

Modern Synchronization Techniques for Reliable Communication

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1. TIME OFFSET: GARDNER TED

Let the m th sample in the r th received time slot be

$$Y_k(m) = X_k + V_k(m), \quad k = 1, \dots, N, m = 1,$$

where X_k is the transmitted symbol in the slot and $V_k(m) \sim \mathcal{N}(0, \sigma^2)$. The decision for the k th symbol is

$$U_k = Y_{k-1} \left(\frac{M}{2} \right) [Y_k(M) - Y_{k-1}(M)] \quad (1.2)$$

A. Plots

2. FREQUENCY OFFSET: LR TECHNIQUE

Let the frequency offset be Δf [1]. Then

$$Y_k = X_k e^{j2\pi\Delta f k M} + V_k, \quad k = 1, \dots, N$$

From (2.1),

$$Y_k X_k^* = |X_k|^2 e^{j2\pi\Delta f k M} + X_k^* V_k$$

$$\Rightarrow r_k = e^{j2\pi\Delta f k M} + \bar{V}_k$$

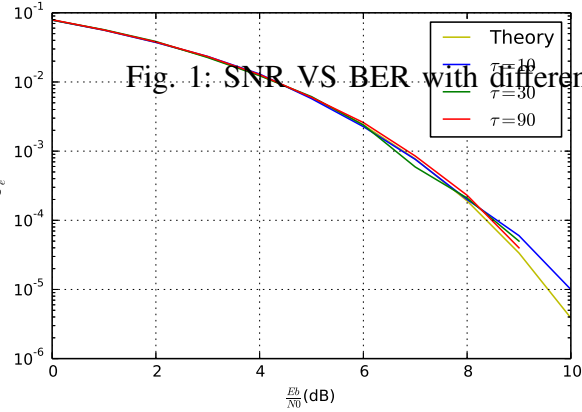


Fig. 1: SNR VS BER with different time offsets

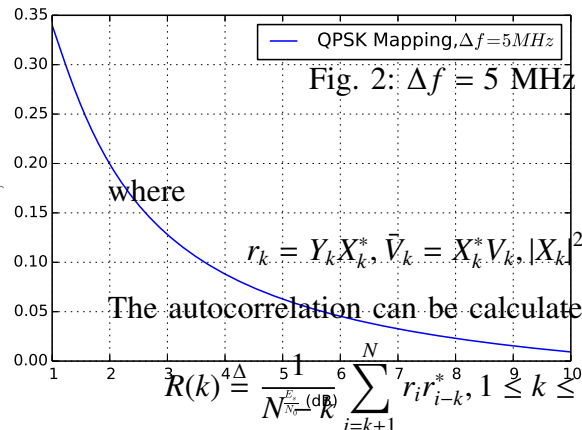


Fig. 2: $\Delta f = 5$ MHz

where

$$r_k = Y_k X_k^*, \bar{V}_k = X_k^* V_k, |X_k|^2 = 1 \quad (2.4)$$

The autocorrelation can be calculated as

$$R(k) = \frac{1}{N-k} \sum_{i=k+1}^N r_i r_{i-k}^*, \quad 1 \leq k \leq N-1 \quad (2.5)$$

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Where N is the length of the received signal. For large centre frequency, the following yields a good

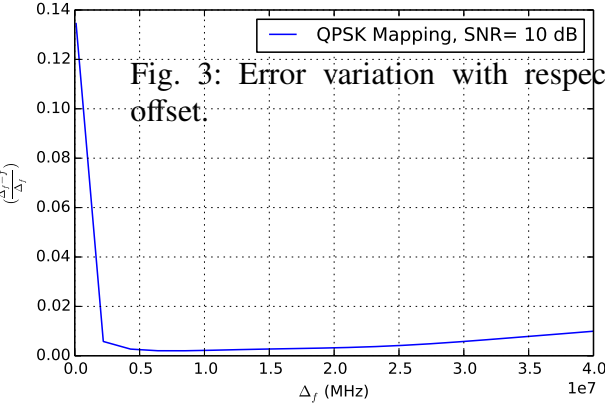


Fig. 3: Error variation with respect to frequency offset.

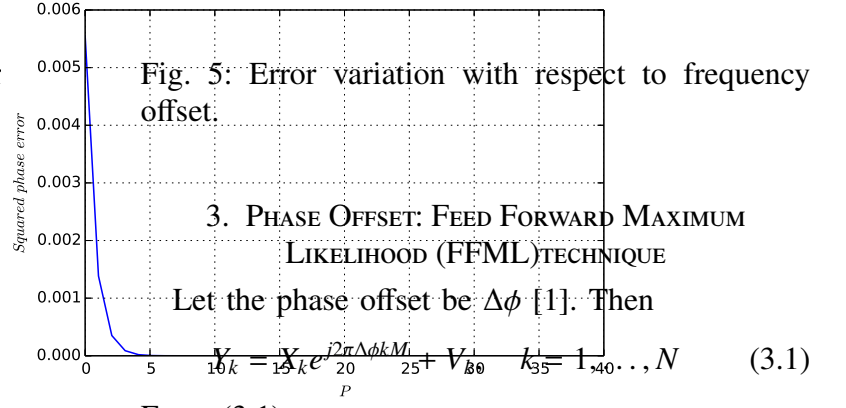


Fig. 5: Error variation with respect to frequency offset.

3. PHASE OFFSET: FEED FORWARD MAXIMUM LIKELIHOOD (FFML) TECHNIQUE

Let the phase offset be $\Delta\phi$ [1]. Then

$$Y_k = X_k e^{j2\pi\Delta\phi kM} + V_k \quad k=1, \dots, N \quad (3.1)$$

From (3.1),

$$Y_k X_k^* = |X_k|^2 e^{j2\pi\Delta\phi kM} + X_k^* V_k \quad (3.2)$$

$$\Rightarrow r_k = e^{j2\pi\Delta\phi kM} + \bar{V}_k \quad (3.3)$$

where

$$r_k = Y_k X_k^*, \bar{V}_k = X_k^* V_k, |X_k|^2 = 1 \quad (3.4)$$

$\hat{\phi}$ can be written as:

$$\hat{\phi}_k = \arg(r_k) \quad (3.5)$$

This equation gives the final estimation of phase

$$\hat{\theta}_f^{(p)}(l) = \hat{\theta}_f^{(p)}(l-1) + \alpha \text{SAW}[\hat{\theta}_f^{(p)}(l) - \hat{\theta}_f^{(p)}(l-1)] \quad (3.6)$$

Where SAW is a saw tooth non-linearity and $\alpha \leq 1$

A. Plots

REFERENCES

- [1] M. Luise and R. Reggiannini: 'Carrier frequency recovery in all-digital modems for burst mode transmissions,' IEEE Trans. Commun., vol. 43, no. 2/3/4, pp. 1169-1178, Feb/Mar/Apr 1995.
- [2] U. Mengali and A. N. D'Andrea: 'synchronization Techniques for Digital Receivers,' New York: Plenum, 1997.

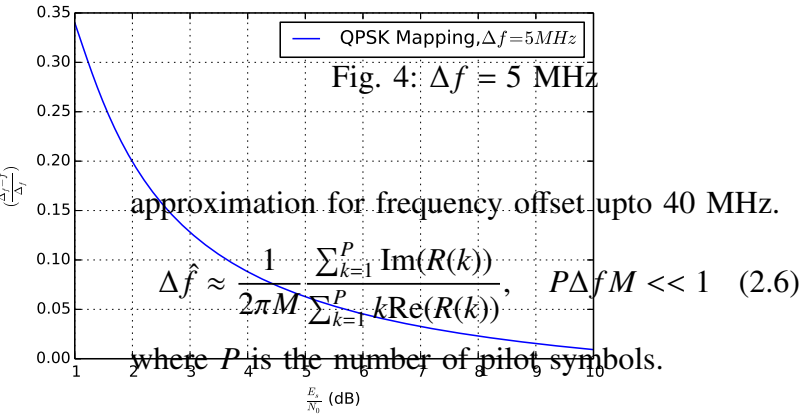


Fig. 4: $\Delta f = 5$ MHz

approximation for frequency offset upto 40 MHz.

$$\Delta\hat{f} \approx \frac{1}{2\pi M} \frac{\sum_{k=1}^P \text{Im}(R(k))}{\sum_{k=1}^P k \text{Re}(R(k))}, \quad P\Delta f M \ll 1 \quad (2.6)$$

where P is the number of pilot symbols.

A. Plots

The number of pilot symbols is $P = 18$. The codes for generating the plots are available at

Fig. 5 shows the variation of the error in the offset estimate with respect to the offset Δf when the SNR = 10 dB. Similarly Fig. ?? shows the variation of the error with respect to the SNR for $\Delta f = 5$ MHz.

