Modeling ground clutter for high-resolution short-range radar at low grazing angles

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ABSTRACT

Short-range radars have got applications as navigation guide for automobiles, helicopters and aircraft landing guidance requirements. The prototype model of W-band short-range radar using FM-CW transmission principle is developed recently at DEAL. In high-resolution scenario, clutter spikes predominate in the backscattering from ground causing a high-degree of false alarm in traditional methods of detection of possible targets. Developing models for high-resolution ground clutter is therefore necessary for a sound strategy to reduce false alarms from clutter spikes. In this paper, we present the high-resolution clutter models being developed for analyzing such backscattering from ground.

Keywords: High-resolution, clutter, FM-CW, radar.

1. INTRODUCTION

Short-range radars are popular as navigation guide for automobiles, helicopters and aircraft landing guidance requirements [1], [2]. Traditionally W-band radars use transmission at 77GHz [1], and frequency modulated continuous wave (FM-CW) is the modulation technique used for short-range detection purposes [2].

It is well established that W-band propagation at 94GHz is capable of penetrating fog and dust that suits its use particularly in adverse weather. There is effectively an improvement of 3.15dB in target radar cross-section (RCS) by transmission at 94GHz than at 77GHz. Still few industry-standard operational radar exist at 94 GHz [3]. This is due to very limited output RF power and non-linearity in phase of FM-CW transmission at 94GHz.

We have developed the prototype model of short-range radar at 94GHz using FM-CW transmission. There are several new features in the model that augment its applications in multiple scenarios. The radar uses very small power (10dBm at RF output), has good sensitivity for targets at ranges within 100m with a range-resolution of around one ft. The scanning mechanism of the radar permits ideally 360° of azimuthal view of the scene, provides information about targets in the scan interval by real-time signal processing and target detection. The elevation beamwidth is kept 30^0 for a large view of the horizon, and for non-zero depression the beam in the elevation touches ground causing a large amount of backscattering from diffused scatterers present on the ground. The prototype model of the short-range radar used for laboratory measurements is shown in Figure 1, and is described in detail in [6].

In FM-CW transmission, the received backscatter power is divided among frequency bins over the beat-frequency bandwidth for detection purposes. The range resolution corresponds to the bandwidth of each frequency bin, and a low sweep frequency of 1.5 KHz in FM-CW modulation provides equivalent high-range resolution for the short-range radar. Backscattering from ground targets have to compete with the clutter power from these diffuse scatterers for detection purposes. This background clutter causes a high-degree of false alarm for traditional methods of detection of possible targets in amplitude or power domain. In this paper, we present the high-resolution clutter models being developed for analyzing backscattering from ground.

2. BACKGROUND OF CLUTTER MODELS

For low-resolution radar, the standard model of clutter due to diffuse radar backscattering is to describe the process as a complex Gaussian distribution. The phase of the instantaneous backscatter is independent of amplitudes and is uniformly distributed in $[0,2\pi)$ considering a large number of independent, identically distributed (*i.i.d.*) scatterers present in the low-resolution cell of observation, and it is assumed that no single scatterer dominates the scene. This model assumes the presence of a finite set of n independent scattering entities, thus interpreting clutter as the result of interference of corresponding n contributions. Assuming n to be large, the probability density function (*pdf*) of clutter is a gamma distribution for integration of power from returns of L sweeps.

$$p_V(v) = \frac{1}{\Gamma(L)}\left(\frac{L}{\sigma^0}\right)^L v^{(L-1)} \exp\left(-\frac{Lv}{\sigma^0}\right), \quad v \geq 0. \tag{1}$$

Here $\Gamma(.)$ is the standard gamma function, and σ^0 is the mean clutter power per unit area in the resolution cell. Estimation of the single parameter σ^0 can be generated from (1) by the method of moments (MoM) as

$$\frac{\left\langle v^k \right\rangle}{\left\langle \sigma^0 \right\rangle^k} = \frac{\Gamma(k+L)}{\Gamma(L)L^k}. \tag{2}$$

However, in a high-resolution radar system a given resolution cell may contain only a few independent scattering entities. This number n itself is a random variable caused by the bunching process of birth-death and migration in high-resolution measurements [4]. Therefore, high-resolution clutter is modeled as modulation of σ^0 by the bunching of scatterers. The modulation decorrelates slowly in sweep-to-sweep measurements compared to the *speckle* phenomenon observed from coherent averaging of diffused scatterers. Incorporation of two degrees of freedom in the *pdf* allows the description of the high-resolution natural clutter as a *compound* model [5]. One component of this compound model is the local power of speckle arising out of the diffused scatterers that decorrelates rapidly. Unlike the low-resolution case, the mean of this local power is not constant, but gets modulated by a slowly varying (nonetheless random) process.

The *pdf* of high-resolution clutter can be described by taking into account a random variable σ signifying the wide variation in mean clutter power σ^0.

$$p_V(v) = \int_0^\infty p_V(v \mid \sigma) p(\sigma) d\sigma, \; v \geq 0 \tag{3}$$

where $p(\sigma)$ is the pdf of σ. Considering $p(\sigma)$ to be gamma distributed, the gamma-gamma *pdf* of the compound Gaussian model of clutter power is [5]

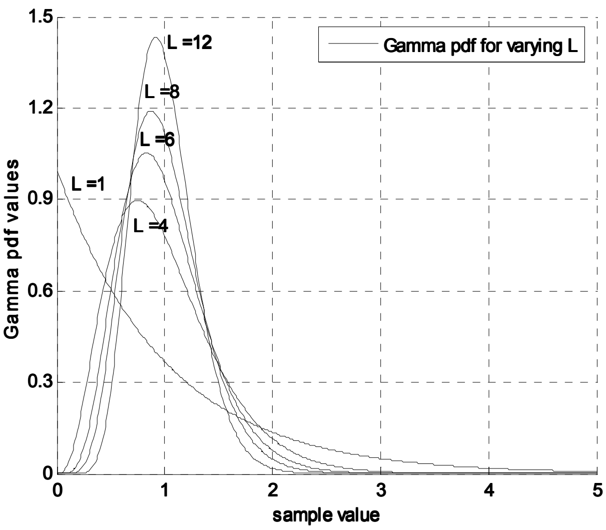
$$p_V(v) = \frac{1}{\Gamma(L)\Gamma(M)}\left(\frac{2LM}{<v>}\right)\left(\frac{LM}{<v>}v\right)^{(L+M-2)/2} K_{M-L}\left[2\left(\frac{LM}{<v>}\right)^{1/2} v\right]. \tag{4}$$

Here M is the shape parameter for the gamma *pdf* $p(\sigma)$, and $K_{M-L}(.)$ is the second kind modified Bessel function of order (M-L). The mean estimate of $<v> = <\sigma>$. Assuming speckle from the high-resolution cell and the modulation in the mean power to be independent of each other, the parameters $<v>$, M can be estimated by the MoM as

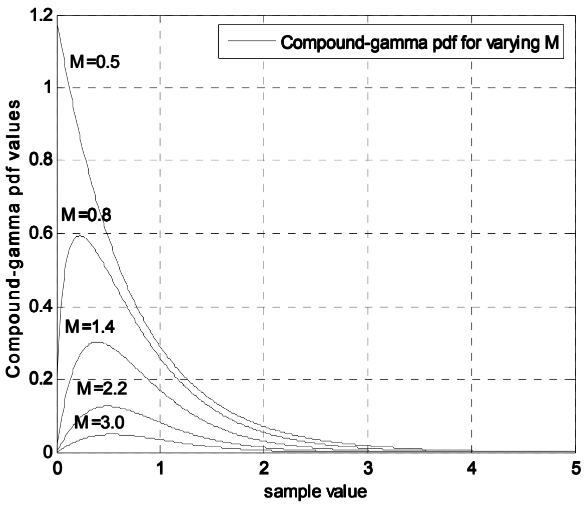
$$\frac{\left\langle v^k \right\rangle}{\left\langle v \right\rangle^k} = \frac{\Gamma(L+k)}{\Gamma(L)L^k}\frac{\Gamma(M+k)}{\Gamma(M)M^k}. \tag{5}$$

This deviation in estimation of moments in (5) from the Gaussian case in (2) shows the compound nature of high-resolution clutter. The compound model of clutter in (4) is a general description of the family of long-tailed *pdf* that fit into backscatter data from various high-resolution observations.

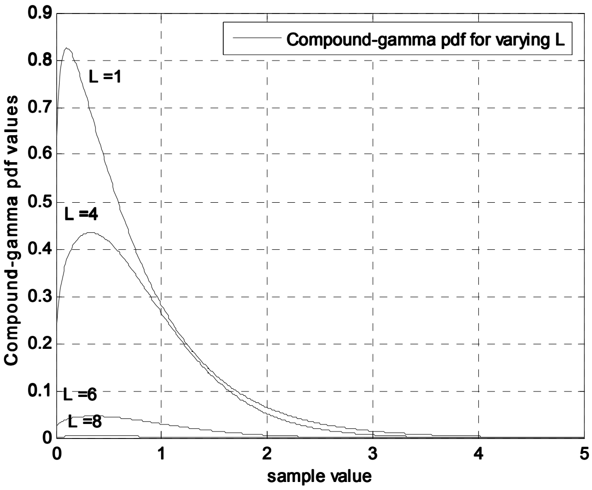
Fig. 1. (a) Rear view of the prototype model of radar with the signal-processing unit housed in side the trolley, (b) front view of the W-band RF sensor mounted on top of trolley with a vehicle target at short distance.



(a)



(b)



(c)

Fig. 2. Distribution plots for clutter: (a) family of gamma *pdf* for varying number of pulses *L*, (b) family of compound-Gaussian *pdf* for varying values of shape parameter *M*, (c) family of compound-gamma *pdf* for varying values of *L*. Mean value of clutter power σ^0 =1 in all the three figures.

Gamma model of low-resolution clutter and the compound-gamma model of high-resolution clutter are shown in Fig. 2(a) and Fig. 2(b)-(c) respectively. The *pdf* in Fig. 2(a) approaches Gaussian nature with increasing L for the low-resolution case, but the long-tailed nature of high-resolution compound clutter distribution is apparent in Fig. 2(b)-(c). In Fig. 2(b), the *pdf* family is drawn with variation in shape (modulation) parameter M. It is seen that with increasing values in M, the mean value in clutter approaches stationarity although the long-tailed nature of distributions confirm presence of spikes in the high-resolution data. The *pdf* family in Fig. 2(c) are drawn for fixed value in modulation parameter, M = 0.6. It is seen that the effect of modulation in σ^0 is nullified with increasing values of L for the compound-gamma model.

3. MODELING CLUTTER FROM OBSERVED GROUND BACKSCATTER

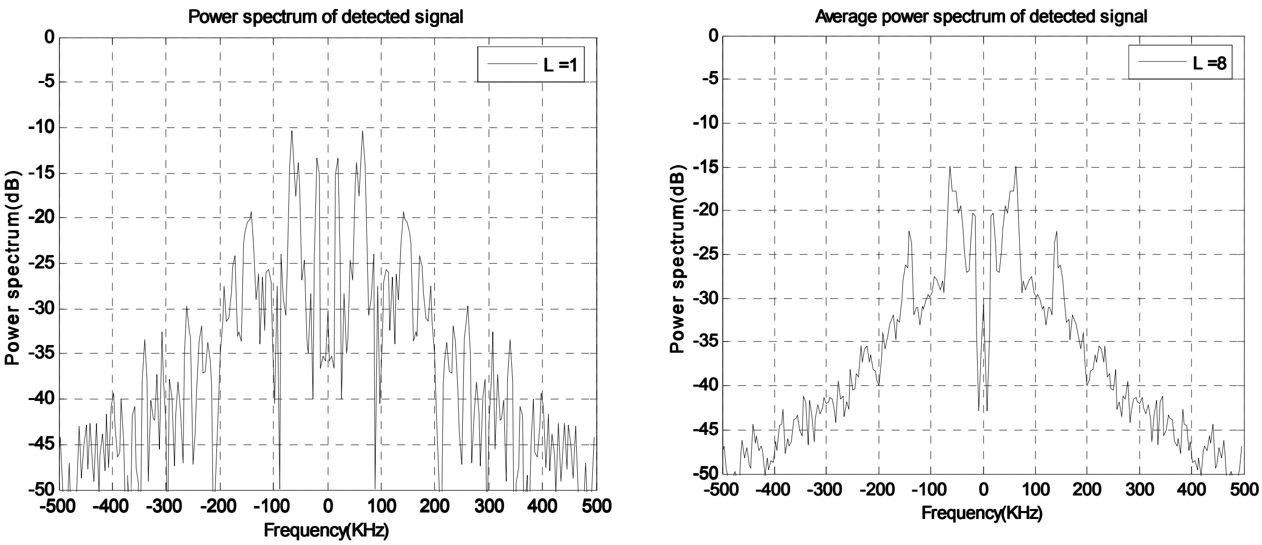


Fig. 3. Power spectrum of detected video signal for the target shown in Fig. 1(b); (a) spectrum distribution for single FM sweep, (b) spectrum after averaging of eight FM sweeps.

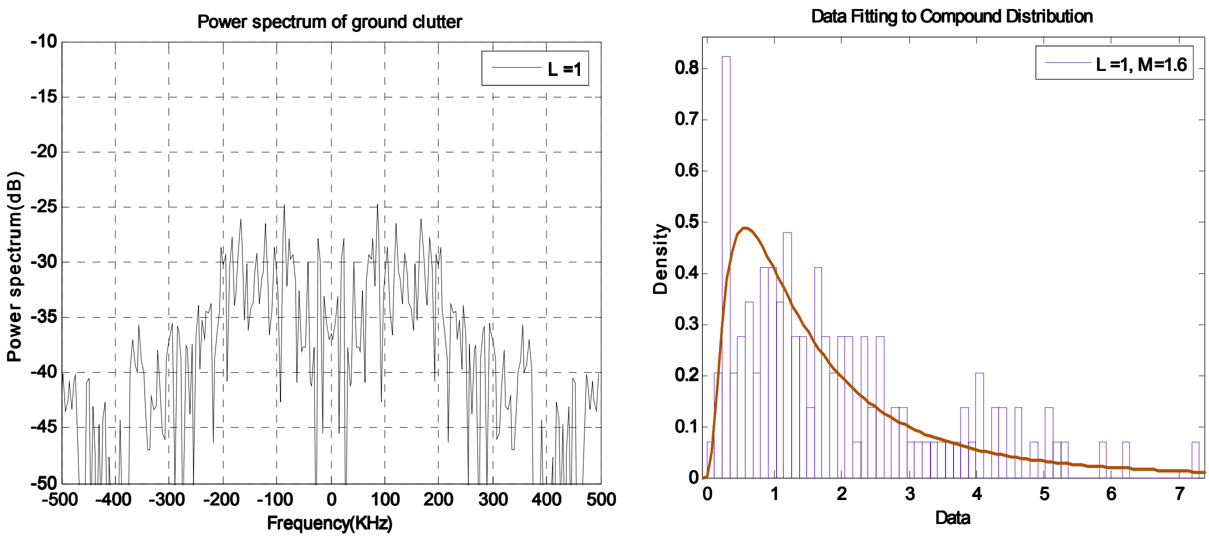


Fig. 4. (a) Spectrum distribution of clutter for diffuse backscattering from ground, (b) compound Gaussian distribution fitting to the histogram of power spectrum; L = 1, M = 1.6.

In this section, we show the results of clutter modeling from diffuse backscattering after detection by the short-range radar shown in Fig. 1. The power spectrum of detected video signal for one FM sweep is shown in Fig. 3(a) and the result after averaging in power domain for eight FM sweeps is shown in Fig. 3(b). The detected target response lies in the frequency bin of 96.54KHz corresponding to a range of 16.43m from the radar shown in Fig. 1(b). The two-sided frequency response of power spectrum is symmetrical as the short-range radar detects only real beat-frequency signals. The fluctuations of target response that are apparent for a single FM sweep are averaged out for eight-sweep response shown in Fig. 3(b). The power spectrum of diffuse backscattering from ground for a single sweep (L =1) is shown in Fig. 4(a) representing clutter for the trial scenario. The peak gain in detected target signal to clutter ratio is 10dB from Fig. 3(b) and Fig. 4(a). The clutter response for positive frequencies is plotted in the histogram in Fig. 4(b). The best fit of compound Gaussian clutter *pdf* model is shown by brown color in Fig. 4(b) that represents M =1.6, a shape parameter value for modulation in σ^0. The mean value of σ^0 can be estimated from repeated trial results of compound clutter model. This would be necessary for determination of appropriate threshold limit to remove clutter from target response for the short-range radar.

4. CONCLUSION

Modeling high-resolution clutter is crucial to isolate false alarm response from spiky ground clutter for the short-range radar at W band. Compound Gaussian clutter models are found to be suitable to account for modulation in mean clutter power σ^0 and are described in the paper. An approach is shown in the paper for the best-fit *pdf* model to describe ground clutter response for the short-range radar.

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