DOES THE USE OF SPREAD - SPECTRUM REDUCE INTERFERENCE ?*

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ABSTRACT

Recently in the commercial satellite communication environment, there has been an interest in using spread-spectrum together with very small antennas at remote sites of a star network to reduce the network cost. Many engineers believe that spread-spectrum alleviates the interference problems which are exacerbated by the use of very small antennas.

This paper shows that spread-spectrum is not an answer to the interference problems. The interference problems can be best resolved through frequency coordination amongst satellite and terrestrial microwave operators. Spread-spectrum, by chewing up bandwidth, makes the coordination more difficult, reduces the number of carriers that can be transmitted and increases intermodulation noise that fall into the carriers.

Spread-spectrum, however, may be needed to widen carrier bandwidths to avoid data obliteration caused by frequency drift and phase noise if the data information rate is very low. It may also be needed to spread the carrier power spectra to meet the power flux density limits set by official regulatory bodies. In the U.S.A., for the fixed satellite service, there are currently no such limits imposed by the FCC at the Ku-band.

I. INTRODUCTION

Spread-spectrum has been widely used in the military communication environment to protect the sent information from being jammed, intercepted and deciphered by the enemy. It has also been used to reduce multipath fading, to acquire high resolution ranging, and to avoid data obliteration caused by frequency drift and phase noise at very low data transmission rate [1,2].

Recently in the commercial satellite communication environment, there has been an interest in using spread-spectrum together with very small antennas, 2 to 6 feet in diameter, at remote sites of a star network to reduce the network cost [2-4]. There are a couple of problems associated with the use of these smaller-than-normally-required antennas; and many engineers believe the use of spread-spectrum is an answer to these problems.

The first problem is the violation of the power flux density limits set by official regulatory bodies. In the U.S.A., for the fixed satellite sevice, this restriction is currently applied only at the C-band (-152 dBW/m ^{2}/4 kHz on the downlink) [11]. This problem may exist because a network employing smaller-than-normally-required antennas will likely require higher-than-normally-required satellite EIRP's to compensate for low gains of its receive antennas in order to maintain the same acceptable signal quality. The high satellite EIRP's will yield excessive power flux densities on earth if the carriers are not sufficiently spread. The use of BPSK over QPSK modulation and 1/2 rate FEC coding will result in a four-time spreading. If this spreading is not sufficient, spread-spectrum seems to be the only solution.

The second problem is the exacerbated interference to and from its neighboring networks. A satellite communication network using very small antennas, which have wide beamwidths and relative high sidelobe gains, will cause excessive interference to its neighboring networks (terrestrial and/or satellite) and will not have much ability to discriminate against interference originated from its neighboring networks. Many engineers have claimed that spread-spectrum reduces interference to and from the network and that the amount of the interference reduction is equal to the relative spreading (also called the processing gain), thus using very small antennas together with spread-spectrum would produce and receive acceptable interference. Some spread-spectrum earth station vendors have gone even further to the extreme to state that their products are immune to interference. On the other hand, many other engineers, including the famous Viterbi [5], totally disagree with the claim, some even say spread-spectrum has the reverse effect on interference; and the rest of the engineers say it depends on the types of interference.

This paper will attempt to assess the claim. Section II will describe the spread-spectrum technique used in the commercial satellite communication environment. Section III will analyze the spread-spectrum effect on interference reduction. Finally Section IV will provide conclusions and recommendations on spread-spectrum and interference reduction.

II. SPREAD-SPECTRUM

Spread-spectrum, according to [1], is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send information; the band spread is accomplished by means of a code which is independent of the data, and a synchronized reception with the code at the receiver is used for despreading and subsequent data recovery.

The signal can be spread by any of these techniques: direct-sequence, frequency-hopping, time-hopping and chirp. Hybrid combinations of these techniques are also used. The direct-sequence technique, due to its simpilicity and low cost in implementation, is suitable for the commercial application. Accordingly, only the direct sequence technique will be described here, for the other techniques and more information about spread-spectrum, one can consult the literature [1-9]. From the direct sequence technique, a Pseudo Random Binary Sequence (PRBS) is generated from a shift register to spectrum spread the information signal at the transmit site. The same PRBS at the receive site is used synchronously to spectrum despread the received signal to get back the information signal. The spreader and the despreader should be identical in functioning and such that when the two combined together serially, they act like an identity operator which is transparent to signals passing through it. A foreign signal (interference or noise) whose bandwidth is small with respect to that of the PRBS, will be spread out at the receive site by the despreader to have a bandwidth about the same size as that of the PRBS. If the bandwidth of a foreign signal is equal to or larger than that of the PRBS, the despreader will not spread out the foreign signal. Note that to distinguish from the information bits, the bits of the PRBS are called chips and that the chip rate must be a multiple of the information bit rate for the spread-spectrum system (the spreader and the despreader) to work properly.

The direct-sequence technique can be implemented at either the baseband or the IF (or RF). If at the baseband, an exclusive-OR gate (also called a modulo-2 adder) can be used as a spreader (or a despreader). At the IF (or RF), a balanced microwave mixer (acted as an ordinary multiplier) can be used.

Figure 1 illustrates the baseband implementation of the direct-sequence technique. The binary information signal S, which is or is not FEC coded, is passed through the spreader at bit rate of Rs. At the output, it becomes the spread signal (S⊕C) where ⊕ is the exclusive-OR operator whose truth table and related property are also

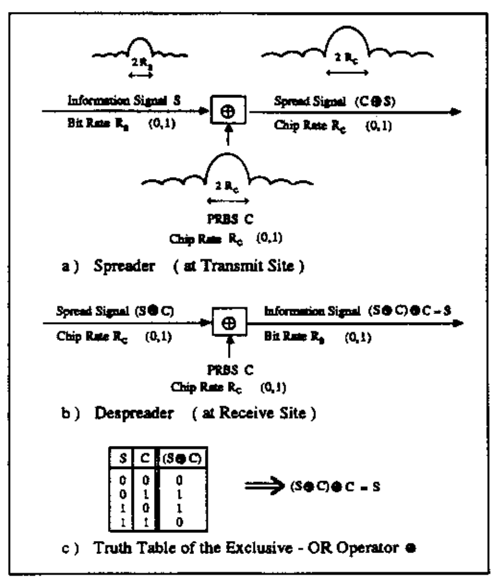


FIGURE 1 - ILLUSTRATION OF BASEBAND IMPLEMENTATION OF SPREAD - SPECTRUM

shown in Figure 1, and C is the PRBS signal of binary digit (chip) rate Rc. Thus the binary digit rate of (S⊕C) is also Rc. Since most of the power of a binary signal of bit rate R (which has a power spectrum of the form $(\mathrm{Sin}X/X)^2$ where $X=\pi f/R$), is concentrated on its power spectrum's mainlobe with its width equal to 2R, one can say that the information signal S is spread by the spreader a factor of (Rc/Rs). (Rc/Rs) is more well known as the processing gain. At the receive site, the spread signal (S⊕C) will be passed through the despreader to come out as (S⊕C)⊕C which is the original information signal S, according to the property of the exclusive-OR operator. Note that if synchronization is not controlled properly or a different PRBS signal C* is used, then the result would be (S⊕C)⊕C* which is different from S. As an illustrative example, say, the processing gain is 3, the PRBS for a period of time (9/Rc) appears as C=110001010 and the information sequence for the same period appears as S=000111111 at the chip rate (converted from S=011 at the bit rate with 0 replaced by 000 and 1 replaced by 111); then the spread sequence, at the chip rate, will be (S⊕C)=110110101; and after despreading, the recovered sequence will become (S⊕C)⊕C=000111111=S which is the original information sequence 011 at the bit rate. If sychronization is not maintained or a different PRBS signal is used so that, say, C*=100010101, then (S⊕C)⊕C*=010100000 which will likely be recognized as 000 at the bit rate.

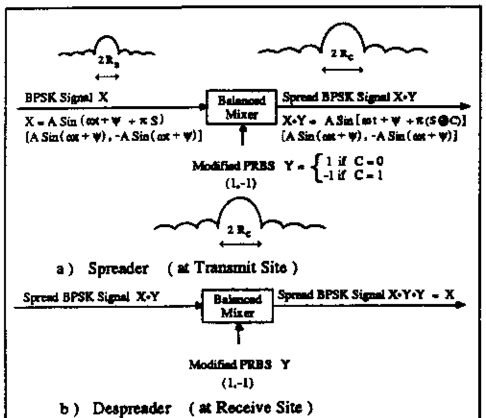
Figure 2 illustrates the IF (or RF) implementation of the direct sequence technique. Input to the spreader is a BPSK signal $X=A\sin(\omega t+\psi+\pi S)$ where A, ω, t, ψ and S are respectively the constant amplitude, the angular intermediate (or radio) carrier frequency, the time, the constant phase and the information signal. Except for a constant phase shift in the frequency and a constant factor in power level, the power spectrum of X and S are the same. After mixing (multiplying), the spread signal is X•Y where '•' is the ordinary multiplication operator and Y is the modified PRBS signal which is related to the original PRBS signal C by the following equation,

$$Y = \begin{cases} 1 & \text{if } C=0 \\ -1 & \text{if } C=1 \end{cases} \qquad (1)$$

The output of the despreader is then X•Y•Y=X which is the original BPSK signal modulated by S. From the truth table of Figure 2, it can be easily justified that

$$X \cdot Y = A\sin(\omega t+\psi+\pi(S \oplus C)) \qquad (2)$$

That is, the output of the IF (or RF) spreader (X•Y) is the BPSK signal modulated by the output of the baseband spreader (S⊕C). To say another way, in theory, it does not make any difference to perform spreading (or despreading) at the baseband through the use of an exclusive-OR gate or at the IF (or RF) through the use of a balanced microwave mixer. In practice, however, due to the carrier lock problem associated with the demodulation process, it is easier to perform despreading before demodulation [2]; that is, it is preferable to despread at the IF.



S	C	X	Y	X•Y
0	0	A Sin(ωt + ψ)	1	A Sin(ωt + ψ)
0	1	A Sin(ωt + ψ)	-1	- A Sin(ωt + ψ)
1	0	-A Sin(ωt + ψ)	1	- A Sin(ωt + ψ)
1	1	-A Sin(ωt + ψ)	-1	A Sin(ωt + ψ)

⟹ X•Y•Y = X   X•Y = A Sin [ωt + ψ + π(S⊕C)]

c) Truth Table of the Mixer

FIGURE 2 - ILLUSTRATION OF IF (or RF) IMPLEMENTATION OF SPREAD - SPECTRUM

III. SPREAD-SPECTRUM EFFECT ON INTERFERENCE

In the previous section, spread-spectrum was described. With respect to interference, it can be summarized as follows :

- At the transmit site, the spreader spreads the signal to have a bandwidth about the same as that of the PRBS signal. The power spectral density of the interference to the neighboring networks is, therefore, reduced.
- At the receive site, the despreader despreads the spread signal to its original bandwidth; and at the same time spreads any other narrowband signals it happens to receive to have bandwidths about the same as that of the PRBS signal. That is, spread-spectrum also reduces power spectral density of the interference from the neighboring networks, if the interference is narrowband (with respect to the PRBS signal).

Nevertheless, the ultimate interference parameter, interested by the engineers, is the interference level I relative to the carrier level C, not the interference power sspectral density Io. These two parameters, at a first glance, seem to be very similar and to contain the same information as the carrier level is assumed to be same. However, they are not so as bandwidth has also to be taken into account. This section will look into the spread-spectrum effect on interference in details. We will consider both interference cases: interference to the neighboring networks and interference from the neighboring networks; whether the neighboring carriers are wideband (FM/TV, 90Mbps PSK/TDMA, ...) or narrowband (FM/SCPC, PSK/SCPC, ...) and whether there is frequency coordination amongst satellite and terrestrial microwave operators. The words wideband and narrowband used here are with respect to the bandwidth of the PRBS signal: if a signal is equal to or wider than the PRBS signal in terms of bandwidth, then it is wideband, otherwise it is narrowband.

III.1 INTERFERENCE TO WIDEBAND NEIGHBORING CARRIER

From Figure 3a, if spread-spectrum is not used, then there will be, say, M interfering carriers falling into the wide bandwidth of an interfered-with carrier (neighboring carrier). As mentioned in Section I, a network using very small antennas will require high satellite EIRP's to compensate for low gains of the antennas. The satellite transponder carrying the interfering carriers, therefore, is operated in a power limited mode: its available power is used up before its bandwidth. Thus the interfering carriers falling into the wideband neighboring carrier are not likely packed in frequency. That is, interference to the wideband neighboring carrier may be acceptable.

If spread-spectrum is used, then as seen from Figure 3b, there will be N of the interfering spread carriers falling into the neighboring carrier. Unless the processing gain is large, there is no guarantee that

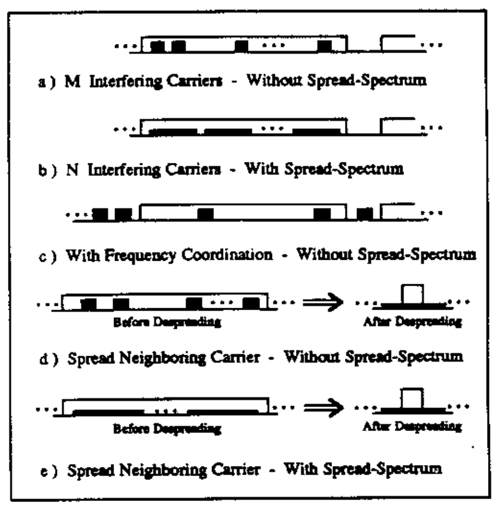


FIGURE 3 - INTERFERENCE TO WIDEBAND NEIGHBORING CARRIER
□ : Interfered-with Carrier (Neighboring Carrier)
■ : Interfering Carrier (Spread or Unspread)

N < M. There is also no guarantee that with spread-spectrum the interference level caused to the neighboring carrier is just acceptable. That is, one may run into either the problem of not spreading the interfering carriers wide enough to produce acceptable interference (underspreading) or the problem of spreading the interfering carriers too wide to efficiently use the transponder capacity (overspreading). Note that by spreading, one reduces or even eliminates spare bandwidth which the engineers can make use of to reduce intermodulation noise falling into the interfering carriers, through proper assignment of frequencies of the interfering carriers [10].

With frequency coordination, one can calculate the maximum number of interfering (spread or unspread) carriers that a wideband neighboring carrier can accommodate and know exactly the locations of the wideband neighboring carriers; and thus one can act accordingly to produce acceptable interference and at the same time maximizing the transponder usage. Also with frequency coordination, one can make use of the space between the wideband neighboring carriers to transmit the interfering carriers, as shown in Figure 3c.

Note that if the wideband neighboring carrier is a spread carrier, the interference to the wideband neighboring carrier after despreading (of the neighboring carrier) is improved over that before despreading, as shown in Figure 3d for the case with unspread interfering carriers and in Figure 3e for the case with spread interfering carriers. The improvement due to the despreading of the neighboring carrier is about the same as the processing gain.

Note also that when the neighboring carriers are high powered and unspread such as FM/TV and high-bit-rate (60 Mbps) PSK/TDMA, then interference to the wideband neighboring carriers will likely be acceptable even without frequency coordination and without the use of spread-spectrum.

III.2 INTERFERENCE FROM WIDEBAND NEIGHBORING CARRIER

As mentioned in Section II, the interfering carrier (neighboring carrier) will not be spread by the despreader as it is already wideband. That is, spread-spectrum does not alleviate the interference problem as seen in Figures 4a and 4b. It, when the interference from the neighboring carrier is acceptable, only makes utilization of the transponder capacity inefficient and chews up spare bandwidth that otherwise can be used to reduce intermodulation noise that fall into the interfered-with carriers.

With frequency coordination, one can make use of the space between the wideband neighboring carriers to place the interfered-with carriers as shown in Figure 4c, and this results in infinitive C/I's.

Note that interference from a high-bit-rate PSK/TDMA neighboring carrier will not likely be acceptable. Interference from an FM/TV neighboring carrier will not likely be acceptable either if the interfered-with carriers are placed close to the center of the FM/TV carrier, say within about ±3 MHz from the carrier center. Interference may be acceptable if the interfered-with carriers are located near the edges of the FM/TV carrier.

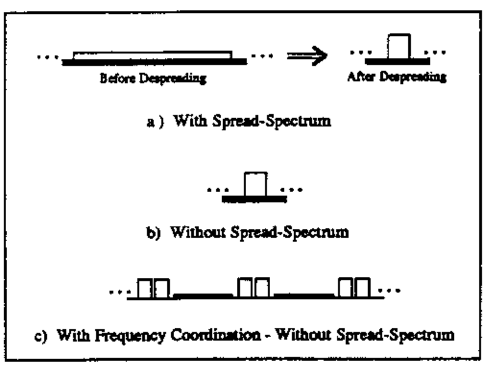


FIGURE 4 - INTERFERENCE FROM WIDEBAND NEIGHBORING CARRIER
□ : Interfered-with Carrier (Spread or Unspread)
■ : Interfering Carrier (Neighboring Carrier)

III.3 INTERFERENCE TO NARROWBAND NEIGHBORING CARRIERS

Without frequency coordination and without the use of spread-spectrum, one likely faces the situation shown in Figure 5a which includes the worst interference case where an interfered-with carrier (neighboring carrier) and an interfering carrier are fully overlapped in frequency; the best interference case where they are not overlapped; and the moderate interference cases where they are partially overlapped. If interference from the worst interference case is acceptable, then there is no need to use spread-spectrum to reduce interference.

When spread-spectrum is used, spread-spectrum acts like a regulator to produce more or less the same C/I for all the cases as shown in Figure 5b. For the worst interference case, C/I's will be improved by an amount equivalent to the processing gain; for the best interference case, C/I's will be reduced from infinitive to the regulated C/I; and for the moderate interference cases, C/I's may be increased or decreased. Note again that without frequency coordination, there is no guarantee that with spread-spectrum the interference levels generated to the neighboring carriers are just acceptable. One likely runs into either the underspreading problem or the overspreading problem.

With frequency coordination, one can create the situation as shown in Figure 5c where the interfering carriers and the interfered-with carriers are not overlapped in frequency to produce infinitive C/I's. In general, some interference can be accepted and there exists antenna discrimination due to the different polarizations and different off-axis gains; these two sets of carriers can be set slightly overlapped each other to maximize the numbers of interfering carriers and interfered-with carriers that can be transmitted with acceptable interference.

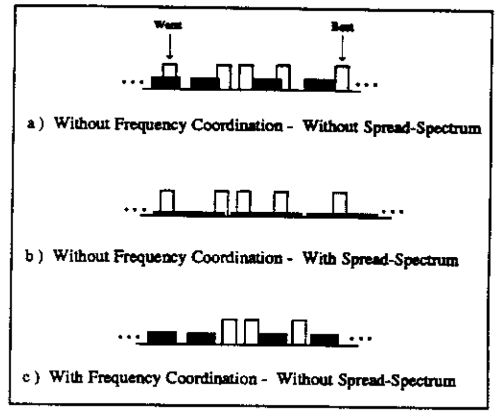


FIGURE 5 - INTERFERENCE TO NARROWBAND NEIGHBORING CARRIERS
□ : Interfered-with Carrier (Neighboring Carrier)
■ : Interfering Carrier (Spread or Unspread)

III.4 INTERFERENCE FROM NARROWBAND NEIGHBORING CARRIERS

Without frequency coordination and without the use of spread-spectrum, one likely faces the situation shown Figure 6a. If interference from the worst interference case of Figure 6a is acceptable, then there is no need to use spread-spectrum to reduce interference.

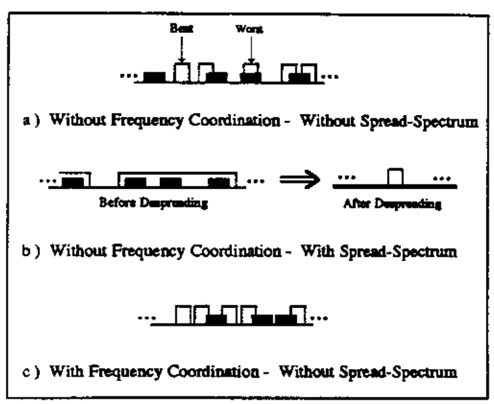


FIGURE 6 - INTERFERENCE FROM NARROWBAND NEIGHBORING CARRIERS
□ : Interfered-with Carrier (Spread or Unspread)
■ : Interfering Carrier (Neighboring Carrier)

When spread-spectrum is used, spread-spectrum acts like a smoother which smooths out the interfering carriers as shown in Figure 6b. The higher the processing gain, the smoother is the interference power spectrum. The improvement in C/I over the worst interference case, however, is more or less independent of the processing gain, and can approximately be computed as the inverse of the bandwidth utilization factor in the neighboring network. Thus there will not be sufficient C/I improvement to make interference from the neighboring carriers acceptable, unless the interfering carriers are packed sufficiently loosely in frequency.

With frequency coordination, as shown in Figure 6c, one can maximize the numbers of interfering carriers and interfered-with carriers that can be transmitted with acceptable interference.

IV. CONCLUSIONS AND RECOMMENDATIONS

From the above analysis, it can be concluded that spread-spectrum is not an answer to the interference problems. For interference from neighboring carriers, spread-spectrum does not provide C/I-improvement if the neighboring carriers are wideband; and if the neighboring carriers are narrowband, spread-spectrum does not provide sufficient C/I-improvement, unless the neighboring carriers are loosely packed in frequency. For interference to neighboring carriers, spread-spectrum can provide acceptable C/I-improvement only if the interfering (considered) carriers are sufficiently spread. The amount of just sufficient spreading cannot, however, be determined in general, unless there is frequency coordination amongst satellite and terrestrial microwave operators. One, therefore, may run into either the problem of underspreading where the interference problems are still left unsolved or the problem of overspreading where the transponder capacity is utilized even more inefficently.

The interference problems can be best resolved through frequency coordination. With frequency coordination, by making use of all known information about the carriers and the networks, one can determine the maximum number of carriers that can be transmitted with acceptable inteference. Spread-spectrum, by chewing up bandwidth, makes the coordination more difficult, reduces the number of carriers that can be transmitted, and increases intermodulation noise that can fall into the carriers.

Nevertheless, besides security reason, spread-spectrum may be used to widen the carrier bandwidths to avoid data obliteration caused by frequency drift and phase noise if the data information rate is very low. It may also be needed to spread the carrier power spectra to meet the power flux density limits set by official regulating bodies. In the U.S.A., for the fixed satellite service, there are currently no such limits imposed by the FCC at the Ku-band, but these may be changed in the future.

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