An Adaptation Method for Synthesizing Arbitrary Line Source Difference Patterns and Its Application to Inverse Scattering Problem

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I. INTRODUCTION

In the synthesis of the continuously distributed line source antennas with arbitrary patterns, the formulas of Taylor sum pattern[1] and Bayliss difference pattern[2] have been mainly used. In this paper, an optimization scheme is newly presented to directly synthesize the desired line source difference patterns from Taylor line source sum pattern formula. In the scheme, the relationship between the difference pattern and the source distribution function is analytically established, and then the distribution is numerically adapted to the specified difference pattern by using an appropriate iterative sampling method. For showing the advantage and usefulness of this scheme, the scheme is applied to the one-dimensional inverse scattering problem compatible with the line source synthesis problem. For example, the corrugated coupled-line coupler which all port impedances are same can be easily designed by the proposed scheme. The reason is that the coupling factor of the nonuniform coupled-line coupler is corresponded to line source space factor and the modal impedance profile is corresponded to the distribution function[3]. The results also show the generality of the design method for the nonuniform transmission lines with the arbitrary reflection properties.

II. SAMPLED FORMULA OF LINE SOURCE PATTERN

Let the line source have a distribution function $g(p)$. Then the related space factor pattern $F(u)$ is given by the following Fourier transform relationship[1].

$$F(u)=\int_{-\pi}^{\pi} g(p)\exp(-jpu)dp \tag{1}$$

Expanding the $g(p)$ as $g(p)=\sum_{n=0}^{N}{}'(a_n\cos(np)+b_n\sin(np))$ by the Woodward's idea [4], $F(u)$ can be rewritten by the restricted set of sampling functions as follows:

$$F(u)=\sum_{m=0}^{N}{}'\pi a_n(Sa(\pi(u-n))+Sa(\pi(u+n)))-j\sum_{n=1}^{N}{}'\pi b_n(Sa(\pi(u-n))-Sa(\pi(u+n))) \tag{2}$$

where $F(n)=\pi(a_n-jb_n)$ and $F(0)=2\pi a_0$. The real and imaginary parts are even and odd u, respectively. The problem we now are considering is how to take full advantage of $F(u)$ for patterns with arbitrary lobe heights for cases not only sum pattern but also

ISBN: 89-86522-79-9 94460©KEES

difference pattern. We introduce the Taylor line source sum pattern[1] compatible with $F(u)$ for lobe control, and then modify it in order to activate the case of $b_n \neq 0$, based on the Orchard's ripple-making theory [4]. The result is as follows:

$$F(u)=A\cdot Sa(\pi u)\cdot \prod_{n=1,\, n\supseteq m}^{N}\left(\frac{n^2}{n^2-u^2}\right)\left(1-\frac{u}{u_n-jv_m}\right)\left(1+\frac{u}{u_n+jv_m}\right), \tag{3}$$

whose real and imaginary parts are even and odd in the entire u domain, respectively. That is, $F(u)=F_e(u)+jF_o(u)$ where $F_o(0)=0$. Thus, the framework of eq.(3) is consistent with that of eq.(2). Here, u_n is the null or dip position in the u domain. v_m cause a dip in position, which creates ripples. u_n and v_m are optimally perturbed for $|F(u)|$, which has the individually prescribed N lobe heights with the furthest lobes exponentially decaying in level according to the coefficient A. For a difference pattern, it is required that $F(0)=0$ and $F(u)$ have no deviation against the regular pattern at $u\neq 0$. Thus, $F_e(u)$ must become odd for $F_e(0)=0$. Once the alteration is done, $F_o(u)$ must become even and then the position of two derivations must be interchanged to maintain the framework, which is consistent with the need to have $g(p)$ be real. Letting the altered $F(u)$ be $F^A(u)=F_o^A(u)+jF_e^A(u)$ and defining $F'(u)=jF^A(u)$ yield $F'(u)=-F_e^A(u)+jF_o^A(u)$. After some algebra on the even $\leftrightarrow$ odd alteration in eq.(2), the following relationships are derived:

$$F_e^A(u)=F_o(u)+D_1\ , \tag{4}$$

$$F_o^A(u)=F_e(u)-D_0-D_2\ , \tag{5}$$

where

$$D_0 = 2\pi a_0\cdot Sa(\pi u), \tag{6}$$

$$D_1=2\pi\sum_{n=1}^{N} b_n\cdot Sa(\pi(u-n)), \tag{7}$$

$$D_2=2\pi\sum_{n=1}^{N} a_n\cdot Sa(\pi(u+n)). \tag{8}$$

In eq.(5), the subtraction by D_0 removes the numerical problem found in the constant A in the case of difference pattern. Thus, the following relationships are obtained:

$$F(u)\leftrightarrow g(p)=\sum_{n=0}^{N}(a_n\cos(np)+b_n\sin(np)), \qquad \text{for sum pattern,} \tag{9}$$

$$F'(u)\leftrightarrow g(p)=\sum_{n=1}^{N}(b_n^A\cos(np)+a_n^A\sin(np)), \qquad \text{for difference pattern,} \tag{10}$$

where b_n^A and a_n^A are the updated $b_n(=-F_o(n)/\pi)$ and $a_n(=F_e(n)/\pi)$ of $F(u)$ which contributes to a prescribed $|F'(u)|$.

III. APPLICATIONS

The error function for null positions adapted to the prescribed lobe peak values is defined by the least square method and the iteration for the minimization goes along with the conjugate gradient method. Fig. 1 shows the sum and difference patterns calculated by eq.(9) and eq.(10) in the case that $b_n=0$. Here, first and second sidelobes are prescribed to -20 dB and N=3. Fig. 2 shows the example of activating $v_m(m=4)$ for prescribed difference pattern with ripples in the case that N=7. For applications to the inverse scattering problem, let us consider the corrugated coupled-line 3-dB bandpass filter along the z axis at 6.5 GHz, aimed at making all ports match the $Z_0=50\Omega$ system. The adopted lobe peak values of $|F'(u)|$ are (0.13, 0.1, 0.1, 0.1, 0.1, 0.883, 0.1, 0.1) for N=8. The first lobe height has been chosen for the condition $Z_{0e}(z) > Z_0$, which has to be satisfied for the physical realization of coupler. The even mode characteristic impedance $Z_{0e}(z)$ is synthesized from the $g(p)$ of eq.(10), because $|F'(u)|$ indicates the coupling factor C in the symmetric coupler under the condition $Z_0=\sqrt{Z_{0e}(z)\cdot Z_{0o}(z)}$ [3]. The overlay optimized by the spectral domain approach was applied for the mode phase velocity compensation. The frequency characteristics are calculated by the usual coupler analysis and then the frequency centering is achieved by the optimization of the coupler length. The coupler was implemented on FR-4 substrate $(\varepsilon_r=4.7, h=1mm)$ and the calculated length is 6.7cm. The calculated results are compared with measured results in Fig. 3, showing good agreement.

IV. CONCLUSIONS

An optimization scheme was newly presented to directly synthesize the desired line source difference patterns from well-known sum pattern formula by developing the generally updated Fourier transform pair. The scheme can be easily applied to the one-dimensional inverse scattering problem. For application, the corrugated bandpass coupler with the specified coupling pattern was designed. The modal characteristic impedance profiles are corresponded to the line source distribution.

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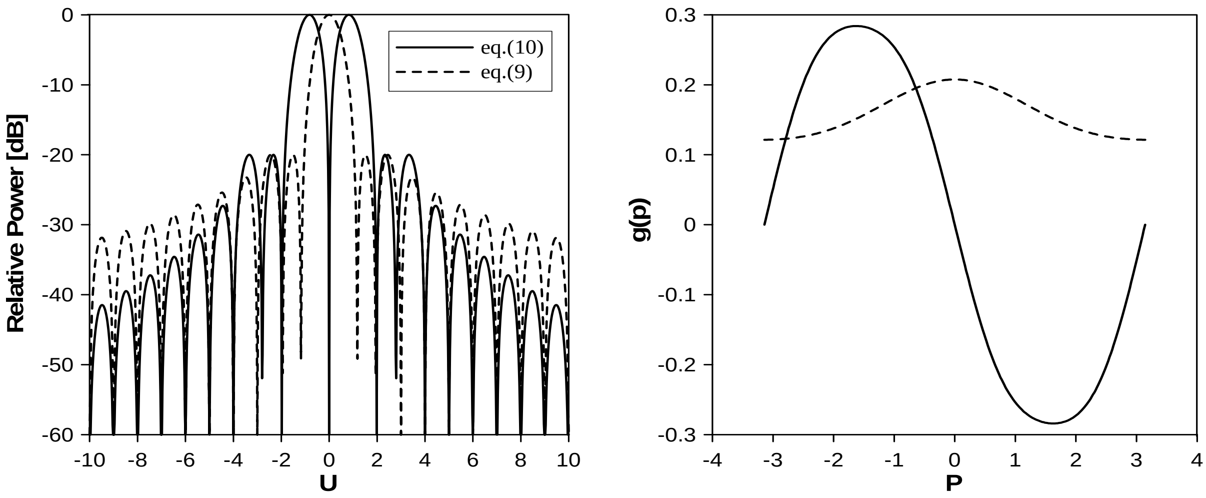
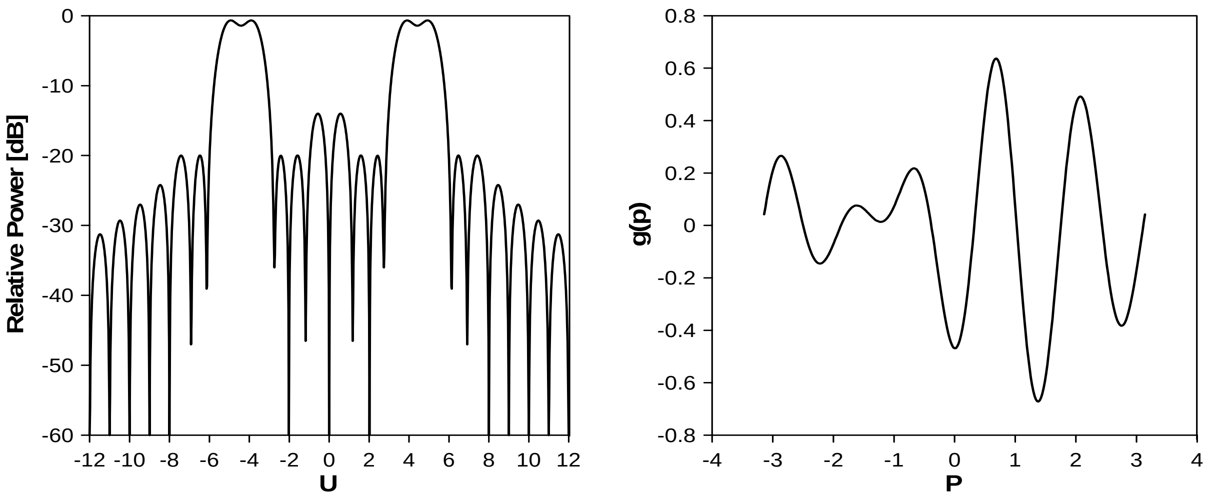


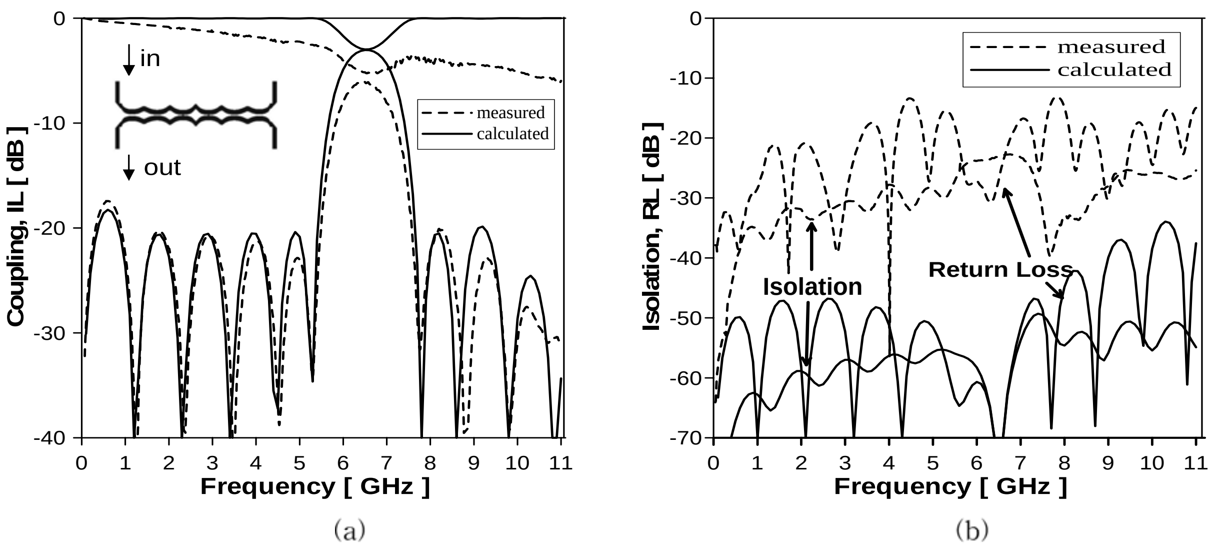
(a) (b)

Fig. 1. Sum and difference patterns simulated by the developed scheme.



(a) (b)

Fig. 2. Synthesized examples of difference patterns with ripple.



(a) (b)

Fig. 3. Frequency characteristics of designed corrugated coupler.