

TERRAIN BIAS ON DOPPLER SYSTEM OUTPUT*

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Abstract

Statistically random rough surfaces cause a spread of their doppler spectrum obtained by a transmit-receive system. This is shown to hold both theoretically as well as experimentally. An x-band radar system flight data and its ultrasonic simulation data constitute the experimental effort. Furthermore, a thorough and complex random variable transformation solution yields a normal distribution for such a doppler signal after mixing and passing it through a low pass filter. This is also verified by experimental data.

Summary

It is a common practice to think of doppler output of a radar or sonar system as monochromatic. In practice the random variation of planetary, earth, and ocean surfaces as well as ocean bottom significantly alter this assumed monochromatic nature of the doppler signal into a frequency band-limited output. In this work it is assumed that the surface heights are normally distributed. Furthermore, the facet approach is used to show their effect on the doppler term. For instance, a transmitted signal: $e_t(t) = \sin \omega_c t$ becomes:

$$e_t(t) = \tilde{A} \sin(\omega_c t + \tilde{\phi}_d + \tilde{\phi}_s)$$

where $\tilde{\phi}_d$ = doppler term = $k \sin(\theta_0 + \tilde{\phi})$

$\tilde{\phi}$ = randomly varying surface slopes (= $\tan \alpha$)

θ_0 = inclination of transmitter-receiver beam

$\tilde{\varphi}_a$ = phase angle due to random amplitude variation $\tilde{A}$.

It has been previously shown that the random amplitude modulation $\tilde{A}$ and its associated phase angle modulation $\tilde{\varphi}$ are strictly surface caused effects, whereas $\tilde{\varphi}_d$ is the surface caused randomly varying doppler term, if one takes out the antenna modulation effects. Furthermore, it is well understood that long time averages of $\tilde{A}$ and $\tilde{\varphi}_d$ show these to be statistically independent, and Rayleigh and uniformly distributed respectively. The surface heights being normally distributed result in their slopes being normally distributed with approximately related, mean, variance, and correlation functions due to the fact that differentiation is a linear operation. Thus it preserves the form of the probability density function of the original variable.

Now the problem resolves down to beating the received signal $e_r(t)$ with the local oscillator producing the carrier frequency ω_c and passing it through the low-pass filter to get rid of $2\omega_c$ term. This results in

$$e'_r(t) = \tilde{A} \sin(\tilde{\varphi}_d + \tilde{\varphi}_a).$$

A transformation of variable $\tan \varphi$ into $\tilde{\varphi}$ and its subsequent transformation into $K \sin(\theta_0 + \tilde{\varphi})$ yields the following probability density functions

$$P_{\tilde{\varphi}}(\varphi) = \frac{1 + \tan^2 \varphi}{\sigma \sqrt{2\pi}} \exp\left[-\frac{\tan^2 \varphi}{2\sigma^2}\right], \text{ for } -\frac{\pi}{2} < \varphi < \frac{\pi}{2}.$$

and it is essentially uniform over the region, and

$$P_{\tilde{\varphi}_d}(\varphi_d) = \frac{1}{\pi (K^2 - \varphi_d^2)^{1/2}}$$

A continuation of this transformation of variables from $\tilde{\varphi}_b, \tilde{\varphi}_a$ to $\tilde{A}$ yields the probability density of $\tilde{\theta} = \tilde{\varphi}_d + \tilde{\varphi}_a$ as

$$p_{\tilde{\theta}}(\theta) = \frac{1}{2\pi^2} \left[\sin^{-1} \frac{\theta+n}{k} - \sin^{-1} \frac{\theta-n}{k} \right]$$

and the corresponding probability density function of $e'(t) = e$:

$$p_e(e) \approx \frac{n}{k} \frac{e^{-x^2/2\beta^2}}{(\beta^2 2\pi)^{1/2}}$$

where $n = \sin^{-1} \theta$ in $-k-n < \theta < k+n$,

which is Gaussian in form.

This result was then verified from experimental data obtained by an x-band doppler system flight over the White Sands area in New Mexico, as well as by the laboratory ultrasonic simulation of the lunar landing radar at the University of Houston. The x-band radar system was the actual landing module radar for the Apollo manned flight mounted in a helicopter and flown at various altitudes and velocities. Similarly, the ultrasonic simulation of the landing module radar package was accomplished by using lead zirconate transducers at 1.0 megacycle frequency. An identical doppler electronics system was built at the University of Houston. Here a complex non-linear lunar model surface was used as the target surface in a 20' diameter, 25' deep water tank.

The results of the experimental data analysis seem to support the theoretical results discussed earlier.