INVESTIGATION OF THE APPROACHES TO MEASURE THE RF CABLE ATTENUATION

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Abstract

In the accelerator facilities, many radio frequency (RF) cables are used as the RF and the beam monitors. In the case of the monitor for high power RF systems and cavities, basic information on the coupling levels and the cable attenuations is provided to obtain these statuses. In general, the frequency characteristic of a RF cable is extracted from the transmission coefficient S_{21} to use a network analyzer.

A control system is usually located far from the place of cavities for the radiation protection. The frequency characteristics of cables cannot practically be measured before the installation, because they are almost cut adjusting the length and attaching a connector under the installation. Then, it is not straightforward to measure the cable attenuation using a network analyzer of S_{21}. Hence the available approaches even in such a case were investigated and the good agreements were obtained.

INTRODUCTION

The RF cables of an accelerator play an important role in the monitors of the RF high power and the transmission systems, the field and the phase of cavities, the beam conditions, and so on. Then, the frequency characteristic of the cable is the fundamental and important information. It has to be obviously measured and known before the operation. In general, it is extracted from the transmission coefficient S_{21} to use a network analyzer. However, when a control system is located far from the place of cavities, this technique cannot be easily used to need the already calibrated cable between these. Although there is the way to install the cables after the measurement of the characteristics, the length of the cable is fixed and cannot freely be changed.

At J-PARC Linac, the injection beam energy will be updated to 400 MeV by adding the Annular Coupled Structure (ACS) section in summer, 2013. Thus, many RF cables for ACS have to be installed and we have to measure those characteristics. In this paper, the cable attenuation was measured using the following available approaches:

- The RF signal with constant wave is inputted from an end of the cable by a signal generator. The transmitted RF is measured at the other end by a power meter.
- When the phase of the reflected wave is rotated by changing of the length of a trombone, the reflected wave is measured. The cable attenuation is extracted by fitting the obtained circle.
- The reflected wave is measured using a network analyzer when a short or an open connector is attached to the other side of the cable. The cable attenuation is calculated from difference of the reflection coefficients.

The Andrew LDF2-50 with the length of 25 m was used as a proof cable in this investigation and the 972 MHz RF, which is the same as the acceleration frequency of ACS was adopted [1]. The measurement of each approach was carried out at least 50 times in the different conditions such as other ports or sensors, re-calibrated detectors and so on. Then, the average value and the standard deviation were calculated in order to evaluate the results quantitatively.

Firstly, the transmission coefficient was measured as usual using a network analyzer and the insertion loss was extracted for the knowledge of the cable characteristic. E5071 of Agilent Technologies was used as a network analyzer and N4431-60007 was adopted as an electronic calibration module. The attenuation of the proof cable was obtained to $-2.851 \pm 0.004(\sigma)$ dB when the frequency of RF is 972 MHz.

TRANSMITTED WAVE USING POWER METER

The measurement of the power level using a power meter is one of the most general approaches. The RF signal with continuous wave is inputted from an end of the RF cable by a signal generator (SG) to obtain a cable characteristic. The power level is measured from the other end of the cable using a power meter. The cable attenuation is calculated from the ratio between the incident power and the transmitted.

SG made by Hewlett Packard (8647A) was used in this measurement. The transmitted power level was measured using the 8542C universal power meters and the 80350A peak power sensors (Gigatronics). The incident power level of SG was adopted to 0 dBm in order to avoid the breakdown of devices although the high-quality results with the more power level can be expected according to the performance of this sensor [2]. The cable attenuation at the 972 MHz RF was obtained to $-2.869 \pm 0.012(\sigma)$ dB in this approach.

The advantage of this approach is to obtain the values directly without the fitting and the calculation. On the other hand, the disadvantage is the imprecision, which can be seen in the larger standard deviation. Although it is potentially improved by the change of the input power, it has a risk for the breakout of a power sensor. It is one of the

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worst scenarios to continue measuring without noticing a broken sensor.

REFLECTED WAVE USING TROMBONE

A unique approach for the measurement of the reflected wave using a trombone was performed. The schematic view of this approach is illustrated in Fig. 1. An end of a cable is connected to a port of a network analyzer and the other is to a trombone. The phase of the reflected wave is rotated by changing of the length of the trombone. Then, the coefficients with components of a real part and an imaginary are obtained. The cable attenuation can be extracted from the radius by fitting of those.

In the actual measurement, the trombone was automatically moved and data were taken using the Programmable Logic Controller(PLC) system and the laptop PC. The data points were collected by about 20 deg. in phase. E8357A of Agilent Technologies was used as a network analyzer and 85092-60009 was adopted as an electronic calibration module.

In this approach, the contribution of the trombone has to be subtracted to obtain the actual cable attenuation. Therefore, data which had only the trombone and did no the cable were also taken to estimate that. Then, two kinds of corrections were performed as follows:

- Each radius was independently obtained by fitting data, and then the contribution of the trombone was subtracted.
- Firstly, each data point was corrected using the result with the same length of the trombone and the actual cable attenuation was extracted by fitting the corrected one.

The cable attenuation of the former was calculated by

$$\frac{-|20\log_{10} R^{\,cable+trombone}|}{2} - \frac{-|20\log_{10} R^{\,trombone}|}{2},$$

where $R^{\,cable+trombone}$ and $R^{\,trombone}$ are the radii by fitting date with the condition shown in Fig. 1 and with only trombone, respectively. Figure 2(a) shows the fitting result. The cable attenuation at the frequency of 972 MHz was obtained to $-2.865 \pm 0.016(\sigma)$ dB by the former correction. In the latter, the equation for the correction was

$$S_{11}{}^{cable,(i)} = \frac{S_{11}{}^{cable+trombone,(i)}}{|S_{11}{}^{trombone,(i)}|},$$

where $S_{11}{}^{cable,(i)}$ represents the corrected data. Moreover, $S_{11}{}^{cable+trombone,(i)}$ is the return coefficient measured in the setup of Fig. 1 and $S_{11}{}^{cable+trombone,(i)}$ is that with only trombone. In Fig. 2(b), the black closed circles represent the measured data ant the red closed squares are the corrected. This corrected data were fitted as the circle and the attenuation was estimated using the obtained radius ($R^{\,cable}$) as

$$\frac{-|20\log_{10} R^{\,cable}|}{2}.$$

It became $-2.865 \pm 0.016(\sigma)$ dB and the same as the former correction at all.

This approach is unique and interesting. The phase rotation of the reflected wave can be confirmed from the distortion-less circle. Additionally, the obtained results were the same as that by the direct measurement of the insertion loss. If the disadvantages were described, the significant one is the measurement time. It was about 2 minutes once in the present setting.

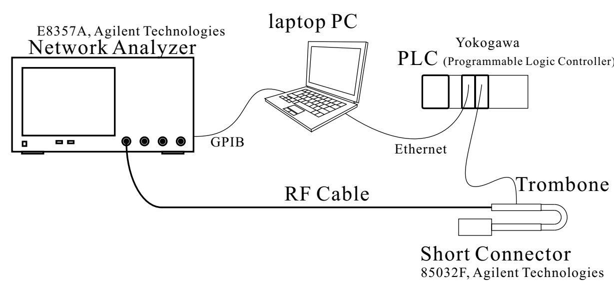

Figure 1: Approach using a network analyzer and a trombone. The trombone was automatically moved and data were taken using the Programmable Logic Controller(PLC) system and the laptop PC.

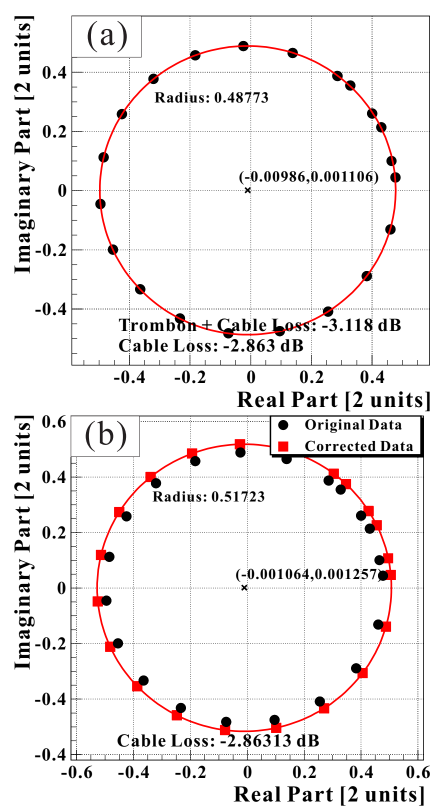

Figure 2: Fitting results of the measurement of the cable attenuation using the trombone. (a) shows the fitting result of the original data. The contribution of the trombone was subtracted after that. The red closed squares of (b) represent the corrected data. The final results of the both corrections were almost the same.

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REFLECTED WAVE USING SHORT AND OPEN CONNECTORS

The measured approach of the reflected wave which goes to the end of the cable and comes back are one of ideas which someone can immediately think. However, if the input return loss ($-|20\log_{10}|S_{11}||$) in S parameters is reduced to half as shown in Fig. 3, this simple approach do not work. Actually, the obtained cable attenuation for the 972 MHz RF was -2.899 dB from the half $-|20\log_{10}|S_{11}||$ when a short connector was used at the other end. It indicated the obvious overestimation in comparison to the direct measurement of the insertion loss (-2.851 dB). On the other hand, the attenuation using an open connector was -2.784 dB. Instead, it was underestimated. It is the reason the reflected wave not only in a connector but also on the way of a cable contributes to the input reflection coefficient S_{11} in this case.

If it is assumed to ignore the high-order contributions, the reflected wave is analyzed for three contributions as shown in Fig. 3. Each contribution has the different behavior in the conditions using a short and an open connector as follows:

case(A) The contribution at a short connector is opposite in phase to that at an open in order to reflect as the fixed end.

case(B) The component using a short or an open connector is not different because the wave is not touched until a connector,

case(C) The phase in a short connector is the same as that in an open because the wave is reflected two times at a fixed ends and reverts to the first.

Here, it is notice that the phase of the only case(A) is inverted in the conditions using the two connectors. Thus, if the reflected wave using a short connector is subtracted from that using an open, the contributions of case(B) and (C) disappear and the component of case(A) is rest. Therefore, the cable attenuation can be defined as follows:

$$\frac{-|20\log_{10}|S_{11}{}^{short} - S_{11}{}^{open}|/2|}{2},$$

where $S_{11}{}^{open}$ and $S_{11}{}^{short}$ are the input reflection coefficients using a short and an open connector, respectively. Having to be careful, those coefficients have the components of a real part and an imaginary. This equation does not indicate the difference of the return losses with a dB unit in each connector.

In the actual measurement, E5071 was used as a network analyzer. The short and the open connectors of 85032F Calibration Kit, which was produced by Agilent Technologies, were adopted. The cable attenuation was obtained to be $-2.845\pm0.002(\sigma)$ dB at the 972 MHz RF.

By this approach, one of the most important advantage is convenient, such as the available device is only network analyzer and the electric power is not used at one end of a cable. In addition, the difference of the absolute value and the standard deviation are least in this investigation, and the measuring time is less than that using a trombone. Furthermore, this approach was examined also to the 324 MHz RF, and the excellent result was obtained. It could be confirmed that this approach is useful for the acceleration frequency in J-PARC Linac.

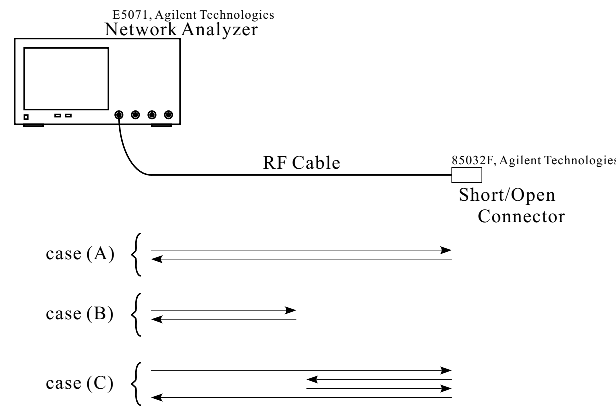

Figure 3: Approach using a network analyzer and connectors. If the reflected wave using a short connector is subtracted from that using an open, the components of case(B) and (C) disappear and the contribution of case(A) is rest.

SUMMARY

The results are summarized in Table 1. If it is assumed that the transmission coefficient using a network analyzer is correct, the cable attenuation is obtained within 1% of the systematic error by all approaches. Among them, the approach using a short and an open connectors, which can be used at the RF with the frequency of 324 MHz, is preferred for us due to convenience.

Thereby, the techniques of measuring the cable attenuation from the control system on the ground to the accelerator tunnel of the underground were established. The attenuation of many cables for the ACS section will be measured using this approach in summer, 2013.

Table 1: Summary of the Obtained Cable Attenuations

Approach	Attenuation [dB]
transmission coefficient S_{21}	-2.851 ± 0.004
using power meter	-2.869 ± 0.012
using trombone	-2.865 ± 0.016
using short/open connector	-2.845 ± 0.002

REFERENCES

[1] http//www.j-parc.jp

[2] Gigatronics Manual 21568, Rev. D., 2001