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On phase measurement in FMCW Radar Systems

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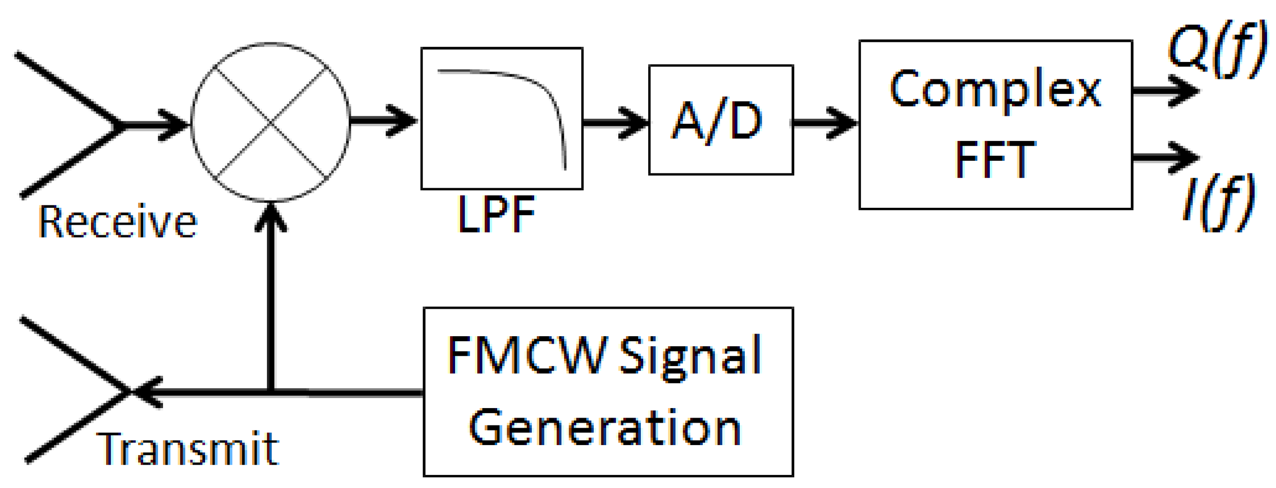
ABSTRACT

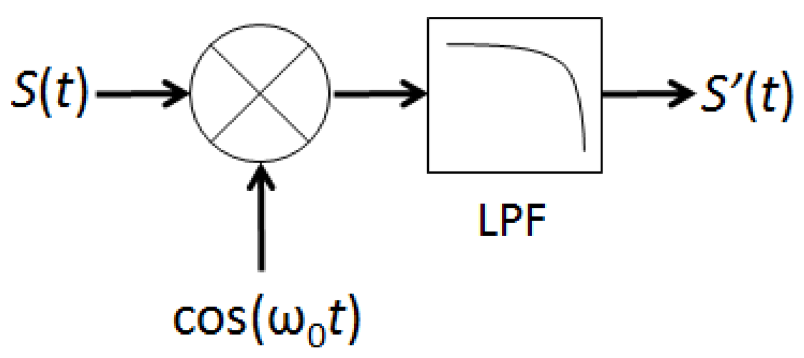
Unlike AM and PM systems, FM systems do not necessarily require the use of a dual I/Q receiver for unambiguous phase measurement. In this paper we describe this phenomenon in detail and work out the conditions when single-channel phase measurements can be used for the reliable measurement of the phase and the Doppler frequency of targets in FMCW radar systems. The developed theory is applied to surveillance and automotive radar systems to determine the velocity bounds for the unambiguous measurement of phase. The influence of phase noise in the same context is discussed. Results of coherent averaging on the data acquired using a single-channel radar system are presented to validate the theory.



Frequency-domain phase measurement using an FMCW radar

ANALYSIS OF MODULATED SIGNALS

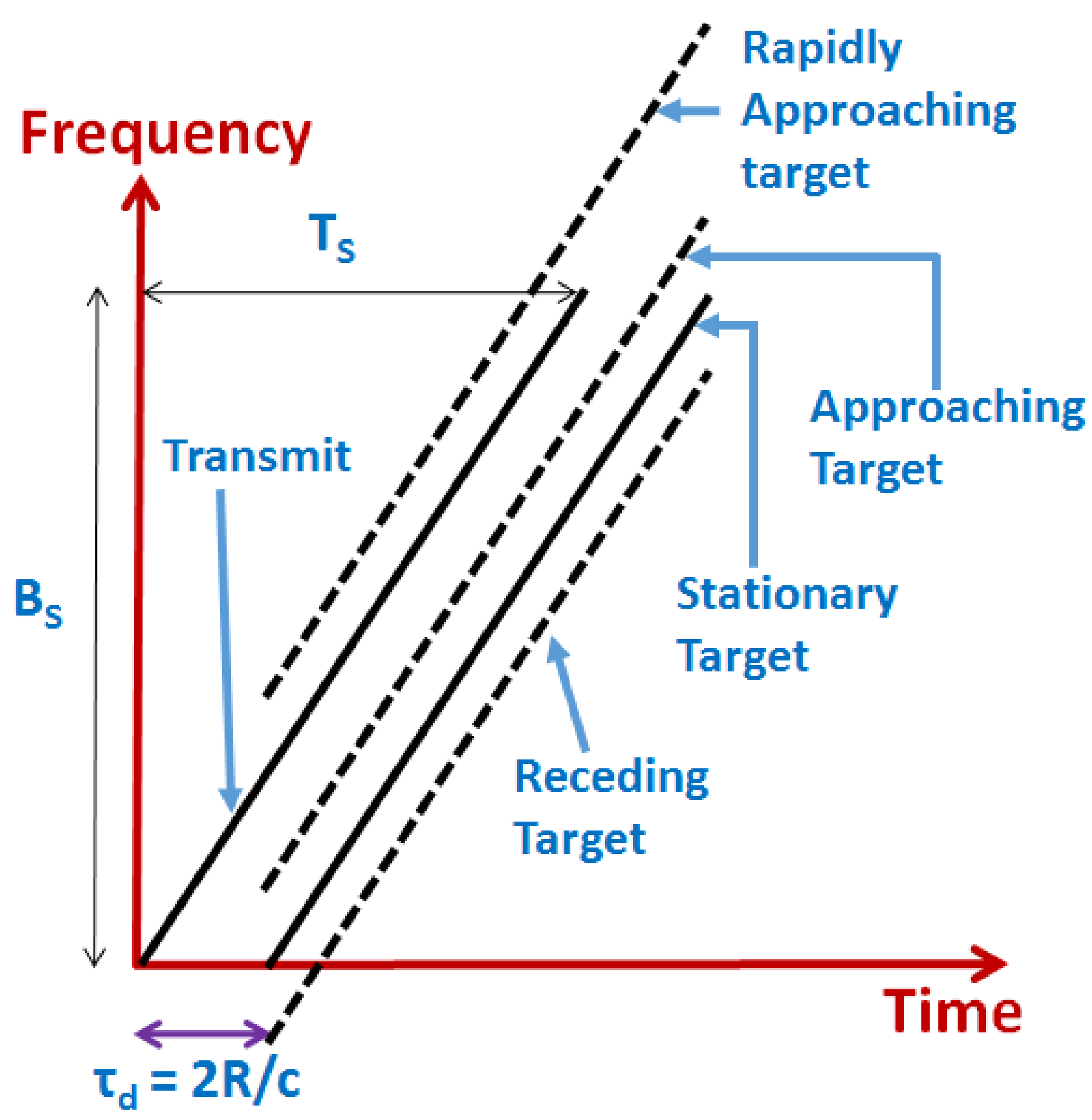
$$S_{AM}(t) = A_1\left[1 + m_a(t)\right]\cos(\omega_0 t + \theta_0) \quad (1)$$
$$S_{PM}(t) = A_2\cos(\omega_0 t + m_\theta(t) + \theta_0)\,;\,|m_\theta| < 1 \quad (2)$$
$$S_{FM}(t) = A_3\cos([\omega_0 - \omega_m]\,t + \theta_0)\,, \quad (3)$$



$$S'_{AM}(t) = A'_1 m_a(t)\cos(\theta_0) \quad (4)$$
$$S'_{PM}(t) \approx A'_2 m_\theta(t)\sin(\theta_0) \quad (5)$$
$$S'_{FM}(t) = A'_3\cos(\omega_m t - \theta_0)\,. \quad (6)$$

Coherent Demodulation.

THE VELOCITY BOUND FOR FMCW RADAR SIGNALS



$$S_{IF}(t) = A_0\cos(2\pi f_{b0}t - \theta_0)\,;\quad |f_{b0}| = \frac{B_S}{T_S}\tau_d. \quad (7)$$

$$f_D = \frac{2\nu}{\lambda} < \frac{B_S}{T_S}\tau_d \Rightarrow \nu < \frac{\lambda B_S R}{c T_S},$$

PARAMETERS OF FMCW RADAR SYSTEMS

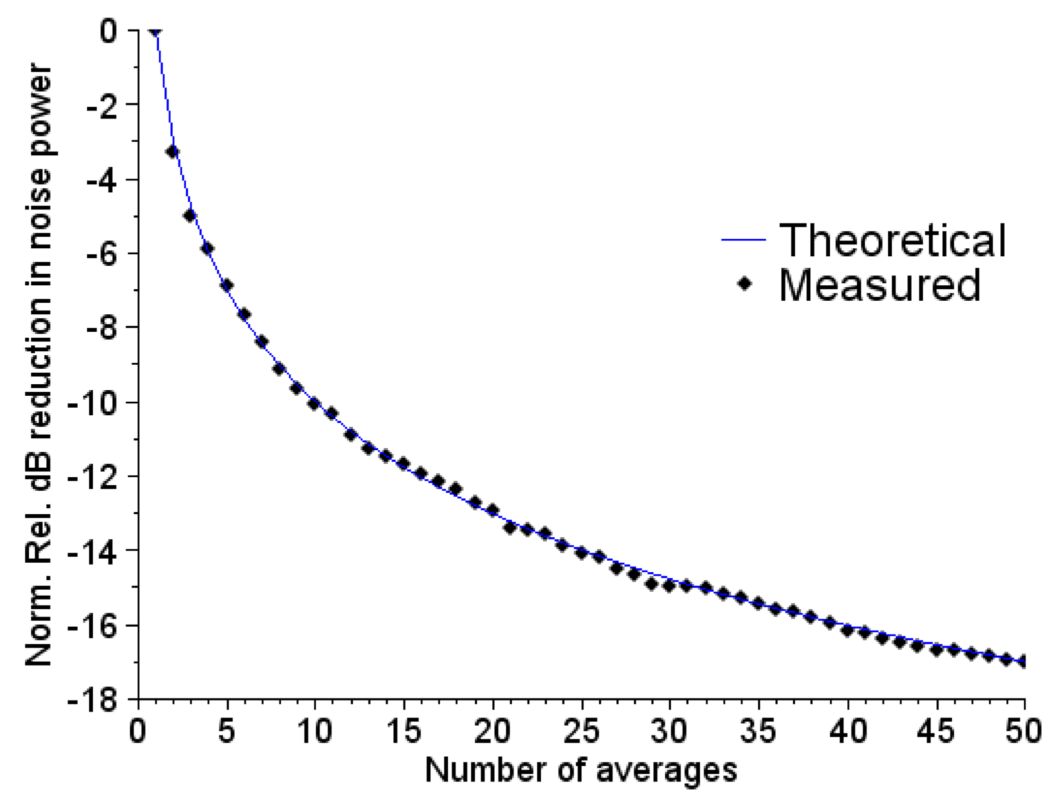
Parameters	Surveillance	Automotive
Carrier Frequency	76.5 GHz	24 GHz
Carrier Wavelength	3.9216 mm	12.5 mm
Sweep Time T_S	2 ms	1 ms
Coherent Processing Interval (CPI)	2 ms	64 ms
Doppler Resolution, $1/CPI$	500 Hz	15.625 Hz
Velocity Resolution, $\lambda/(2CPI)$	0.98 m/s	0.0977 m/s
Swept Bandwidth B_S	600 MHz	150 MHz
Doppler Shift at 1 m/s	510 Hz	160 Hz

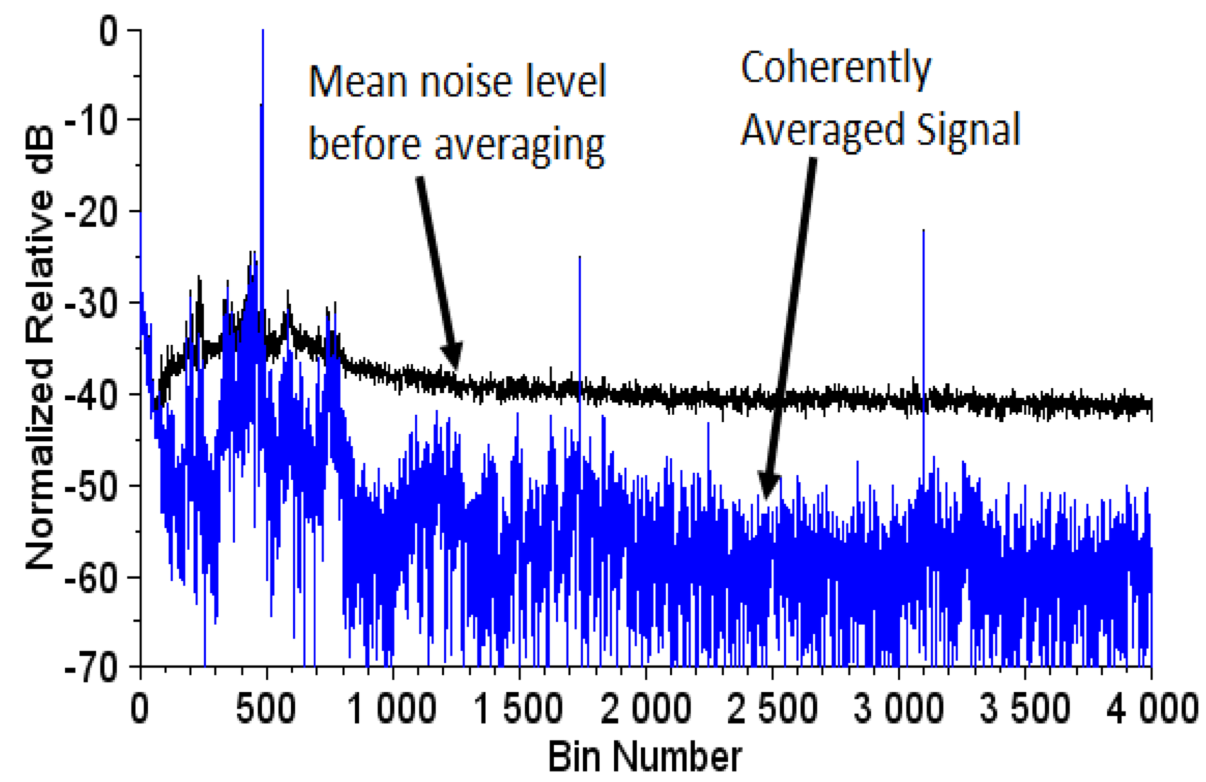
MAXIMUM VELOCITY CALCULATIONS

Range	Surveillance		Automotive	
	m/s	mph	m/s	mph
1 m	3.92	8.77	6.25	14
10 m	39.2	87.7	62.5	140
100 m	392	877	625	1400

- The triangular sweep has the Doppler limit on both the up-sweep and the down-sweep (i.e. approaching as well as receding targets).
- Other waveforms employing only the up-ramp or the down-ramp will have the Doppler limit for approaching or receding targets only.

MEASUREMENT RESULTS





CONCLUSION

In this work we analysed the effectiveness of the FMCW radar architecture employing only a single channel detector followed by complex FFT processing to extract the phase information. A mathematical analysis of various modulation schemes was presented to give the idea a strong theoretical foundation. It was found that the said radar architecture successfully measures the phase information for static targets. For moving targets a maximum velocity condition was derived for unambiguous phase measurement. Practical examples demonstrated that this condition is easily met in a wide variety of applications. Coherent averaging performed on measurements from a surveillance FMCW radar system shows an improvement in SNR according to the theoretical prediction, signifying reliable phase measurement.