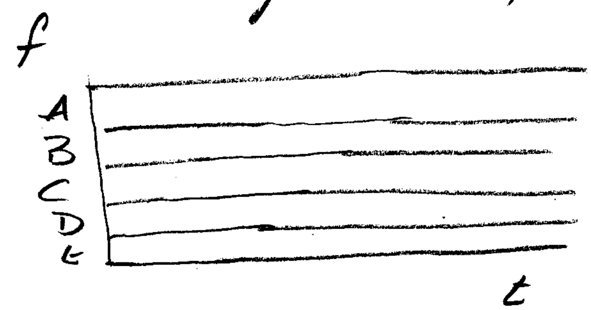
9.5 CDMA

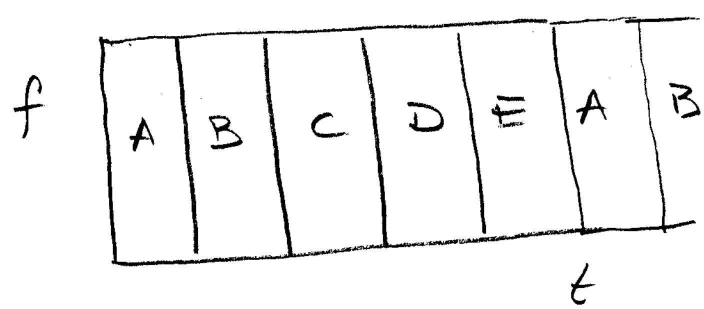
- CDMA rests on a specialized modulation format that is:
  - resistant to delay spread (and actually exploits it)
  - resistant to interference from other users

- It comes down to pulse shape and interference suppression. We are used to smooth pulses that minimize bandwidth and keep the users orthogonal by



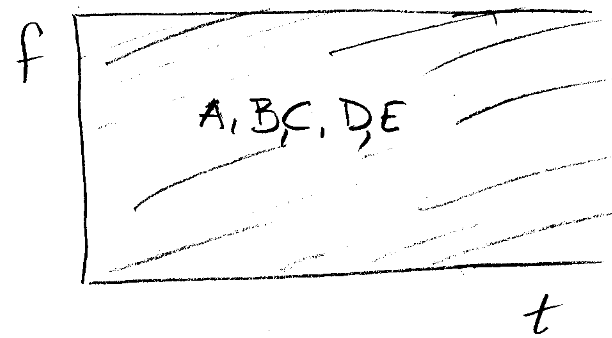
FDMA

or



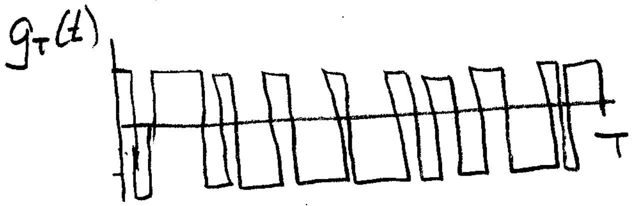
TDMA

In contrast, in CDMA, all users occupy all time and frequency, and are distinguished by spreading code.



CDMA

- The pulse shape:



N_c chips, duration $T_c = \frac{T}{N_c}$

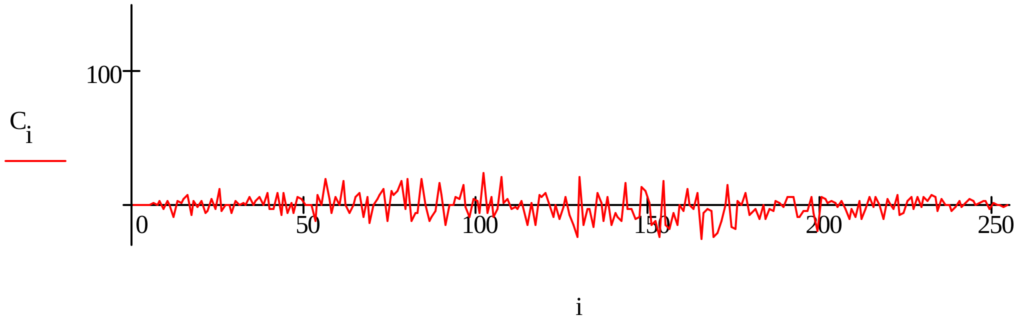
- The signal occupies N_c times the original bandwidth.
  Standard CDMA: $N_c = 128$, 9.6 ksym/s
- Each user has own "spreading sequence", such sequences having
  - low cross correlation

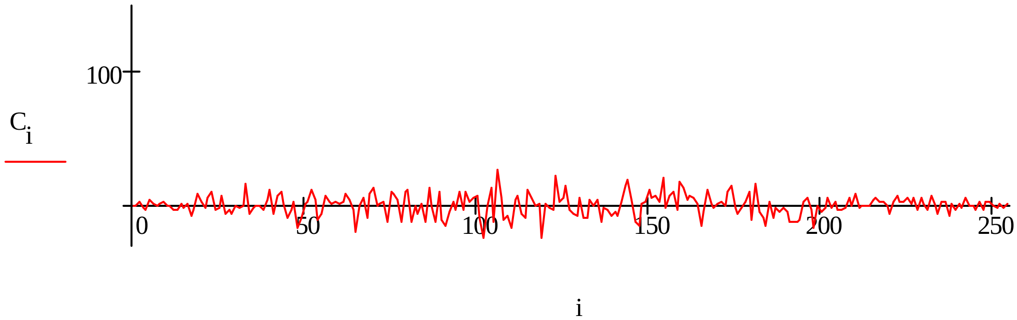
$$C_{i,j}(n) = \sum_{k=0}^{N_c-1} s_i(k)\, s_j(k-n)$$

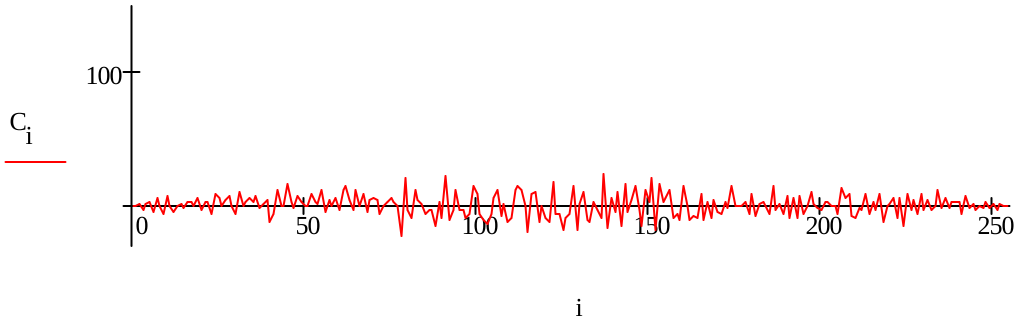
  - "thumbtack" autocorr'n

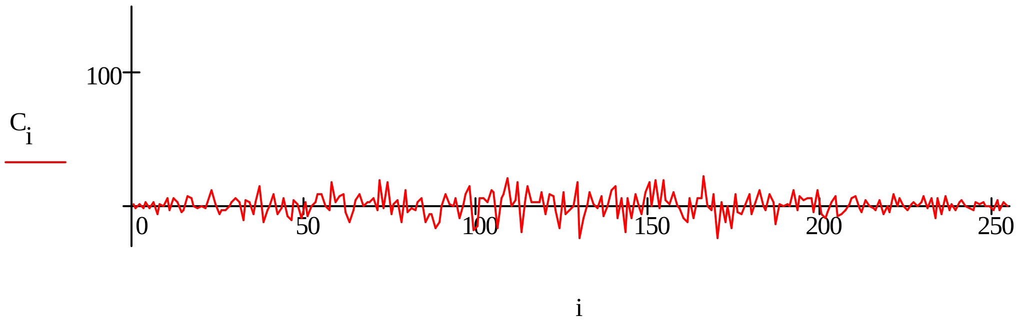
$$R_i(n) = \sum_{k=0}^{N_c-1} s_i(k)\, s_i(k-n)$$

Crosscorrelations of some randomly selected 128-chip sequences:

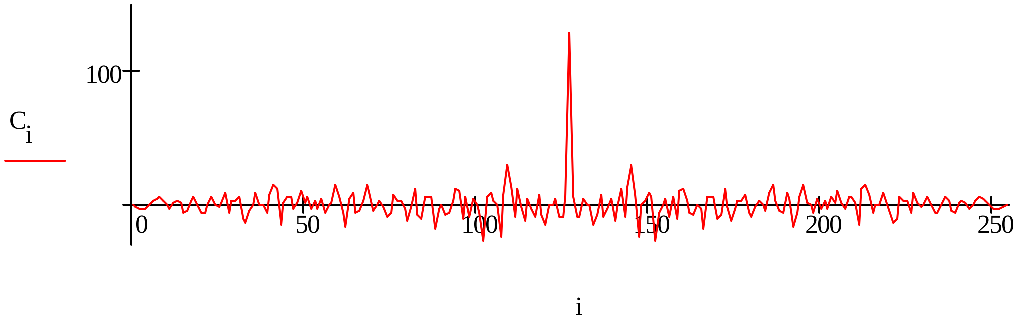


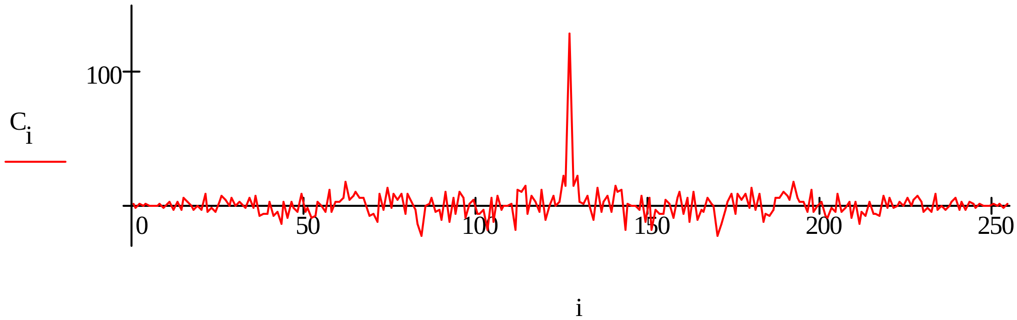


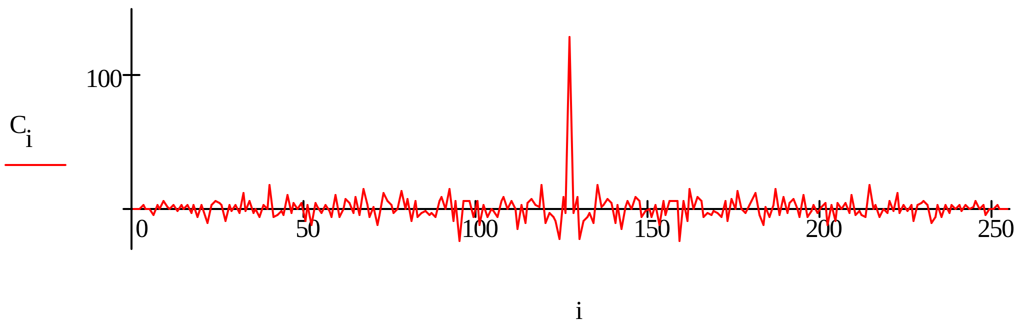


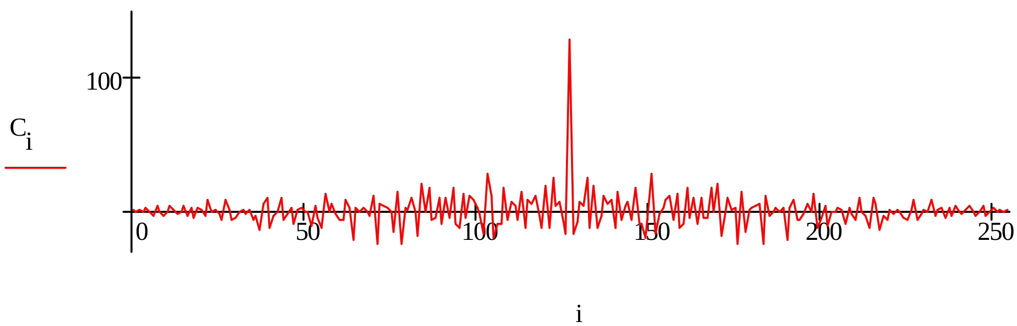


Autocorrelations of some randomly selected 128-chip sequences:

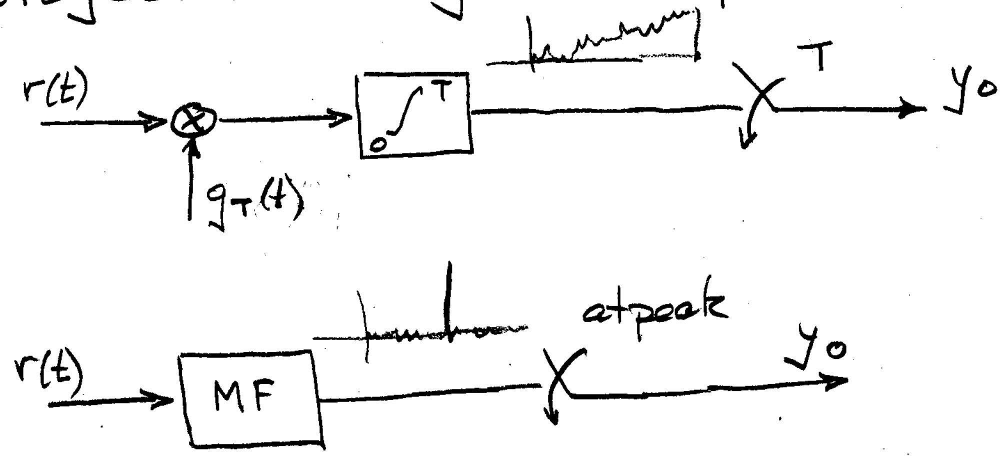








- Optimum receiver in white noise
  - project onto signal subspace as usual



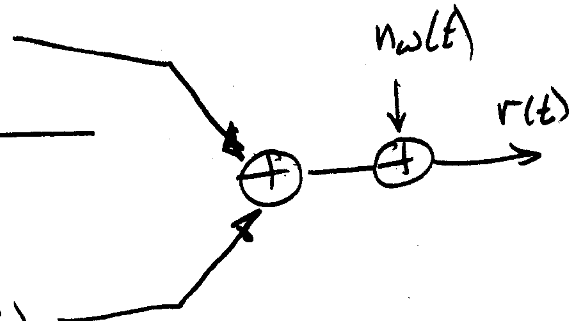
Timing must be N_c times more accurate.

- Performance is same as usual $P_b = Q(\sqrt{2\gamma_b})$

- Now consider two users received in white noise

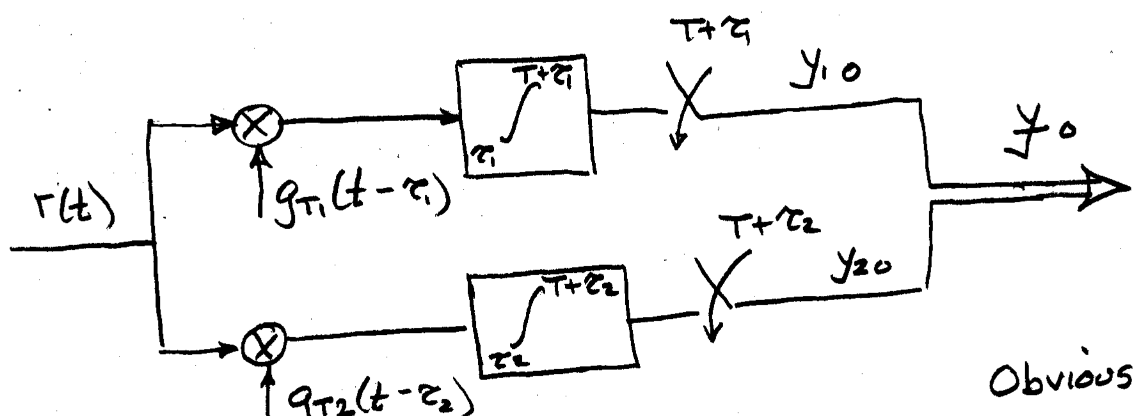
$$s_1(t) = \sum_i a_i\, g_{T1}(t - iT - \tau_1)$$

$$s_2(t) = \sum_i a_i\, g_{T2}(t - iT - \tau_2)$$



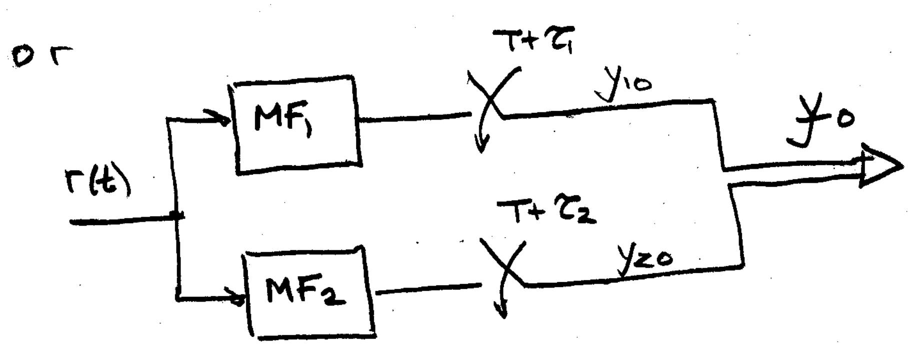
- what is the signal subspace?
  basis functions $g_{T1}(t - \tau_1)$ and translates
  $g_{T2}(t - \tau_2)$ and translates

- Optimum receiver for symbol 0 is therefore



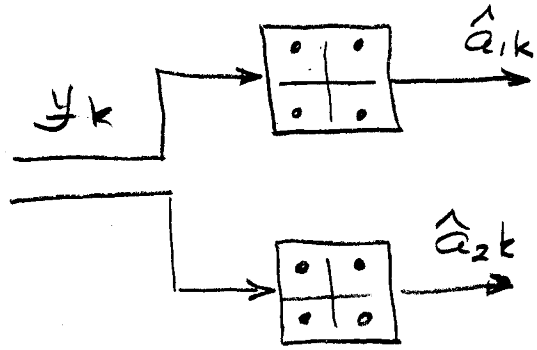
Obvious extension to more users.

or



- In principle, the optimum processing of the sample vector is
  - → If all users aligned in time, then make a decision on all user data at once for time k, then move to time $k+1$.
  - → If users are not aligned, then $\underline{y}_k$ depends on user data $\underline{a}_k$ and $\underline{a}_{k-1}$. Joint Viterbi.
  - → Active research — exponential growth.

- In practice, the crosscorrelations are so low that y_{1k} depends only on user 1, a_{1k}
  y_{2k} - - - - - - - - - - 2, a_{2k}



$$y_{1k} = R_1 a_{1k} + C_{12} a_{2k} + v_k$$

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  - → If all users aligned in time, then make a decision on all user data at once for time k, then move to time $k+1$.
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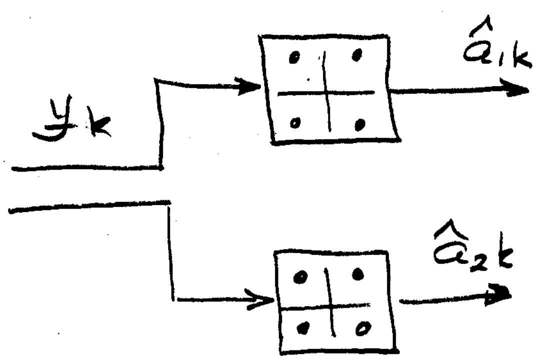

$$y_{1k} = R_1 a_{1k} + C_{12} a_{2k} + \nu_{1k}$$

$$y_{2k} = C_{21} a_{1k} + R_2 a_{2k} + \nu_{2k}$$