Non-Coherent Discrete Chirp Fourier Transform for Modulated LFM Parameter Estimation

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Introduction

Linear frequency modulated (LFM) waveforms play a significant role in both military and civilian detection and ranging applications. Based on LFM, researchers have designed a **phase shift keying (PSK)** modulated LFM waveform to enable both communication and radar functions simultaneously. Estimating the chirp rate and the carrier frequency of data modulated LFM waveforms are therefore of interest in defence applications. In the previous research, the **discrete chirp-Fourier transform (DCFT)** was proposed to estimate the parameters for non-modulated waveforms. However, the DCFT method is limited with respect to the transform length and the estimation range. Thus, this paper proposes a generalised **coherent DCFT** that extends the previous DCFT method. We also introduce a novel **non-coherent DCFT** to improve parameter estimation for PSK modulated LFM waveforms.

System Model

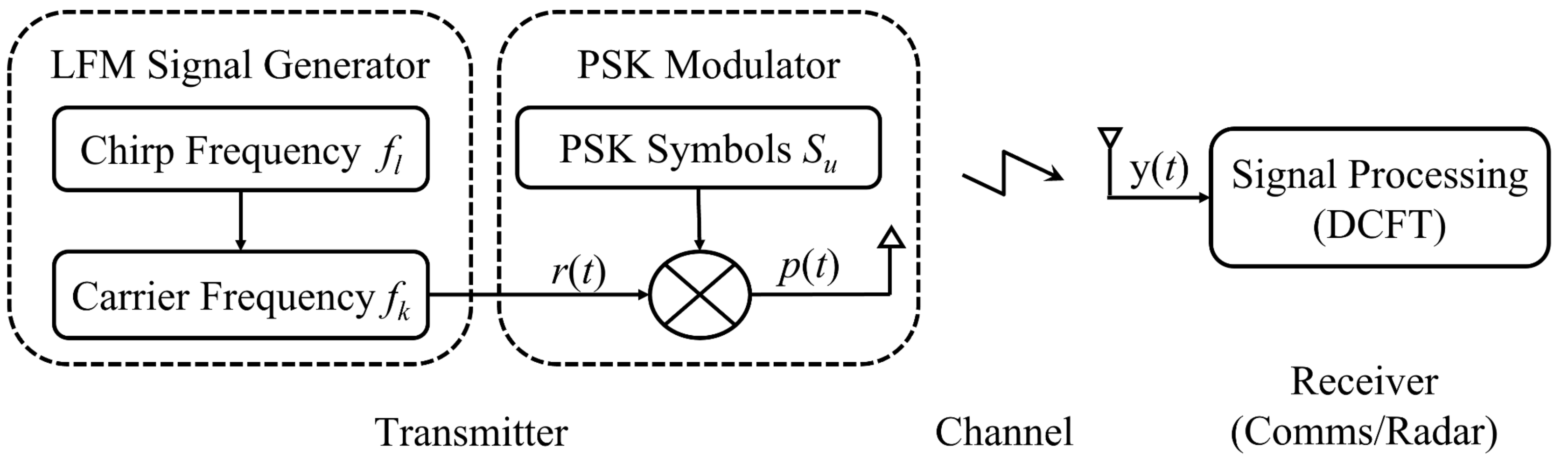


Fig. 1. Joint Radar and Communications System Model.

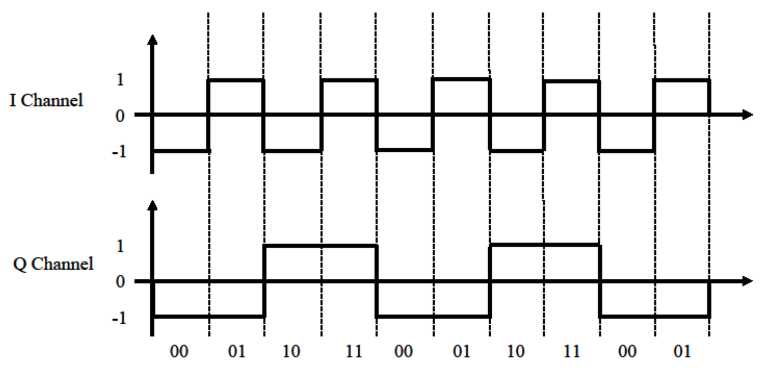


Fig. 2. Example of QPSK symbols.

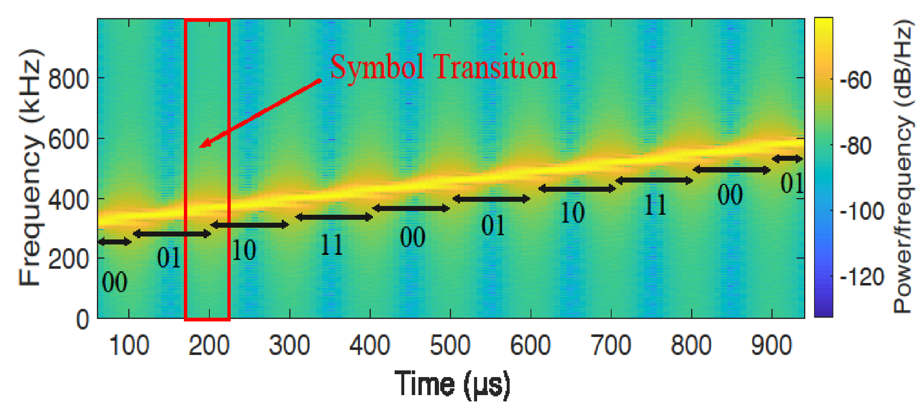


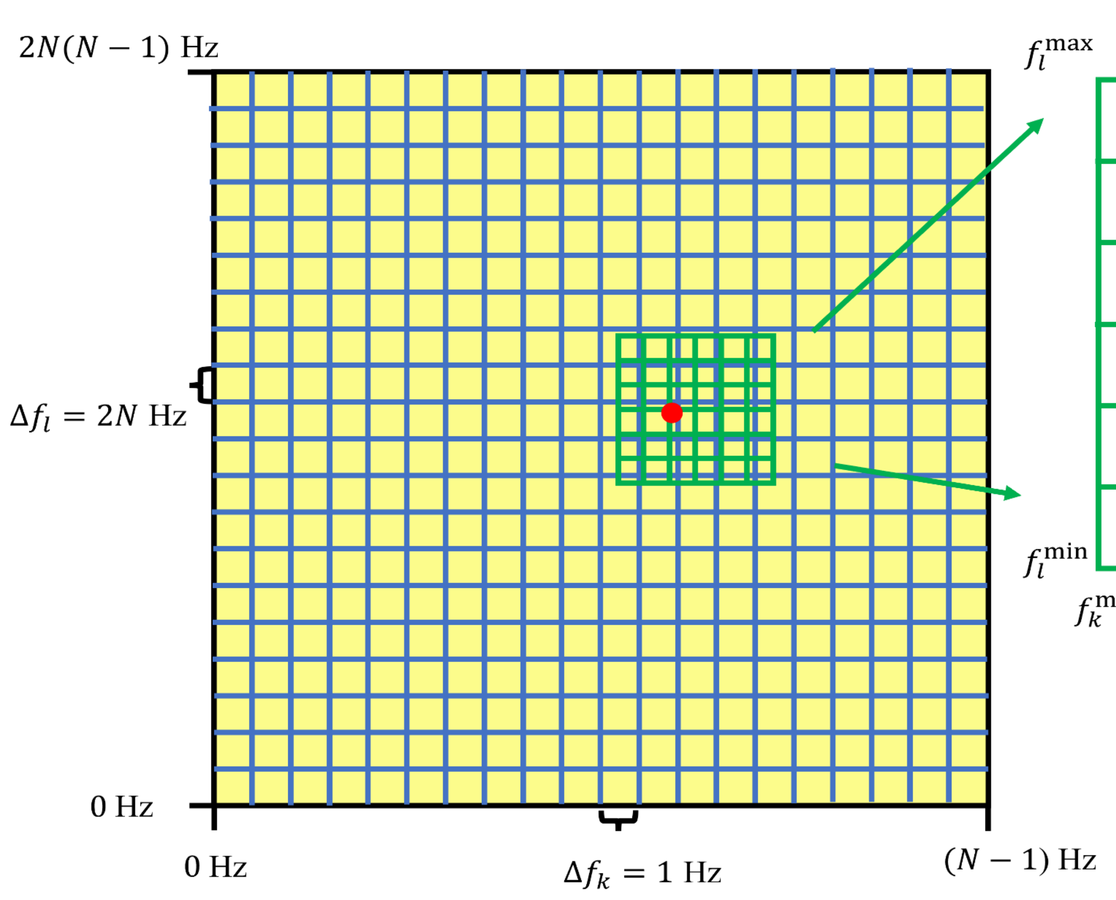
Fig. 3. Spectrogram of QPSK-LFM waveform.

Coherent DCFT

- When $W_N = \exp(-2\pi j/N)$ and the data length of $x[n]$ is N, the N-point traditional DCFT is

$$X[l,k] = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x[n] W_N^{ln^2+kn}, \qquad l,k = 0,1,\cdots,N-1.$$

- We modify the above DCFT into the coherent DCFT by
  1. specifically restricting the estimation ranges as ($f_l^{\min}$, $f_l^{\max}$), ($f_k^{\min}$, $f_k^{\max}$) – as shown in the green grid;
  2. determining the length of the the DCFT K depending on the demands of resolution.



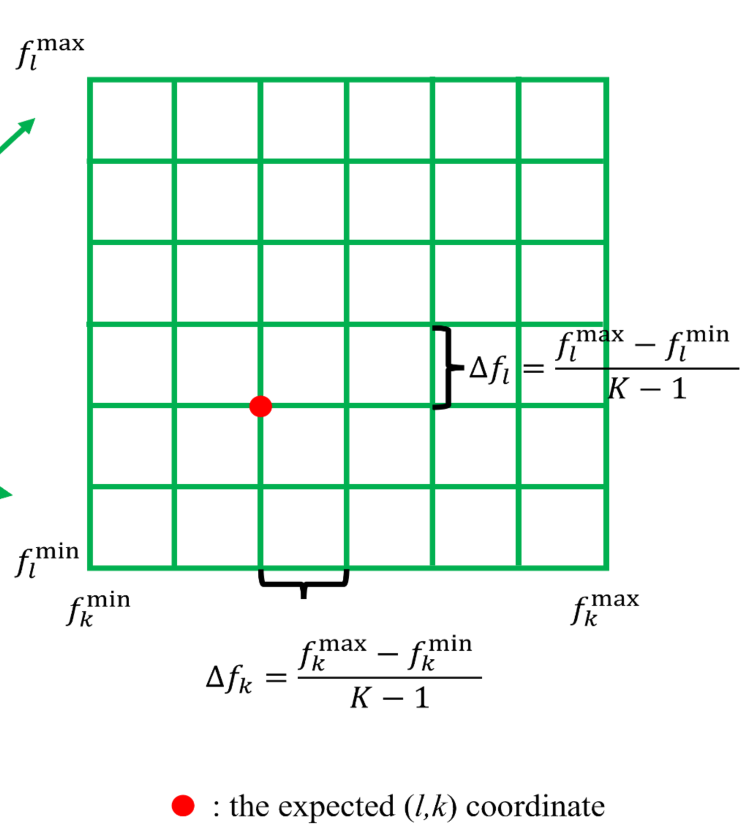
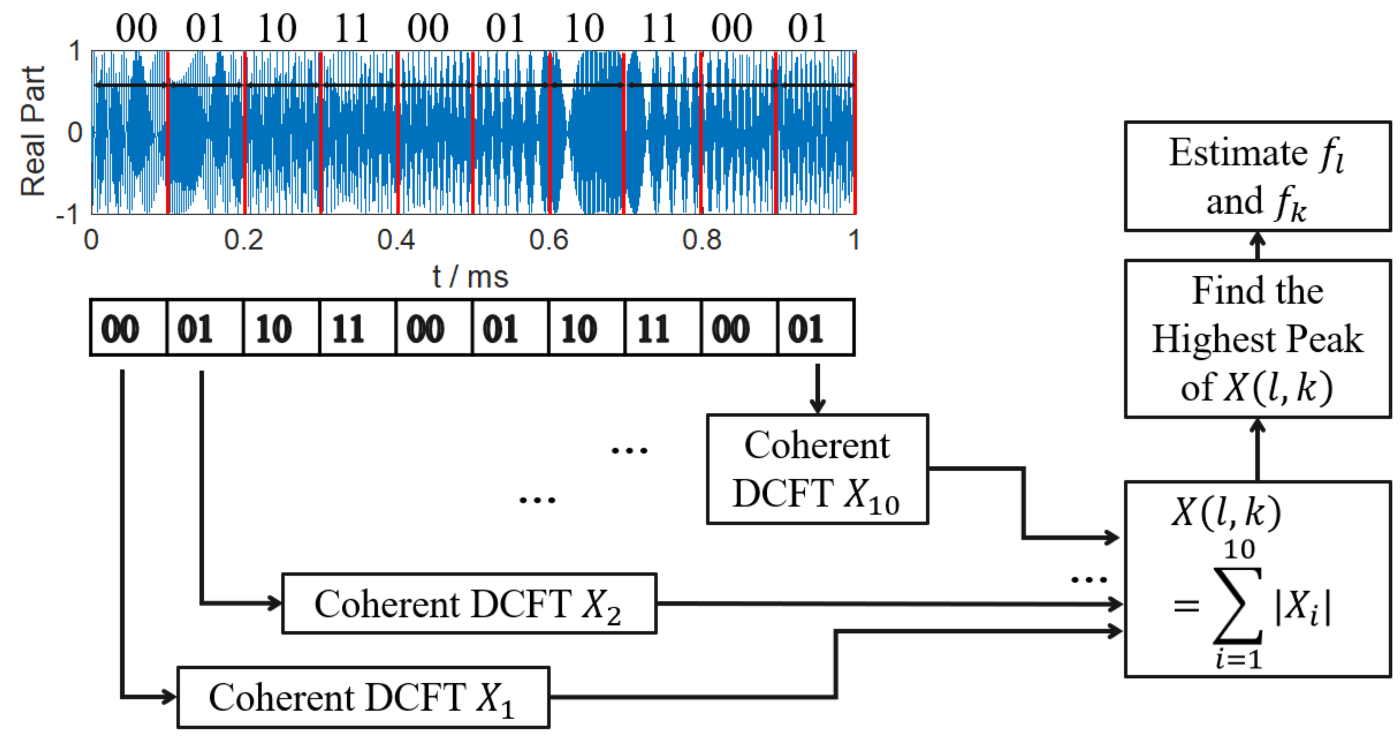


Fig. 4. Traditional DCFT method. Fig. 5. Coherent DCFT.

Non-Coherent DCFT

- Designed specifically for radar-comms waveforms.
- For example, when there are 10 symbols for the radar-comms

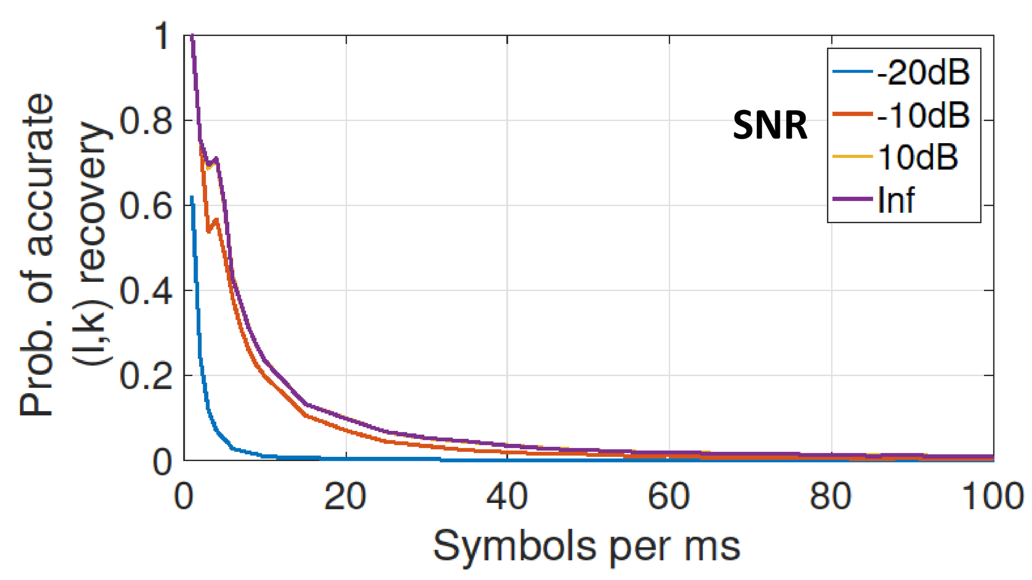


- When $W_K = \exp(-2\pi j/K)$, the K-point non-coherent DCFT is

$$X[l_2,k_2] = \frac{1}{\sqrt{N}} \sum_{i=1}^{M} \left| \sum_{n=m_i}^{m_i+n_i-1} x[n] W_K^{(al_2+c)n^2+(bk_2+d)n} \right| \qquad l_2,k_2 = 0,1,\cdots,K-1.$$

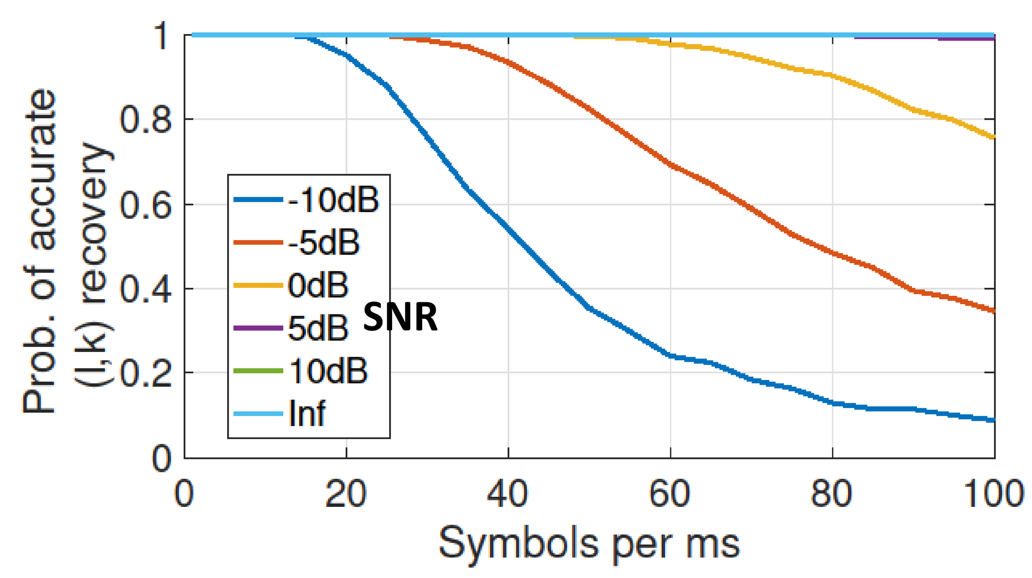
Simulations

- The coherent DCFT for the QPSK-LFM waveform:



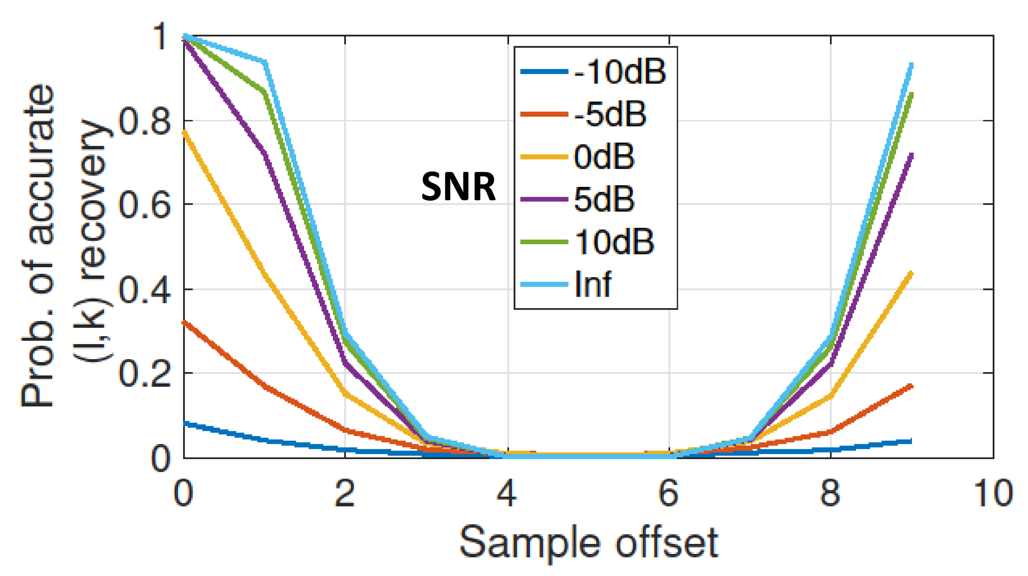
- a dramatic reduction in accurate recovery as the number of symbol rates and the SNR decreases;
- not suited to estimate the parameters of the QPSK-LFM signal.

- The non-coherent DCFT for the QPSK-LFM waveform:



- the dominant factor to estimate parameters is the SNR;
- degrades as the SNR reduces or the symbol rate increases;
- suitable for the QPSK-LFM waveform.

- The imperfect synchronisation scenario for the non-coherent DCFT:



- higher accuracy is achieved at the lowest or highest sample offsets
- is much more severe than the presence of noise.

Conclusions

1. The paper proposes a coherent variant of the DCFT to circumvent the inflexibilities of the standard DCFT.
2. The paper designs the non-coherent DCFT for detecting PSK-modulated LFM waveforms.
3. Simulation results have shown that the accuracy of recovery can remain high at a high SNR for a small synchronisation error.

References
[1] Xiang-Gen Xia, "Discrete chirp-Fourier transform and its application to chirp rate estimation," IEEE Trans. Signal Process., vol. 48, no. 11, pp. 3122–3133, 2000.
[2]F. K. Coutts, J. Thompson and B. Mulgrew, "Learning a Secondary Source From Compressive Measurements for Adaptive Projection Design," 2021 Sensor Signal Processing for Defence Conference (SSPD)., 2021, pp. 1-5

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