Narrowband Registration of Ultra-Wideband Signal

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Abstract. The research of various parameters influence on the Fresnel reflector focusing properties in particular spatial sizes, the focal point position, etc. is conducted. The version of using a flat Fresnel reflector for receiving ultra-wideband signals with the use of Wiener filtering is suggested.

1. Problem of receiving UWB signals
Main distinctive feature of ultra-wideband (UWB) signals is a very wide band of occupied frequencies and they usually have pulse signals form. UWB signals become more widely used in practice: radiolocation, radiotomography, communication, etc. Preferential using of narrowband electronics is the deterrent factor in this development path. If the problem of generating UWB signals is almost solved, the problem of receiving such signals is still actual. Using stroboscopic receivers or high-speed ADCs are two alternative approaches in solving this problem but both of them are quite complicated. The solution of the problem with using narrowband systems and technologies of solving inverse problems is suggested in present work. Fresnel mirror is considered as an example of narrowband device. The ability of amplifying signals without high energy cost is its main advantage [1–3].

2. Flat Fresnel reflector modeling
Let a flat wave propagates in free space with a given Descart coordinate system. It incident at a certain angle to the axis $z$, $\mathbf{k} = (-k \sin \alpha, 0, -k \cos \alpha)$ – a wave vector, $k = 2\pi f / c$ – its module (figure 1).
The origin of the coordinates is combined with a mirror imaged point of the expected focus \( r_0 = (0,0,0) \). The reflector is located on height \( h \). A phase shift of the reflectors axial line of is: \( \varphi_0 = kr_0 = 0 \). The phase shift of the reflected wave at an arbitrary point \( r = (x,y,h) \) is determined as

\[
\varphi = kr + kr = k(\sqrt{x^2 + y^2 + h^2} - x \sin \alpha - h \cos \alpha).
\]

Formula \([4–5]\) \( \Delta \varphi = \varphi - \varphi_0 = m\pi, \ m = 0, 1, 2,... \) determines the location of Fresnel zones. Even values \( m \) correspond to in-phase zones, the odd \( m \) to the antiphase ones. In general, the zones shape represents concentric ellipses. The effect of focus can be obtained by opening even zones or obscuring the odd ones. Besides changing the contribution of antiphase components to the opposite sign would lead to in-phase addition of all Fresnel zones \([6]\). This can be done by changing the phase of the odd or even zones (corrugation reflector surface), what is represented in figure 2. As a result it will provide significant field intensity increasing in the focal point.

If the incident angle is fixed \( \alpha = 0^o \) Fresnel zones will take the form of concentric circles. Calculations of the field intensity distribution in focal area are made using Huygens-Fresnel-Kirchhoff method \([5]\):

\[
E(r) = -2 \iiint_S E_0(r_j) w(r_j) \frac{d}{dz} G(r - r_j) dS,
\]

\( w(r_j) \) is equal to 1 for in-phase Fresnel zones and -1 for antiphase ones, \( G(r - r_j) \) – Green’s function:

\[
G(r - r_j) = -\exp{\frac{ik}{4\pi |r - r_j|}}.
\]

This formula represents convolution integral and calculates using direct and inverse Fourier transforms and Weyl spectral decomposition for normal derivative of the Green’s function \([5]\):

\[
\frac{d}{dz} G(r) = \frac{1}{2\pi} \iint \exp(iz\sqrt{k^2 - u^2 - v^2}) \exp{i(ux + vy)} dudv.
\]

3. Field distribution in focal area

The investigated reflector was calculated for following parameters: estimated frequency \( - f = 24 \) GHz, incident angle \( - \alpha = 45^o \) and height of the focus \( - h = 15 \) cm. Consider the field intensity distribution in the focal plane for various cases.

The figure 3 shows the distribution of the reflected radiation intensity, depending on focusing height. It’s obvious that focus area is rather localized in space.
The observation point displacement leads to a rapid decrease of the field intensity $F$. It shows that flat Fresnel reflector has a good spatial focusing ability. If the same device is used for other incident angles, the focal point will move in the corresponding direction (figure 4).

For particular case at angle $\alpha = 45^\circ$ changing frequency $f$ leads to shifting the focal point along the focus line for investigated reflector (figure 5).

Such spatial behavior of the focal point is similar for parabolic reflector but there is a significant distinction. Position of the focal point defines only by the geometry of the reflective surface and there is no frequency dependence for parabolic reflector [7].

4. UWB signal and Fresnel focusing
Currently, UWB pulses are used extensively in many industries. But there are some problems with receiving such signals which are connected with their short duration. Consider the opportunity of using flat Fresnel reflectors for registration UWB pulses.

Consider the UWB signal incident normally to the reflectors surface. Its duration is $\tau = 0.2$ ns (figure 6a). The spectrum of this signal is quite wide and it occupies the band from 0 to 40 GHz (figure 7a). Registration of such a signal is a big problem.
Further investigations are connected with UWB signal interaction with narrowband device - Fresnel reflector. Figure 8 represents frequency response of Fresnel reflector for signals which were received in focal point. Operating frequency was changed $f_0 = 10$ GHz to combine it with UWB pulse spectrum maximum. It is obvious that Fresnel reflector is typical narrowband device but it has bandwidth near the combination frequencies $3f_0$ and $5f_0$. If the received signal at the focal point bandwidth is limited 0-20 GHz, the output UWB signal will be similar with “long” sinusoid whose frequency is $f_0 = 10$ GHz. Digitization of such signal can be carried out with the using a narrowband quadrature receiver. This signal carries information about original UWB signal despite of its narrowband. This will be used to restore the input UWB signal.
Output narrowband signal is a result of UWB signal spectrum filtration with known frequency response of Fresnel reflector. UWB signal spectrum reconstruction can be carried out by conducting the inverse operation with using regularized Wiener filtering (figure 6b). This operation corresponds to the solution of the inverse problem of UWB pulse reconstruction [8] or otherwise, compression of narrowband signals.

5. Conclusion
The proposed approach allows using Fresnel reflector for receiving UWB signals from ordinary narrowband devices.

Present work is done for increasing the competitiveness of Tomsk State University.

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