논문 2007-44TC-9-7

넓은 대역폭이 소거된 소형 UWB 안테나 설계

(Design of the Wideband Notched Compact UWB Antenna)

김철복[*], 임정섭[**], 이호상[**], 장재삼[**], 정영호[**], 조동기[**], 이문수[***]

(Cheol-Bok Kim, Jung-Sup Lim, Ho-Sang Lee, Jae-Sam Jang,
Young-Ho Jung, Dong-Ki Jo, and Mun-Soo Lee)

요 약

본 논문에서는 최근 발표된 UWB 주파수 허용대역(3.1~4.8 GHz, 7.1~10.2 GHz)을 만족하기 위해 두 개의 부채꼴 루프 안테나를 대칭적으로 놓음으로써 넓은 주파수 대역을 소거할 수 있는 UWB 안테나를 설계한다. 설계된 안테나의 패치면에 inverted_L 모양의 슬릿을 삽입함으로써 소거하고자 하는 4.8~7.1 GHz의 넓은 주파수 대역을 소거할 수 있었다. 최적화하여 제작된 UWB 안테나는 3.1 GHz이상에서 -10dB 이하의 반사손실 값을 가지고, 1 ns 이하의 군지연과 선형적인 위상특성을 가졌다. 패치면에 inverted-L 모양의 슬릿을 삽입한 안테나는 4.8~7.1GHz의 대역 내에서 -10dB이상의 반사손실과 5 ns의 군지연, 비선형적인 위상 및 이득감소특성을 가졌다. 제작된 안테나의 방사패턴은 각각의 주파수에서 무지향성의 특성을 나타내었다.

Abstract

In this paper, a novel wideband notched compact UWB antenna is designed to satisfy the licensed UWB frequency bandwidth(3.1~4.8 GHz, 7.1~10.2 GHz) by symmetrically arranging two adjacent sectorial loop antennas. The widevband(4.8~7.1 GHz) notch can be obtained by inserting the inverted-L shaped slits on the patch. The designed UWB antenna has return loss lower than -10dB at 3.1 GHz and over, group delay value lower than 1 ns and the linear phase property. The optimized UWB antenna inserted the inverted-L shaped slits has return loss great than -10dB, 5 ns of group delay, nonlinear phase and decreased gain properties over the frequency band, 4.8 GHz to 7.1 GHz.

Keywords : Wideband notch, inverted-L shaped slit, UWB(ultra-wideband)

Ⅰ. 서 론

In order to use the limited frequency resources effectively, UWB(ultra-wideband) technology is currently under consideration for many applications such as satellite communication, wireless mobile communication, broadcasting and so on. It can be used at the existing wireless communication frequencies without mutual interference. In addition, there are many advantages of the UWB technology such as low dissipation power and high data transmission rate(500 Mbps ~ 1 Gbps).

These advantages are considered as various applications in commercial and military communications, radar systems. For example, UWB technology has been applied to ACAS(airborne collision avoidance system), GPR(ground penetrating radar), IDR(intrusion detection radar), Precision Geolocation System. UWB technology was recently adapted for wireless USB and it will be adapted for PC, mobile, home network in the future.

---

[*] 학생회원, [**] 정회원, 경상대학교 전자공학과
(Gyeongsang National University, Dept. Electronic Engineering)
[***] 평생회원, 경상대학교 공학연구원
(Engineering Research Institute, Gyeongsang National University)

※ 이 연구는 2007년도 경상대학교 학술진흥지원사업 연구비에 의하여 수행되었음(RPP-2007-033)
접수일자: 2007년3월13일, 수정완료일: 2007년9월4일

In 2002, the Federal Communication Commission (FCC) in United States officially released the regulations for UWB technology and the spectrum from 3.1 GHz to 10.6 GHz is allocated for unlicensed UWB measurement, medical and communication applications with EIRP less than -41.3 dBm/MHz. However UWB system may cause some interference with a few systems such as WLAN and GPS. Therefore, UWB system needs a function to keep out of the interferences. Moreover the reserved frequency band for mobile services, 4.2~4.8 GHz, is to be approved by 2010. Therefore, a UWB antenna should have a notched frequency band for its radiation. Accordingly, A few kinds of techniques to notch some frequency bands of the UWB antenna have been studied[2~4] but most of them have a notch function only for the limited narrow band.

In this paper, we design a coupled sectorial loop antenna for UWB communication and examine its performances depending on its geometrical parameters. Next, a UWB antenna by inserting a pair of the inverted-L shaped slits is designed to notch wideband (4.8~7.2 GHz) including WLAN bandwidths and examined its performances depending on the geometrical parameters of the slits. Finally, the antenna performances in the frequency and time domains are to be evaluated for the fitness in the UWB communication services.

Ⅱ. Design of the UWB antenna

A. Coupled sectorial loop UWB antenna

The basic configuration of the designed coupled sectorial loop UWB antenna(CSLA)[1] is shown in Fig. 1(a). To have a ultra-wideband for UWB communication, the input impedance of the antenna should be matched well at the every frequency. The input impedance can be controlled by connecting two identical antennas in parallel as shown in Fig. 1(b). Therefore, an antenna can have a property of wide bandwidth.

In this case, the input currents I_1 and I_2 are same due to the symmetry. However the direction of magnetic field of two loops is opposite each other. It rise to a strong mutual coupling. For the two-port system of the antennas shown in Fig. 1(b), the following equations can be written:

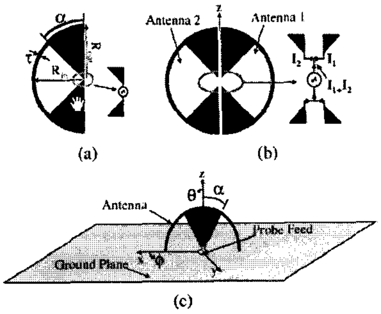


그림 1. (a)부채꼴 루프 안테나(SLA: sectorial loop antenna)의 구조, (b)쌍부채꼴 루프 안테나(CLSA: coupled sectorial loop antenna)의 구조, (c)접지면 위에 놓인 반쪽 쌍부채꼴 루프 안테나 구조

Fig. 1. (a)configuration of a sectorial loop antenna(SLA), (b)configuration of a coupled sectorial loop antenna(CSLA). (c) Half of a CSLA above a ground plane.

$$\begin{cases} V_1 = Z_{11}I_1 + Z_{12}I_2 \\ V_2 = Z_{21}I_1 + Z_{22}I_2 \end{cases} \tag{1}$$

where, V_1, I_1, V_2 and I_2 are the input voltages and currents of antenna #1 and #2 respectively. Z_{11} is a self input impedance of antenna #1 and Z_{22} is a self input impedance of antenna #2. Z_{12} and Z_{21} are a mutual impedance of the two antennas. In this case, reciprocity mandates that $Z_{12} = Z_{21}$ and the symmetry requires that $Z_{11} = Z_{22}$.

When the two antennas are fed with a single source, we will have $V_1 = V_2$ and in consideration of symmetry, $I_1 = I_2 = I$. Therefore, the input impedance of the antenna can be obtained from equation:

$$Z_{in} = \frac{1}{2}(Z_{11} + Z_{12}) \tag{2}$$

In order to obtain a wide-band operation spectral variations of Z_{11} and Z_{12} must counteract each other. That is, when the real(imaginary) part of Z_{11} increases with frequency the real(imaginary) part of

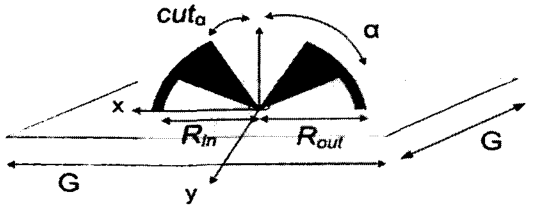


그림 2. 설계된 CSLA의 구조

Fig. 2. Configuration of the designed CSLA.

표 1. 최적화된 CLSA의 설계값

Table 1. Parameters of the optimized CLSA.

	Value
R_{out}	22 mm
R_{in}	21.5 mm
α	70 °
G	100 mm
cut_α	30 °

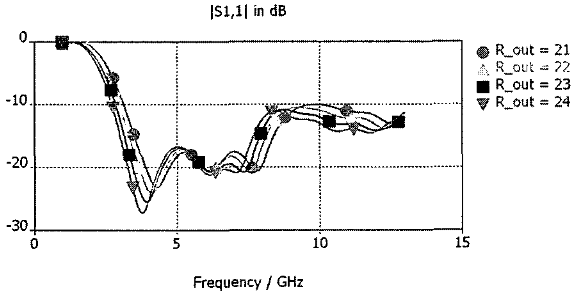


그림 3. R_{out}의 값에 따른 반사손실

Fig. 3. Simulated return losses of the different R_{out} values.

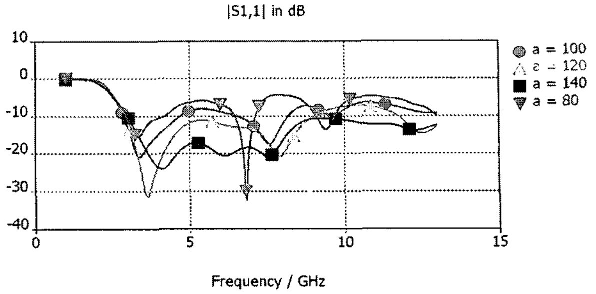


그림 4. α의 값에 따른 반사손실

Fig. 4. Simulated return losses of the different α values.

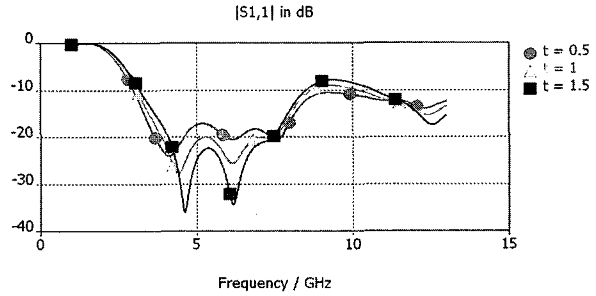


그림 5. τ의 값에 따른 반사손실

Fig. 5. Simulated return losses of the different τ values.

Z_{12} should decrease so that their average remains constant. If we determine the bandwidth of UWB antenna from 3.1 GHz to 10.6 GHz, the lowest frequency for radiation can be obtained approximately as follows:

$$f_l = \frac{c}{(\pi - \alpha + 2) R_{out} \sqrt{\epsilon_{eff}}} \tag{3}$$

where ϵ_{eff} is the effective dielectric constant, c is the speed of light, α and R_{out} are the geometrical parameters of the antenna. From the equation, we can design a optimized antenna by controlling the geometrical parameter values such as α, R_{out} and $-R_{in}$[1].

We can make a much smaller and lighter UWB antenna by removing the significantly non-distributed part of the antenna patch. The configuration of the designed CSLA is shown in Fig. 2.

A designed UWB antenna is simulated by CST Microwave Studio(MWS) based on the finite integration method(FIM). The optimized values of each physical dimension of the proposed antenna are shown in Table 1. Fig. 3 shows the antenna's return losses depending on the R_{out} values. The figure indicates that the lowest operation frequency become lower according to increasing the R_{out} value. Fig. 4 shows the antenna's return losses depending on the α. The antenna has a wide bandwidth at $\alpha = 70°$.

Fig. 5 shows the antenna's return losses depending on the τ which is the difference between R_{out} and R_{in}. The antenna has the lowest return loss at $\tau = 0.5\,mm$.

B. Wideband notched coupled sectorial loop UWB antenna

A designed UWB antenna in the previous section

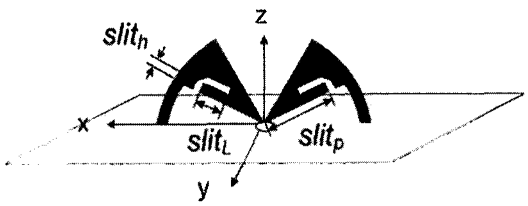


그림 6. 설계된 FN-CSLA의 구조

Fig. 6. Configuration of the designed FN-CSLA.

has a bandwidth from 3.1 GHz to 10.6 GHz. Therefore, it needs a function to notch the bandwidth from 4.8 GHz to 7.1 GHz to avoid the interference with WLAN and to satisfy the UWB regulation. There are many techniques to notch the band such as the method of inserting a U-shaped slot[2], the method of removing the parts of the patch[3] and the method of inserting a V-shaped slot[4]. However those methods can notch only the narrow bandwidth. It doesn't comply with the UWB regulation. That is, they can not notch the wide bandwidth from 4.8 GHz to 7.2 GHz. Therefore, a wideband frequency notched CSLA(FN-CSLA) inserting a pair of inverted-L shaped slits on the patch is proposed in this paper. Fig. 6 shows the configuration of the FN-CSLA.

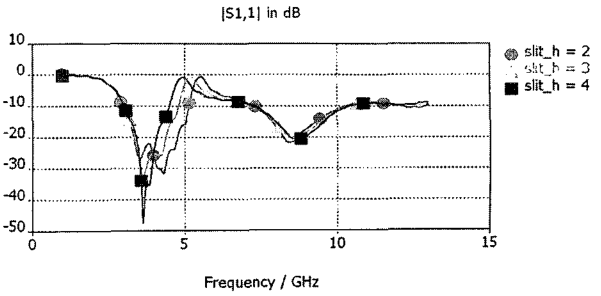
The notched frequency can be determined from the following approximate equation[5]:

$$f_L \simeq \frac{2c}{slit_L + slit_h} \tag{4}$$

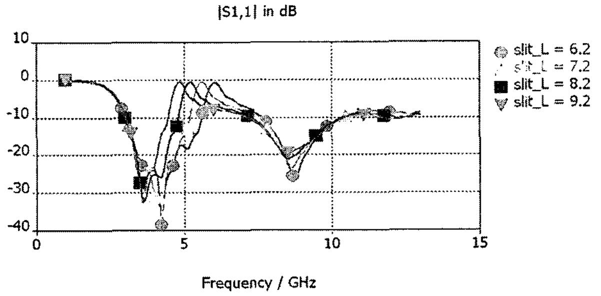
where c is the speed of the light, $slit_p$ is the distance from the center of the antenna patch to slits and $slit_h$ and $slit_L$ are the length of the slits as shown in Fig. 6. The width of the slits, $slit_w$, is 0.1 mm. At that time, the sum of the length, $slit_L + slit_h$, is a half-wavelength at the notched frequency. The length, $slit_p$, is related with the notched beamwidth.

Fig. 7 shows the return losses depending on the lengths of $slit_p$, $slit_h$ and $slit_L$. We can also see that the notched frequency is changed by controlling the parameters. That is, the longer the slits become, the lower the notched frequency is.

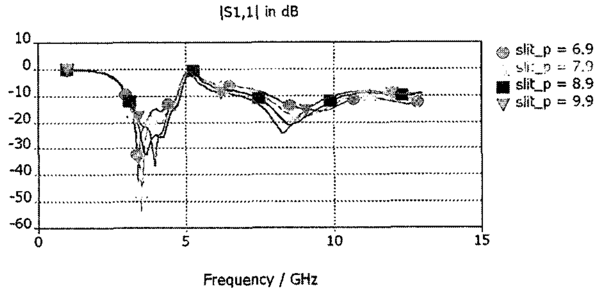
Based on the calculated results of the Fig. 8, we can find that the currents are concentrated near the slits at the notched frequency, while they are distributed mostly near the edges of the patch at the other frequencies. Therefore, we can expect that inserted slits have a function to notch the particular frequency.



(a) Return loss depending on $slit_h$ values



(b) Return loss depending on $slit_L$ values

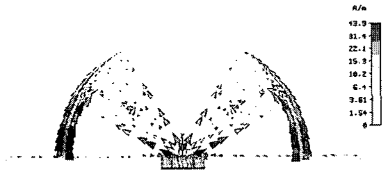


(c) Return loss depending on $slit_p$ values

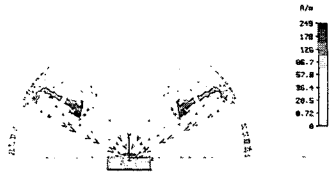
그림 7 슬릿의 파라미터에 따른 반사손실

Fig. 7. Simulated return losses of the different $slit_h$, $slit_L$, $slit_p$ values.

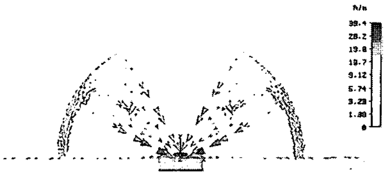
Fig. 9 shows the equivalent-circuit model for the antennas, which have a shunt stub and antenna resistance(R_a)[5]. When the length of $slit_L + slit_h$ is a half-wavelength at the notched frequency, the stub plays a short circuit. Therefore, it prevents the



(a) 3.5GHz



(b) 5GHz



(c) 8GHz

(d) 10.2GHz

그림 8. 시뮬레이션 된 안테나의 표면 전류밀도

Fig. 8. Simulated surface currents of the notched antenna.

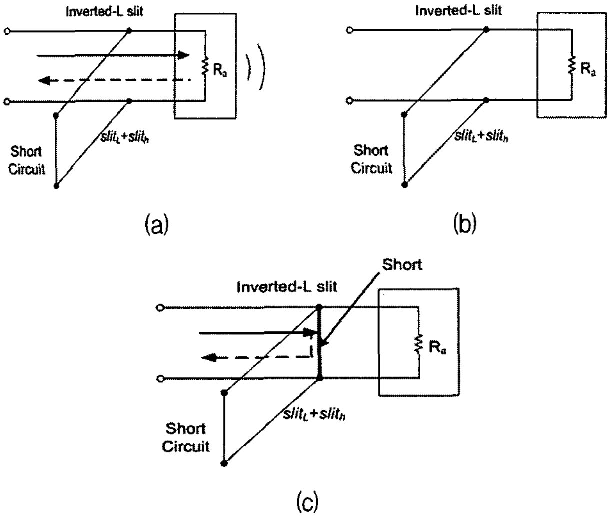


그림 9. (a)안테나의 개념적인 등가회로, (b)공진주파수 대역에서의 등가회로, (c)소거된 주파수대역에서의 등가회로.

Fig. 9. (a)Conceptual equivalent circuit model for antenna, (b)equivalent circuit model at the passband frequency, (c) equivalent circuit model at the notched frequency.

antenna from impedance matching at the notched frequency.

C. Characteristics in the Time Domain

The group delay and phase linearity are important parameters in UWB antenna properties. The group delay is defined as

$$\tau_g = -\frac{\partial \phi}{2\pi \partial f} \tag{5}$$

where ϕ is the far-field phase and f is frequency. The UWB antenna must have a phase linearity in the resonant frequency. If the group delay exceeds 1 ns, the phases are no longer to be linear in the far-field region and a pulse distortion is occurred.

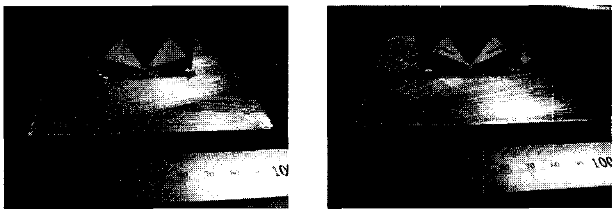
Ⅲ. Fabrication and Measurement

Table 2 shows the values of the designed UWB antenna's parameters. A patch is fabricated on a thin substrate with thickness of 0.508mm and dielectric constant of 2.5 and mounted on a 100×100mm square ground plane. Fig. 10 shows the photographs of the

표 2. 최적화된 UWB 안테나의 설계값

Table 2. Parameters of the optimized UWB antennas.

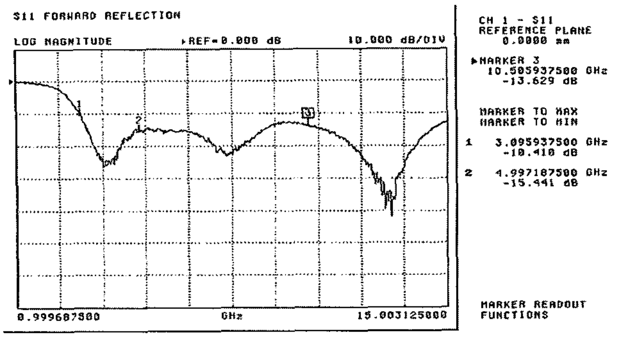
	CSLA	FN-CSLA
R_{out}	22mm	22mm
τ	0.5mm	0.5mm
α	70°	62.5°
cut_α	30°	30°
$slit_p$	-	8.9mm
$slit_L$	-	8.2mm
$slit_h$	-	3mm
$slit_w$	-	1mm



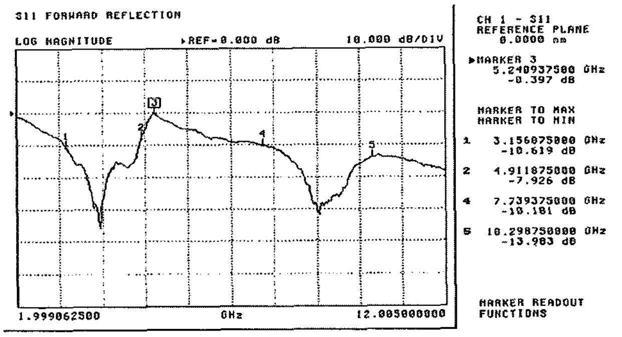
(a) CSLA (b) FN-CSLA

그림 10. 제작된 안테나의 사진

Fig. 10. Photographs of some fabricated prototypes.



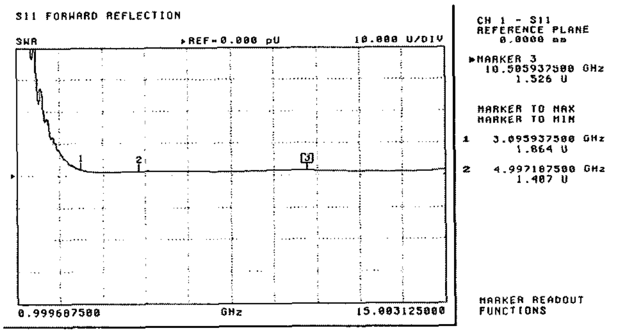
(a) CSLA



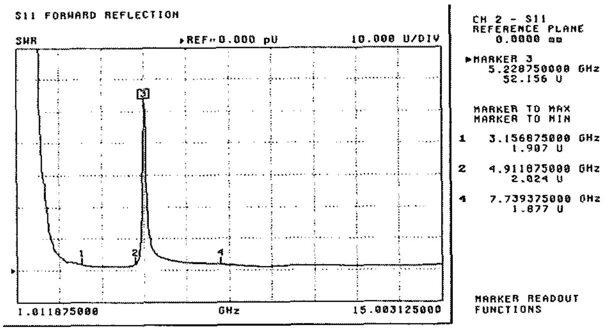
(b) FN-CSLA

그림 11. 측정된 UWB안테나의 반사손실

Fig. 11. Measured return losses of the UWB antennas.



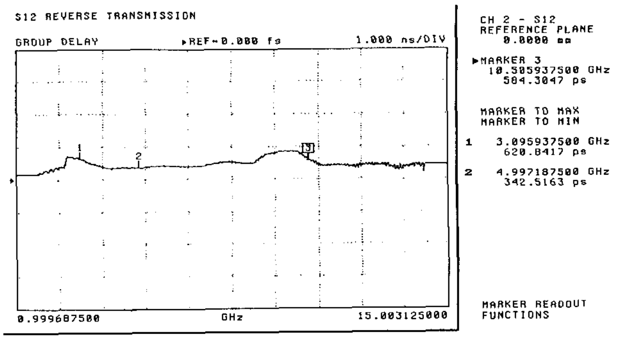
(a) CSLA



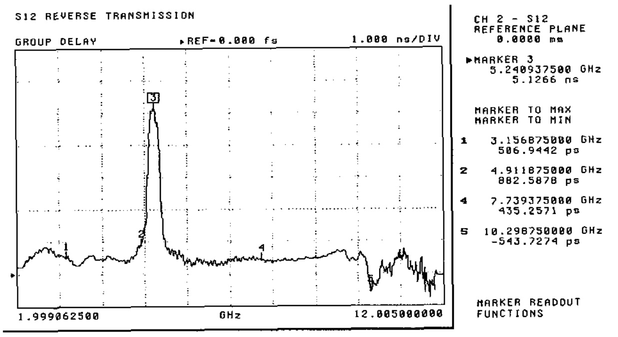
(b) FN-CSLA

그림 12. 측정된 UWB안테나의 VSWR

Fig. 12. Measured VSWR of the UWB antennas.



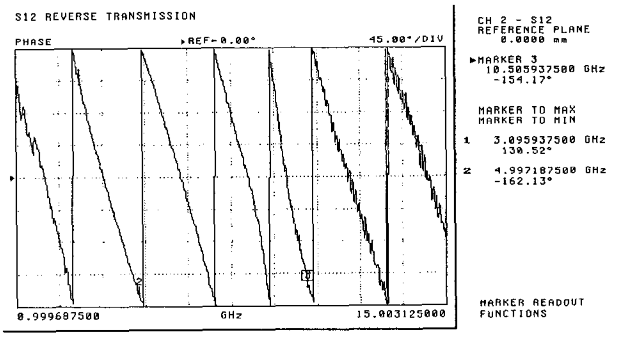
(a) CSLA



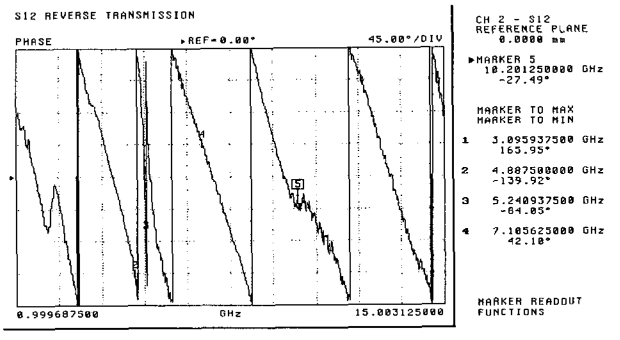
(b) FN-CSLA

그림 13. 시간영역에서 측정된 군지연

Fig. 13. Measured group delays in the time domain.



(a) CSLA



(b) FN-CSLA

그림 14. 시간영역에서 측정된 위상 선형성

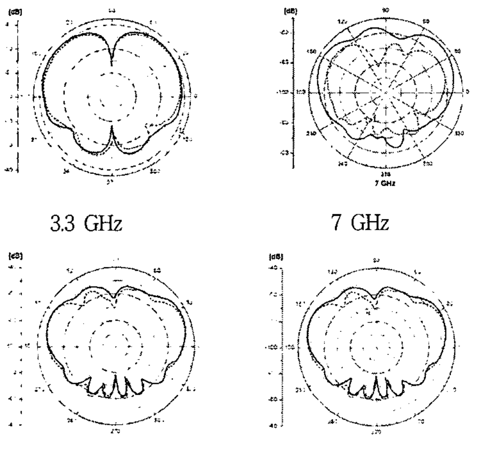
Fig. 14. Measured phase linearities in the time domain.

fabricated UWB antennas.

Antenna properties are measured by the Network Analyzer(Anitzu 37369). Fig. 11 and Fig. 12 show the measured return losses and VSWRs.

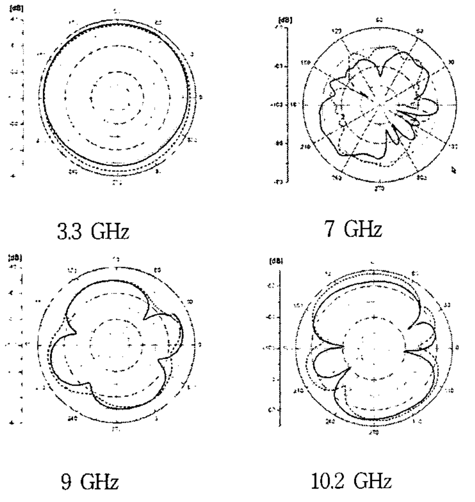
CSLA's return losses is less than -10 dB and VSWR is less than 2 dB at the resonated frequencies. But FN-CSLA's return losses is over -10 dB and VSWR is over 2 dB from 4.8 GHz to 7.1 GHz.

The group delay and phase of UWB antennas are measured without additional devices such as a LNA. In our experiments two antennas were separated at a distance of 60 mm in consideration of the low output power of network analyzer.


3.3 GHz 7 GHz

9 GHz 10.2 GHz

(a) E-plane radiation patterns


3.3 GHz 7 GHz

9 GHz 10.2 GHz

(b) H-plane radiation patterns

그림 15. 제작된 안테나의 방사패턴

Fig. 15. Measured 4radiation patterns of the UWB antennas.

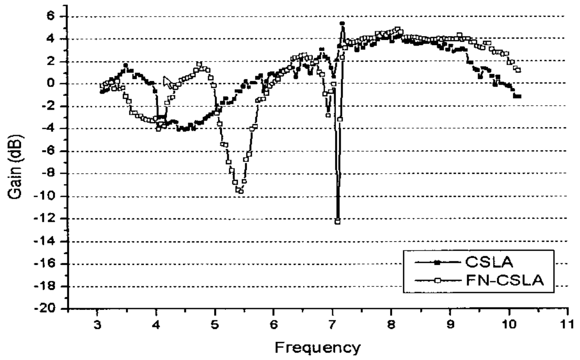


그림 16. 제작된 안테나의 이득

Fig. 16. Measured gains of the UWB antennas.

Fig. 13 shows the group delay of UWB antennas. If the group delay variation exveeds 1 ns, the phases are no longer to be linear in far-field region and a pulse distortion is caussed. We can see that the value of group delay is less than about 0.5 ns in CSLA. However the value of group delay in FN-CSLA is about 5ns at the notched frequency.

Fig. 14 shows the phase of UWB antennas. We can see that the phase of CSLA is linear but one of FN-CSLA is nonlinear at the notched frequency.

Fig. 15 shows the radiation patterns of the UWB antennas. They are similar with the radiation pattern of the monopole antenna. But the number of the sidelobe are increased at the high frequency. Fig. 16 shows the gains of UWB antennas. The gain of FN-CSLA decreased shapely at 5.6 GHz and 7.1 GHz.

In this paper, A CLSA has VSWR less than 2 dB, group delay less than 1 ns, and phase linearity over the band from 3.1 GHz to 15 GHz. We can expect that there is no pulse distortion in UWB communication. On the other hand, a FN-CSLA has VSWR lager than 2 dB, group delay of 5 ns, phase non-linearity and the low gain properties at the notched frequency. Therefore, we can expect that a FN-CLSA have a function to notch the particular frequency controlling.

Ⅳ. Conclusion

In this paper, a FN-CSLA has been designed. The lowest frequency of the CSLA can be determined by the radius of the sector. And a good impedance matching over wideband can be obtained by controlling the angle of the sector. Inverted-L shaped slits are inserted on the fan-type arms to notch the wideband. The notched frequency bandis determined by the positions and lengths of the slits. For the UWB communication services, the designed FN-CSLA has good performances in return loss over -10dB, group delay of 5 ns, radiation patterns and gain reduction in the notched bandwidth.

Reference

[1] N. Behdad and K. Sarabandi, “A compact antenna for ultrawide-band application.”, *IEEE Transactions on antenna and propagation*, vol. 53, no. 7, pp. 2185-2192, July 2005.

[2] Y. J. Cho, K. H. Kim, D. H. Choi, S. S. Lee, S. O. Park, “A miniature UWB planar monopole antenna with 5-GHz band-rejection filter and the time-domain characteristics.”. *IEEE Transactions on antenna and propagation*, vol. 54, no. 5, May 2006

[3] S. Y. Chen, P. H. Wang, P. Hsu, “Uniplanar; og-periodic slot antenna fed by a CPW for UWB applications.”, *IEEE Antenna and Wireless Propagation Lett.*, vol. 5 2006.

[4] Y. Kim, D. H. Kwon, “CPW-fed planar ultra wideband antenna having a frequency band notched function.”, *Electron Lett.*, vol. 40, no. 7, 1st April 2004.

[5] W. S. Lee, D. Z. Kim, K. J. Kim, J. W. Yu, “Wideband planar monopole antennas with dual band-notched characteristics.” *IEEE Transactions on Microwave Theory and Techniques*, vol. 54, no. 6, June 2006.

저자소개

김철복(학생회원)
2006년 2월 경상대학교
전자공학과 학사 졸업.
2006년 3월~현재 경상대학교
전자공학과 석사과정.
<주관심분야 : 안테나 설계, RF 회로, 전자장 수치해석, Particle swarm optimization, Metamaterial>

이호상(정회원)
1994년 경상대학교
전자공학과 학사 졸업
1997년 경상대학교
전자공학과 석사 졸업
2005년~현재 경상대학교
전자공학과 박사 과정
1994년~현재 한국수자원 공사
<주관심분야 : 안테나, 레이더 시스템, 무선통신>

정영호(정회원)
1996년 경상대학교
전자공학과 학사 졸업
2001년 경상대학교
전자공학과 석사 졸업
2003년~현재 경상대학교
전자공학과 박사 과정
1997년~현재 한국항공 선임연구원
<주관심분야 : 무선통신, 안테나, 전자장 수치해석>

이문수(평생회원)
1970년 한국항공대학교
통신공학사 학사 졸업
1980년 한양대학교 전자통신
공학과 석사 졸업
1984년 한양대학교
전자통신공학 박사 졸업
1981년~1986년 제주대학교 통신공학과 부교수
1986년 9월~1987년 8월 미국 COMSAT 연구소
연구원
1999년 6월~1999년 8월 Syracuse 대학교
방문교수
2004년 1월~2005년 2월 미시시피 대학교
방문교수
1987년~현재 경상대학교 전자공학과 정교수
<주관심분야 : 마이크로파, 무선통신, 안테나, Metamaterial>

임정섭(정회원)
2001년 경상대학교
전자공학과 석사 졸업
2005년~현재 경상대학교
전자공학과 박사 과정
1999년~현재 (주)KT근무
<주관심분야 : MW공학, 안테나, Wibro, Metamaterial>

장재삼(정회원)
1997년 경상대학교
전자공학과 학사 졸업
2000년 경상대학교
전자공학과 석사 졸업
2006년~현재 경상대학교
전자공학과 박사 과정
1997년~현재 한국항공 선임연구원
<주관심분야 : 이동통신, RF, PLL, 안테나>

조동기(정회원)
1999년 경상대학교
전자공학과 학사 졸업
2001년 경상대학교
전자공학과 석사 졸업
2004년~현재 경상대학교
전자공학과 박사 과정
2000년~현재 한국소니전자
<주관심분야 : 무선통신, 안테나>