A Study on the Tapered Balun for the UWB UHF Coupler

Jae-Gu Choi*, Sang-Hwa Yi*, Kwang-Hwa Kim* and Young-Chul Rhee**

Abstract - The UWB UHF coupler for GIS PD detection requires a balun (balance to unbalance transformer) to show its inherent UWB characteristics. In order to reduce the size of the balun and to make it practical in the conventional GIS, a novel tapered coaxial balun with a dielectric was proposed for the UWB UHF coupler. The performance of the proposed balun was verified through a series of simulations, measurements and experiments. As a result, both the conventional balun and the proposed balun, which has a length equal to one third of that of the conventional balun, demonstrated good S11 characteristics, whereas the efficiency of the proposed balun increased as much as about 30% in comparison to the conventional one.

Keywords: tapered balun, UWB, UHF, coupler, GIS PD

1. Introduction

A number of PD detection methods using the various PD phenomena such as light, sound, vibration and electromagnetic waves have been proposed [1-4]. It is widely known that the ultra high frequency (UHF) method that detects the electromagnetic wave of PD pulses in a gas insulated space is one of the most competitive methods due to its high sensitivity and robustness to noises [5,6].

The UHF coupler is the most important component in the diagnostic system using the UHF method because it should be able to catch those pulses with a rise time shorter than one nanosecond [7], which means it should be an ultra wide band (UWB) coupler with the bandwidth ranging from hundreds of MHz to several GHz. Therefore, a UWB UHF coupler is more desirable for the detection of the PD pulses because the UWB characteristics of the detected PD signals hold extensive information for identifying the type and the location of the defect in the GIS.

However, the UWB UHF coupler requires a balun (balance to unbalance transformer) in order to show its inherent UWB characteristics [8]. There have been few studies regarding the UWB balun for the UWB UHF coupler in the field of GIS PD detection not only domestically but also abroad. A tapered coaxial balun was introduced in [9]. However, it is not practical for the conventional GIS because of its long length.

In this paper, in order to reduce the length of the balun and to make it most practical, the authors proposed a novel tapered coaxial balun with a dielectric as a UWB balun for the UWB UHF coupler. Return loss (S11) and field distribution were considered through the simulations and the measurements. Furthermore, experiments for the performance verification of the proposed balun were carried out with the purpose of comparing it with the conventional one.

2. Fundamental Theory

Consider the tapered balun, where

$$Z(z) = Z_0 e^{az}, \qquad \text{for } 0<z<L, \tag{1}$$

as indicated in Fig. 1(a) [10]. At z = 0, $Z(0) = Z_0$ and At z = L, $Z(L) = Z_L = Z_0 e^{aL}$. The reflection coefficient response, Γ is as follows:

$$\Gamma = \frac{\ln Z_L / Z_0}{2} e^{-j\beta L} \frac{\sin \beta L}{\beta L} \tag{2}$$

where β is the propagation constant of the taper.

The magnitude of the reflection coefficient in (2) is sketched in Fig. 1(b). It can be seen that the peaks in $|\Gamma|$ decrease with increasing length of the taper and that the length should be greater than $\lambda/2(\beta L > \pi)$ to minimize the mismatch at low frequencies.

The proposed tapered balun in Fig. 2 uses an alumina dielectric (ε_r = 9.5) between the center conductor and the tapered conductor to reduce the length of the balun. The length of the proposed balun could be reduced to about 95 mm by the effect of the dielectric, as compared with the conventional balun that is 300mm in length. The center conductor of the proposed balun is 1 mm in diameter and the tapered conductor is 12 mm in diameter. Therefore, the

* Power Facility Diagnosis Research Group, KERI, Korea. (jgchoi@keri,re,kr)
** Department of Information and Communication Engineering, Kyungnam University, Korea. (micropt@kyungnam.ac.kr)
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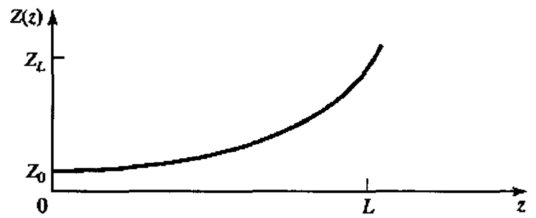
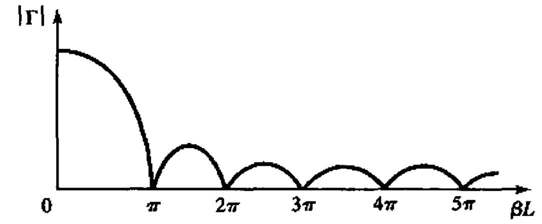
impedance of the balun near the connector is matched to Z_0 (50 ohm) and the impedance of the balun near the antenna feed is matched to Z_L.



(a)Variation of impedance
(Z: impedance, z: position on the taper)



(b) Resulting reflection coefficient magnitude response
Fig. 1 A matching section with a taper

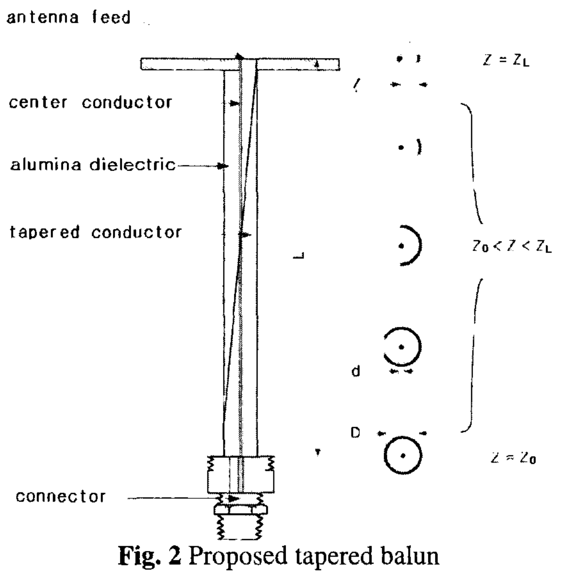
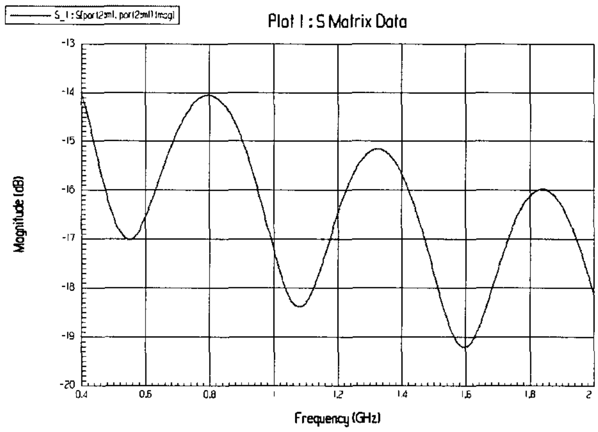


Fig. 2 Proposed tapered balun

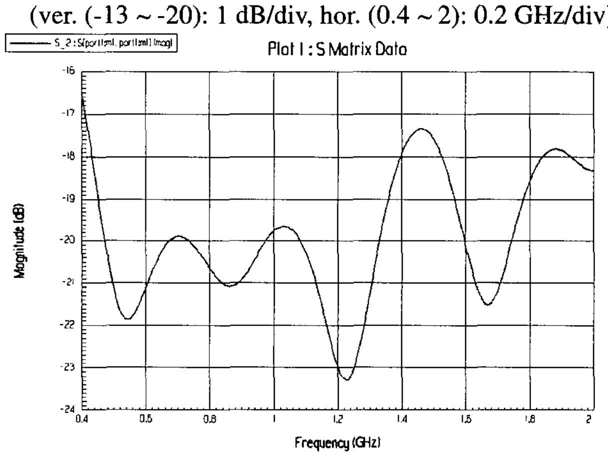
Conversely, in the case of the conventional balun used for the comparative study, the center conductor is 2 mm in diameter and the tapered conductor is 4.6 mm in the inner diameter. Therefore, the impedance of the conventional balun near the connector is also matched to Z_0 (50 ohm). In addition, the impedance of the balun near the antenna feed is also matched to Z_L.

3. Simulation Results and Discussion

Before the experiments of the performance verification with the proposed balun in comparison with the conventional one, the authors investigated the S11 characteristics and the field distribution of the baluns and measured the S11 characteristics. The simulation tool, HFSS (high frequency structure simulator version 8.5) was used for the simulation.



(a) Simulated S11 of the proposed balun
(ver. (-13 ~ -20): 1 dB/div, hor. (0.4 ~ 2): 0.2 GHz/div)



(b) Simulated S11 of the conventional balun
(ver. (-16 ~ -24): 1 dB/div, hor. (0.4 ~ 2): 0.2 GHz/div)
Fig. 3 S11 characteristics of the baluns

The S11 characteristics of the baluns are shown in Fig. 3. In Fig. 3, (a) and (b) describe the simulated S11 of the proposed balun and the conventional balun, respectively. It can be seen that both baluns demonstrate excellent S11 characteristics because they guaranteed the S11 characteristics of −14 dB in the bandwidth between 0.5 GHz and 2.0 GHz, which was the aimed bandwidth of the baluns. It can be seen that the characteristics of the conventional balun are slightly superior to the proposed balun.

The field distribution (y-z section) of the proposed balun is shown in Fig. 4. The antenna feed and the coaxial connector of the balun are placed at the orgin (0, 0, 0) and on the y axis (0, 95, 0), respectively. The symmetrical field in the coaxial connector becomes unsymmetrical in the antenna feed. In this case, the length of the balun is 95 mm and the operation frequency is 1.0 GHz of which the wavelength is 30 cm. In Fig. 4, 1 wavelength in the balun coincides well with 9.5 cm because the guide wavelength is inversely proportional to $\sqrt{\varepsilon_r}$ of the dielectric.

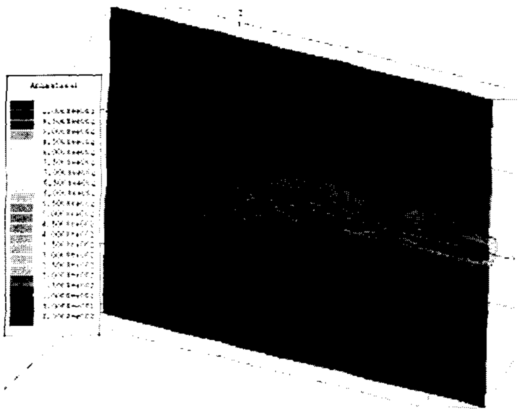


Fig. 4 Field distribution (y-z section) of the proposed balun

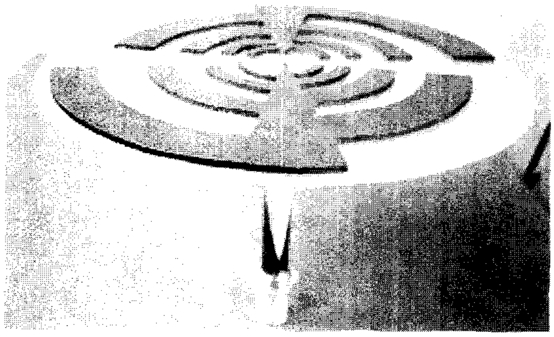
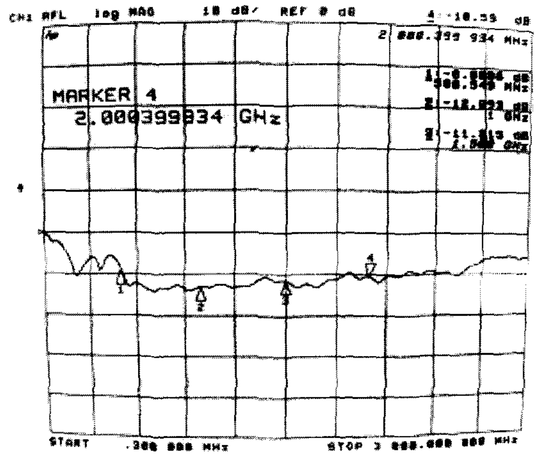


Fig. 5 Proposed UWB balun attached to UHF coupler

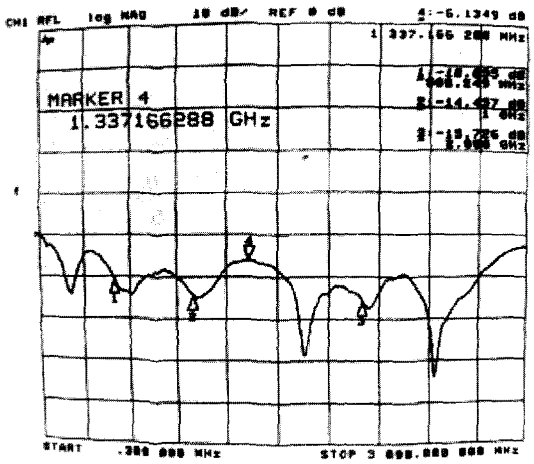
5. Experimental Results and Discussion

The proposed balun and the conventional balun were fabricated as mentioned in section 2. Fig. 5 shows the proposed UWB balun attached to the UHF coupler, the bandwidth of which is 0.5 ~ 2.0 GHz. The S11 characteristics of the baluns attached to the log-periodic coupler were measured using a network analyser (HP, 8753D, 30 kHz ~ 3 GHz). The results are shown in Fig. 6. In Fig. 6 (a), the coupler with the proposed balun displays relatively flat characteristics under –10 dB in the bandwidth, whereas the coupler with the conventional balun exhibits poor characteristics around 0.8 GHz and 1.3 GHz. It is a concern that the conventional balun may attenuate the signal around the frequencies. It is thought that these poor characteristics of the conventional balun have resulted from the spacers used to maintain the gap distance between the centre conductor and the tapered conductor. The spacers were not used in the proposed balun, which is one of the merits of the proposed balun because the alumina dielectric in the proposed balun also serves as a spacer. From the results of the measurements, the proposed balun showed superior UWB characteristics to the conventional balun.

The experiments for the performance verification of the proposed balun in comparison with the conventional balun were carried out using the 362 kV mock-up gas-insulated bus (GIB) shown in Fig. 7. In the figure, the pulse generator emits pulses of 0.5 ns rise time through the conical coaxial bus for matching into the GIB. The input charges



(a) Measured S11 of the coupler with the proposed balun (ver.: 10 dB/div, hori. (0 ~ 3): 0.3 GHz/div)



(b) Measured S11 of the coupler with the conventional balun (ver.: 10 dB/div, hor. (0 ~ 3): 0.3 GHz/div)

Fig. 6 S11 characteristics of the coupler with the baluns

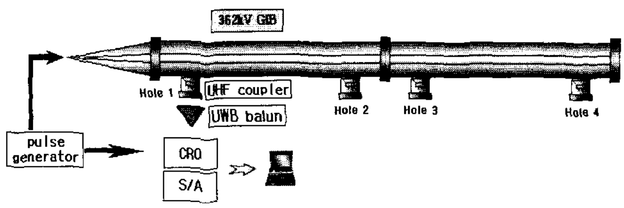
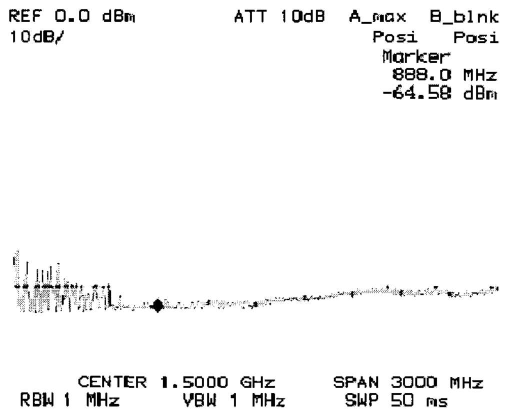


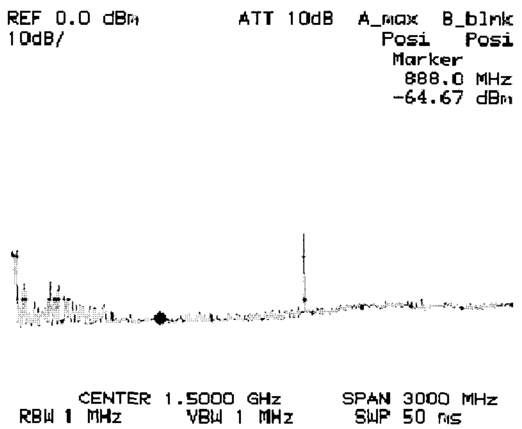
Fig. 7 Experimental setup for performance verification of the baluns

emitted from the pulse generator were 10, 20, 50, 100, 200 and 500 pC. The signals detected by the UHF coupler with the balun in the hand hole were analyzed by measuring instruments such as an oscilloscope (LeCroy, wavePro 960, 2 GHz / 16 GS/s, 16 Mpts) and a spectrum analyzer (Advantest, R3131A, 9 kHz – 3 GHz).

The results of the performance verification of the baluns in the frequency domain are shown in Fig. 8 when the input charge was 200 pC. The detected spectrum ranges up to approximately 600 MHz in both (a) and (b) because the emitted pulse has a 0.5 ns rise time. The spectral component around 1.8 GHz in Fig. 8 (b) is originated from the communication noise from a cellular phone. It can be seen that the sensitivity of the coupler with the proposed balun is higher than that of the coupler with the conventional balun. Furthermore, it is thought that the higher sensitivity of the coupler with the proposed balun has resulted from the flatter S11, especially in the bandwidth between 600 MHz and 1,000 MHz.



(a) coupler with the proposed balun
(ver.: 10 dB/div, hori. (0 ~ 3): 0.3 GHz/div)



(b) coupler with the conventional balun
(ver.: 10 dB/div, hori. (0 ~ 3): 0.3 GHz/div)

Fig. 8 Performance verification of the baluns in frequency domain (input charge: 200 pC)

Fig. 9 describes an example of the detected signal in time domain by the coupler with the proposed balun when the input charge was 200 pC. The results of the performance verification of the baluns in time domain were obtained by picking the positive maximal value in Fig. 9 as shown in Fig. 10. The magnitude of the signal from the coupler with the proposed balun was about 30% higher on average than that from the coupler with the conventional balun, as expected in the S11 characteristics of the baluns.

From the experimental results, it is believed that the proposed balun has positive performance as a UWB balun and the UWB UHF coupler can be more easily fabricated, transported, installed and operated due to the reduced length of the balun.

Fig. 9 Detected signal by the coupler with the proposed balun (ver.: 20 mV/div, hor.: 50 ns/div, input charge: 200 pC)

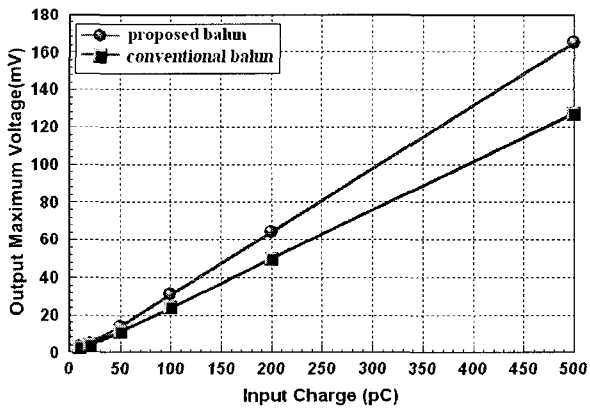


Fig. 10 Performance verification of the baluns in time domain

6. Conclusion

The tapered balun with the alumina dielectric was proposed as a UWB balun for UWB UHF couplers. Through a series of simulations before the experiments of performance verification, the following characteristics of the balun were achieved in comparison with the conventional balun, i.e., (1) both baluns showed excellent S11 characteristics, (2) the guide wavelength of the proposed balun could be verified by considering the field distribution of the balun.

The following are the results of the experiments for the performance verification, (1) the proposed balun displayed flatter S11 characteristics than the conventional balun, and (2) the sensitivity of the coupler with the proposed balun was higher than that of the coupler with the conventional balun in both frequency-domain and time-domain considerations.

It is thought that the proposed balun performs well as a UWB balun and the UWB UHF coupler can be more easily fabricated, transported, installed and operated due to the reduced length of the balun.

Now that the UWB UHF coupler system including the coupler itself and the balun has been completed, hereafter, a study on the UWB low-noise amplifier is needed.

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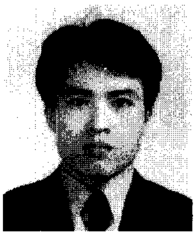
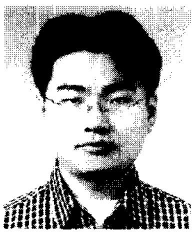
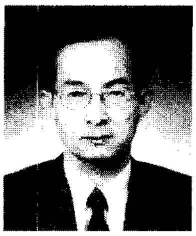


Jae-Gu Choi
He received his B.S. and M.S. degrees in Electrical Engineering from Kyoungpook National University, Daegu, Korea in 1994 and 1996, respectively. Currently, he is a Senior Researcher at the Korea Electrotechnology Research Institute (KERI) in Korea. His research interests include high voltage engineering and its applications, and digital signal processing. He is a member of the Korean Institute of Electrical Engineers (KIEE).



Sang-Hwa Yi
He received his B.S. degree in Eelectronic Engineering from Korea University, Seoul, Korea in 2001 and his M.S. degree in Electronic Engineering from the Pohang University of Science and Technology in 2003. Currently, he is a Researcher at the Korea Electrotechnology Research Institute (KERI) in Korea. His research interests include high voltage engineering and microwave engineering. He is a member of the Korean Institute of Electrical Engineers (KIEE).



Kwang-Hwa Kim
He received his B.S., M.S. and Ph. D. degrees in Electrical Engineering from Pusan University, Pusan, Korea in 1981, 1983 and 1992, respectively. Currently, he is a Principal Researcher and the Director of the Power Facilities Diagnosis Research Group at the Korea Electrotechnology Research Institute (KERI) in Korea. His research interests include the diagnosis of power facilities, high voltage engineering and its applications. He is a member of the Korean Institute of Electrical Engineers (KIEE).

Young-Chul Rhee
He received his B.S. degree in Electrical Engineering from Kwangwoon University, Seoul, Korea in 1976, the M.S. degree in Electrical Engineering from Yonsel University, Seoul, Korea in 1978, and the Ph.D. degree in Electrical Engineering from Ajou University, Suwon, Korea in 1992. From 1978 to 1981, he was a member of facility in Electrical Engineering with Korea Naval Academy. From 1988 to 1990, he was a Visiting Professor with the University of Melbourne, Melbourne, Australia. From 1985 to 2000, he had been with Electrical Engineering, Kyungnam University, where he was a Professor. Since 2000, he has been with Information and Communication Engineering, Kyungnam University where he is currently a Professor.