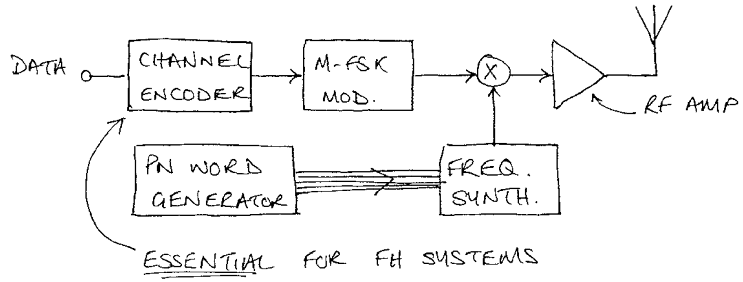
FREQUENCY - HOPPING SPREAD SPECTRUM

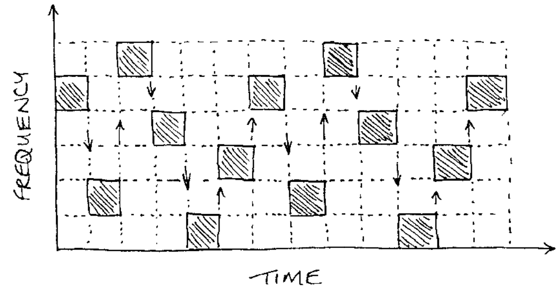
①

* DATA IS MODULATED USING FSK OR M - FSK.
* THESE TWO, OR MORE FREQUENCIES ARE TRANSLATED TO THE CARRIER FREQUENCY.
* THE CARRIER FREQUENCY IS NOT CONSTANT, BUT IS CAUSED TO HOP TO SPECIFIC FREQUENCIES SELECTED BY A PN - SEQUENCE
* THE HOP-RATE IS DETERMINED BY THE CLOCK FREQUENCY OF THE PN WORD SEQUENCE GENERATOR. - THE HOP RATE IS INDEPENDENT OF THE DATA RATE, ALTHOUGH IT MAY BE SYNCHRONIZED WITH IT.
* TYPICAL HOP RATES 10 HOPS s^{-1} TO 10^5 HOPS s^{-1}. SLOW HOP SYSTEMS ARE EASY TO BUILD, BUT ARE NOT VERY SECURE (AND DO NOT HANDLE MULTI-PATH FADING WELL).
* FAST HOP SYSTEMS HAVE GOOD INTERFERENCE REJECTION PROPERTES BUT THEY REQUIRE VERY AGILE SYNTHESIZERS - DIRECT DIGITAL SYNTHESIS (DDS).

FREQUENCY - HOPPING TRANSMITTER

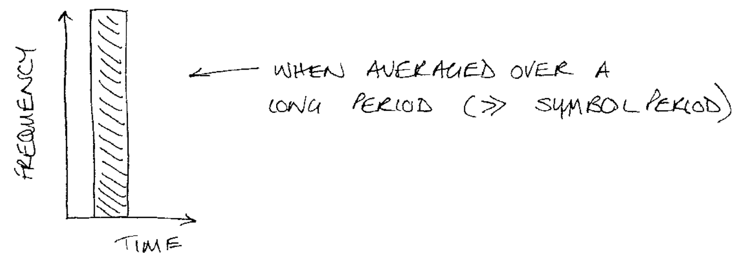
②



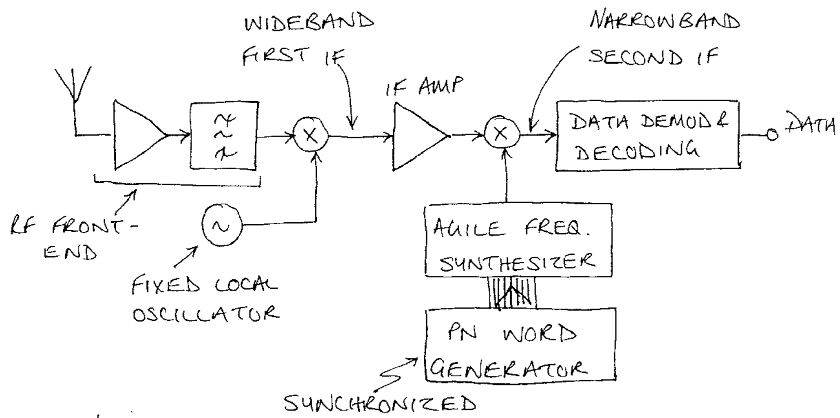


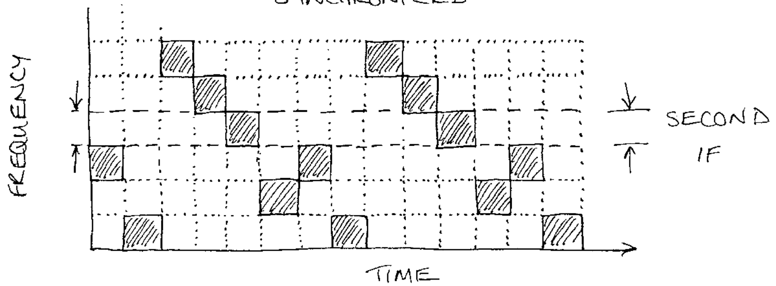
IDEALIZED TIME-FREQUENCY PLOT

▨ - MFSK SPECTRUM

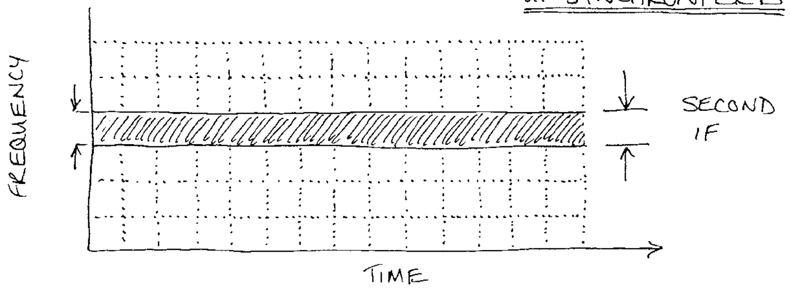


FREQUENCY - HOPPING RECEIVER





UNSYNCHRONIZED



SYNCHRONIZED

* THE FREQUENCY SYNTHESIZER TAKES A FINITE TIME TO HOP FROM ONE FREQUENCY TO ANOTHER.

* THE OUTPUT FROM THE IF OF THE WANTED CHANNEL HAS A SHORT PERIOD AROUND EACH HOP WHERE THE SIGNAL IS LOW AND PRONE TO INTERERENCE

* THIS CAN CAUSE INTER-SYMBOL INTERFERENCE AND DATA ERRORS.

* TO MINIMIZE THESE ERRORS, IT IS COMMON TO USE INTERLEAVING TECHNIQUES AND APPLY ERROR DETECTION AND/OR CORRECTION CODES - CONVOLUTION OR BLOCK CODES

* CURRENT TECHNOLOGY ALLOWS FH - BANDWIDTHS OF SEVERAL GHz - MUCH LARGER THAN THAT OF DSSS SYSTEMS

* FHSS HAS THERFORE THE CAPACITY TO GIVE HIGHER PROCESS GAINS THAN DSSS.

FREQUENCY HOPPING EXAMPLE

SUPPOSE WE HAVE A DATA RATE OF 2400 BITS^{-1}, MODULATED USING 8-ary FSK.

THE SYMBOL RATE IS;

$$R_S = \frac{R_b}{\log_2 8} = \frac{2400}{3} = 800 \text{ SYMBOLS } s^{-1}$$

THAT IS, THE SYMBOL PERIOD IS;

$$T_S = \frac{1}{R_S} = \frac{1}{800} = 1.25\text{ms.}$$

IF THE CARRIER IS TO BE HOPPED ONCE PER SYMBOL, AND THE HOPPING IS TO BE TIME-SYNCHRONOUS WITH THE SYMBOL BOUNDARIES, THE HOPPING RATE IS 800 HOPS s^{-1}.

SYMBOL (3 BITS SYMBOL^{-1})		FSK TONE
000	→	f_0 + 175Hz
001	→	f_0 + 125Hz
010	→	f_0 + 75Hz
011	→	f_0 + 25Hz
100	→	f_0 − 25Hz
101	→	f_0 − 75Hz
110	→	f_0 − 125Hz
111	→	f_0 − 175Hz

f_0 - NOMINAL CARRIER FREQ (−NOT FIXED)

SUPPOSE WE WISH TO SEND THE FOLLOWING MESSAGE SEQUENCE;

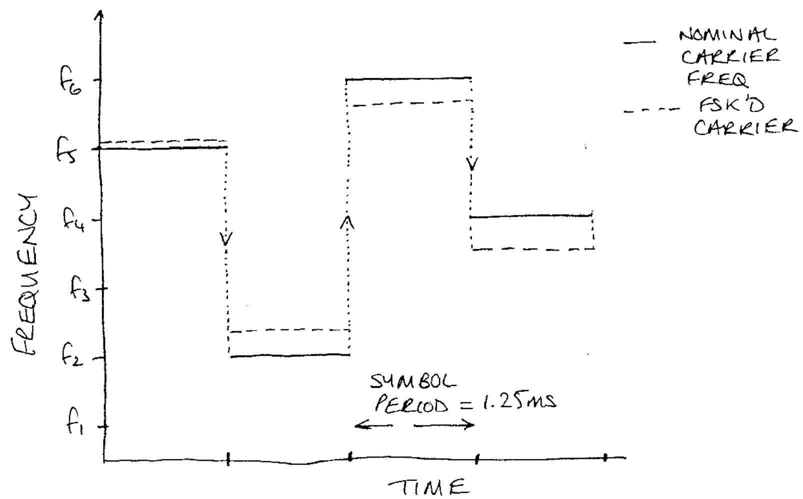
011 001 110 111

THIS SEQUENCE GETS CONVERTED INTO A SEQUENCE OF TONES BY THE 8-ary FSK MODULATOR;

$f_0 + 25$, $f_0 + 125$, $f_0 - 125$, $f_0 - 175$

THIS TONE SEQUENCE IS NOW SPREAD BY MIXING IT WITH A PSEUDO-RANDOM FREQUENCY CARRIER ($f_5, f_2, f_6, f_4, f_1, f_3, f_5, \ldots$)

$f_5 + 25$, $f_2 + 125$, $f_6 - 125$, $f_4 - 175$

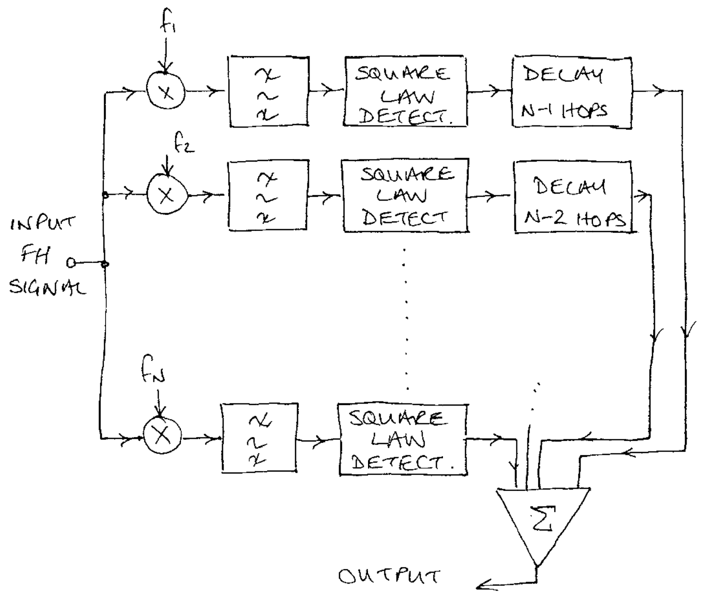


SYNCHRONIZATION FOR FH-SS

AS IN THE DIRECT-SEQUENCE CASE, SYNCHRONIZATION CONSISTS OF TWO PARTS

* ACQUISITION - COARSE ALIGNMENT
* TRACKING - CONTINUOUS FINE ADJUSTMENT

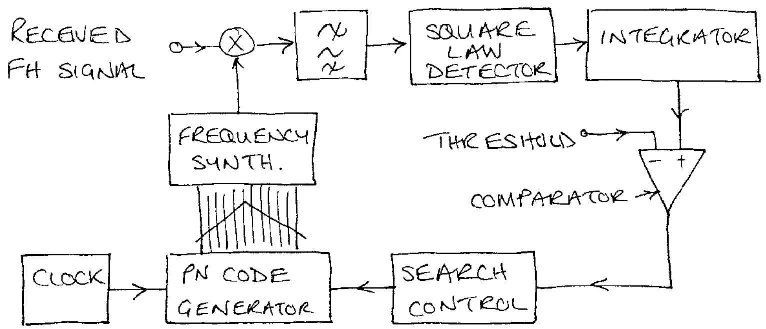
PARALLEL ACQUISITION



HOPPING SEQUENCE : $f_1, f_2, f_3, \dots f_N, f_1, f_2, f_3, \dots f_N, f_1 \dots$

* THE FREQUENCIES IN THE HOPPING SEQUENCE ORDER ARE APPLIED TO THE INPUTS OF "N" MATCHED FILTERS.
* THE MATCHED FILTER DETECTOR IS A FORM OF NON-COHERENT DETECTOR - AS IN THE DSSS CASE WE USUALLY OPT FOR NON-COHERENT SOLUTIONS
* WHEN THE INPUT HOPPING SEQUENCE MATCHES THE HOPPING SEQUENCE INPUT TO THE MATCHED FILTER STAGES A LARGE OUTPUT IS PRODUCED

SERIAL ACQUISITION



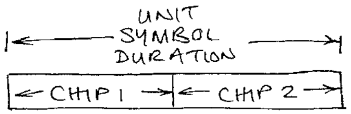
OPERATION IS SIMILAR TO THE SERIAL DS ACQUISITION SYSTEM.

FAST HOPPING / SLOW HOPPING FHSS

FREQUENCY HOPPING SYSTEMS CAN BE CLASSIFIED INTO BEING EITHER FAST OR SLOW HOPPING

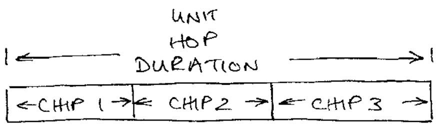
- * FAST-FREQUENCY-HOPPING (FFH)
  >1 HOPS PER BIT/SYMBOL
- * SLOW-FREQUENCY-HOPPING (SFH)
  >1 BITS PER HOP
  SYMBOLS

IN DS-SS WE USED THE TERM "CHIP" TO REFER TO THE DURATION OF THE PN CODE SYMBOL. THE TERM "CHIP" IS ALSO USED IN FHSS TO CHARACTERIZE THE SHORTEST UNINTERRUPTED WAVEFORM IN THE SYSTEM.



1 CHIP = 1/2 SYMBOL DURATION

FFH
(2 HOPS PER SYMBOL)

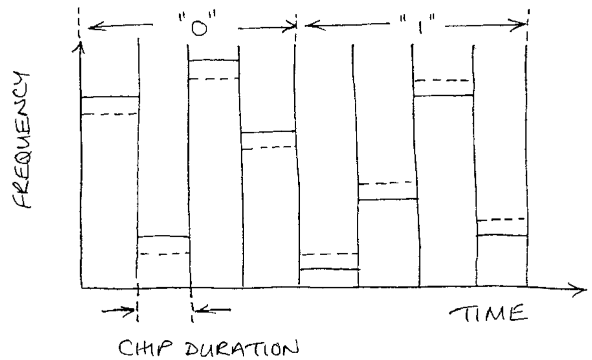


1 CHIP = 1 SYMBOL DURATION

SFH
3 SYMBOLS PER HOP

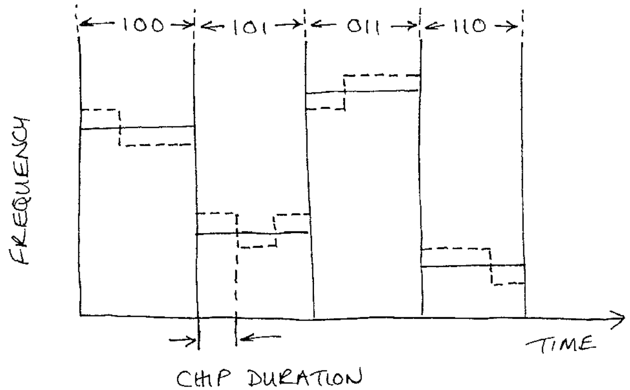
FOR EXAMPLE;

FAST-FREQUENCY HOPPING; 4 HOPS PER BIT



SYMBOL DURATION = 4 CHIPS

SLOW-FREQUENCY HOPPING; 3 BITS PER HOP



FREQUENCY HOPPING WITH DIVERSITY

DIVERSITY IS OFTEN USED IN COMMUNICATIONS SYSTEMS TO COMBAT INTERFERENCE – IMPROVING ITS IMMUNITY TO NOISE, JAMMING OR FADING.

DIVERSITY IS FREQUENTLY USED IN CONJUNCTION WITH FREQUENCY HOPPING SPREAD-SPECTRUM SYSTEMS TO COMBAT MULTI-PATH INTERFERENCE.

IN THE SIMPLEST CASE, WE CAN TRANSMIT THE SAME SYMBOL MULTIPLE TIMES. FOR EXAMPLE SUPPOSE WE HAVE A MESSAGE SEQUENCE OF FOUR SYMBOLS $S_1, S_2, S_3\ S_4$ SUPPOSE WE TRANSMIT THE SYMBOL $N=4$ TIMES, THE TRANSMITTED SEQUENCE IS;

$S_1, S_1, S_1, S_1, S_2, S_2, S_2, S_2, S_3, S_3, S_3, S_3, S_4, S_4, S_4, S_4.$

EACH SYMBOL IS TRANSMITTED AT A DIFFERENT HOPPING (CARRIER FREQUENCY)

SUMMARY OF THE ADVANTAGES / DISADVANTAGES OF DIRECT-SEQUENCE AND FREQUENCY HOPPING

DIRECT SEQUENCE SYSTEMS

ADVANTAGES

* BEST BROADBAND NOISE ANDANTI JAM PERFORMANCE
* MOST DIFFICULT TO DETECT
* BEST DISCRIMINATION AGAINST MULTIPATH.

DISADVANTAGES

* REQUIRES A WIDEBAND CHANNEL WITH LITTLE PHASE DISTORTION
* LONG ACQUISITION TIME
* FAST CODE GENERATOR
* HAS A NEAR-FAR PROBLEM IN CDMA

FREQUENCY - HOPPING SYSTEMS

ADVANTAGES

* GREATEST AMOUNT OF SPREADING LARGEST PROCESS GAINS
* CAN BE PROGRAMMED TO AVOID SPECIFIC PARTS OF THE RF SPECTRUM
* RELATIVELY SHORT ACQUISITION TIME
* LESS AFFECTED BY THE NEAR-FAR PROBLEM IN CDMA SYSTEMS

DISADVANTAGES

* REQUIRES A VERY COMPLICATED AND AGILE FREQUENCY SYNTHESIZER – ANALOGUE SYSTEMS ARE TOO SLOW TO HOP AND SETTLE – DIRECT DIGITAL SYNTHESIS IS THE CURRENT METHOD OF CHOICE
* NOT USEFUL FOR RANGING APPLICATIONS
* REQUIRES ERROR CORRECTION / DETECTION DUE TO ERROR BURSTS AT TIME OF HOP

JAMMING

SPREAD-SPECTRUM SYSTEM ARE OFTEN USED FOR THEIR ANTI-JAM QUALITIES.

THE GOALS OF A JAMMER ARE TO DENY RELIABLE COMMUNICATIONS TO HIS ADVERSARY AND ACCOMPLISH THIS AT MINIMUM COST.

THE GOALS OF THE COMMUNICATOR ARE TO DEVELOP A JAM-RESISTANT COMMUNICATION SYSTEM UNDER THE FOLLOWING ASSUMPTIONS;

1) COMPLETE INVULNERABILITY IS NOT POSSIBLE

2) THE JAMMER HAS A PRIORI KNOWLEDGE OF MOST SYSTEM PARAMETERS, SUCH AS FREQUENCY TIMING ETC.

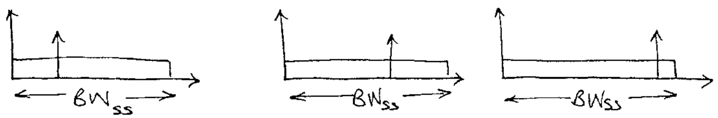
3) THE JAMMER HAS <u>NO</u> A PRIORI KNOWLEDGE OF THE PN-SPREADING OR HOPPING CODES.

THE FUNDAMENTAL DESIGN RULE IS TO MAKE IT AS EXPENSIVE AS POSSIBLE FOR A JAMMER TO SUCEED.

OPTIONS FOR JAMMERS

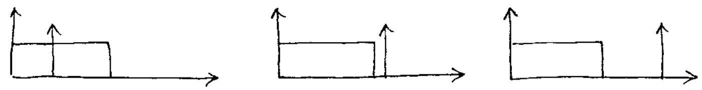
FULL BAND NOISE

FIRST SYMBOL SECOND SYMBOL THIRD SYMBOL



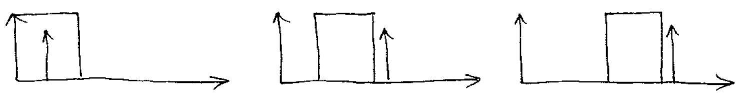
PARTIAL BAND NOISE

FIRST SYMBOL SECOND SYMBOL THIRD SYMBOL



STEPPED NOISE

FIRST SYMBOL SECOND SYMBOL THIRD SYMBOL



- SAME NOISE POWER

PARTIAL-BAND TONES

FIRST SYMBOL SECOND SYMBOL THIRD SYMBOL

STEPPED TONES

- IN ALL CASES THE TRADE-OFF IS BETWEEN BANDWIDTH OCCUPANCY FOR GREATER POWER SPECTRAL DENSITY - THE AREA UNDER THE CURVE REMAINS THE SAME

JAMMER – SIGNAL POWER RATIO

WHEN WE LOOKED AT ERROR PERFORMANCE, OUR PRIMARY "FIGURE OF MERIT" WAS;

$$\frac{E_b}{N_0} = \frac{\text{AVERAGE BIT ENERGY}}{\text{NOISE POWER SPECTRAL DENSITY}}$$

NOW WE HAVE TO CONSIDER ADDITIONAL INTERFERENCE IN THE FORM OF AN INTENTIONAL JAMMING SIGNAL, SO WE NOW LOOK AT;

$$\frac{E_b}{N_0 + J_0}$$, WHERE J_0 IS THE JAMMER PSD.

WE ASSUME THAT THE JAMMER POWER J IS SPREAD UNIFORMLY OVER THE SPREAD SPECTRUM BANDWIDTH SUCH T AT;

$$J_0 = \frac{J}{BW_{ss}}$$

SINCE THE JAMMER PSD, J_0, IS MUCH LARGER THAN THE NOISE PSD, N_0 THE SIGNAL TO NOISE PARAMETER USUALLY USED IS E_b/J_0.

WE CAN DEFINE $(E_b/J_0)_{REQD}$ AS THE BIT ENERGY PER JAMMER NOISE PSD REQUIRED TO MAINTAIN A GIVEN ERROR PROBABILITY.

THE BIT ENERGY E_b CAN BE WRITTEN AS

$$E_b = ST_b = \frac{S}{R}$$

WHERE; S – RECEIVED SIGNAL POWER
T_b – BIT DURATION
R – BIT RATE

HENCE

$$\left(\frac{E_b}{J_0}\right)_{REQD} = \left(\frac{S/R}{J/BW_{ss}}\right)_{REQD}$$

$$= \frac{BW_{ss}/R}{(J/S)_{REQD}}$$ ← THIS IS THE PROCESS GAIN, G_P

$$= \frac{G_P}{(J/S)_{REQD}}$$

HENCE:

$$\left(\frac{J}{S}\right)_{REQD} = \frac{G_P}{(E_b/J_0)_{REQD}}$$

FOR GOOD JAMMER-REJECTION CAPABILITY WE WANT A LARGE $(J/S)_{REQD}$. THIS IS THE AMMOUNT OF JAMMING POWER REQUIRED TO ADVERSELY AFFECT THE ERROR PERF. OF THE SYSTEM.