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An Application of Sensor Array Processing in Characterizing One Dimensional Surface Roughness

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Abstract

Part of array signal processing is focused on engineering of angular interferometry to study and characterize the properties of radiating sources and media of propagation, among the applications of array processing we find telecommunications for radio signals, geophysics for seismic waves and maritime communications for underwater acoustical sources. In this paper, we discuss the possibility of applying array processing techniques to partially characterize one dimensional surface roughness of rectangular plate, we propose a system composed of three identical arrays of sensors in far field region relatively to the rectangular plate. The principle of one dimensional roughness description is based on azimuth angle and Fraunhofer criterion. The system consists of one transmitted plane wave and three arrays that intercept the backscattered specular component and diffuse field in several directions, using a combination of multidimensional received signals that are linearly polarized, we construct one characteristic function resulting from angular scan in visible domain of uniform linear array of sensors. The proposed system is supported by numerical simulation.

Keywords: *Array signal processing, one dimensional roughness, rectangular plate, angular interferometry, diffuse reflection, specular reflection.*

1. Introduction

The objective of array processing [1,2] is the exploitation of spatial and temporal interferences of intercepted wave fronts in order to study and measure the properties of radiating sources such the directions of propagation composed of azimuth and elevation angles [1], the polarization of waveforms [3], theirs frequency spectra and theirs powers. Array processing can also be used to study the properties of propagation medium [4] which consists of many processes including, diffraction [5] when waves encounter objects and apertures whose dimensions are comparable to the carrier wavelength, reflection and refraction when waves strike different medium described by relative permittivity and permeability for electromagnetic waves [6].

Concerning the reflection phenomenon, it can divided into three categories, the first is when the surface of reflection is very flat, the reflection is considered specular [7,8,9] the angle of incidence equals the angle of reflection, if the surface presents some protuberances or small irregularities, the reflection beam consists of specular part which contains the majority of energy and the diffuse part where the propagating secondary sources take several directions concentrated around the mean [7,8,9], the last case is when the surface is very rough, the reflection is diffuse such as no direction is privileged [7,8,9]. These three types are valid for both acoustic [10] and electromagnetic

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propagations where the description of roughness is relative the wavelength of incoming waves, per example for light waves (visible domain starting approximately from $\lambda = 400$ nm to $\lambda = 700$ nm) the reflection is specular for plane mirrors and most of the surfaces are considered to be rough.

Given these cases of reflection process, characterizing the radiation sources [11,12] in an environment that contains different geometric constructions with different degree of roughness, needs to consider the case of diffuse reflection [11,12], in this case the wave fronts passing through the array of antennas consists of a waveform of the main source plus a contribution from large numbers of scattering secondary sources, a theoretical and statistical models [12] are employed to perform spectral and spatial analysis of signals obtained by the elements of the arrays.

Many papers [11,12,13,14] have dealt with the angle of arrival estimation problem in the presence of diffuse reflection case where multipath rays must be taken into account in order to precisely describe the position and the characteristics of radiating sources.

The best description of diffuse surfaces is the statistical distribution; the height of the irregularities is described as random variable sampled from well known distribution such as Gaussian one [15]. The study of such surfaces is performed using profilometric [16] and optical techniques [8,16,17], the global shapes of protuberances are analyzed with optical interferomety using reflected laser beams [17]. In the other hand, the random roughness can be classified into one dimensional [17,18], two dimensional profile [19,20] or even three dimensional [20]. Verification of degree of roughness is an important step in many industrial sectors such as the verification of substrate of some electronic devices [21] and the quality of signal transmission over the sea surface which can be under calm and rough states [12].

Unlike the ongoing researches that are focused on the characteristics of radiating sources in the presence of rough surfaces [11,12,13,14], the objective of this letter is the partial characterization of one dimensional surface roughness of rectangular plates using high resolution and narrowband array processing with respect to the far field condition [1], the scattering secondary sources resulting from diffuse reflection process are considered as secondary radiating sources besides the specular or coherent component of the reflection [7,8,9].

We propose a prototype of surface profile verification using three arrays of sensors and single transmitter in normal incidence relatively to the plane of the plate to be characterized, the sensors are of electromagnetic types, we propose a combination of three angular spectra into single spectrum that can be statistically evaluated to verify the state of constructed plate such as to build a system with binary decision, either the plate is well built and contains little roughness profiles or it requires reevaluation and corrections.

In the second part of the present letter, we describe the geometry of the prototype and the high resolution narrowband employed technique to analyze the intercepted reflected beams by the plate from three directions, next we explain the combination of the three spectra. In the third part, we perform a numerical simulation as step to verify the proposed methodology.

2. Proposed Prototype for on Dimensional Roughness Characterization

In this part, we explain the prototype of surface roughness [15,17,18,19,20] study using a group of arrays of antennas and single transmitter of wave towards the plate with normal incidence, before discussing the implementation of high resolution angle of arrival techniques [1,2], let us describe the type of surface's irregularities we are focused on.

The roughness of surface is considered as random fluctuations [15,19] of protuberances that compose the material type of the surface, thus the roughness is random, and it can be described by two dimensional [19,20] or one dimensional function [17,18], we focus here on the last category, the statistical description of the randomness states that the height of the irregularities is modeled as random variable following Gaussian probability density function [15]. For simplicity, we consider a rectangular plate with one dimensional roughness where an example is drawn in Figure 1.

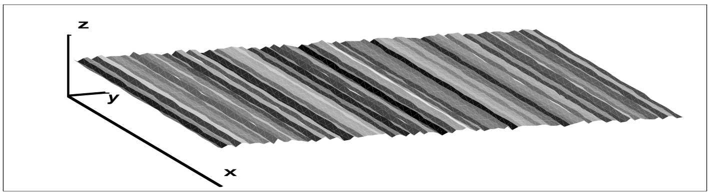

Figure 1. Example of Rectangular Plate with one Dimensional Roughness Profile z=f(y)

The plate is placed in (x, y) plane, the lines of roughness are parallel to x axis, the height of the roughness z is random variable sampled from Gaussian probability density function $\mathrm{N}(<z>, \Delta z)$. Given normal incidence of the plane wave, the surface is rough if the Fraunhofer condition [22] is verified:

$$\Delta z > 0.03\lambda \tag{1}$$

Δz is the standard deviation of roughness. The objective is to partially study the quality of plate's construction where the aim is to obtain a plate with specular or diffuse reflectance, this configuration can represent the case of certain substrate of conducting material on the plate, or per example the quality of acoustic reverberation in civil engineering. We propose the roughness quantification using narrowband angular interferometry [1,2].

Let us consider a geometry in Figure.2, three arrays are placed around the plate to test, the frontal array is composed of an odd number of sensors such as the central element is the transmitter of the waveform towards the plate in normal incidence $\theta = 0^{\circ}$.

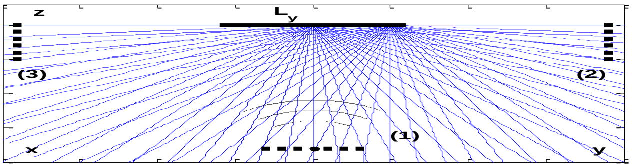

Figure 2. Prototype for One Dimensional Roughness Test of Rectangular Plate, using Three Arrays of Sensors and Single Transmitter

The rectangular plate generates the reflected rays and the diffraction effect on the edges is omitted, all the arrays are placed in far field region and have the same length $D = (N-1)d$, N is the number of elements and $d = f(\lambda)$ is the inter-element distance. The plate is placed at distances verifying the condition of the Fraunhofer region of propagation:

$$r_i > \frac{2D^2}{\lambda} \tag{2}$$

Where r_i such that (i=1,2,3) is the distance from the plate to the i^{th} array. In Figure 2, we illustrate two scattering points on the plate, as we can remark the rays from the two diffusive points are in the visible regions of the arrays, the echoes will be intercepted by the three subsystems, for simplicity we consider the case of narrowband transmission, the sensors of the arrays are identical dipoles with the same operational frequency f_c and same fractional beam width FBM=8% , the transmitting element must have different geometry so as to minimize the mutual effect near left and right dipoles, a waveguide can be used for this purpose. Concerning the orientation of the dipoles, we discuss the states of polarization [3] of both incident and scattered fields based on results reported in [23,24,25].

In fact, it was found that for visible light, the depolarization of linear polarized light on material is considerable and prominent in the case of white sand [23], it means that for weakly rough surfaces, if the incident field is linearly polarized, the depolarization process will no suppress all linear components of the electric field relatively to the roughness of the surface. Additionally, for infrared domain, it was shown that the degree of polarization is dependent on the degree of roughness of glass and metallic surfaces and the angle of incidence [24]. Therefore, having vertically oriented antennas with vertically transmitted waveform, we anticipate capturing a fraction the vertical component of the reflected field. In another study related to diffuse reflectance of rough silver surface [25], it was found that for transverse electric field incident on plate with wavelength of $\lambda = 457.9$ nm and normal incidence, the reflected field still contains the transverse component. From these results we overlook the problem of polarization by studying the reflected beams using vertically polarized electromagnetic waves given a vertically transmitted signal of the array's central element.

As basic principle, all the sensors are parallel and aligned with x axis. We begin by describing the emitted waveform by the central element of the first array, the electric field [1] coming from the single element is generally described by the following expression:

$$E_x(t) = s_0(t)e^{j(\omega t-\phi)} \tag{3}$$

The unit of E_x is V/m, $\omega = 2\pi f_c$ is the angular frequency in rad/Hz, $s_0(t)$ is the envelope of the waveform and ϕ is the initial phase. The reflected plane wave by the plate will be transformed into diffuse components in several directions and the coherent component will return to the first array with angle of arrival $\theta = 0^\circ$. The induced voltage in sensors by the scattered field is presented in vector form after down conversion by removing the carrier term $e^{j\omega t}$ [1], for the first, second and third arrays respectively, the signal models [1,26] are given by the following expressions:

$$\begin{cases} x_1(t) = s_c(t)a(\theta = 0^\circ) + \sum_{i=1}^{P} s_i(t)a(\theta_i) + n(t) \\ x_2(t) = \sum_{i=1}^{P'} s_i'(t)a(\theta_i') + n'(t) \\ x_2(t) = \sum_{i=1}^{P''} s_i''(t)a(\theta_i'') + n''(t) \end{cases} \tag{4}$$

Where $x(t) \in C^{N\times 1}$ is the signal vector in V at instant $t = 1,...,K$ where K is the total number of samples. s_c(t) is the coherent component of diffuse reflection received by the first array. $P \gg 1$, $P' \gg 1$ and $P'' \gg 1$ are the number of scattering elements on the plate where in general we have $P \neq P' \neq P''$. The scalars s(t) , $s'(t)$ and $s''(t)$ are the envelopes of scattering points, theirs statistical properties are based on transmitted pulse $s_0(t)$. $a(\theta_i) \in C^{N\times 1}$, $a(\theta_i') \in C^{N\times 1}$ and $a(\theta_i'') \in C^{N\times 1}$ are the steering vectors of the i^{th} angle of arrival that depends of the geometry of the arrays [1,26], for uniform linear arrays, the vector is $a(\theta_i)=\left(1,e^{-j2\pi\lambda^{-1}d\sin\theta_i},...,e^{-j2\pi\lambda^{-1}d(N-1)\sin\theta_i}\right)^T$. The steering matrix is therefore written as $A=[a(\theta_1),...,a(\theta_P)]$. The vectors $n(t)\in C^{N\times1}$, $n'(t)\in C^{N\times1}$ and $n''(t)\in C^{N\times1}$ are vectors of additive noise which is considered to be complex random process with zero mean [1].

Given the above model, we implement a high resolution angular interferometric technique to analyze the angles of arrival of scattering points of the plate. We note that the angle of arrival estimation for central array is performed with one missing element in the center which is the transmitting element, this effect will not have too much impact on the shape of angular spectrum. For precise quantification we need to mitigate the coherence between the envelopes of scattering points $(s(t),s'(t),s''(t))$, this is possible by controlling the shape of emitted envelope $s_0(t)$ which we consider as random process with zero mean. Thus, we assume the statistical independence between components of three subsystems as given by the following relations:

$$\begin{aligned} &< n_i(t)n_i^*(t+\tau) > &&= \sigma^2\delta(\tau) \\ &< n_i(t)n_j^*(t) > &&= \sigma^2\delta_{ij} \\ &< s_i n_j^*(t) > &&= 0 \\ &< n(t)n^+(t) > &&= \sigma^2 I_N \end{aligned} \tag{5}$$

Where $i=1,...,N$, $j=1,...,P$, P' or P''. The operator $<.>$ denotes the time average, $\delta(\tau)$ is Dirac function, δ_{ij} is Kronecker function, σ^2 is the relative noise power on subsystem and I_N is the identity matrix. Angular beam scan is generally based on second order statistics [1], the spectral matrix is given by the following relation:

$$\Gamma = < xx^+ > = A < ss^+ > A^+ + \sigma^2 I_N \tag{6}$$

Where $(.)^+$ denotes the Hermitian operation. A beam forming based method called Minimum Variance Distortionless Response (MVDR) [27] is based on maximizing the output power of the array in steering direction while maintaining a gain of unity of other directions. The localization function whose peaks indicate the provenance of scattered elements is given by:

$$f_\psi(\theta)=\frac{1}{\psi^+\Gamma^{-1}\psi} \tag{7}$$

The steering vector relatively to the first sensor is given by the following expression:

$$\psi(\theta)=\left(1,e^{-j2\pi\lambda^{-1}d\sin(\theta)},...,e^{-j2\pi\lambda^{-1}(N-1)d\sin(\theta)}\right)^T \tag{8}$$

θ is in the visible domain Ω that corresponds to each subsystem relatively to the normal of the array, As we see in Figure 2, the visible region for the first array is $\Omega_1=\left[\frac{-\pi}{2},\frac{\pi}{2}\right]$, for right array we have $\Omega_2=\left[\frac{-\pi}{2},0\right]$ and for the third array the complementary domain is $\Omega_3=\left[0,\frac{\pi}{2}\right]$.

All the arrays are connected to single processing unit, we get three spectra $f_1(\theta)$, $f_2(\theta)$ and $f_3(\theta)$. Let us take the same angular step $d\theta$ for the three functions, the two vectors f_2 and f_3 have the same size while f_1 has the double size. For complete characterization of the surface reflectance, we propose a concatenation of the three spectra as the following:

$$\begin{cases} f' = [\, f_2 \mid f_3 \,] \\ f = f_1 + f' \end{cases} \tag{9}$$

$f(\theta)$ describes the reflectance relatively to the ideal case of specular reflection of plate with no roughness, let us describe theoretically the shape of $f(\theta)$ in this case. The specular reflection is described by the law of reflection where the angle of incidence equals the angle of reflection and diffuse components of electric field are absent, given normal incidence, $f(\theta)$ contains single peak. It is possible to implement other high resolution angle of arrival techniques [1,2] for this purpose, the choice of MVDR method is based on two criteria, first is it beam forming based spectrum, the amplitudes of the peaks are proportional to the powers of radiating sources. In fact we can prove the theoretical expression of the peak's amplitude $f_{MVDR} = \left(\psi^+ \Gamma^{-1} \psi\right)^{-1}$ in the case of specular reflection as follows, the inverse of spectral matrix, based on Woodbury matrix identity, is given by the expression:

$$\Gamma^{-1} = \frac{1}{\sigma^2}\left(\frac{1}{\sigma^2} A < ss^+ > A^+ + I_N\right)^{-1} = \frac{1}{\sigma^2}\left(I_N - A\left(\sigma^2 < ss^+ >^{-1} + A^+ A\right)^{-1} A^+\right) \tag{10}$$

Since we have one reflected echo $P = 1$, we get the following simplification:

$$\Gamma^{-1} = \frac{1}{\sigma^2}\left(I_N - a_1\left(\frac{\sigma^2}{\sigma_1^2} + a_1^+ a_1\right)^{-1} a_1^+\right) \tag{11}$$

For angular beam scan, when the scan vector ψ coincides with the steering vector of source $\psi = a_1$, the scalar $a_1^+ \Gamma^{-1} a_1$ is then reduced into the following expression:

$$a_1^+ \Gamma^{-1} a_1 = \frac{a_1^+}{\sigma^2}\left(I_N - a_1\left(\frac{\sigma^2}{\sigma_1^2} + a_1^+ a_1\right)^{-1} a_1^+\right) a_1 = \frac{N}{\sigma^2} - \frac{N^2}{\sigma^2}\left(\frac{\sigma^2}{\sigma_1^2} + N\right)^{-1} = \frac{1}{\sigma_1^2 + \sigma^2 N^{-1}} \tag{12}$$

Next, the theoretical expression of the peak's amplitude is proportional to the power of the reflected wave:

$$f_{MVDR} = (a_1^+ \Gamma^{-1} a_1)^{-1} = \sigma_1^2 + \frac{\sigma^2}{N} \tag{13}$$

In the presence of large numbers of scattering elements $P \gg 1$, the spectrum $f(\theta)$ is also a function of the relative powers of sources. Indeed, it was shown in [28] that MVDR spectrum gave better resolution in the case of large number of radiating sources if they are not coherent. Let us illustrate an example in Figure 3, an array of fourteen elements with half wavelength inter-distance, we compare two spectra, the first is for specular reflection $P = 1$ and the second is for $P' = 400$ sources whose angles of arrivals are uniformly distributed in the range $[-20^\circ, 10^\circ]$.

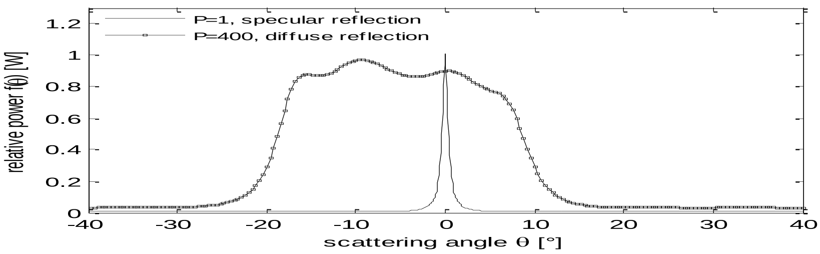

Figure 3. Simulated Specular and Diffuse Reflections with 400 Radiating Sources from -20° to 10° using MVDR Technique on Array of Half Wavelength Spaced 14 Sensors

We can remark that the MVDR technique is convenient in this case of diffuse reflection even if $A \in C^{14\times 400}$ because, firstly the objective is a characterization of the spectrum not the bearing estimation, we already know the positions of the irregularities, secondly the other high resolution techniques are not suitable in this case such as the ESPRIT algebraic technique [1] and the Propagator operator [26]. Indeed, the MVDR operator is of full rank unlike the rank one operators such as the Min Norm [1], Pisarenko Harmonic decomposition and Maximum Entropy techniques [26], per example the subspace based techniques rely on the decomposition of spectral matrix $\Gamma = U\Lambda U^{+}$ where $U \in C^{N\times N}$, the localization operator is extracted from U based on the order of the eigenvalues of Γ (diagonal elements of Λ), where the signal and noise subspace are $U=[U_S, U_n]$ with $U_s \in C^{N\times P}$ and $U_n \in C^{N\times N-P}$, the projector into the noise subspace is $P_n = U_n U_n^{+}$, it is clear that for diffuse reflection case $P' >> N$, it is difficult to select U_n. The theoretical expression in equation (13) is the same for basic beam forming [1] spectrum defined by the relation:

$$f_{bf}(\theta) = \frac{1}{N^2}\psi^{+}\Gamma\psi \tag{14}$$

For the same case of single source, the amplitude of the peak when $\psi = a_1$ is given by:

$$f_{bf} = \frac{1}{N^2} a_1^{+}a_1a_1^{+}a_1\sigma_1^2 + a_1^{+}a_1\sigma^2 = \sigma_1^2 + \frac{\sigma^2}{N} \tag{15}$$

However this method presents a drawback of low resolution, the spectrum cannot separate two sources such as their angular difference $|\theta_i - \theta_j|$ is less than Rayleigh angular resolution limit of array that is approximately:

$$\theta_{limit} \approx \frac{\lambda}{D} \tag{16}$$

Let us now discuss the repartition of the radiating power for the system, the input power transmitted from the central element σ_0^2 is transformed into coherent backscattered component of the field σ_c^2, absorbed power by the plate σ_a^2 where it is considered negligible, diffuse power in several directions where the majority of the component is intercepted by the three arrays, we consider that the total number of scattering points is $P+P'+P"$, and finally diffuse power in other polarized states, besides the vertical component, where we denote M as the number of scattering sources, the power repartition can be described by the following equation:

$$\sigma_0^2 = \sigma_c^2 + \sum_i^{P}\sigma_i^2 + \sum_j^{P'}\sigma_j^2 + \sum_k^{P''}\sigma_k^2 + \sigma_a^2 + \sum_l^{M}\sigma_l^2 \tag{17}$$

Data analysis of echoes is based on the first four parts of the above equation while the two last parts are overlooked. Since we can set the conditions of the experiment, we ensure that all the elements of the arrays are calibrated and that the testing signal has higher power relatively to the internal noise of the sensors σ^2 which is equivalent to higher Signal to Noise Ratio defined by the relation $SNR = 10log_{10}(\sigma_s^2/\sigma^2)$. For performance analysis of the proposed system, we present some numerical results in the next section.

3. Numerical Results

In this section we conduct a numerical simulation to study the effectiveness of the system composed of three arrays for surface roughness quantification. We consider a rectangular plate given by width, height and thickness L_x=10 cm, L_y=10 cm and L_z=2 mm. One side of the plate is characterized by random one dimensional

roughness with standard deviation approximately $\Delta z = 0.4$ mm, the lines of protuberances are parallel to x axis similarly to the example given in figure 1. Three arrays each consisting of $N = 15$ dipoles vertically placed along x axis and single transmitting antenna, the operational frequency is $f_c = 25$ GHz and the uniform distance between the antennas is half the wavelength $d = \lambda / 2 = 0.6$ cm, this value gives the array's length $D = (N - 1)d = 8.4$ cm and the Fraunhofer criterion of roughness is 0.375 mm. The central array is parallel to the plate as described in Figure 2, with distance $r_1 = 1.25$ m and other arrays are perpendicular to the plate with distances $r_2 = r_3 = 2D^2 / \lambda = 1.176$ m.
We consider that transmitted waveform has power of $\sigma_0^2 = 2$ W where its half is diffused into different polarized states, the coherent backscattered field has power of $\sigma_c^2 = 0.55$ W while 0.45 W is diverged into other directions where the majority is intercepted by three arrays. The envelope of the transmitted signal $s_0(t)$ is chosen as random process with zero mean.

For diffuse reflection simulation, data analysis is performed after the acquisition of the array signals with number of samples $K = 400$. We consider that for the central array, the received signals $x_1(t)$ are from $P = 800$ equipowered scattering points with directions of arrival being random variables in the range $\left[-20^\circ, 20^\circ\right]$ where the total power is 0.15 W and the signal to noise ratio is $\text{SNR}_1 = 20$ dB, plus specular component defined by the level of $SNR_c = 25$ dB.

For the second array, we suppose that the signals $x_2(t)$ are linear superposition of $P' = 400$ equipowered radiating sources where the directions of arrivals are randomly in the range $\left[-90^\circ, 0^\circ\right]$, the total power is also 0.15 W and $\text{SNR}_2 = 25$ dB. Next, we consider, for the third array, that $P'' = 500$ sources coming from directions randomly chosen in range $\left[0^\circ, 90^\circ\right]$, with $SNR_3 = 25$ dB.

It is assumed that all the envelopes of sources $s(t)$ are modeled by complex random signals with zero mean, therefore, the sources are not correlated. We simulate the collected echoes by computing the angular localization functions, using MVDR technique, which are $(f_1(\theta), \Omega_1)$ for the first array, $(f_2(\theta), \Omega_2)$ and $(f_3(\theta), \Omega_3)$ for the second and the third arrays respectively, the angular step is chosen as $d\theta = 0.1^\circ$. After combining the three spectra by means of equation (9), the obtained function $f(\theta)$ is compared with that of specular reflection case $f_s(\theta)$. In Figure 4, we normalize and transform the spectra $f(\theta)$ and $f_s(\theta)$ into Cartesian coordinates where the horizontal segment represents the dimensions L_y and L_z of the plate.

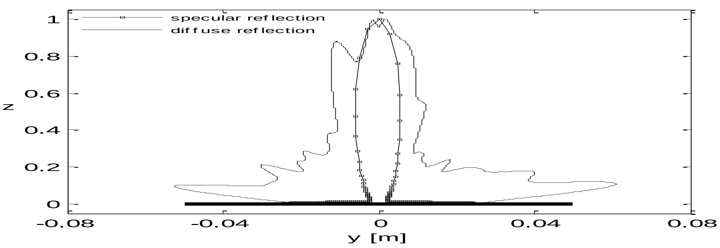

Figure 4. Simulated Specular and Diffuse Reflections of Rectangular Plate with One Dimensional Roughness $\Delta z = 0.4$ mm, using combined MVDR Spectra from Three Arrays of Vertical Sensors with Wavelength $\lambda = 1.2$ cm

The shape of diffuse reflection localization function obtained from the three arrays is considerably successful in detecting the multi paths of diffused rays from the plate into several directions, as we described above the case of diffuse reflection with coherent component, we remark from the figure that f contains the coherent component in normal direction, which is wider than that of f_s. Statistical analysis between two spectra can be effectuated using different tools, we choose the correlation coefficient ρ as metric, and its value for two unnormalized spectra is:

$$\rho = \frac{<(f-<f>)(f_s-<f_s>)>}{\sqrt{<(f-<f>)^2><(f_s-<f_s>)^2>}} \simeq 0.22 \tag{18}$$

Based on this value, we consider that for linearly polarized component of scattered field, this plate has 22% of desired reflectance according to the reference plate. As summary, In some industrial processes, the quality of construction of rectangular plate can be statistically characterized using far field or near field array processing procedure with chosen threshold of correlation coefficient and Fraunhofer criterion of roughness.

The proposed setup is considered as possible alternative method for surface roughness test instead of using optical methods where it is not mandatory to function with very large number of sensors. The system does not need very special conditions to operate and it can be used to test both sides of the plate. Indeed, depending of the degree of roughness it is possible to study the state of the plate using only the central array $f_1(\theta)$. Additionally, the engineering of the system is easy such as we can manually change the orientation of the dipoles and analyze the collected echoes for each angle of rotation in order to study the possible polarizations of diffuse reflection. Finally, the generalization of the system into two dimensional roughness profiles test is possible using two dimensional arrays such as rectangular and circular types.

4. Conclusion

We have proposed, in this paper, a prototype to partially characterize one dimensional surface roughness using system composed of three identical arrays of antennas and single transmitter of the reference signal towards the rectangular plate in normal incidence. The model is based array signal processing spectral technique where the reflection consists of coherent component plus diffused elementary sources in the far field. Multidimensional signal models are based on linearly polarized reflected echoes. In order to characterize the reflectance of metallic plate, not only the backscattering field was studied but also the diffused field using arrays placed perpendicularly to the plate, protuberances measurements were performed by combining three beam forming based spectra. As preliminary test of the proposed system, numerical simulation was carried out for both specular and diffuse reflections.

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