; in addition, the higher temperature and humidity also caused accelerated aging. The exposure test was run for 21 days without any signs of abnormalities in the switch.

A total of 82 evaluation points were checked in accordance with the recommendations of JEITA IT-1004 (March 2011) for a Class S3 (total of more than 51 evaluation points) environment with high temperature and humidity and multiple gases. Table 5 shows the test contents and Table 6 lists the JEITA IT-1004 active gas environment classifications.

Moreover, at the actual evaluation test, the same test was al performed simultaneously using a printed circuit board without the resin coating to confirm the relative effect of the resin coating. The results showed that corrosion occurred at the boundary between the lead frames of electronic parts on the printed circuit board and the resin coating; shorts were formed by bridging between lead frames causing equipment faults. These results confirmed the usefulness of the corrosion countermeasures in the NA2000 Series. Figure 6 shows a magnified image of a corroded through hole and Figure 7 shows a magnified image of a shorted electrical part.

Table 5 Corrosive Gas Test Mixture

	Test Conditions (mixture of two gases)	
	Item	Description
1	H_2S	20 ppm
2	Cl_2	1 ppm
3	Temperature	40°C
4	Humidity	90%
5	Time	21 days

Table 6 JEITA IT-1004 Corrosive Gas Environment Classification

Environment	Class	Total Evaluation Points
Good environment with low temperature and humidity and no gases detected	Class A	≤9
Common environment with relatively low humidity and almost no gases	Class B	10 to 25
Environment with relatively high humidity and a few gases	Class S1	26 to 36
Environment with high temperature and humidity and some gases	Class S2	37 to 50
Environment with high temperature and humidity and high gas concentrations	Class S3	≥51

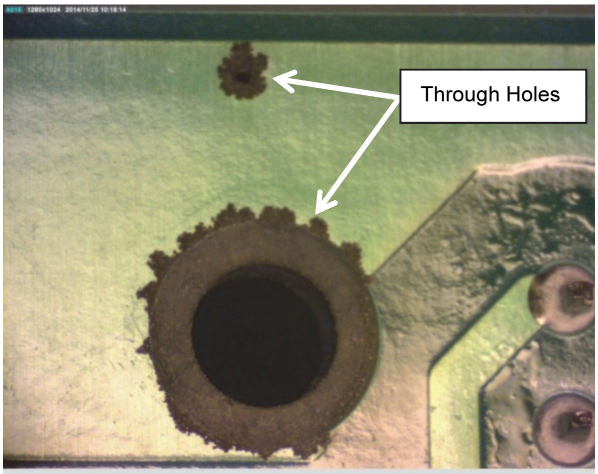


Figure 6 Corroded Through Hole (Magnified)

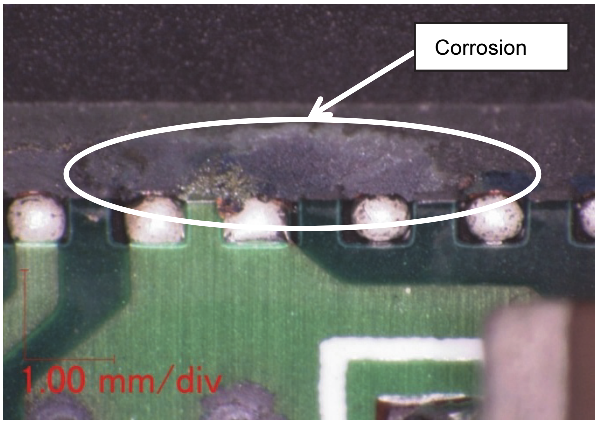


Figure7 Corroded Electrical Parts (Magnified)

5 Functions

The key specifications of this switch are listed in Table 7.

6 Conclusions

We have explained some of the functions and technologies used in development of the new NA2000 Series Ethernet switch for industrial use. With its high environmental durability and reliability, this switch is ideal for introducing Ethernet networks into various industrial sites requiring upgraded processes, reduced costs, and increased productivity.

Future network equipment will be required to meet even more severe environmental durability and reliability standards and we are continuing with research into new equipment meeting users' expectations for developing social and communications infrastructure.

References

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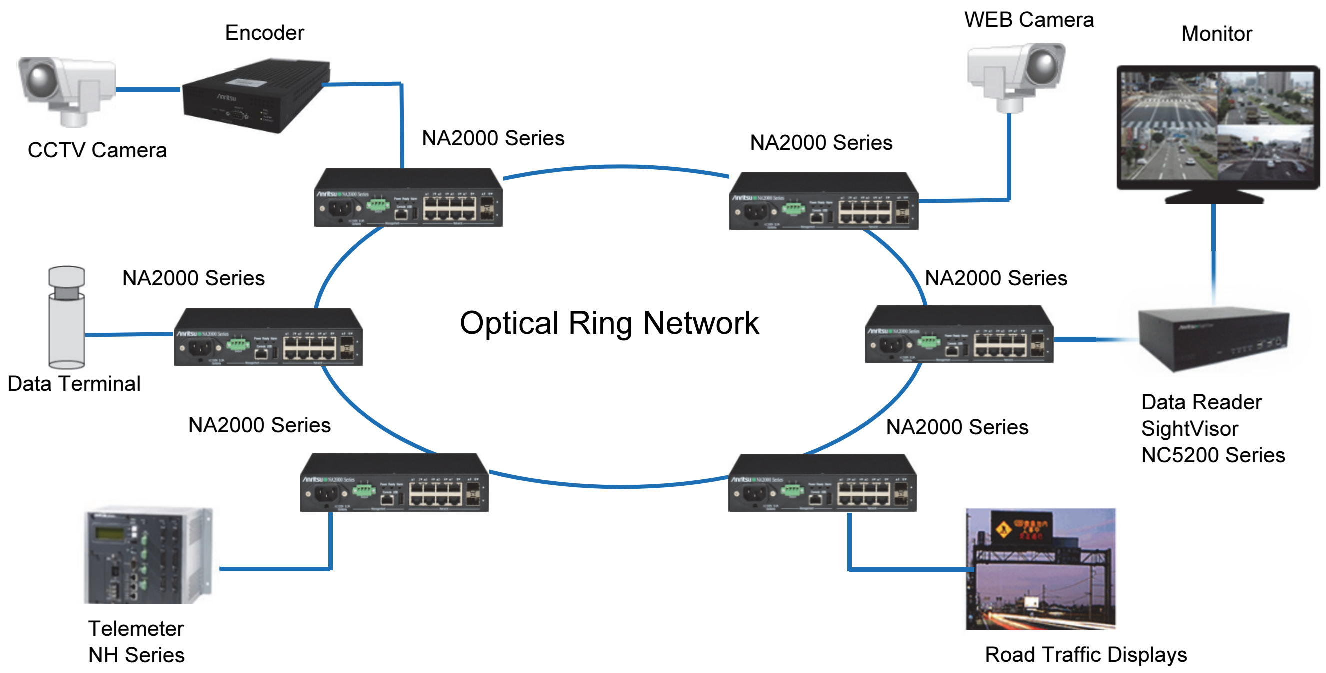

Figure 8 Typical System using NA2000 Series

Table 7 Key Specifications

Model			NA2011A	NA2012A	NA2013A
Number of Network Ports	10/100/1000BASE-T		8		
	SFP	100BASE-FX	2		
		1000BASE-X			
Switch Functions	Switching Capacity		20 Gbit/s		
	Packet Transfer Performance		14.8 Mpacket/s		
	VLAN		Port-based VLAN, VLAN Tagging		
	Registered MAC Address Count		16,000		
	Fault Bypass Function		High-speed AQR++ switching (50 ms avg.) 256 levels max. STP (IEEE802.1D), RSTP (IEEE802.1w)		
	Multicast Function		IGMP Snooping (V1/V2)		
	Other		Strom Control, Port Mirroring		
QoS Function	Priority Control		IEEE802.1p (Port, CoS)		
Management Function	Admin Protocol		SNMPv1/v2c		
	Maintenance Interface		Serial (RJ-45), Telnet		
Operation and Maintenance Functions	Access Control		Password-limited Access		
	Setting/Firmware Updates		USB (External Boot/Update), FTP		
	Syslog		○		
	Alarm Relay		Port Fault, Abnormal Temperature, Abnormal SFP, Hardware Fault		
Environmental Resistance	EMC (IEC61000-4) Industrial Use		○		
	Corrosion-proof		○*Option	—	—
External Dimensions			210W × 42H × 200D mm (Excluding Protrusions)		
Mass			1.3 kg max.		
Design			Fanless, Vent-free		
Operating Environment	Temperature		–20° to +60°C		
	Relative Humidity		10 to 95% (No Condensation)		
Power Supply	Rated Voltage		100 Vac	24 Vdc	48 Vdc
	Power Consumption		30 VA max.	16 W max.	16 W max.

Publicly available