United States of America

OUT-OF-BAND 40 DB BANDWIDTH OF EARTH EXPLORATION-SATELLITE SERVICE (ACTIVE) AND THE SPACE RESEARCH SERVICE (ACTIVE) SARS AND RANGE SPECTRUM OVERSAMPLING NOISE-TO-SIGNAL RATIO

1. Introduction

Annex 8 “OOB Domain Emission Limits for Primary Radar Systems” of the ITU-R Recommendation SM.1541 includes active spaceborne sensors in the EESS (active) and SRS (active) as space-based radars covered by this recommendation. The waveform characteristics of the spaceborne SARs within the Earth Exploration-Satellite Service (Active) and the Radiolocation Service determine the SAR range spectrum oversampling noise-to-signal ratio (N/S). The multiplicative noise from the SAR range spectrum oversampling is typically budgeted as part of the overall multiplicative noise ratio (MNR) of the SAR system. Optimizing the MNR by selecting the waveform characteristics typically yields increased spectra roll-off and improves the spectra roll-off and resulting OOB 40 dB bandwidth. This document presents an analysis of the selection of waveform characteristics to optimize the SAR range spectrum oversampling noise-to-signal ratio (N/S) and the effect upon the out-of-band (OOB) 40 dB bandwidth

2. Calculation of Range Spectrum Oversampling MNR

Synthetic aperture radars (SARs) within the EESS (active) typically have different modes for SAR imaging, SAR interferometry, and moving target indication (MTI). The active spaceborne sensor typically uses the synthetic aperture radar stripmap technique to obtain low azimuth resolution, uses the spotlight technique to obtain fine azimuth resolution, and uses MTI techniques for motion detection. The linear FM pulse compression technique is used to obtain both low and fine range resolution. However, the linear frequency versus time history in both azimuth and range suffers degradation with the introduction of multiplicative noise, one component of which is the range spectrum oversampling noise. The range spectrum oversampling noise ratio is dependent on the time-bandwidth product (TBP), since the range spectrum skirts fall off faster with increased TBP.

For instance, the MNR contributors are assumed to be below –20 dB for the low and fine resolution stripmap modes, and -35 dB for the fine resolution spotlight mode, as shown in Table 1. The calculation of the range spectrum oversampling MNR (OMNR) is similar to that for the azimuth ambiguity sidelobe ratio (AASR) and it is the ratio of the summation over the processed part of the aliased range offset video spectrum to the summation over the processed part of the bandwidth of the range offset video spectrum, which is the following:

$$OMNR = \frac{\sum_{m\neq 0}\int_{-B/2}^{B/2} S\ \left(f+mf_s\right)df}{\int_{-B/2}^{B/2} S\ \left(f\right)df}$$

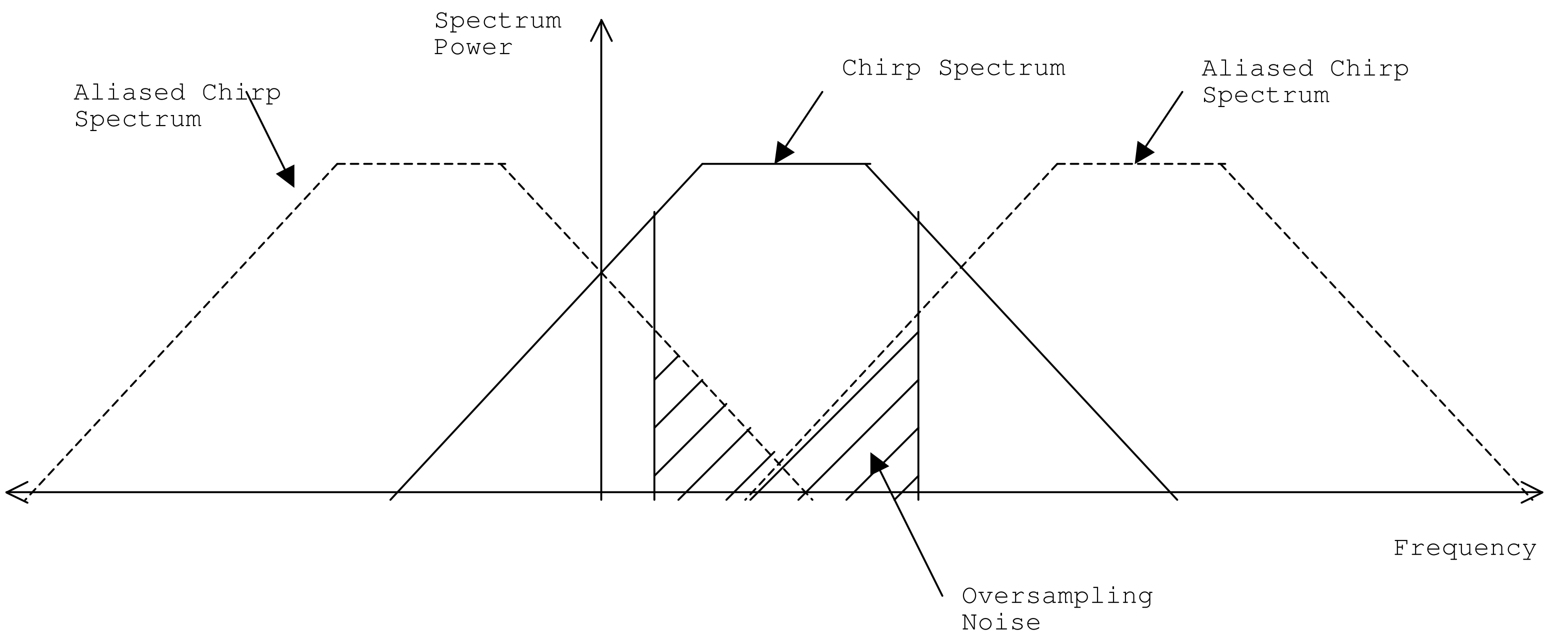


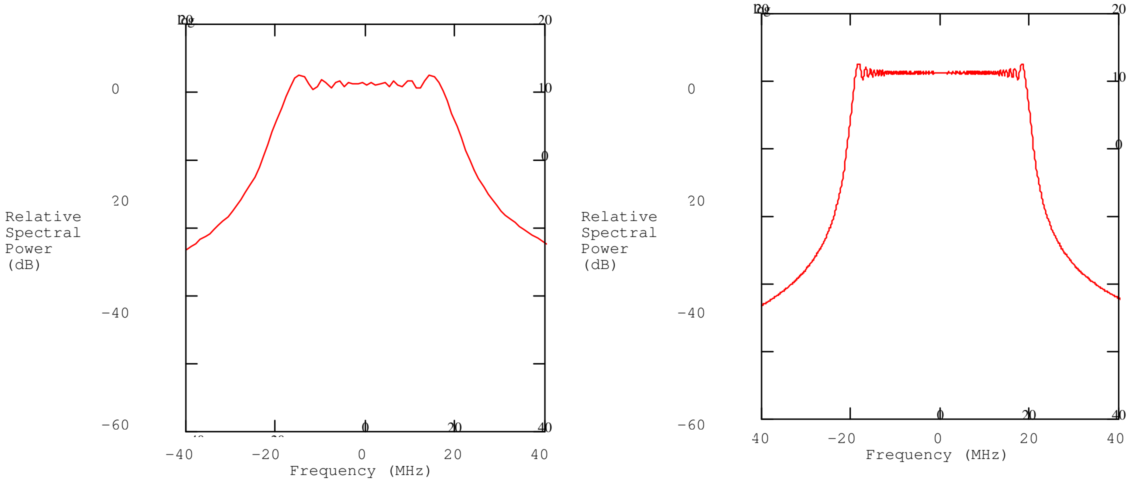
Figure 1. Aliased Range Spectrum with Oversampling Multiplicative Noise

where B is the range bandwidth, S is the range power spectrum, and f_s is the oversampling frequency (typically 1.125 B). Figure 1 illustrates the aliased multiplicative noise spectrum from oversampling.

Table 1. SAR Multiplicative Noise Ratio (MNR)			
MNR Components	Low Res Stripmap (dB)	Hi Res Spotlight (dB)	Hi Res Stripmap (dB)
Range Spectrum Oversampling	-20 to -39	-29 to -35	-37
Azimuth Ambiguity	-20	-35	-20
Range Ambiguity	-20	-35	-20
Integrated Sidelobe Ratio	-20	-35	-20
Quantization Noise	-21 (4 bits)	-45 (8 bits)	-21 (4 bits)
Total (dB)	-13.2 to – 14.2	-26.5 to – 28.9	-14.2

Table 2 shows the range oversampling MNR (OMNR) for the various typical SAR modes and MTI modes. Figure 2 shows the range spectrum for chirp time-bandwidth products of 40 and 400 for rectangular pulses. Figure 3 shows the range oversampling MNR versus oversampling factor (1.125 to 1.5) for three values of TBP (40, 400, and 4000). Figure 4 shows the range spectrum for chirp time-bandwidth products of 40 and 400, for trapezoidal pulses.

Table 2. Range Oversampling MNR for Rectangular Pulses				
Mode	Bandwidth (MHZ)	Pulse-width (micro-sec)	Time-Bandwidth Product	Range Oversampling MNR (dB)
Low and Fine Resolution Stripmap SAR	40	1 to 100	40 to 4000	-20 to -39
Fine Resolution Spotlight SAR	80	5 to 20	400 to 1600	-29 to -35
MTI	3 to 10	20 to 106.7	60 to 1067	-24 to -33



(a) (b)

Figure 2. Chirp Spectrum with Rectangular Pulse
(a) bandwidth=40 MHz, pulsewidth=1 microsec (b) bandwidth=40 MHz, pulsewidth=10 microsec

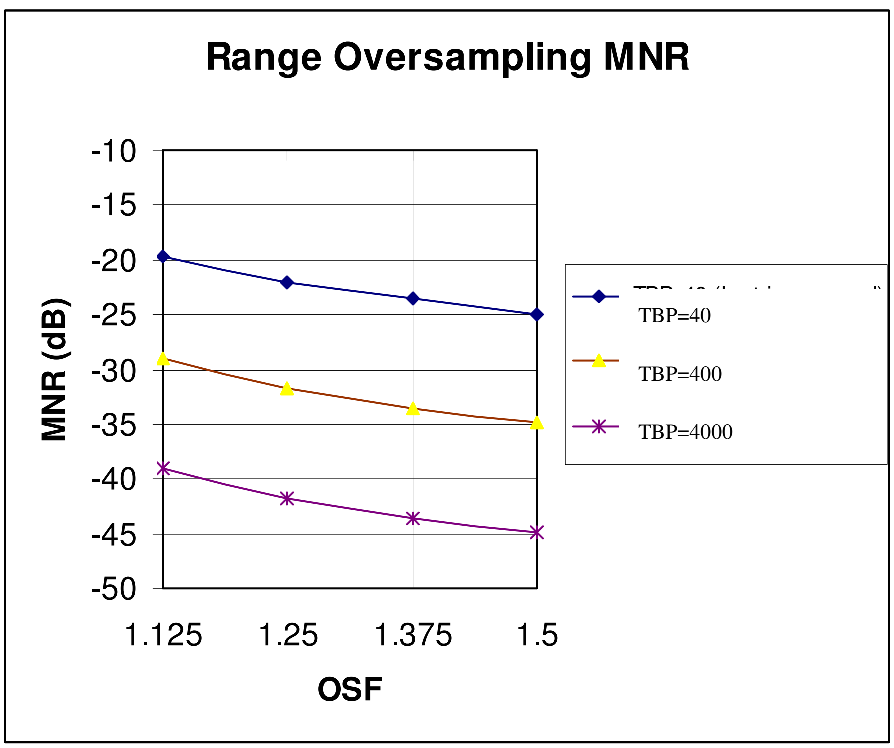
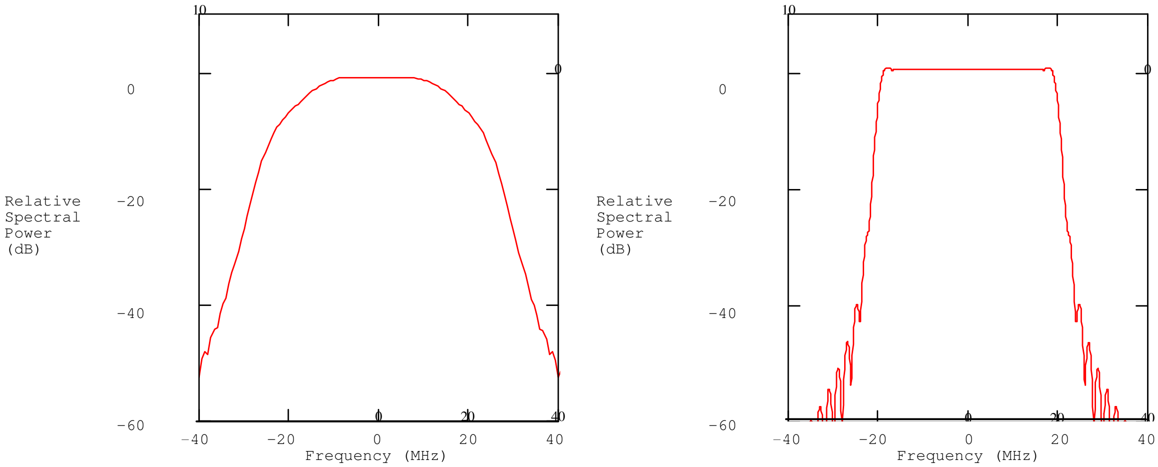


Figure 3. Range Oversampling MNR Versus Range Oversampling Factor for Rectangular Pulse



(a) (b)

Figure 4. Chirp Spectrum with Trapezoidal Pulse
(b) bandwidth=40 MHz, pulsewidth=1 microsec, t_r=t_f=0.4 microsec (b) bandwidth=40 MHz, pulsewidth=10 microsec, t_r=t_f=0.4 microsec

3. Effect on Necessary Bandwidth and Out-Of-Band 40 dB Bandwidth

In Annex 8 "OOB Domain Emission Limits for Primary Radar Systems" of the ITU-R Recommendation SM.1541 are given formulas for necessary bandwidths and 40 dB bandwidth. For frequency modulated pulse radars, the necessary bandwidth (20 dB bandwidth) formula exceeds the symmetrical trapezoidal pulse case by twice the frequency deviation B_c:

$$B_n = \frac{1.79}{\sqrt{t \cdot t_r}} + 2B_c \qquad (1)$$

For FM-pulse radars, the 40 dB bandwidth is:

$$B_{-40} = \frac{7.6}{\sqrt{t \cdot t_r}} + 2\left[B_c + \frac{0.065}{t_r}\right] \qquad (2)$$

Table 3 compares the frequency deviation B_c, the necessary bandwidth B_n, and the 40 dB bandwidth B_{-40} for a rectangular pulse, a trapezoidal pulse, and the ITU-R Rec SM.1541 equations.

Table 3. Comparison of B_c, B_n, and B_{-40} for Rectangular Pulse, Trapezoidal Pulse, and ITU-R Rec SM.1541 Equations

Pulse	Band-width (MHZ)	Pulse-width (micro sec)	Rise and fall time (micro sec)	Fre-quency Devia-tion (B_c)	Neces-sary Band-width (B_n)	40 dB Band-width (B_{-40})
Rectangular						
TBP=40	40	1	0.001	40.0	66.9	352.6
TBP=400	40	10	0.01	40.0	47.1	97.5
Trapezoidal						
TBP=40	40	1	0.4	40.0	56.0	69.4
TBP=400	40	10	0.4	40.0	42.8	47.6
ITU-R Rec SM.1541						
TBP=40	40	1	0.4	40.0	82.8	92.3
TBP=400	40	10	0.4	40.0	80.9	84.1