Intersystem and Intrasystem Interference with Signal Imperfections

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***ABSTRACT*-Analytical techniques have been developed and accepted as effective ways to assess the approximate effects of interference from Global Navigation Satellite System (GNSS) signals to the reception of signals from the same or other GNSSs. The methodology has been used to determine the effects of interference from different signals transmitted by the same system (intrasystem interference) and interference from signals transmitted by other systems (intersystem interference). However, the current methodology assumes that the set of transmitted signals is merely the superposition of ideally specified signals. In fact, transmitted signals have imperfections, and these imperfections can affect the level of interference. This paper extends the interference assessment methodology to include the effect of signal imperfections, adding consideration of different types of signal imperfections and evaluating their effect on intrasystem and intersystem interference.**

INTRODUCTION

As more signals occupy frequency bands used for Global Navigation Satellite Systems (GNSS), and as signal powers increase, interference from other signals transmitted by the same system (intrasystem interference) and interference from signals transmitted by other systems (intersystem interference) warrant increasingly careful consideration.

Analytical techniques that predict the level of interference are particularly useful in design studies and other assessments during preliminary consideration of new or modified GNSSs, since the analytical techniques enable rapid quantification of interference effects with reasonable accuracy.

A methodology for analytically predicting effects of intersystem and intrasystem interference is described in [1]. It builds on extensive work originally performed in the context of spread spectrum communications, applications to radionavigation in [2] and [3], and applications to consideration of future GNSS signals in [4] and [5].

As described in [6], output signal-to-noise plus interference ratio (SNIR) describes how interference affects receiver functions such as acquisition, data demodulation, and carrier tracking, but interference affects code tracking differently. In many cases of interest, however, the effect on code tracking is less significant than other effects, allowing focus on output SNIR. A quantity called effective C/N_0, denoted $(C/N_0)_{eff}$, was introduced to reflect the effect of interference on characteristics at the input of the receiver, avoiding receiver-specific details such as integration time and use of coherent or noncoherent processing. Finally, for studies emphasizing spectra of signals and interference, a parameter called the spectral separation coefficient (SSC) was introduced [4] to distinguish the effects of spectral shape from effects of interference power.

One common type of signal imperfection is incompletely suppressed carrier, producing an undesired narrowband component with power concentrated around the carrier frequency. While diligent transmitter designs suppress this undesired power far below the power of the desired signals, the remaining power potentially contributes to intersystem and intrasystem interference.

Another type of imperfection involves intermodulation products caused by nonlinear combination of multiple signals at the transmitter. Intermodulation products may be intentionally introduced when more than two constant-modulus signals are multiplexed onto a single carrier. Techniques such as Interplex [7] and majority voting [8] are examples of multiplexing approaches produce intermodulation products inherently, while producing a constant modulus signal.

The final category of imperfection dealt with in this paper is broadly called "spurious." In this paper, spurious emissions are considered to be all in-band RF power other than the desired signals, the incompletely suppressed carrier, and intermodulation products.

The next section provides basic problem formulation, while the following section provides models for interference effects of signal imperfections. The last two sections provide numerical examples and summarize the findings, respectively.

FORMULATION

This section summarizes the derivation of basic expressions, verifies their applicability even when signal and interference deviate somewhat from underlying assumptions, and describes how to assess interference power from multiple satellites in a constellation.

Spectral Separation Coefficients

The performance of many aspects of GNSS receiver performance (including signal acquisition, carrier tracking,

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data demodulation, but not code tracking accuracy) is described uniquely by the signal-to-noise-plus-interference ratio (SNIR) at the output of the correlator or matched filter. The SNIR is defined as the mean-squared of the output divided by the variance of the output. Although slightly different expressions result from the use of coherent processing (where the carrier phase of the reference signal is matched to that of the received signal) and noncoherent processing (where the reference is not phase-matched), the resulting expressions for SSCs and $(C/N_0)_{eff}$ are the same, so only coherent processing is considered here.

SSCs describe the spectral coupling between an interfering signal having unit-power spectral density[2] $G_\iota(f)$ normalized (unit area) over some interference bandwidth that is larger than the receive bandwidth, and a reference signal having unit-power spectral density $G_s(f)$ normalized over infinite bandwidth. There are two equivalent ways to evaluate SSCs for finite receiver bandwidths: evaluate the SSC over infinite bandwidth and then apply a loss factor that depends on the receiver bandwidth, the interference spectrum, and the signal spectrum, or evaluate the SSC directly over the receiver bandwidth. This paper uses the latter approach for simplicity. SSCs can also be computed using the transfer function representing receiver filtering and other processes in the receiver, based on the equations in [3]. Since accounting for the magnitude and phase response of the transfer function can be arduous, this paper approximates the effect of filtering at the receiver as merely ideal bandlimiting using a rectangular passband with bandwidth β_r corresponding to the width of the rectangle.

SSCs are readily evaluated when the spectrum of either the interference, or the reference signal, or both, are smooth in the sense that they can be approximated as a linear function of frequency over bandwidths corresponding to the reciprocal of the integration time used in the correlator. This approximation applies when either the interfering signals or the reference signal, or both, use long spreading codes, or when there are many interfering signals displaced from each other in time and phase, or when the period of channel symbols for either the interfering signal or the reference signal (or both) is as short or shorter than the correlator integration time.

Under these conditions, the SSC between the interference and the reference signal is

$$\kappa_{\iota s} = \int_{-\beta_r/2}^{\beta_r/2} G_\iota(f) G_s(f) df. \tag{1}$$

Even when the above conditions do not apply, the SSC defined in (1) represents an average SSC.

Effective Carrier-to-Noise Density Ratio

The effective C/N_0 is obtained from [1],

$$\left(\frac{C_s}{N_0}\right)_{eff} = \frac{C_s L_s}{L_n N_0 + I_{ext} + I_{GNSS}}, \tag{2}$$

where L_s is the processing loss in the desired signal, L_n is the processing loss in the noise, I_{ext} is the effective interference from external sources, and I_{GNSS} is the effective interference from the combination of intersystem and intrasystem GNSS interferers.

From [1], the composite GNSS effective interference from a combination of K sets of intrasystem and intersystem signals is defined as

$$I_{GNSS} = \sum_{k=1}^{K} C_k L_{ks} \kappa_{ks}, \tag{3}$$

where C_k is the received power of the aggregate interference from all signals with power spectral density $G_k(f)$, L_{ks} is the implementation loss (a positive numerical value less than unity representing losses in received power of the interference having power spectral density $G_k(f)$ due to filtering, analog-to-digital conversion, and other factors in receiver processing) in a receiver whose desired signal has power spectral density $G_s(f)$, and κ_{ks} is the spectral separation coefficient

$$\kappa_{ks} = \int_{-\beta_r/2}^{\beta_r/2} G_k(f) G_s(f) df. \tag{4}$$

MODELS OF SIGNAL IMPERFECTIONS

This section introduces three different types of imperfection in transmitted signals and provides analytical models for how they affect $(C/N_0)_{eff}$.

Incompletely Suppressed Carriers

An incompletely suppressed carrier is manifested by a narrowband component at the center frequency of the transmitted signal set. For example, Fig. 1 shows the spectrum of test transmitters for a binary offset carrier signal with 10×1.023 MHz subcarrier and 5×1.023 MHz spreading code rate, denoted BOC(10,5). The blue trace shows the spectrum from a first-generation transmitter, labeled "Lm Tx," displaying an incompletely suppressed carrier. The red trace shows the spectrum from a second-generation transmitter, labeled "Polaris," which has much better carrier suppression.

[2] Signals are represented by their complex envelopes, and filters by their lowpass equivalents, so all frequencies are relative to the carrier frequency.

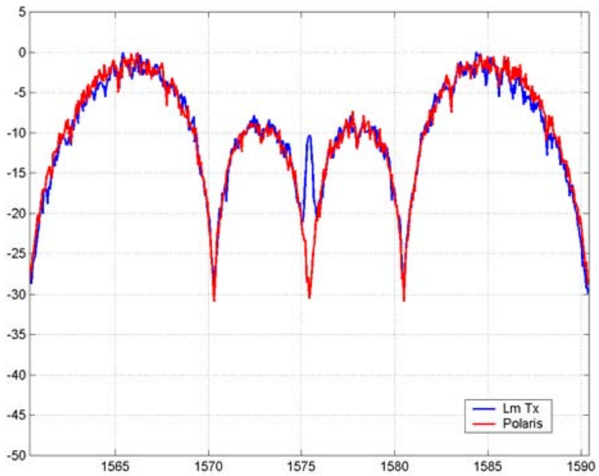

Fig. 1. Spectra of Test Transmitters for M-Code Signal, Displaying Incompletely Suppressed Carrier on Lm Tx

Assume that all satellites in the same constellation display equivalent levels of imperfectly suppressed carrier, and that the desired signal and all interfering signals share the same center frequency. Let the normalized power spectral density of the aggregate imperfectly suppressed carriers from satellites in the nth constellation be denoted $G_{n,c}(f)$, with aggregate received power $C_{n,c}$. The SSC between incompletely suppressed carriers in this constellation and the desired signal is then

$$\kappa_{n,cs} = \int_{-\beta_r/2}^{\beta_r/2} G_{n,c}(f) G_s(f) df. \tag{5}$$

Typically, the bandwidth of the imperfectly suppressed carrier is much smaller than the spreading code rate of the desired signal. In this case, the SSC (5) can be approximated as

$$\kappa_{n,c} \cong \max\left(G_s(0), \phi\right), \tag{6}$$

where ϕ represents a lower limit imposed by phase noise or other factors in a receiver.

Incompletely suppressed carrier tends to be more important to interference assessment when the interfering signals have balanced modulations, such as binary offset carrier (BOC) [9], and the desired signal has a non-return-to-zero modulation such as binary phase-shift keying with rectangular symbols, denoted BPSK-R.

As an example, consider interfering signals having BOC(10,5) modulation, and a desired signal with BPSK-R modulation and spreading code rate 1×1.023 MHz, denoted BPSK-R(1). When the interference power is normalized over 30×1.023 MHz bandwidth, and the receiver employs a 24 MHz bandwidth with rectangular passband, the SSC between interference and desired signal numerically evaluates to –87.1 dB/Hz. The SSC between the incompletely suppressed carrier of the BOC(10,5) interference and the desired signal, assuming that (6) applies, is –60.1 dB/Hz. As long as the power in the incompletely suppressed carrier is small enough, the BOC(10,5) interference dominates the effect of the incompletely suppressed carrier. Since the SSC of the incompletely suppressed carrier is 27 dB greater than the SSC of the interference itself, one might expect that when the power in the incompletely suppressed carrier is 10 dB lower than the amount that its SSC exceeds that of the BOC(10,5) interference, or 37 dB below the power in the BOC(10,5) interference, the incompletely suppressed carrier would have little effect.

Fig. 2 shows numerical results for a BPSK-R(1) desired signal received at –158.5 dBW, thermal noise at –201.5 dBW/Hz, aggregate BOC(10,5) interference at different power levels, and different levels of carrier suppression. For this artificial example, there is no interference from other signals, including those having the same spectrum as the desired signal, and no external interference. These numerical results confirm that when the carrier is suppressed 35 dB below the BOC(10,5) interference power, the imperfectly suppressed carrier has only a small additional contribution to the $(C/N_0)_{eff}$, even when there no interference from other sources to mask the effect.

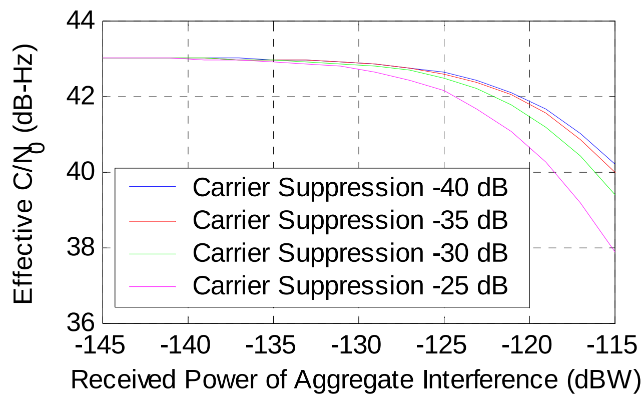

Fig. 2. Effective C/N_0 for BPSK-R(1) Desired Signal with BOC(10,5) Interference and Different Levels of Incompletely Suppressed Carrier Power below the Interference Power

As another example, consider interfering signals having BOC(1,1) modulation, and a BPSK-R(1) desired signal. When the interference power is normalized over 30×1.023 MHz bandwidth, and the receiver employs a 24 MHz bandwidth with rectangular passband, the SSC between interference and desired signal numerically evaluates to –67.8 dB/Hz. The SSC between the incompletely suppressed carrier of the BOC(1,1) interference and the desired signal, assuming that (6) applies, is –60.1 dB/Hz. As long as the power in the incompletely suppressed carrier is small enough, the BOC(1,1) interference dominates the effect of the incompletely suppressed carrier. Since the SSC of the incompletely suppressed carrier is 7.7 dB greater than the SSC of the interference itself, one might expect that when the power in the incompletely suppressed carrier is 10 dB lower than the amount that its SSC exceeds that of the BOC(10,5) interference, or 17.7 dB, that the incompletely suppressed carrier would have little effect.

Fig. 3 shows numerical results for a BPSK-R(1) desired signal received at –158.5 dBW, thermal noise at –201.5 dBW/Hz, BOC(1,1) interference at different power levels, and different levels of carrier suppression. For this artificial example, there is no interference from other signals, including those having the same spectrum as the desired signal, and no external interference. These numerical results confirm that only when the carrier power becomes as large as 15 dB below the BOC(1,1) interference power, does the imperfectly suppressed carrier begin to affect the $(C/N_0)_{eff}$.

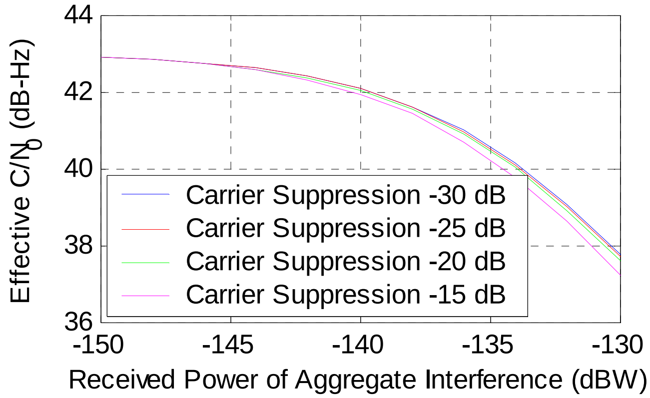

Fig. 3. Effective C/N_0 for BPSK-R(1) Desired Signal with BOC(1,1) Interference and Different Levels of Incompletely Suppressed Carrier Power below the Interference Power

The effect of suppressed carrier on intrasystem and intersystem interference can be determined for each constellation by establishing the power in the aggregate imperfectly suppressed carriers from satellites in that constellation. The contribution of imperfectly suppressed carrier from N constellations is an extension to (3):

$$I_{\text{GNSS}} = \sum_{k=1}^{K} C_k L_{ks} \kappa_{ks} + \sum_{n=1}^{N} C_{n,c} L_{n,cs} \kappa_{n,cs}, \tag{7}$$

where $L_{n,cs}$ is the reduction in power of the interfering incompletely suppressed carriers due to receiver processing imperfections.

Intermodulation Distortion

Intermodulation distortion arises from nonlinear distortion of multiple signals multiplexed onto a single carrier. Techniques like Interplex modulation and majority voting are known to produce intermodulation distortion in order to maintain a constant modulus composite transmitted signal comprising three or more constant modulus biphase signals. When the nth constellation's transmissions include intermodulation distortion having aggregate received power $C_{n,i}$ with normalized power spectral density $G_{n,i}(f)$, the corresponding spectral separation coefficient is

$$\kappa_{n,is} = \int_{-\beta_r/2}^{\beta_r/2} G_{n,i}(f) G_s(f) df. \tag{8}$$

In general, the spectral shape and the received power of the intermodulation distortion depends on the modulations of the other signals being transmitted, their power levels, and the nonlinear mechanism producing the distortion.

For example, when Interplex is used to multiplex a BPSK-R(1) signal onto one phase of a carrier, and BPSK-R(10) and BOC(10,5) modulations in phase quadrature, the intermodulation distortion has the same spectral shape as a BOC(10,10) modulation. The SSC of this BOC(10,10) intermodulation distortion with a desired BPSK-R(1) signal is –87.2 dB/Hz. When the received power of the BPSK-R(1) signal is –158.5 dBW, the received power of the BPSK-R(10) signal is –161.0 dBW, and the received power of the BOC(10,5) signal is –157.0 dBW, the received power of the BOC(10,10) Interplex intermodulation from each satellite would be –159.5 dBW. In contrast, if the received power of the BPSK-R(1) signal is –157.0 dBW, the received power of the BPSK-R(10) signal is –159.0 dBW, and the received power of the BOC(10,5) signal is –150.0 dBW, the received power of the BOC(10,10) Interplex intermodulation would be –152.0 dBW from each satellite.

The effect of intermodulation distortion on intrasystem and intersystem interference can then be determined for each constellation by establishing the power in the aggregate intermodulation distortion from satellites in that constellation. The contribution of intermodulation distortion from N constellations is an extension to (7):

$$I_{\text{GNSS}} = \sum_{k=1}^{K} C_k L_{ks} \kappa_{ks} + \sum_{n=1}^{N} C_{n,c} L_{n,cs} \kappa_{n,cs} + \sum_{n=1}^{N} C_{n,i} L_{n,is} \kappa_{n,is}, \tag{9}$$

where $L_{n,ci}$ is the reduction in power of the intermodulation distortion due to receiver processing imperfections.

Since the spectrum and the power of the intermodulation product can vary with transmitter design and power of the transmitted signals, the interference effects can be limited by identifying setting $L_{n,ci}$ to unity (indicating no reduction in power due to receiver processing imperfections), a maximum power of the intermodulation product from each constellation, and a maximum SSC between the intermodulation product interference and each desired signal.

In the previous example, the maximum received power of the intermodulation product from each constellation could be identified, the largest allowable SSC between intermodulation product and BPSK-R(1) could be –87.2 dB/Hz, the largest allowable SSC between intermodulation product and BPSK-R(10) could be –77.3 dB/Hz, the largest allowable SSC between intermodulation product and BOC(10,5) could be –74.4 dB/Hz, and the largest allowable SSC between intermodulation product and BOC(1,1) could be –82.5 dB/Hz., where these SSCs are computed using a BOC(10,10) spectrum. Even if other transmitter designs employ different multiplexing techniques and different components, and signal powers change, as long as the power of the intermodulation product does not exceed the maximum allowable level, and the SSC to each desired signal is not exceeded, it is certain that contribution of intermodulation product interference to $(C/N_0)_{eff}$ of each desired signal will not exceed a known value.

Spurious Emissions

Spurious emissions account for all other in-band emissions from the transmitter. The characteristics of spurious emissions can vary, and when the nth constellation's transmissions include spurious emissions with aggregate received power $C_{n,s}$ and normalized power spectral density $G_{n,s}(f)$, the corresponding spectral separation coefficient is

$$\kappa_{n,ss} = \int_{-\beta_r/2}^{\beta_r/2} G_{n,s}(f) G_s(f) df. \tag{10}$$

For the remainder of this paper, it is assumed that the aggregate received spurious emissions from a satellite constellation have a spectrally flat distribution over the transmit bandwidth of the satellites, β_t, yielding

$$G_{n,s}\left(f\right)=\begin{cases}\dfrac{1}{\beta_t}, & \left|f\right|\le\beta_t/2\\ 0, & \text{elsewhere.}\end{cases} \tag{11}$$

Substituting (11) into (10), assuming that the transmit bandwidth exceeds the receive bandwidth, yields

$$\kappa_{n,ss}=\frac{1}{\beta_t}\int_{-\beta_r/2}^{\beta_r/2}G_s\left(f\right)df. \tag{12}$$

In some cases where the desired signal's power is well contained in the receiver bandwidth, (12) can be approximated

$$\kappa_{n,ss}\cong\frac{1}{\beta_t}. \tag{13}$$

The contribution of spurious emissions from N constellations is an extension to (9):

$$\begin{aligned}I_{\text{GNSS}}=&\sum_{k=1}^{K}C_k L_{ks}\kappa_{ks}+\sum_{n=1}^{N}C_{n,c}L_{n,cs}\kappa_{n,cs}\\&+\sum_{n=1}^{N}C_{n,i}L_{n,is}\kappa_{n,is}+\sum_{n=1}^{N}C_{n,s}L_{n,ss}\kappa_{n,ss},\end{aligned} \tag{14}$$

where $L_{n,si}$ is the reduction in power of the spurious emissions due to receiver processing imperfections.

NUMERICAL RESULTS

The effect of signal imperfections on results previously evaluated in [1] can now be examined. Table 1 provides fundamental parameters needed to quantify interference effects, accounting for interference from a Satellite-Based Augmentation System (SBAS) as well as from medium-earth orbit (MEO) constellations. All losses in processing signal imperfections are assumed to be 0 dB.

TABLE 1
PARAMETER VALUES FOR INTERFERENCE ANALYSIS

Parameter	Numerical Value
$C_{s,spec,\min}$ is the minimum specified received power of the desired signal	Variable (dBW)
$G_{ant,\min}$ is the minimum antenna gain of the receiver antenna at minimum user elevation angle	–4.5 dB
L_s is the effective power loss of the desired signal due to signal processing and bandlimiting in the receiver and imperfections in the signal	–2 dB
L_n is the effective reduction in noise power density due to signal processing and bandlimiting in the receiver	0 dB
N_0 is the assumed receiver thermal noise density floor	–201.5 dBW/Hz
I_{ext} is the effective interference density from external interference sources	–206.5 dBW/Hz
$C_{k,\max,sat}$ is the maximum specified power per satellite for the k th set of interfering signals	Variable (dBW)
G_{agg} is the aggregate gain factor describing the ratio of maximum aggregate received power from a constellation to the maximum received power of an individual signal	12 dB for MEO constel-lation, 8 dB for SBAS
L_{ks} is the processing loss in the k th set of interfering signals	–1 dB

Table 2 lists minimum and maximum received power levels for different signals. Minimum power levels are employed for desired signals, while maximum power levels are employed for interfering signals. It is assumed that the Galileo PRS signal is out of L1 band, so that its contributions to L1 interference are assumed to be negligible.

TABLE 2
GNSS RECEIVED POWERS

Signal or Signal Imperfection	Minimum Received Power (dBW)	Maximum Received Power (dBW)
GPS C/A code	–158.5	–153
GPS P(Y) code	–160	–155.5
GPS Earth Coverage M Code	–157	–150
Galileo OS	–157 (I and Q)	–154 (I and Q)
GPS L1 Imperfectly Suppressed Carrier	Not Applicable	Variable
GPS L1 Intermodulation Distortion	Not Applicable	Variable
GPS L1 Spurious Emissions	Not Applicable	Variable
Galileo L1 Imperfectly Suppressed Carrier	Not Applicable	Variable
Galileo L1 Intermodulation Distortion	Not Applicable	Variable
Galileo L1 Spurious Emissions	Not Applicable	Variable

SSC values over receiver bandwidths of 24 MHz are given in Table 3, with nominal values for SSCs involving signal imperfections.

TABLE 3
SPECTRAL SEPARATION COEFFICIENT VALUES

Desired Signal	Interference	SSC (dB/Hz)
C/A code	C/A code	–60.0[1]
C/A code	P(Y) code	–69.9
C/A code	M code	–87.1
C/A code	BOC(1,1)	–67.8
C/A code	Incompletely Suppressed Carrier	–60.1
C/A code	Intermodulation Product	–87.2
C/A code	Spurious Emissions	–74.9
BOC(1,1)	C/A code	–67.9
BOC(1,1)	P(Y) code	–70.2
BOC(1,1)	M code	–82.4
BOC(1,1)	BOC(1,1)	–64.8
BOC(1,1)	Incompletely Suppressed Carrier	–100.0
BOC(1,1)	Intermodulation Product	–82.5
BOC(1,1)	Spurious Emissions	–74.9
Note 1. This value is used instead of the theoretical value of –61.8 dB/Hz to account for effects of short codes.		

Numerical results have been generated to assess the combined effects of intrasystem and intersystem interference on open signals in L1 band. Two different desired signals, GPS C/A code and a future signal using BOC(1,1), are both considered. GPS is modeled as transmitting P(Y) code, M code, C/A code, and the BOC(1,1) signal, while Galileo is modeled as transmitting only the BOC(1,1) signal in L1 band. It is assumed that the GPS and Galileo satellites each transmit the same signal imperfections, although this is probably an oversimplified assumption. Numerical values from the preceding tables are employed, as is the methodology described in [1] as augmented in (14).

Fig. 4 shows $(C/N_0)_{eff}$ for the two different desired signals, with different levels of received aggregate imperfectly suppressed carrier power and no interference from spurious emissions. The $(C/N_0)_{eff}$ shown for BOC(1,1) is based on desired signal power in only one phase of the carrier, although the interference is from both phases. Even though the received power of the desired BOC(1,1) signal is 1.5 dB less than the received power of the desired C/A code signal, the $(C/N_0)_{eff}$ values without signal imperfections are similar, due to the lower self-interference of the BOC(1,1) modulation. The different curves for each signal result from different levels of intermodulation distortion, with received aggregate levels of –150, –145, –140, –135, –130, and –125 dBW. Because of its spectral null at band center, BOC(1,1) is negligibly affected by imperfectly suppressed carrier, while C/A is visibly affected once the aggregate power of imperfectly suppressed carrier exceeds approximately –160 dBW. Conversely, since BOC(1,1) has wider bandwidth, it is affected more by intermodulation distortion than is C/A.

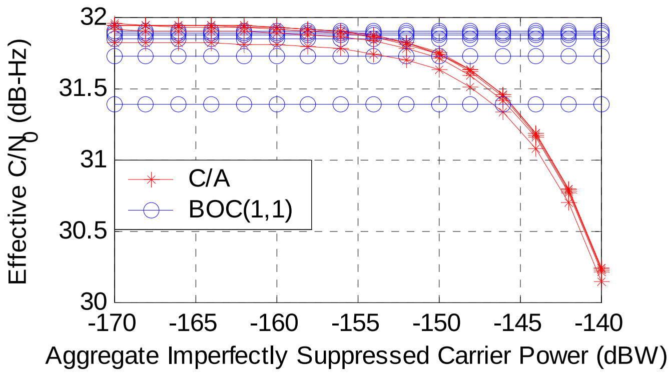

Fig. 4. Effective C/N_0 with Imperfectly Suppressed Carrier Power and Different Levels of Intermodulation Distortion

Fig. 5 shows the same data as in Fig. 4, but plotted against aggregate intermodulation distortion power, with different curves for different powers of aggregate imperfectly suppressed carrier ranging from –170 to–140 dBW in 2 dB steps. These results confirm C/A's greater sensitivity to interference from imperfectly suppressed carrier, and BOC(1,1)'s greater sensitivity to interference from intermodulation distortion.

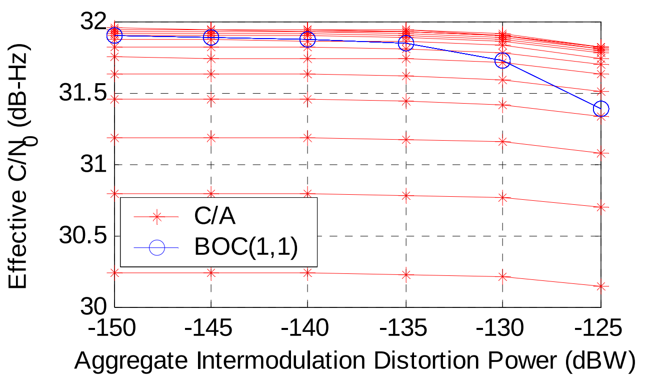

Fig. 5. Effective C/N_0 with Intermodulation Distortion and Different Levels of Imperfectly Suppressed Carrier

Fig. 6 shows $(C/N_0)_{eff}$ for the two different desired signals, with different levels of spurious emissions and no imperfectly suppressed carrier power. The different curves for each signal result from different levels of spurious emissions having received aggregate levels of –160, –155, –150, –145, –140, and –135 dBW. Both modulations are affected similarly by spurious emissions, but since BOC(1,1) has wider bandwidth, it is affected more by intermodulation distortion than is C/A.

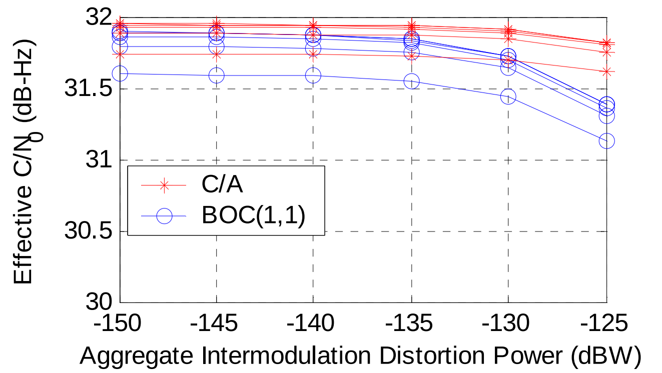

Fig. 6. Effective C/N_0 with Intermodulation Distortion and Different Levels of Imperfectly Suppressed Carrier

Fig. 7 shows the same data as in Fig. 6, but plotted against aggregate spurious emissions power, with different curves for different powers of intermodulation distortion with received aggregate levels of –150, –145, –140, –135, –130, and –125 dBW. These results confirm that C/A and BOC(1,1) are equivalently sensitive to spurious emissions modeled has having flat spectrum over the transmit bandwidth.

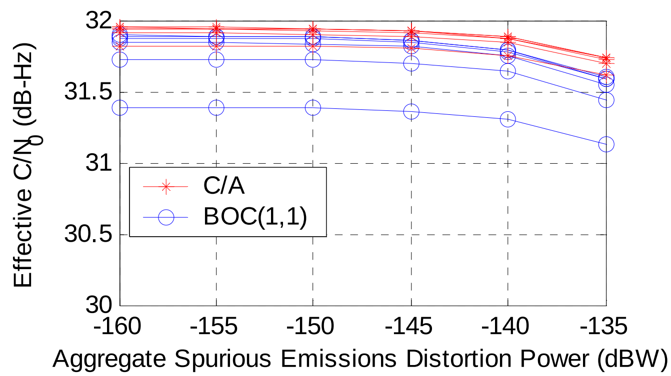

Fig. 7. Effective C/N_0 with Spurious Emissions and Different Levels of Intermodulation Distortion

To assess the consequences of all three signal imperfections combined, consider the benchmark case with no imperfections, leading to $(C/N_0)_{eff}$ of 31.9 dB-Hz for C/A code the desired signal, and the same $(C/N_0)_{eff}$ for BOC(1,1) the desired signal. Suppose that the aggregate received power of imperfectly suppressed carrier from each constellation is –150 dBW (corresponding to received power of imperfectly suppressed carrier from each satellite of –165 dBW), the aggregate received power of intermodulation distortion from each constellation is –135 dBW (corresponding to received power of intermodulation distortion from each satellite of –150 dBW), and the aggregate power of spurious emissions from each constellation is –140 dBW (corresponding to received power of spurious emissions from each satellite of –155 dBW). For the SSC values shown in Table 3, the combination of these imperfections yields $(C/N_0)_{eff}$ of 31.7 dB-Hz for C/A code a desired signal, and the same $(C/N_0)_{eff}$ for BOC(1,1) a desired signal.

Determining whether the effect of these signal imperfections is significant depends upon how the resulting values of $(C/N_0)_{eff}$ compare to minimum acceptable values.

CONCLUSIONS

Complete assessment of RF interference accounts for all transmissions from a satellite; not only the intended signals but also signal imperfections contribute to RF interference. This paper extends the previously introduced methodology for assessing intrasystem and intersystem interference to account for three types of signal imperfections: imperfectly suppressed carrier, intermodulation distortion, and spurious emissions. Models for each type of imperfection have been provided, allowing definition of additional spectral separation coefficients, so that their additional effects can be considered.

Numerical results show that desired signals having different modulations exhibit different degrees of sensitivity to the different types of signal imperfections. When satellite transmitters exhibit very low levels of signal imperfections, evaluations of intrasystem and intersystem interference using only idealized signals may be adequate, while if satellite transmitters produce higher levels of signal imperfections, it is important to account for these imperfections in assessing interference.

The approach outlined here can be used to help establish acceptable levels of signal imperfections in future GNSS systems.

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