SPREAD SPECTRUM SO FAR...

SPREAD SPECTRUM SYSTEMS UTILIZE VERY WIDE BANDWIDTHS AND LOW SIGNAL-TO-NOISE RATIOS

THE BANDWIDTH SPREADING IS PERFORMED BY USING A HIGH SPEED PN-SEQUENCE

FUNDAMENTAL OPERATION OF

* FREQUENCY HOPPING
* DIRECT SEQUENCE

AND

PN-SEQUENCES;

* MAXIMAL CODES - IRREDUCIBLE/PRIMITIVE POLY
* HOW TO TEST FOR MAXIMALITY
* GOLD CODES - COMBINED MAXIMAL CODES

PROCESS GAIN

SPREAD-SPECTRUM SYSTEMS DEVELOP A "PROCESS GAIN" FROM THE SPREADING AND DE-SPREADING PROCESS.

THE DIFFERENCE IN INPUT AND OUTPUT SIGNAL-TO-NOISE IN ANY PROCESSOR IS ITS PROCESS GAIN.

FOR EXAMPLE, FOR A SYSTEM WITH AN INPUT SIGNAL-TO-NOISE RATIO OF 10dB AND AN OUTPUT SIGNAL-TO-NOISE RATIO OF 16 dB WOULD HAVE A PROCESS GAIN OF 6dB

PROCESS GAIN CAN BE ESTIMATED FROM THE FOLLOWING EMPIRICAL RELATIONSHIP;

$$\text{PROCESSGAIN} = G_p = \frac{BW_{RF}}{R_{INFO}}$$

BW_{RF} - BANDWIDTH OF THE TRANSMITTED SIGNAL (SPREAD-SPECTRUM) (Hz)

R_{INFO} - INFORMATION RATE OF THE BASEBAND CHANNEL (BITS S^{-1})

FOR A FREQUENCY HOPPING SIGNAL, BW_{RF} IS EQUAL TO "M" TIMES THE CHANNEL BANDWIDTH, WHERE "M" IS THE NUMBER OF CHANNELS AVAILABLE

DIRECT SEQUENCE SYSTEMS

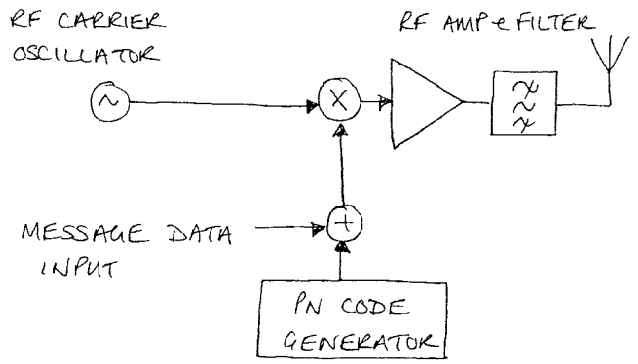
IN THIS TYPE OF SPREAD-SPECTRUM SYSTEM THE DATA IS MODULATED BY A PSEUDO-NOISE. SEQUENCE

THE METHOD OF MODULATING THE PN CODE ONTO THE DATA IS USUALLY ACHIEVED BY MODULO-2 ADDITION OF THE PN CODE ONTO THE DATA - SOMETIMES CALLED SEQUENCE INVERSION KEYING.

THIS PRODUCES A BINARY STREAM AT THE CHIP RATE OF THE PN CODE, THIS SPREADS THE BANDWIDTH FROM THAT OF THE DATA TO THAT OF THE HIGHER SPEED PN SEQUENCE

THIS DATA STREAM IS MODULATED (PSK OR QPSK etc) ONTO THE RF CARRIER.

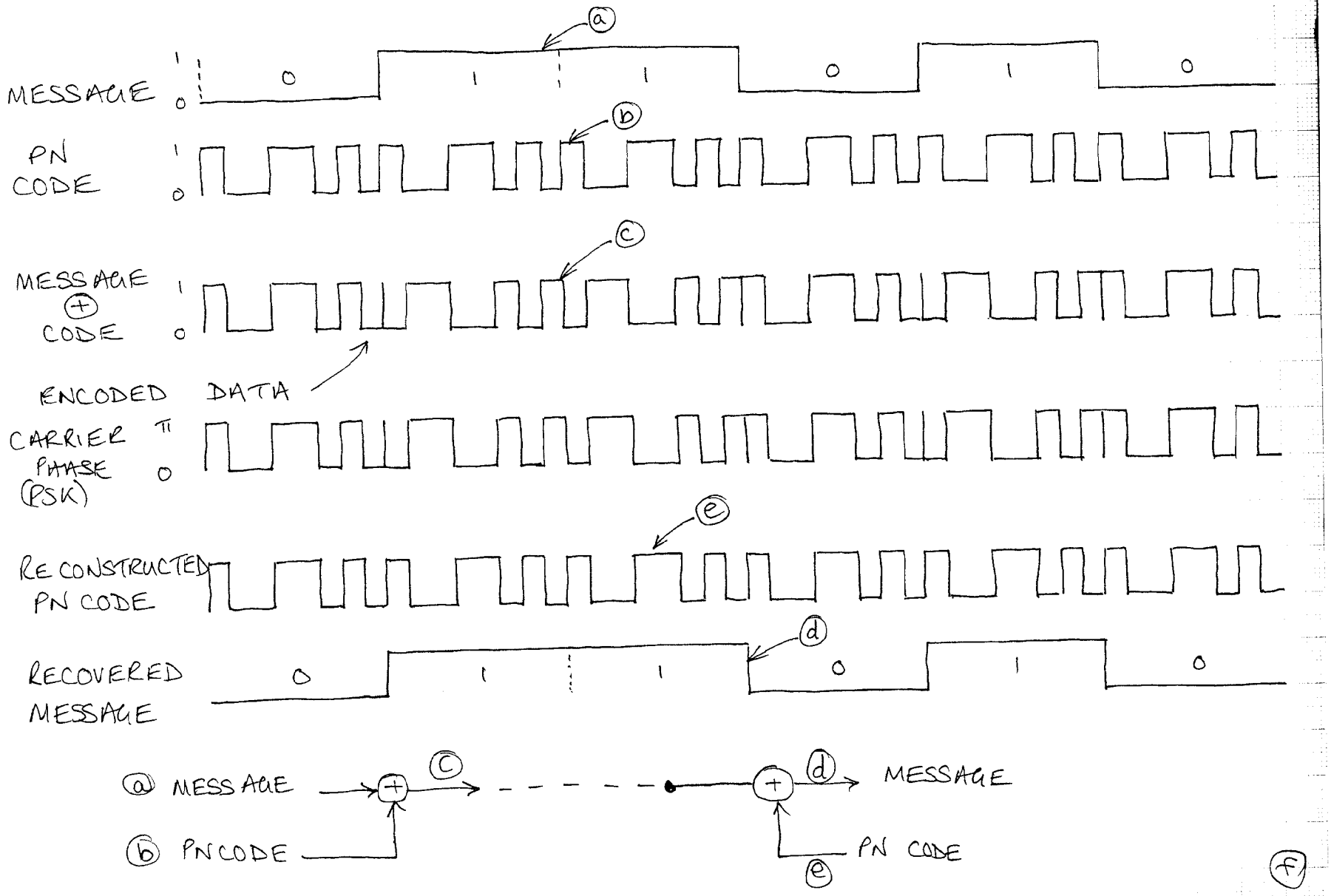
DIRECT SEQUENCE TRANSMITTER



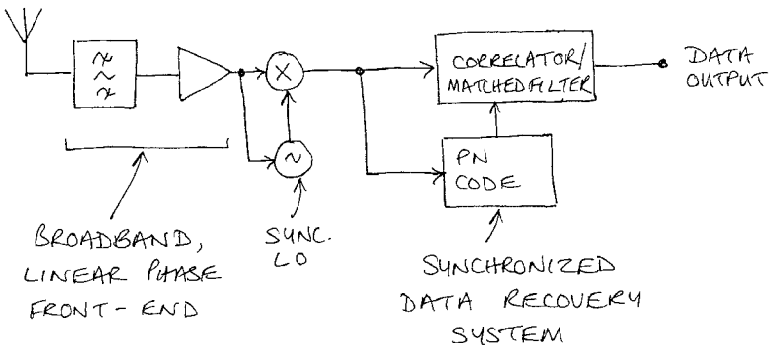
* AFTER LINEAR AMPLIFICATION THE SIGNAL MUST BE BAND-PASS FILTERED TO ENSURE THAT ENERGY DOES NOT "SPILL-OVER" INTO ADJACENT BANDS

* IT IS IMPORTANT TO HAVE THE OUTPUT FILTER HAVE AS LINEAR A PHASE RESPONSE AS POSSIBLE

* SPREAD SPECTRUM SIGNALS HAVE A LARGE BANDWIDTH (WIDE BAND). THIS CAN RESULT IN HAVING TO USE LOWER GAIN ANTENNAS THAN MIGHT BE USED IN CONVENTIONAL NARROW BAND SYSTEMS


MESSAGE
PN CODE
MESSAGE ⊕ CODE
ENCODED DATA
CARRIER PHASE (PSK)
RECONSTRUCTED PN CODE
RECOVERED MESSAGE
0
1
π
a
b
c
d
e
f
@ MESSAGE
b PN CODE
MESSAGE
PN CODE

DIRECT SEQUENCE RECEIVER



IN THE RECEIVER, THE HIGH SPEED CODE-MODULATED DATA IS DE-SPREAD BACK TO THE ORIGINAL WANTED DATA STREAM BY EITHER A CORRELATION OR MATCHED-FILTER DETECTOR WITH THE RECEIVED CODED DATA AND A SYNCHRONIZED REPLICA OF THE PN CODE.

THIS REMOVES THE HIGH SPEED PN SEQUENCE AND COLLAPSES THE SIGNAL BANDWIDTH TO THAT OF THE ORIGINAL UNSPREAD DATA. HOWEVER ANY NOISE ADDED TO THE SPREAD-DATA IN THE CHANNEL, AND WHICH IS NOT CORRELATED TO THE SEQUENCE IS MOSTLY REMOVED IN THE CORRELATION PROCESS.

SYNCHRONIZATION

CENTRAL TO THE DE-SPREADING PROCESS IS THE NEED TO PERFECTLY SYNCHRONIZE THE RECEIVED SPREAD SIGNAL WITH A LOCALLY GENERATED CODE REPLICA IN THE RECEIVER

⇒ MUCH OF THE COMPLEXITY OF A SPREAD SPECTRUM RECEIVER LIES IN THE SYNCHRONIZATION CIRCUITRY.

IT IS NOT NECESSARY FOR THE DATA BITS TO BE IN ANY WAY SYCHRONIZED WITH THE PN-SEQUENCE.

HOWEVER, IN ORDER TO MAKE LIFE EASY, THE DATA BITS ARE OFTEN CLOCKED BY THE START OF THE PN SEQUENCE, AND FOR EACH DATA TO LAST FOR AN ENTIRE SEQUENCE PERIOD

THUS, IN THIS WAY IF THE PN SEQUENCE CONTAINS "L" CHIPS BEFORE THE SEQUENCE REPEATS, THE DATA WORD IS SPREAD BY "L" TIMES THE DATA BIT CLOCK RATE

TO GAIN AND MAINTAIN SYNCHRONIZATION AN ACQUISITION AND TRACKING LOOP IS NECESSARY.

THE ACQUISITION STAGE CONSISTS OF BRINGING THE TWO SPREADING SIGNALS INTO COARSE ALIGNMENT

ONCE THE RECEIVED SPREAD-SPECTRUM SIGNAL HAS BEEN ACQUIRED, THE SECOND STEP, CALLED TRACKING TAKES OVER AND MAINTAINS THE BEST POSSIBLE FINE ALIGNMENT BY MEANS OF A FEEDBACK LOOP.

THERE ARE MANY TYPES OF TRACKING LOOP. THE MOST COMMON ARE;

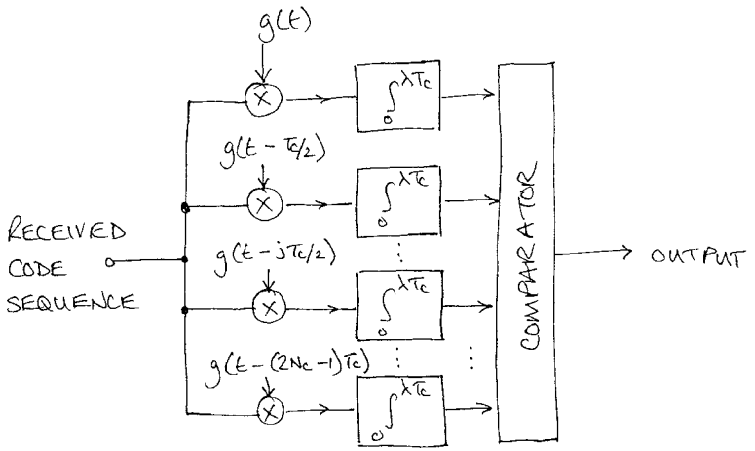
* DELAY LOCKED LOOP (DLL)
* TAU-DITHER LOOP (TDL)

FOR SIMPLE DIRECT-SEQUENCE SYSTEMS USING SHORT CODES, A "SLIDING" CORRELATOR CAN BE USED FOR BOTH ACQUISITION AND TRACKING.

THE SLIDING CORRELATOR WORKS BY HAVING THE RECEIVER'S PN-CODE CLOCK RUN SLIGHTLY FASTER OR SLOWER UNTIL IT "SLIDES" INTO LOCK, AT WHICH POINT THE TRACKING LOOK IS ACTIVATED

ACQUISITION FOR DIRECT SEQUENCE S-S.

PARALLEL SEARCH



$g(t)$ - LOCALLY GENERATED CODE
T_c - CHIP PERIOD, N_c - NUMBER OF CHIPS

* $g(t)$ IS AVAILABLE WITH DELAYS FROM 0 TO $(2N_c - 1)T_c$ IN HALF-CHIP ($T_c/2$) STEPS.
* EACH CORRELATOR EXAMINES λ CHIPS AFTER WHICH THE $2N_c$ CORRELATOR OUTPUTS ARE COMPARED
* THE LOCALLY GENERATED CODE CORRESPONDING TO THE CORRELATOR WITH THE LARGEST OUTPUT IS CHOSEN

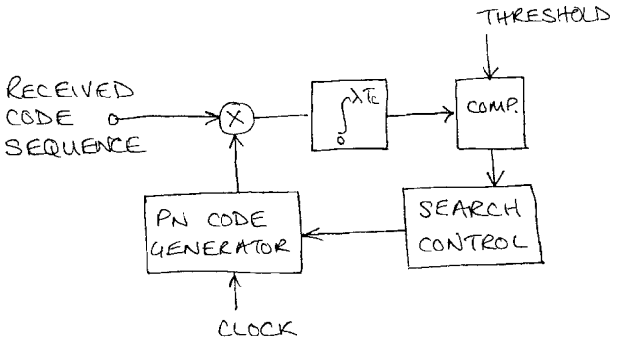
CONCEPTUALLY THIS IS THE SIMPLEST ACQUISITION SYSTEM, BUT HAS HIGH COMPLEXITY FOR LARGE CODES.

THE CURRENT TREND FOR SOFTWARE RADIO SYSTEMS MAKES THIS LESS OF AN ISSUE IF YOU CAN AFFORD IT!

DURING EACH CORRELATION λ CHIPS ARE EXAMINED HENCE THE MAXIMUM TIME FOR ACQUISITION

$$(T_{ACQ})_{MAX} = \lambda T_c$$

SERIAL SEARCH



* AT INTERVALS OF λT_c (THE SEARCH DWELL TIME) THE OUTPUT OF THE CORRELATOR IS EXAMINED

* IF THE CORRELATOR OUTPUT IS BELOW A PREDETERMINED FIXED THRESHOLD, THE PHASE OF THE PN-SEQUENCE GENERATOR IS INCREMENTED BY A FRACTION OF A CHIP (USUALLY ½)

* THIS CONTINUES FOR AS MANY TIMES AS IS NECESSARY UNTIL THE OUTPUT FROM THE CORRELATOR EXCEEDS THE THRESHOLD. - AT THIS POINT THE CODE HAS BEEN ACQUIRED.

THE MAXIMUM ACQUISITION TIME, ASSUMING WE SEARCH IN ½ CHIP INCREMENTS IS;

$$(T_{ACQ})_{MAX} = 2N_c \lambda T_c$$

- $2N_c$: Nº CHIPS IN THE PN CODE
- λ: Nº CHIPS EXAMINED
- T_c: CHIP DURATION

THIS IS MUCH SIMPLER TO IMPLEMENT THAN THE PARALLEL SYSTEM, BUT TAKES POTENTIALLY $2N_c$ TIMES AS LONG TO ACQUIRE THE CODE

TRACKING FOR DIRECT SEQUENCE S-S

TRACKING LOOPS CAN BE CLASSIFIED AS BEING EITHER COHERENT OR NON-COHERENT.

COHERENT TRACKING CAN ONLY BE PERFORMED IF THE CARRIER FREQUENCY AND PHASE ARE KNOWN EXACTLY.

IN MOST CASES WE DON'T KNOW THE EXACT PHASE OF THE CARRIER SO WE HAVE TO USE NON-COHERENT TRACKING. THE REASONS FOR NOT KNOWING THE CARRIER PHASE ARE MANY FOLD, FOR EXAMPLE DOPPLER SHIFTS FROM MOBILE SYSTEMS.

TRACKING LOOPS CAN BE EITHER;

* FULL-TIME, FOR EXAMPLE DLL
* TIME-SHARED, FOR EXAMPLE TDL

THE DELAY LOCKED LOOP

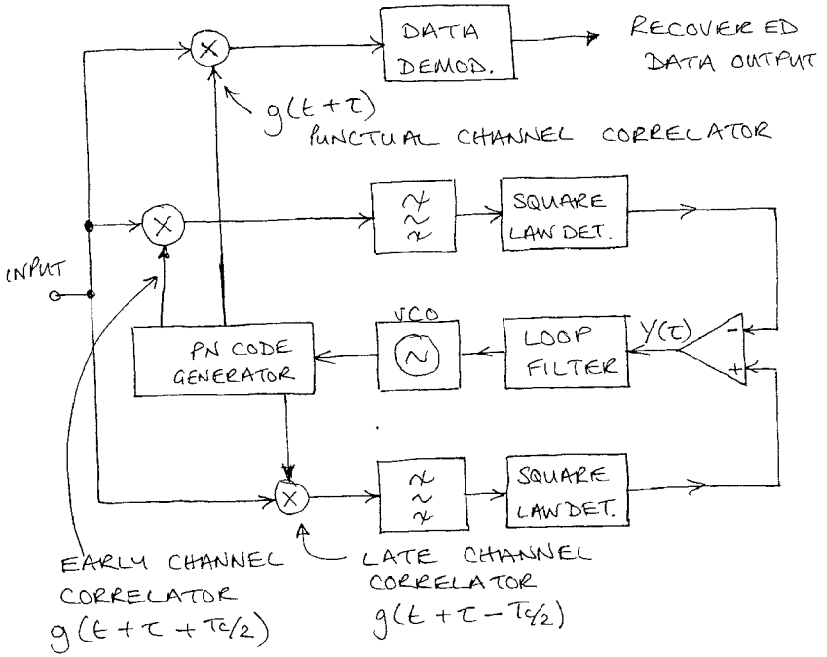
THE DELAY LOCKED LOOP MAINTAINS SYNCHRONIZATION BY COMPARING DE-SPREAD SIGNAL STRENGTHS IN CORRELATOR CHANNELS WHICH ARE RETARDED OR ADVANCED RELATIVE TO THE PUNCTUAL DATA DEMODULATION CHANNEL.

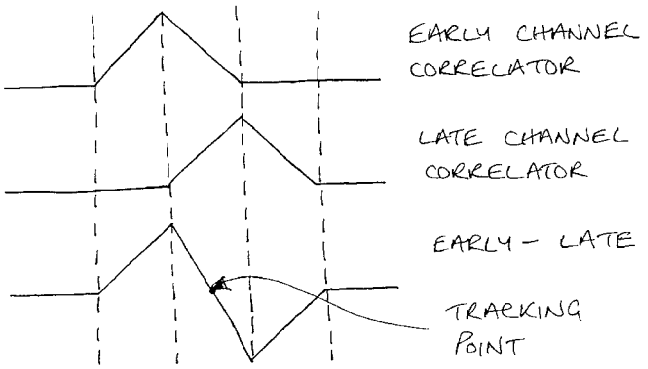
A CONTROL VOLTAGE IS PRODUCED BY SUMMING THE LATE AND EARLY CHANNEL SIGNAL STRENGTHS IN A DIFFERENCE AMPLIFIER.

THIS SIGNAL CONTROLS THE FREQUENCY OF THE RECEIVER'S CODE CLOCK, ENSURING THAT THE PN SEQUENCES IN THE RECEIVER AND TRANSMITTER REMAIN SYNCHRONIZED.

ONE OF THE SHORTFALLS OF THE DELAY-LOCKED-LOOP IS THE REQUIREMENT THAT THE INPUTS TO THE DIFFERENCE AMPLIFIER MUST BE PRECISELY GAIN MATCHED. IF THIS IS NOT THE CASE, THE LOOP ERROR CAUSES THE SYSTEM TO WANDER.

DELAY LOCKED LOOP (½ CHIP)





THE TAU-DITHER LOOP

THE TDL OVERCOMES THE PROBLEMS OF GAIN MATCHING INHERENT IN THE DLL, IT ALSO HAS THE ADVANTAGE OF BEING SIMPLER TO IMPLEMENT.

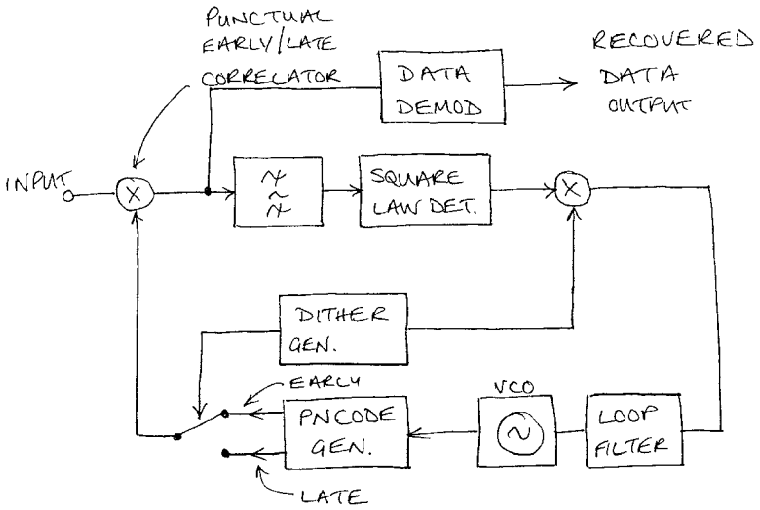
THE TDL IS CALLED A TIME-SHARED TRACKING LOOP SINCE THE EARLY AND LATE CORRELATOR OUTPUTS ARE NOT SIMULTANEOUSLY.

THE PN CODE GENERATOR IS DRIVEN BY A CLOCK SIGNAL WHOSE PHASE IS DITHERED BACK AND FORTH CONTINUALLY. IN THIS CASE THE LOOP ERROR IS ALWAYS TO-ING AND FRO-ING, POSITIVE AND NEGATIVE.

THE SIGNAL-TO-NOISE RATIO IS SLIGHTLY WORSE THAN THE DLL (BY ABOUT 1dB)

AFTER DE-SPREADING, THE SIGNAL NEEDS TO BE DEMODULATED. IN ORDER TO DEMODULATE PSK OR QPSK WE NEED TO RECOVER THE PHASE - THIS IS USUALLY PERFORMED BY A COSTAS LOOP.

TAU - DITHER LOOP (TDL)



ELECTRONICS WORLD & WIRELESS WORLD
SEPTEMBER / OCTOBER 1993

GOOD EASY TO UNDERSTAND INTRO
TO DIRECT SEQUENCE SPREAD SPECTRUM