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A NEW ANTIJAM ACQUISITION SCHEME FOR FREQUENCY HOPPING SPREAD SPECTRUM RECEIVER

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طريقة جديدة للتزامن فى منظومات إستقبال المدى المنتشر ذو القفز التردد ى

خلاصة :

فى منظومات الإتصالات ذات القفز الترددى يتم التزامن بين منظومة المرسل و منظومة المستقبل عن طريق إرسال شفرة متعارف عليها فى بداية الإرسال لفترة زمنية معينة . و التعرف على هذه الشفرة و إستخدامها للتزامن يتم فى العادة إما بطرق البحث المتوازية أو المتتالية . وقد وجد أن طرق البحث المتوازية تتطلب تكلفة عالية فى البناء إذا قورنت بالطرق المتتالية و لكنها فى العادة تتقارب أسرع من طرق البحث المتتالية .

هذا البحث يقدم طريقة مستحدثة للتزامن المتتالى ذات مقاومة عالية للتداخلات أثناء عملية التزامن - أيضا يقدم البحث النموذج الرياضى لتحليل إحتماليات التزامن الصحيح و إحتماليات التزامن الخاطىء فى وجود شوشرة أو تداخلات عند بعض أو كل ترددات المدى المستخدم . و قد أثبتت النتائج المستخلصة من النموذج الرياضى تفوق الطريقة المستحدثة عن الطريقة المتوازية فى مقاومة الشوشرة و التداخلات .

ABSTRACT

In frequency hopping (FH) spread spectrum systems, synchronisation of the frequency synthesiser at the receiver side with that at the transmitter side can be accomplished by preambles or unmodulated tone patterns appended to the beginning of the message transmissions. Pattern detection at the receiver may be implemented either by parallel (matched filter) or serial search systems. Parallel search provides fast acquisition on the expense of circuit complexity. On the other hand, serial search provides better performance on the expense of long acquisition time.

In this paper, a new antijam serial search acquisition scheme is introduced. An analytical model for the probabilities of correct acquisition and false alarm is also established. The performance of the new scheme is evaluated for two types of jamming: partial band noise jamming and partial band multitone jamming. Results obtained from the mathematical model show the superiority of the new scheme as compared to the parallel search scheme reported elsewhere.

I-INTRODUCTION

Spread spectrum (SS) is a technique in which an already modulated signal is modulated a second time in such a way as to produce a waveform which interferes in a barely noticeable way with any other signal operating in the same frequency band [1]. Thus, a receiver tuned to receive a specific AM or FM broadcast would probably not notice the presence of a spread spectrum signal operating over the same frequency band. Similarly, the receiver of the spread spectrum signal would not notice the presence of the AM or FM signal. Therefore, we say that interfering signals are "transparent" to spread spectrum signals and spread spectrum signals are transparent to interfering signals.

In order to provide the "transparency" described above, the spread spectrum technique modulates an already modulated waveform (data modulation), either using amplitude or wideband frequency modulation, so as to produce a very wideband signal.

The means by which the spectrum is spread is crucial. Several of the techniques [2] are "direct-sequence" modulation in which a fast pseudorandomly generated sequence causes phase transitions in the carrier containing data, "frequency hopping", in which the carrier is caused to shift frequency in a pseudorandom way, and "time hopping" wherein bursts of signal are initiated at pseudorandom times. Hybride combinations of these techniques are frequently used.

Although the first use of SS was in military communications, there is a growing interest in the use of this technique for mobile radio networks (radio telephony, packet radio, and amateur radio), timing and positioning systems, multiple access satellite communications and etc.

In frequency hopping (FH) spread spectrum systems, we often use frequency shift keying (FSK) for the data modulation. If binary FSK is used, the FH signal can be written as [3]

$$x(t) = A \, \mathrm{Sin}\,\{ \int [w_c + (\Delta w)p(t)]\, dt \} \qquad (1)$$

where Δ w is the frequency shift from carrier and p(t) is a binary switching function with possible states +1. The carrier frequency, w_c, in the FH signal is a constant for an interval T_h and then changes to another (preselected) frequency for the next interval of time, the rate at which the changes are made is called the frequency hopping rate f_h . A block diagram of a modulation system to generate a FH/SS signal is shown in Fig. 1. The frequency synthesiser produces a constant amplitude sinusoid whose frequency is determined by the digital pseudorandom (PN) code supplied to the synthesiser. In the receiver, the frequency hopping is removed by mixing the FH signal with a local oscillator signal that is hopping synchronously with the transmitted signal. The incoming signal is mixed with the frequency hopping carrier to produce a data modulated signal at the intermediate frequency. This intermediate frequency signal is then demodulated using noncoherent or differentially coherent FSK techniques.

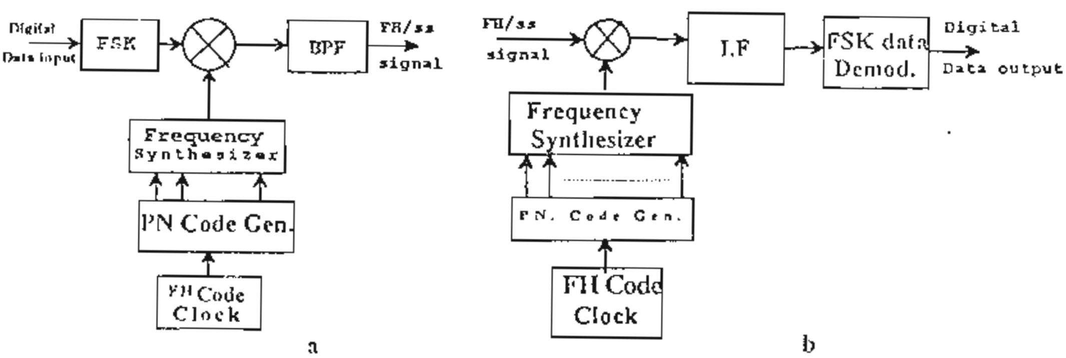


Fig. 1, Block Diagram of Frequency Hopping(FH)System.
a)Transmitter, b)Receiver

waveform shown in Fig. 3(a). On the other hand, if f_i is continuously jammed, the output of the threshold comparator will look like the waveform shown in Fig. 3(b).

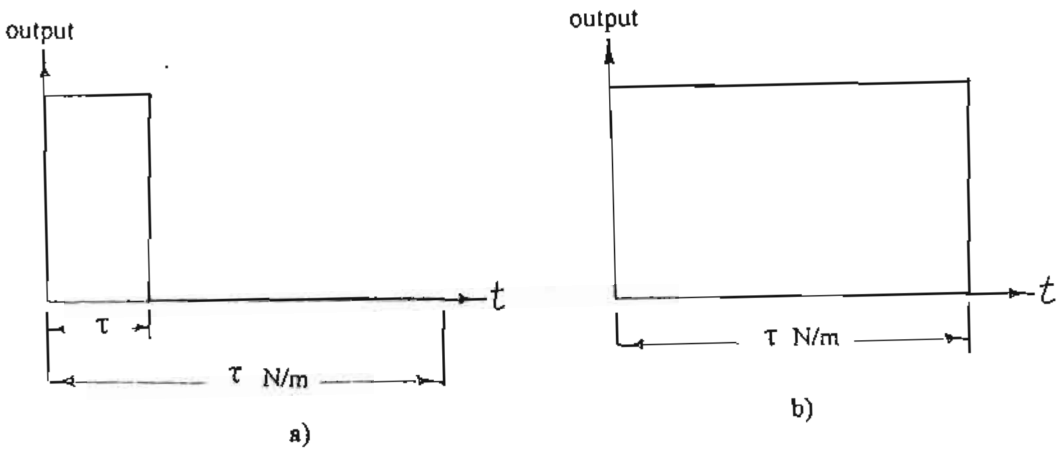


Fig. 3, Output of the Threshold Comparator
a)Without Jamming b)With Jamming

The output from the threshold comparator is serial-to-parallel converted through an N/m-stage serial-to-parallel (S/P) converter. In this S/P converter the serial shift is running at a frequency f_h and the parallel load is running at a frequency mf_h/N . All parallel outputs except the last are applied to an OR gate whose output is used to drive an m-stage upcounter(1). The last parallel output is used to drive another m-satage upcounter(2).The former counter counts the number of jammed channels whereas, the latter counts the number of correct acquired channels. After N hops, the magnitude of the digital words in both counters are compared and a decision is made on whether the magnitude of the digital word in the up counter(2) is greater or less than that in the up counter(1). If it is greater, a clock of frequency f_h is activated and used to drive the PN code generator whose output controls the normal frequency sythesiser. Otherwise, the acquisition process is repeated.

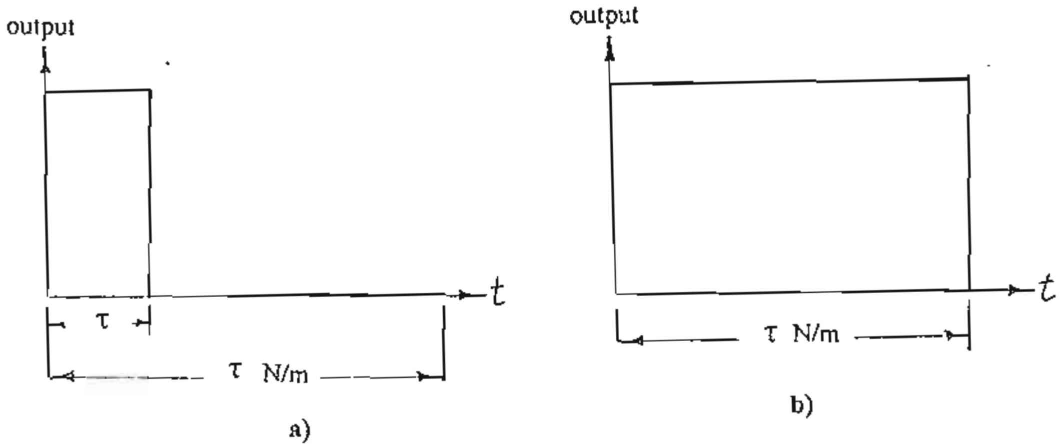
III-DETECTION PROBABILITIES FOR THRESHOLD COMPARATOR

Referring back to Fig. 2 , the band pass filter output r(t) can be represented by the superposition of signal, noise, and jamming waveforms. When the signal is present for the kth hop, it is assumed to be given by:

$$S_k(t) = \sqrt{2E_h/\tau}\ \ \mathrm{Cos}\,(2\pi f_o t + \theta_k); \quad (k-1)\tau < t < k\tau \qquad (2)$$

where $E_h = S\tau$ is the received energy in one hop (one channel) and θ_k is a random carrier phase. With or without a signal or jamming, it is assumed that r(t) contains zero-mean band pass Gaussian noise with power $\sigma^2_N = \eta_o B$ where η_o is the one-sided noise power spectral density and B is the bandwidth of the band pass filter. The noise waveforms in the N hops are considered to be statistically independent.

waveform shown in Fig. 3(a). On the other hand, if f_1 is continuously jammed, the output of the threshold comparator will look like the waveform shown in Fig. 3(b).



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Two kinds of partial band jamming are considered, noise jamming and multitone jamming. Under partial band noise jamming, it is assumed that the jammer places noise with power J in a band that is qB Hz wide, that is, q hops of the total N hops are jammed. If the jamming were spread over the total hopping bandwidth W=NB, the jammer power spectral density is given by

σ_J= J/W. When a particular acquisition hop is jammed, it contains jamming noise power equal to

$$\sigma^2_J = J/q = \eta_J B/(q/N) > \eta_J B \tag{3}$$

Under partial band multitone jamming, it is assumed that q jamming tones are placed in q of the total N hopping channels, not necessarily adjacent, each with power J/q. If present in the kth hop, the jamming waveform is given by,

$$j_k(t) = \sqrt{2J/q}\ \mathrm{Cos}(2\pi f_o t + \phi_k) \tag{4}$$

where ϕ_k is a random carrier phase.

The false alarm and detection probabilities of the threshold comparator are now considered for three particular cases: no jamming, noise jamming, and stationary multitone jamming.

Case 1: No Jamming

Without jamming, the band pass filter output r(t) is a band limited stationary Gaussian noise (thermal noise) plus the acquisition signal S(t). Therefore, the output of the square-law detector is either Rayleigh (no carrier) or Rician (carrier present) random variable. Hence, the false alarm and detection probabilities of the threshold comparator in a particular acquisition hop are given by [9];

$$P_{00} = P_r\{ Z_k > \grave{\mu} \mid \rho = 0, J=0\} = \mathrm{EXP}\,(-\mu^2/2) \tag{5}$$

and

$$P_{10} = P_r\{ Z_k > \grave{\mu} \mid \rho > 0, J=0\} = Q(\sqrt{2\rho}\ , \mu) \tag{6}$$

where

$$\rho = E_b/\eta_o = B\,\tau\, S/\sigma^2_N$$

$$\mu = \grave{\mu}/\sigma_N$$

$$Q(a,b) = \int_b^{\infty} \mathrm{EXP}(-(a^2 + x^2)/2)\, I_o(ax)\, dx$$

and

$I_o(x)$ is the modified Bessel function of the first kind and zero order.

Case 2: Noise Jamming

With noise jamming in a given hop, the effective noise power becomes

$$\sigma^2 = \sigma_N^2 + \sigma_J^2$$

$$= \sigma_N^2 (1 + K) \tag{7}$$

where $K = \sigma_J^2 / \sigma_N^2$

The false alarm and detection probabilities of the threshold comparator in this case are given by;

$$P_{01} = P_r\{ Z_k > \grave{\mu} \mid \rho = 0, J=0, J_m=0\} = \mathrm{EXP}(- \mu^2/2(1+K)) \tag{8}$$

and

$$P_{11} = P_r\{ Z_k > \grave{\mu} \mid \rho = 0, J>0, J_m=0\}$$

$$= Q(\sqrt{2\rho/(1+K)}, \mu/\sqrt{1+K}) \tag{9}$$

Case 3: Multitone Jamming

A jamming tone by itself appears to be a signal, therefore, the false alarm probability will be similar to that given in case 1, that is;

$$P_{01} = Q(\sqrt{2J_m/q\,\sigma_N^2}, \mu) = Q(\sqrt{2K}, \mu) \tag{10}$$

when both acquisition signal and jamming tone are present simultaneously, the resultant signal amplitude at the kth hop is given by;

$$A = \sqrt{2}\sqrt{S + J_m/q + 2\sqrt{SJ_m/q}\,\mathrm{Cos}(\theta_k - \phi_k)} \tag{11}$$

Therefore, the effective SNR is given as;

$$\rho_1(\beta) = A^2/2\,\sigma_N^2$$

$$= (S + J_m/q + 2\sqrt{SJ_m/q}\;\mathrm{Cos}\,\beta)/\sigma_N^2$$

$$= \rho\;[1 + K + 2\sqrt{K}\;\mathrm{Cos}\,\beta\,] \tag{12}$$

where $\beta = \theta_k - \phi_k$

The threshold detection probability in this case is given by [9];

$$P_{11} = 1/2\pi \int_0^{2\pi} Q(2\rho_1(\beta), \mu)\, d\beta \tag{13}$$

The above integral can easily be performed numerically.

IV-ANALYSIS FOR ACQUISITION PROBABILITIES

The contents of the up-counter(1), referred to as L, reflects the activity of jammer during a time interval $N\tau$, whereas the contents of the up-counter(2), referred to as D, during the same time interval $N\tau$ reflects the activity of acquisition in the m preselected hops. The probability that the output D takes a certain integer value i is;

$$P_r\{D=i \mid (\text{n channel jammed , envelope of f1} > \mu)\}$$
$$= \sum_{j_{min}}^{j_{max}} \binom{n-1}{j-1}\binom{m-n}{i-j} (P_{H1})^{j-1}(1-P_{H1})^{n-j}(P_{H0})^{i-j}(1-P_{H0})^{m-n-i+j} \quad +$$
$$\sum_{jj_{min}}^{jj_{max}} \binom{n-1}{j-1}\binom{m-n-1}{i-j-1} (P_{H1})^{j-1}(1-P_{H1})^{n-j}(P_{H0})^{i-j-1}(1-P_{H0})^{m-n-i+j} \qquad (14)$$

where

N=total number of hopping channels
m=number of preselected acquisition channels
q=total number of jammed channels
n=number of jammed channels in the m acquisition channels
H=1 if acquisition tones are present and H=0 if they are not,

and

$$j_{min} = \max(1,\ i-m+n) \qquad (15)$$

$$j_{max} = \min(n,i) \qquad (16)$$

$$jj_{min} = \max(0\ ,\ i-m+n) \qquad (17)$$

$$jj_{max} = \min(i-1\ ,\ n) \qquad (18)$$

In a similar way, the probability that the output L takes a certain value is given by;

$$P_r\{L=l \mid (\text{n channels jammed , envelope of f1} > \mu)\}$$

$$= \sum_{r_{min}}^{r_{max}} \binom{n}{r}\binom{m-n}{l-r} (P'_{01})^{r}(1-P'_{01})^{n-r}(P'_{00})^{l-r}(1-P'_{00})^{m-n-l+r} \qquad (19)$$

where

$$P'_{00} = \sum_{k=1}^{N/m-1} \binom{m-1}{k} (P_{00})^{k}(1-P_{00})^{m-1-k} \qquad (20)$$

and

In FH/SS networks, synchronisation of the frequency synthesisers at both channel ends may be accomplished by the use of unmodulated tone patterns appended to the beginning of the message transmissions [2,4]. Detection of the tone pattern and the time at which it is received constitutes acquisition, which establishes receiver timing to an accuracy that is easily tracked during reception of the actual messages. Pattern detection can be implemented either by serial search [2,5] or by a parallel search (matched filter) [4,6,7]. In parallel search, if there are N tones in the pattern, there will be N matched filters that monitor the hopping frequencies simultaneously using N envelope detectors and delay circuitry to obtain a decision threshold. Miller et al [8] have recently reported a parallel search scheme for antijam FH acquisition. In this scheme, the matched filter output is compared to an adaptive threshold that is derived from a measurement of the number of acquisition channels (hops) being jammed. The network provided lower probability of false acquisition as compared to nonadaptive threshold schemes on the expense of high circuit complexity.

On the other hand, the serial search scheme monitors only one frequency at a time, requiring only one detection circuit but taking longer time to make a decision. It is important to note that FH/SS systems are susceptible to partial band jamming, in which case the jammer transmits a signal whose bandwidth is relatively small compared to that of the SS/FH signal and is concentrated in a portion of the band being used. The possibility that the receiver may be jammed during the synchronisation process motivates the selection of long code acquisition sequences, favoring a serial search system in order to prevent false acquisition.

In this paper, we introduce a novel approach for serial search acquisition scheme. This scheme is designed to reduce false acquisition due to jamming, reduce the acquisition time to that of the parallel search, and to reduce the circuit complexity far less than the parallel search scheme.

II-THE NEW APPROACH

The new arrangement is shown in Fig. 2. It is assumed that the FH signal's acquisition pattern consists of unmodulated output of the frequency synthesiser at the transmitter. Let us assume the number of hops (frequencies) to be N. Hence, at the beginning the transmitter sends a few periods each of N hops. Only m (m < N) of these frequencies are monitored in each acquisition phase using a ROM controlled frequency synthesiser producing tones at frequencies offset by a constant frequency f_o from the selected frequencies for acquisition. These m hops used for acquisition are chosen uniformally spaced from the N hopping frequencies. In other words, the duration between each two of these hops is equal to N/m hops. Digital codes correspond to these m selected frequencies are stored in the ROM for use during acquisition process. To be more specific, let N=128, m=16, then N/m=8, that is for a total of 128 hopping frequencies, codes corresponding only to 16 hopping frequencies are stored in the ROM where each of these 16 frequencies lasts for a duration of 8 hops during acquisition process.

The theory of operation for the antijamming acquisition network shown in Fig. 2 during acquisition process may be explained as follows. At the beginning of the acquisition process, the ROM controlled frequency synthesiser provides $(f_1 + f_o)$, the multiplier (mixer) outputs f_o if and only if the FH signal received is f_1 . This f_1 may be transmitted either by the friendly transmitter or by a jammer. In both cases the output from the threshold comparator activates the clock of the ROM whose frequency will be $m\ f_h / N$. Therefore, the ROM controlled frequency synthesiser continues to provide $(f_1 + f_o)$ for a period of N/m hops, then the synthesiser provides $(f_{1+N/m} + f_o)$ for a period of m hops and so on. If there is no jamming present, the output of the threshold comparator during the N/m period will be similar to the

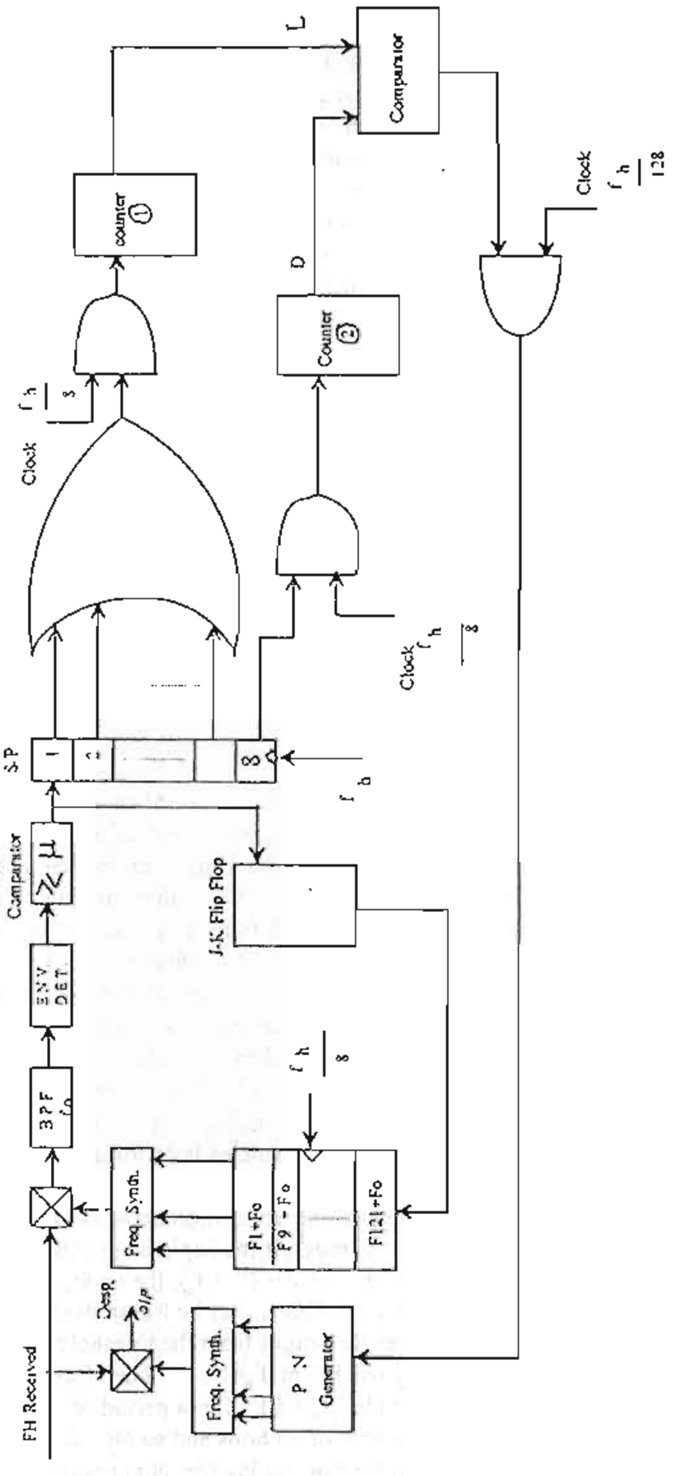

Fig. 2, The New Acquistion Scheme Proposed.

$$P'_{01} = \sum_{k=1}^{N/m-1} \binom{m-1}{k} (P_{01})^k (1-P_{01})^{m-1-k} \tag{21}$$

For stationary jammer, particular acquisition hops are either jammed or not continuously. The probability that n hops out of the m acquisition hops are jammed given that q out of the total N hops are jammed is given by;

$$P_r(n=n_1) = \frac{\binom{m}{n_1}\binom{N-m}{q-n_1}}{\binom{N}{q}} \tag{22}$$

$$\text{where} \quad \max(0, m-N+q) \leq n_1 \leq \min(m, q) \tag{23}$$

Therefore, the probability that an acquisition is declared is expressed by;

$$P_A = \sum_{n1=0}^{\min(m,q)} P_r(n=n_1)\, P_r(\text{env. of } f1 > \mu \mid n=n1) P_r(D>L \mid (n=n_1, \text{env. of } f1 > \mu))$$

$$= \sum_{n1} \frac{\binom{m}{n_1}\binom{N-m}{q-n_1}}{\binom{N}{q}} [\, n/m\, P_{H1} \sum_{l=0}^{m} \sum_{r} \binom{n}{r} (P'_{01})^r (1-P'_{01})^{n-r} \cdot \binom{m-n}{l-r} (P'_{00})^{l-r} (1-P'_{00})^{m-n-l+r}$$

$$\cdot \sum_{D=L}^{m} \sum_{j} \binom{m-n}{i-j} (P_{H0})^{i-j} (1-P_{H0})^{m-n-i+j} \binom{n-1}{j-1} (P_{H1})^{j-1} . (1-P_{H1})^{n-j} + (1-n/m)\, P_{H0} \sum_{l=0}^{m} \sum_{r}$$

$$\cdot \binom{n}{r} (P'_{01})^r (1-P'_{01})^{n-r} \cdot \binom{m-n}{l-r} (P'_{00})^{l-r} (1-P'_{00})^{m-n-l+r} \cdot \sum_{D=L}^{m} \sum_{jj} \binom{m-n-1}{i-jj-1} (P_{H0})^{i-jj-1} (1-P_{H0})^{m-n-i+jj} .$$

$$\binom{n}{jj} (P_{H1})^{jj} . (1-P_{H1})^{n-jj}] \tag{24}$$

Where
$r_{min} = \max(0, l-m+n)$
$r_{max} = \min(n,l)$

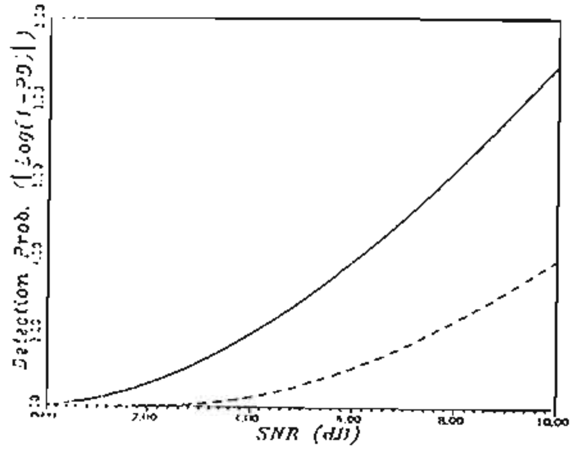

Fig. 4, Correct Acquisition Probability Versus SNR.

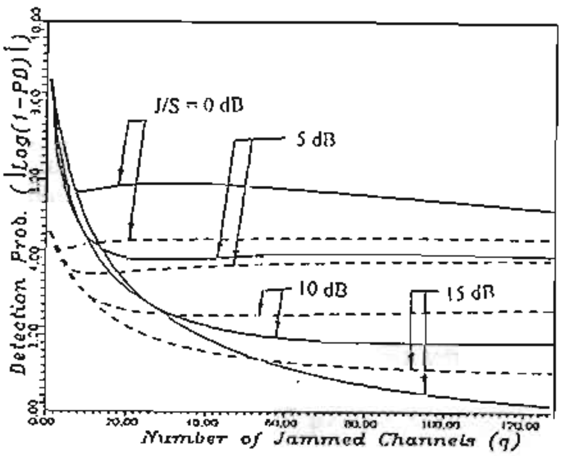

Fig. 5, Correct Acquisition Probability Versus No. of Jammed Hops for Full Band Noise Jamming with SNR = 10 dB.

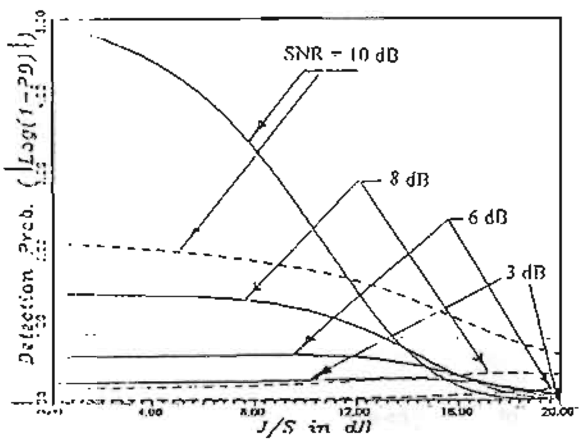

Fig. 6, Correct Acquisition Probability Versus J/S Ratio for Full Band Noise Jamming With Different Values of SNR.

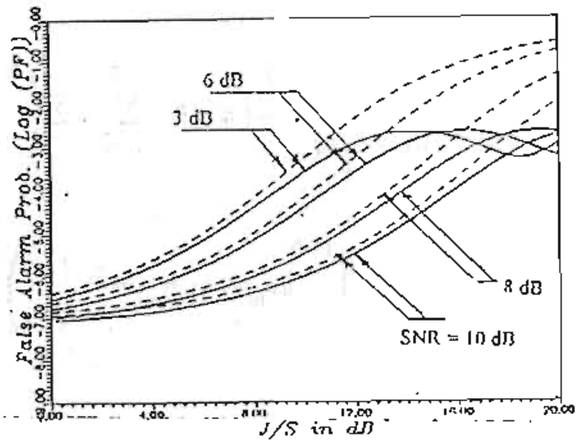

Fig 7, False Acquisition Probability Versus J/S Ratio for Full Band Noise Jamming With Different Values of SNR.

In all figures, serial search is represented by solid lines and parallel search by dashed lines.

Or

$$P_A = \begin{cases} P_D & ; H=1 \\ P_F & ; H=0 \end{cases} \tag{25}$$

where P_D is the probability of correct acquisition and P_F is the probability of false acquisition respectively.

V-RESULTS AND DISCUSSION

In the preceding sections we have developed analytical expressions for the acquisition and false alarm probabilities with and without jamming for the serial search acquisition scheme introduced in this paper. Here, results obtained from the analytical model are presented and discussed. Moreover, results obtained from the parallel search scheme introduced by Miller et al [8] is considered for comparison.

Fig. 4, shows the correct acquisition probability (P_D) as a function of SNR. Solid line shows the results obtained from the serial search introduced in this paper, whereas, dashed line shows the results obtained from the parallel search scheme. It can be seen that for a given value of SNR, the serial search provides higher probability of correct detection than the parallel search method. Note that, for convenience of presentation the value of $|\mathrm{Log}_0(1\text{-}P_D)|$ is used instead of P_D to expand the Y-axis, for example, if P_D=0.9, then $|\mathrm{Log}_0(1\text{-}P_D)|=1$, if P_D=0.99, then $|\mathrm{Log}_{10}(1\text{-}P_D)|=2$, and so on.

In case of multitone jamming, the probability of correct detection as a function of the number of jammed channels is shown in Fig. 5. These results are obtained for full band noise jamming with SNR= 10 dB and different values of tone jamming-to-signal (J/S) ratio. Once again, solid lines show the results of serial search and dashed lines show the results of parallel search. It can be seen that for a given number of jammed channels, serial search outperforms parallel search. Moreover, the detection probabilities are reduced as J/S is increased for both methods.

Fig. 6, shows the variation of correct detection probability as a function of tone jamming-to-signal (J/S) ratio for full band noise jamming with different values of SNR for serial search (solid lines) and parallel search (dashed lines) respectively. It is seen that the detection probability obtained from serial search is much higher than that obtained from parallel search for given values of SNR ans J/S.

Fig. 7, shows the variation of false acquisition probability as a function of the ton jamming-to-signal (J/S) ratio for full band noise jamming with different values of SNR for serial search (solid lines) and parallel search (dashed lines) respectively. It is seen in general that the false acquisition probability increases as J/S increases for both methods. However, the false acquisition probability obtained from the serial search is always less than that obtained from the parallel search method for given values of J/S and SNR. Moreover, the serial search shows its superiority over parallel search at higher values of J/S ratio, since the highest value from serial search is about 10^{-3} as compared with 5×10^{-1} from parallel search method.

VI-CONCLUSIONS

A serial search acquisition scheme for frequency hopping spread spectrum receiver has been introduced. The mathematical models for the probability of correct acquisition (P_D) and probability of false acquisition (P_F) for two particular cases: 1) Gaussian noise jamming and 2)multitone jamming are established.

From the results of the comparison study, it is noticed that the serial search method provides higher values of correct acquisition probabilities and lower values of false acquisition