SMALL-SATELLITE SYNTHETIC APERTURE RADAR SYSTEMS DESIGN CONSIDERATIONS

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As part of New Zealand's recent endeavours to acquire spaceborne surveillance capability for monitoring maritime activities, the development of Small-Satellite Synthetic Aperture Radar (Small-Sat SAR) systems has been an active field of research. A salient feature of the Small-Sat SAR is its compact profile, making it relatively inexpensive to manufacture and launch. However, to maintain cost-effectiveness and compactness, restrictions on the size and performance compromise to the onboard componentry (e.g., antennas and signal processing hardware) are inevitable.

In this paper, the major implications of these restrictions on the performance of the Small-Sat SAR systems are discussed. Firstly, the spatial resolution of the SAR is closely related to the physical dimension of the antenna. In order to achieve full resolution potential in both azimuth (i.e., the direction of the satellite motion) and ground range (i.e., the direction perpendicular to the satellite motion), the antenna of the SAR must first satisfy the minimum surface area condition [pg. 21, 1] given by

$$A_a = W_a L_a > 4V_r \lambda R_m \frac{\tan(\theta_y)}{c} \tag{1}$$

where W_a and L_a are the width and length of the antenna respectively, V_r is the relative velocity between the satellite and the target, R_m is the distance between the satellite to the centre of the radar footprint, θ_y is the incidence angle of the signal, and c is the speed of light. For antennas that satisfy (1), the Small-Sat SAR system can provide the sufficient spatial resolution required for monitoring maritime activities. For example, a SAR system with a look angle of 40° with an antenna surface area of $3m^2$, transmitting a 100 MHz bandwidth signal can provide spatial resolution up to $\Delta x = 1.69$ m in the azimuthal direction and $\Delta y = 3.87$ m in the ground range direction.

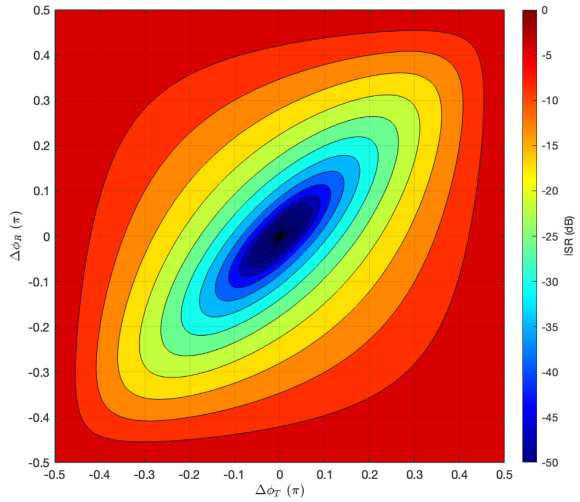

Fig 1. ISR at varying values of phase IQ mismatch at TX (ϕ_T) and RX (ϕ_R)

Secondly, a further restriction to consider is the specification of the onboard electronics. In Small-Sat SAR, the use of low-cost, off-the-shelf components is usually essential to maintain cost-effectiveness. Consequentially, noise generated from various non-ideal components can affect the overall accuracy of the SAR. For example, a possible signal quality degradation may be observed at quadrature mixers as IQ phase mismatches [pg. 71, 2] occur. As shown in (2), phase mismatch at the transmitting (i.e. ϕ_T) and receiving (i.e. ϕ_R) could introduce an unwanted conjugated signal:

$$y(t) = \alpha(\phi_T, \phi_R) \cdot s_{tx}(t-\tau) + \beta(\phi_T, \phi_R) \cdot s_{tx}^*(t-\tau) \tag{2}$$

where $\alpha_\phi(\phi_T, \phi_R)$ and $\beta_\phi(\phi_T, \phi_R)$ are two-dimensional mismatch functions, $s_{tx}(t-\tau)$ is the transmitted signal with propagation delay τ. In practice, the impact of the conjugate signal may be thresholded in design by investigating ISR (i.e., the ratio between the $|\beta|^2$ and $|\alpha|^2$), as shown in Fig. 1.

Other non-idealities of onboard electronics may include phase noise in stable local oscillators, quantisation clipping in ADC/DAC, and non-linearities in power amplification [pg. 48, 2]. As these imperfections propagate along the signal processing chains, an 'informed' design strategy for architecture using per-component simulations is likely to be essential to minimise the performance impact of the proposed Small-Sat SAR.

1. J.C. Curlander, R. N. McDonough, *Synthetic Aperture Radar Systems and Signal Processing*, John Wiley & Sons Inc., USA, 1991.
2. L. Smaini, *RF Analog Impairments Modeling for Communication Systems Simulation Application to OFDM-based Transceivers*, *John Wiley & Sons,* United Kingdom, 2012.