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Manufacturing LNA Board for GPS Antenna and Proposal of Verification Method

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ABSTRACT

This paper manufactured an active GPS antenna for ground vehicles and presented a method to verify the performances of the antenna and component technology of the low noise amplifier (LNA) board manufacturing. The manufactured GPS antenna is an active antenna where microstrip patch and LNA board were combined. The main performances were standing wave ratio, antenna gain, and axial ratio, and all satisfied the target specifications. The proposed component technology can be utilized as a basis data in which the performance of LNA board can be compensated in the mass production process inspection, and employed as a method to verify whether antennas are properly working in environmental tests.

Keywords: GPS, LNA, active antenna, coupler loss, relative gain

1. INTRODUCTION

A global positioning system (GPS) antenna is an equipment to receive GPS signals transmitted from above about 20,000 km and it is highly important to design GPS antennas accordingly (Kim 2013).

A microstrip patch antenna (Pues & Van de Capelle 1984) is light and inexpensive, which is suitable for mass production. Thus, it has been widely used as mass-production antennas. Antennas for mass production are divided into passive and active types according to installation environments, and designed accordingly. Generally, passive antennas are used when antenna gain loss due to cables is small. They are typically employed in aviation fields. Active antennas used by combining low noise amplifier (LNA) board and patch have high gain characteristics (Robert et al. 1992, Ormiston et al. 1998), and employed when signals are lost due to cables. The antenna designed in this paper was manufactured as an active antenna because signals were lost due to cables.

The structure of the designed antenna element consists of microstrip patch using duplex feeding and LNA board mounted in the lower part of the patch. The signals received through double feeding generate a phase difference of 90° through the coupler to create a circularly polarized wave and the signals are amplified through the LNA board. A method that measures coupler-mounted LNA board gain is different between development and mass-production phases. During the development phase, the performance of LNA board gain can be measured after removing the attached coupler. However, the performance cannot be measured during the mass-production phase because attachment and detachment of the product are impossible. Thus, it is necessary to have a method to compensate a coupler loss after measuring the LNA board gain including the coupler.

In addition, since the finished antenna should have no defect to be used in various environments, its reliability has to be verified through environmental tests. However, the verification of antenna gain performance cannot be done in an environmental test place without anechoic chamber, so that whether antenna is properly operated or not cannot be verified before and after an environmental test. Thus, it is necessary to have an alternative test method that can verify an antenna gain.

This paper proposed a method to verify the component technologies for the LNA board fabrication test process of active GPS antenna for ground vehicles and finished antenna.

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Table 1. Target specification of GPS antenna.

Main characteristics of GPS antenna	Required standard
LNA gain	43 ± 2 dB
LNA noise figure	< 3.5 dB
VSWR	< 2.0 : 1
Antenna gain	47 ± 2 dB
Aixal ratio	< 3 dB

The manufactured antenna satisfied the target specifications such as voltage standing wave ratio (VSWR), antenna gain, and axial ratio, which were the main performances in antenna manufacturing. In Section 2, antenna design, in Section 3, antenna manufacturing, in Section 4, component technologies for LNA board fabrication and verification, and in Section 5, conclusions are presented.

2. ANTENNA DESIGN

The active GPS antenna consisting of a patch, LNA board, and apparatus should satisfy the target specifications regarding the main performances presented in Table 1. The main performances are LNA board gain in active antenna, LNA noise index to minimize noise in the front end of LNA, VSWR that represents a return loss performance of the assembled antenna signal, antenna gain measured after patch and LNA are assembled to the apparatus, and axial ratio that represents a circularly polarized wave performance of the antenna. In Section 2, simulation results of the patch and LNA were derived.

2.1 Patch Design

A microstrip patch antenna is structured with a dielectric whose thickness and relative dielectric constant are h and ε_r on the thin grounded conductor plate, over which a conductive microstrip line whose thickness, width, and length are t, W, and L is printed (James & Hall 1989, Balanis 1997, Kim et al. 2011). Some of the electromagnetic waves from the square-shape microstrip patch antenna are propagated to the inside of the substrate, and some of them are propagated to the atmosphere. Thus, effective dielectric constant ε_{reff} can be defined as presented in Eq. (1).

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}} \tag{1}$$

A patch of the microstrip antenna looks larger than its physical length by Δl due to the fringing effect. Δl can be represented by a function of ratio (W/h) of effective dielectric constant ε_{reff} and width's height.

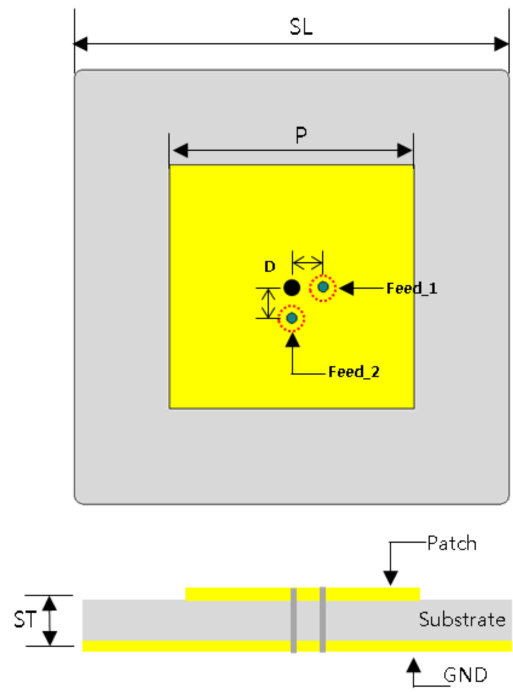

Fig. 1. Designed patch shape.

$$\frac{\Delta l}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{2}$$

A length of the patch is extended by Δl so the total length of the patch is

$$L = L + 2\Delta l \tag{3}$$

Here, L is

$$L = \frac{C}{2f_r\sqrt{\varepsilon_{reff}}} \tag{4}$$

Here, the resonance frequency can be calculated via Eq. (5).

$$f_{r_0} = \frac{C_0}{2(L+2\Delta l)(\sqrt{\varepsilon_{reff}})} \tag{5}$$

The antenna designed based on the theory value in Eq. (5) is shown in Fig. 1. A high dielectric constant substrate whose relative dielectric constant is 9.2 was used for the patch to obtain the effect of increase in bandwidth and size reduction, and the patch was designed to have a shape of double feeding structure for the generation of circularly polarized wave using a coupler. The patch design elements are substrate length (SL), substrate thickness (ST), patch size (P), feeding distance (D). As a parameter used in the design simulation, the patch was designed to be used at 1.57542 GHz, which was an operating frequency.

Figs. 2 and 3 show the parameters of patch size and feeding

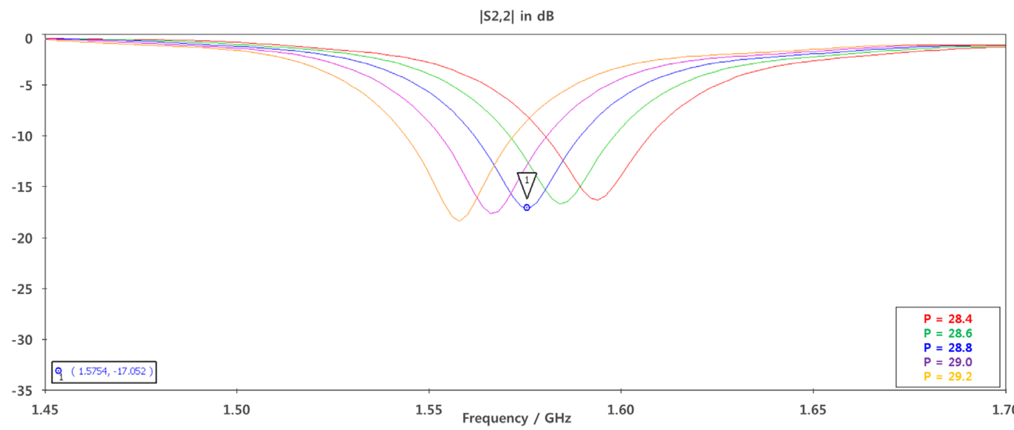

Fig. 2. Patch size parameter.

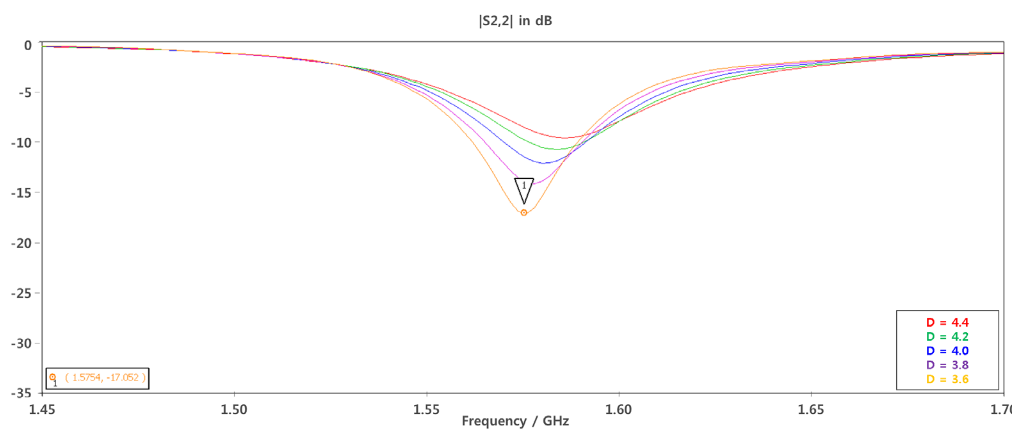

Fig. 3. Feed interval parameter.

Table 2. Design variable value of the patch (unit: mm).

Variable	Dimension
SL	50
ST	5.08
P	28.8
D	3.6

distance among the design elements, which verified the satisfaction of performances which was less than –10 dB of reflection coefficient at the operating frequency 1.57542 GHz. The length and height of the substrate were set according to the housing size, and the design values determined by the parameters are summarized in Table 2.

2.2 LNA Design

The designed LNA was mounted in the lower part of the patch. It was designed in the LNA board shape to be used as one of the antenna elements along with the patch. Fig. 4 shows the block diagram of the LNA. The configuration of the LNA board is divided into coupler part for circularly polarized wave and LNA part for signal amplification. The LNA part consists of front-end amplifier, rear-end amplifier, band pass filter, and power unit.

The main performances of the LNA are noise index, 1 dB output compression point (OP1dB), and gain. Among them, noise index is an important concept in the receiving end that has to receive weak signals including many noises. It is a critical index that plays a decisive role in amplifying the first signal in the receiving end. OP1dB represents a saturation level according to the input power. As OP1dB becomes higher, saturated input power is increased so that the system operates without performance degradation. In addition, a gain is a performance that represents how much the signal inputted to the LNA board is amplified. The LNA board in this study was designed to minimize noise in the front-end amplifier and satisfy the gain performance that is targeted in the rear-end amplifier.

Fig. 5 shows the simulation result of the LNA board gain. Impedance matching was conducted while changing element values in the LNA to satisfy the target gain of the LNA board, through which, elements and element values were designed to satisfy the target specifications. Table 3 summarizes the

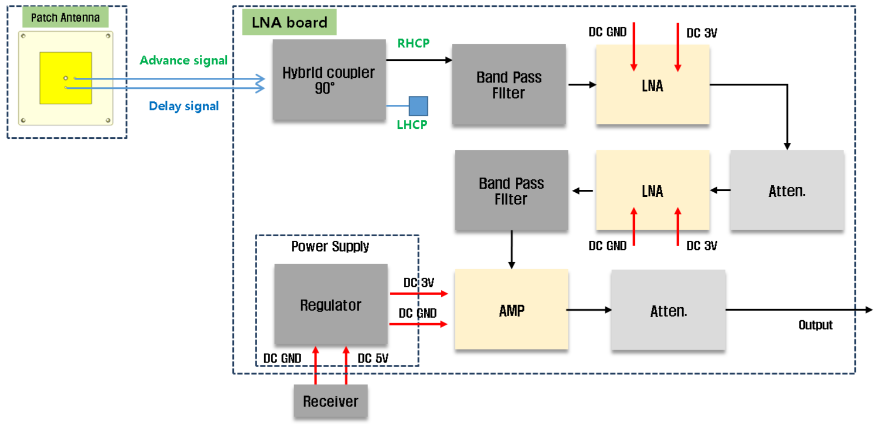

Fig. 4. LNA design block diagram.

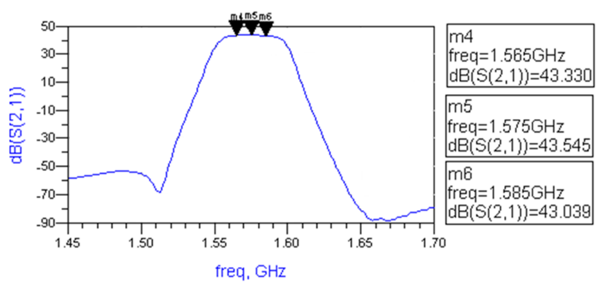

Fig. 5. LNA board gain simulation result.

Table 3. LNA design simulation result.

Item	Simulation result
Gain	43.55 dB
Noise figure	2.47 dB

simulation results of LNA gain and noise index, which verify the satisfaction of the target specifications.

3. ANTENNA FABRICATION

3.1 Patch Fabrication

Fig. 6 shows the fabricated patch. The patch was fabricated based on the variables determined through simulations. A substrate with high dielectric constant, which is used in the fabrication, was used to have a large bandwidth and advantages for miniaturization.

The performance of the single patch must be verified before the antenna is assembled because operating frequency and gain are determined by the resonance point and reflection loss performance, which are the most important factors in the reception of GPS signals as the patch is positioned in the front-end of the system. The VSWR in the single patch should satisfy 2.0:1 or lower at 1.57542 GHz of operating frequency, and the measurement results of the

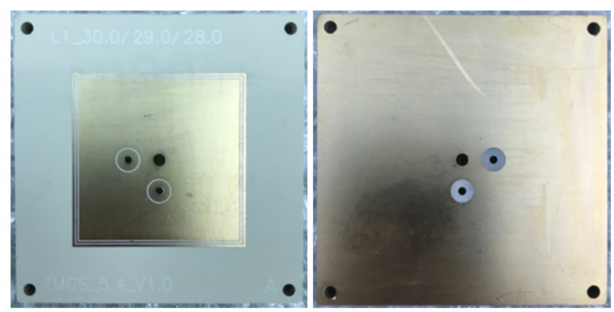

Fig. 6. Produced patch.

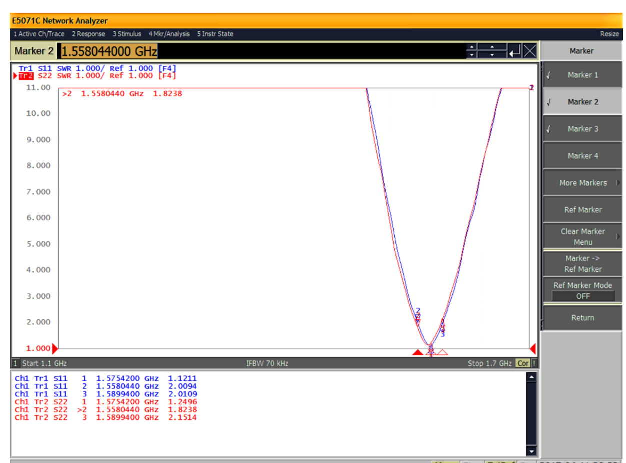

Fig. 7. Measurement result of patch produced.

fabricated patch satisfied the target performance as verified in Fig. 7. The measurement results were verification results of single patch performance only. The final performance of the GPS antenna is determined after assembling LNA board, radome, housing, gasket, and output adapter.

3.2 LNA Fabrication

Fig. 8 shows the fabricated LNA board, which is fabricated

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Fig. 8. Produced LNA board.

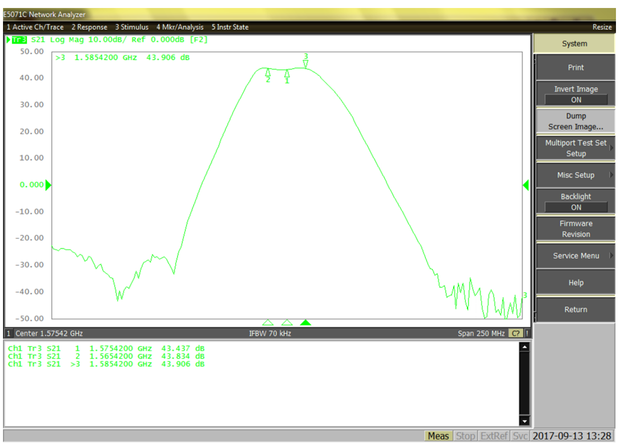


Fig. 9. LNA gain measurement result.

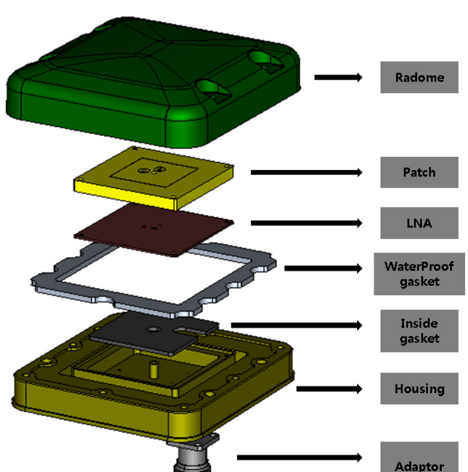


Fig. 10. Configuration of active GPS antenna.

as an output format using cables. A gasket for shock absorption was mounted between housing and LNA board to overcome the vibration of the output cable in the fabricated LNA board.

Fig. 9 shows the measurement results of LNA gain. The measured LNA gain was 43.44 dB, which satisfied the target specification. However, 43±2 dB is the development specification without including the coupler. When the coupler is included, the LNA gain will be reduced by 4 dB approximately. Since a coupler cannot be attached or detached in the future mass-production process, a coupler loss should be calculated and compensated.

Fig. 11. Structure of active GPS antenna.

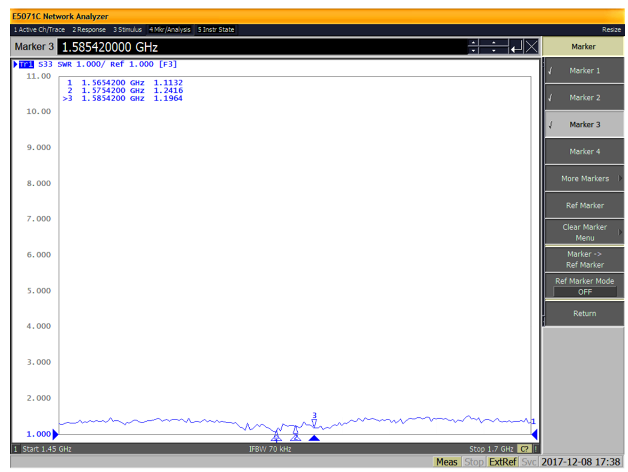


Fig. 12. Measurement result of active GPS antenna VSWR.

3.3 Active GPS Antenna Fabrication

The active GPS antenna is a final finished product to which antenna elements that combines the patch and LNA board are applied to the apparatus. The configuration diagram of the active GPS antenna is shown in Fig. 10. The active GPS antenna consists of radome, patch, LNA board, gasket, housing, and output adapter. Fig. 11 shows the outer appearance of the fabricated active GPS antenna. Figs. 12-14 show the main performances of the antenna: VSWR, antenna gain, and axial ratio. The measurement results showed that the antenna satisfied all target specifications at 1.57542 GHz of operating frequency. Table 4 summarizes the measurement values of the active GPS antenna.

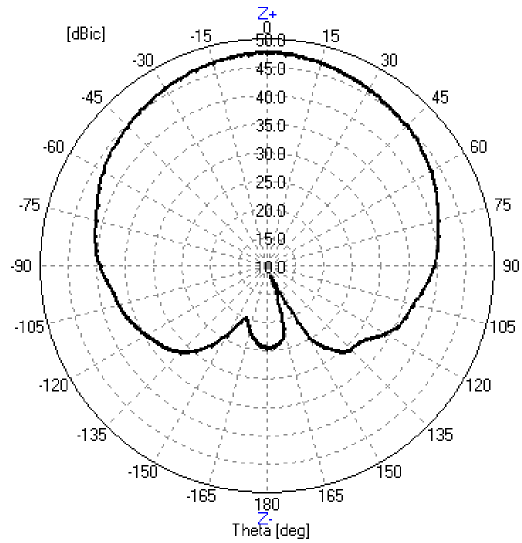


Fig. 13. Measurement result of active GPS antenna gain.

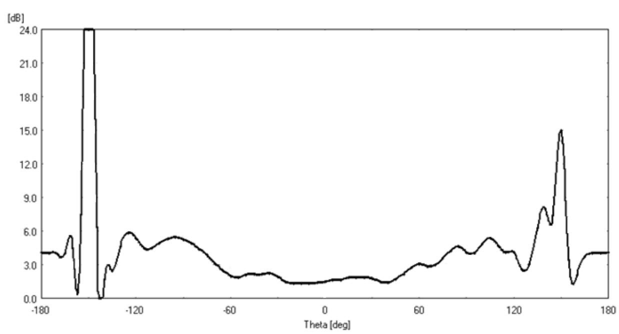
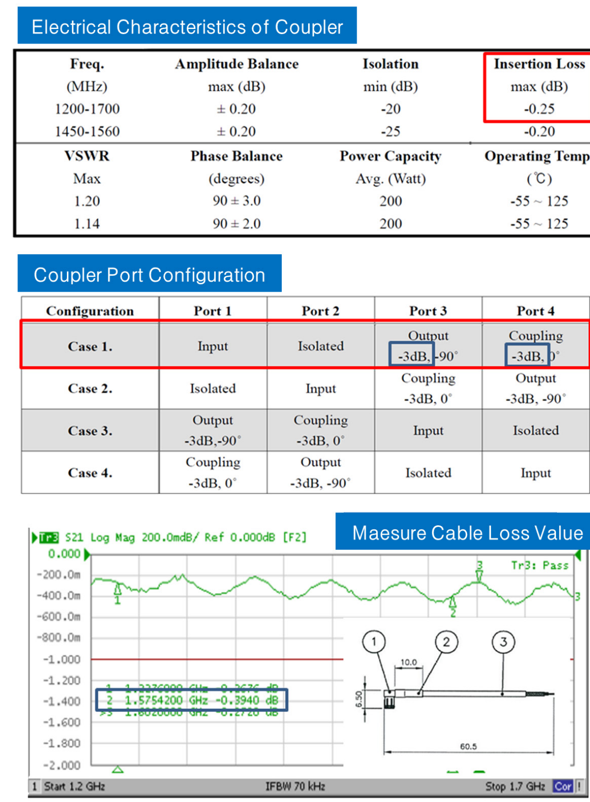


Fig. 14. Measurement result of active GPS antenna axial ratio.

Table 4. Measurement result of completed active GPS antenna.

Item	Measurement result
Antenna VSWR	1.24 : 1
Antenna gain	47.46 dB
Antenna axial ratio	1.47 dB



Electrical Characteristics of Coupler

Freq. (MHz)	Amplitude Balance max (dB)	Isolation min (dB)	Insertion Loss max (dB)
1200-1700	± 0.20	-20	-0.25
1450-1560	± 0.20	-25	-0.20
VSWR Max	**Phase Balance** (degrees)	**Power Capacity** Avg. (Watt)	**Operating Temp.** (℃)
1.20	90 ± 3.0	200	-55 ~ 125
1.14	90 ± 2.0	200	-55 ~ 125

Coupler Port Configuration

Configuration	Port 1	Port 2	Port 3	Port 4
Case 1.	Input	Isolated	Output -3dB, -90°	Coupling -3dB, 0°
Case 2.	Isolated	Input	Coupling -3dB, 0°	Output -3dB, -90°
Case 3.	Output -3dB,-90°	Coupling -3dB, 0°	Input	Isolated
Case 4.	Coupling -3dB, 0°	Output -3dB, -90°	Isolated	Input

Fig. 15. Coupler loss value calculation basis.

4. PROPOSAL OF COMPONENT TECHNOLOGY FOR FABRICATION AND VERIFICATION OF THE LNA BOARD

4.1 Proposal of Calculation Method of a Coupler Loss

The gain specification of the developed LNA board is 43±2 dB. In the existing development phase, LNA board gain is measured by connecting a cable from the next end of the coupler without attaching a coupler. However, a coupler should be included in the measurement since parts cannot be attached or detached in the mass-production phase of the product. This measurement method is cumbersome because the specification has to be set differently between development and mass-production phases as a gain is lost by a coupler.

In this section, a method that calculated a coupler loss was proposed to set the same specification for mass-production and development phases. The proposed method can be used conveniently to determine whether the target specification in the mass-production phase is satisfied after calculating a reliable coupler gain loss.

$$\text{Total coupler loss (4.03 dB)} = \text{Coupler loss (3.25 dB)} + \text{Measured cable loss (0.78 dB)} \quad (6)$$

Eq. (6) refers to a calculation equation of total coupler loss. It was created based on the calculation basis in Fig. 15. Fig. 15 shows the data sheet characteristics of the coupler and measured loss of RG178 cable assembly whose cable length is approximately 60 mm. The coupler had a total loss of 3.25 dB: 3 dB of output loss and 0.25 dB of insertion loss. The cable has a total loss of 0.78 dB: each 0.39 dB of input and output measurement cables. Thus, the combined total coupler loss is approximately 4 dB.

Fig. 16 shows the measurement results of LNA board gain measured with the attached coupler. The measured LNA board gain was 39.56 dB, which was insufficient in terms of the development specification. However, 4 dB, which was derived

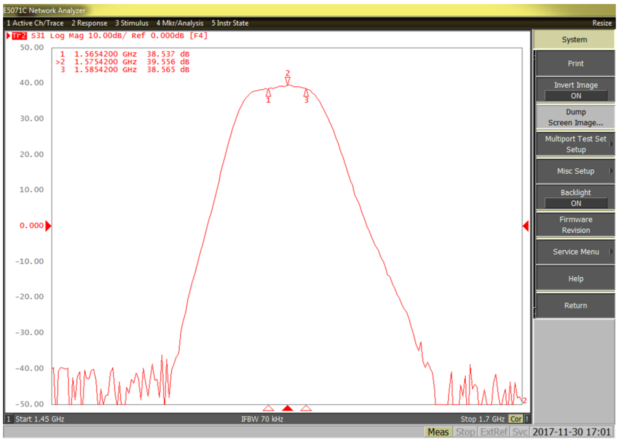


Fig. 16. LNA gain with coupler.

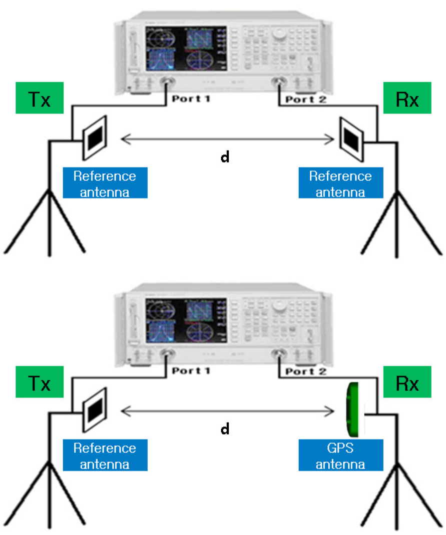


Fig. 17. Relative gain measurement configuration.

based on the calculation basis of coupler loss in Fig. 15, was added for compensation. The compensated LNA gain was 43.56 dB, which satisfied the specification. The proposed calculation basis was verified that it can be used in both of LNA board gain specification and development specification during mass-production process inspection.

4.2 Proposal of Calculation Method of Relative Gain Reference

The finished active GPS antenna is used in antennas for ground vehicles and environmental tests should be conducted to ensure the reliability of the antenna since no performance-related or mechanical problems should be found. The performances that are needed to verify the normal operation of the antenna before and after the environmental test are VSWR and antenna gain. The antenna should be

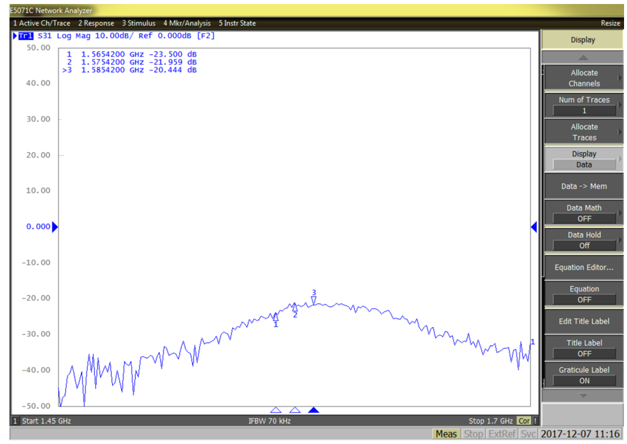


Fig. 18. Reference antenna gain measurement.

measured in an anechoic chamber to verify the antenna gain performance. However, the antenna gain performance cannot be verified in an environmental test place without anechoic chamber, and the use of an antenna chamber before and after the environmental test is time consuming and costly. Thus, this section proposed a method to calculate the relative gain reference that can determine whether normal operation is run without the use of antenna chamber before and after the environmental test. The relative gain is employed as a simple test item in replace of the antenna gain.

The relative gain is a method of calculation by measuring a difference in gain between reference antenna whose value is already known and GPS antenna. Fig. 17 shows the configuration diagram of relative gain measurement. For reference antenna, two passive antennas with 4 dB or higher gain are used. The measurement method is as follows: two reference antennas are placed distance d apart from each other to measure a reference gain S21, and the reference antenna at the receiving side is replaced with the GPS antenna to measure gain S21. The GPS antenna measurement value is increased by LNA gain of the GPS antenna compared to the reference gain, and the measurement value and a gain of the reference antenna, which is 4 dB, are added to calculate the relative gain reference. Fig. 18 shows the reference gain measurement value, and Fig. 19 shows the measurement results of increased gain after the replacement with GPS antenna. Eq. (7) presents an equation to calculate the relative gain reference. The relative gain value produced from the equation was 46.90 dB, which verified that it can be used as a reference to verify whether the active GPS antenna was operated normally before and after the environmental test.

$$\text{Relative gain (dB)} = \text{GPS antenna S21 value} - \text{Reference antenna S21 value} + \text{Reference antenna gain value} \quad (7)$$

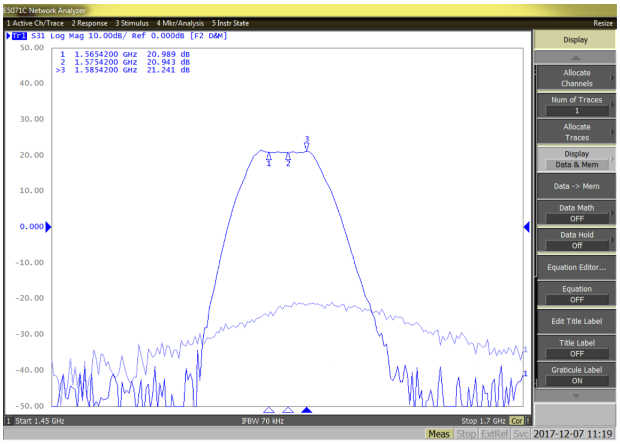


Fig. 19. GPS antenna gain measurement.

5. CONCLUSIONS

This paper manufactured an active GPS antenna for ground vehicles. The manufactured antenna was used in 1.57542 GHz which was a GPS L1 band, and satisfied all target specifications. In addition, a method to compensate a loss due to a coupler when measuring the LNA gain during mass-production process and a method to verify a performance before and after environmental test of active GPS antenna were proposed, and thereby validated that mass production capability and the reliability of antennas can be ensured.

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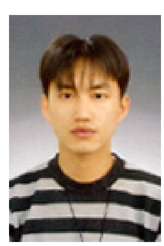

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