1 Narrowband receiver signal

The narrow-band RWP signal at the output port of the low noise amplifier can be written as

$$S_{rx}(t) = A(t)\cos\left[\omega_c t + \Phi(t)\right].$$

All available information about the scattering process is contained in the amplitude and phase modulation of the received signal $S_{rx}(t)$. It is technically difficult to sample such a signal, therefore a demodulation step is performed first, which essentially removes the irrelevant carrier frequency ω_c while the modulation information contained in the instantaneous amplitude $A(t)$ and the instantaneous phase $\Phi(t)$ remains unchanged.

2 Demodulation: Analytic signal

For demodulation, a new signal $S^+(t)$ with the Fourier spectrum $\hat{S}^+$ is created:

$$\hat{S}^+(\omega) = \hat{S}(\omega) + \mathrm{sgn}\left[\omega\right]\hat{S}(\omega).$$

This operation removes the negative part of the original signal spectrum. The signal $S^+(t)$ is called the analytic signal or pre-envelope of $S(t)$, see McDonough and Whalen (1995) .

In the time domain, it is formed as

$$S^+(t) = S(t) + i\mathcal{H}\left[S(t)\right],$$

where the operator $\mathcal{H}$ denotes the Hilbert transform.

The analytic narrowband signal can be written as

$$S^+(t) = \left[\tilde{S}(t)e^{i\omega_c t}\right],$$

where $\tilde{S}(t)$ is the complex envelope of the original signal. Multiplication of $S^+(t)$ with $e^{-i\omega_c t}$ removes the carrier and gives the complex envelope

$$\tilde{S}(t) = S^+(t)e^{-i\omega_c t} = (S(t) + i\mathcal{H}\left[S(t)\right])e^{-i\omega_c t} = I(t) + iQ(t),$$

where the real part of the complex envelope is the so-called in-phase $I(t)$ and the imaginary part $Q(t)$ the quadrature phase of the signal. The Hilbert transform is not easily implemented in real systems. Instead, the in-phase and quadrature-phase components are determined using a quadrature demodulator. Details depend on the receiver architecture of the RWP.

3 Range gating

For a fixed beam direction, RWP transmit a series of short electromagnetic pulses, each one separated by a time interval ΔT. For a single pulse, the sampling in time allows the determination of the radial distance of the measurement using the well-known propagation speed of the wave group. The maximum distance for unambiguously determining the measurement distance is limited by the pulse separation or inter-pulse-period ΔT and $h_{max} = c\Delta T/2$ is called the maximum unambiguous range. ΔT has to be set sufficiently high to prevent range aliasing problems, that is arrival of backscattering signals from the preceding pulse after the next pulse is transmitted. For a typical wind profiler it is if the order of $10^{-4}s$.

Range gating is usually done in the A/D process using sample and hold circuitry. The sample strobe required for range gating and pulse repetition is provided by the radar controller. If the range sampling frequency is given by $1/\Delta t$ and N_h is an integer denoting the number of range gates with $\Delta T < N_h \Delta t$, then signal $\tilde{S}(t)$ is obtained at the discrete grid

$$\tilde{S}[j,n] = \tilde{S}(t_0 + j\Delta t + n\Delta T)\ , j = 0, \ldots, N_h - 1, \quad n = 0, \ldots, N_T - 1.$$

For each range gate j, that is for the height $c/2 \cdot j \cdot \Delta t$, a discrete time series of the complex envelope of the signal with a sampling interval of ΔT is obtained (Hardware effects like the group delay of the pulse in the radar electronics are ignored for simplicity).

4 RWP raw data

For every range gate, a complex time series is obtained as

$$S[n] = S_I[n] + iS_Q[n], \qquad n = 0, ..., N_T - 1.$$

Note that the range gate index and the tilde denoting the complex envelope are suppressed for convenience.

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