Nonlinearity Compensation for Super-Positioning Satellite System with Interference Canceller

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***Abstract*—The Carrier Super-Positioning Satellite System is a promising telecommunication system because the efficiency of frequency usage is twice as much of that in existing satellite systems. Interference canceller used in the carrier super-positioning system is greatly effected by the nonlinear distortion of satellite TWTA. A scheme of the nonlinearity compensation for P-MP VSAT network has been proposed by us before. In this paper we propose and verify a new method to compensate the nonlinearity of satellite TWTA for P-P system to improve the interference canceller for the Carrier Super-Positioning System.**

***Keywords*-satellite; frequency reuse; nolinear compensation; interference canceller.**

I. Introduction

As the traffic demand for high speed data and images increases, effective utilization of frequency resources of satellite communications is more important than ever. Carrier super-positioning is a promising telecommunication system for frequency reuse since the frequency efficiency becomes double that of existing satellite systems. In this system outbound signal (outgoing from the station) and the inbound signal (incoming to the station) can use common frequency band which are conventionally used in separate bands. In this system, the signal sent from the station becomes the interference to the station itself, and the interference shall be removed by the interference canceller which is discussed in this paper.

The interference canceller is realized by generating its replica and subtracting it from the received signal [1]-[5]. In this process, some parts of the interference remaine not cancelled unless the waveform of generated replica is exactly the same as that of interference. One of the major reasons of the difference comes from the nonlinear distortion which the received signals suffer from the satellite transponder TWTA (Traveling Wave Tube). The effects of the nonlinear TWTA on to the conventional communications systems have ever been reported[6][7]. On the other hand, the effects of the nonlinearity on the canceller performance have been reported by us in the previous papers [8]. And a method has been proposed to compensate the nonlinearity by

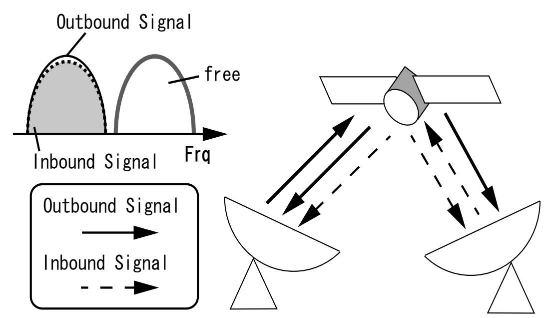

Figure 1. Typical carrier super-positioning systems for Point to Point network

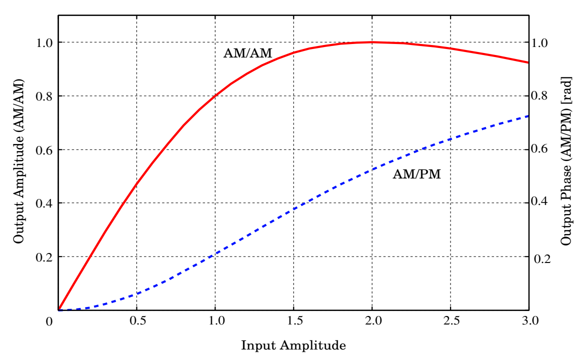

Figure 2. Nonlinear characteristics of TWTA

intentionally giving same nonlinearity to the replica as that of satellite TWTA. This method is , however, applicable only to the P-MP VSAT system in which the power of outbound signal in much large than that of inbound[9][12].

In this paper, we will show the nonlinear compensation method in the P-P system in which the power of both inbound and outbound signal in the same.

One network is composed of two large Hub stations. And a wide band outbound(OB) carrier is sent from the Hub to another wider band inbound(IB) carriers are from another, to the Hub. This is called a point-to-point network. Figure 1 shows the point-to-point network.

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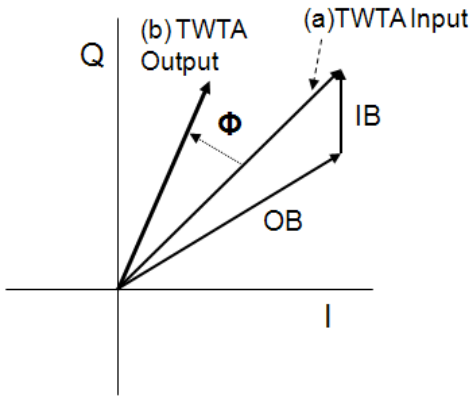

Figure 3. Signal vectors of TWTA Input and Output

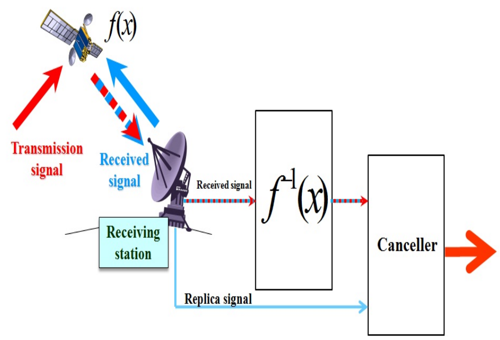

Figure 4. Interference canceller-introduced nonlinear compensations

II. EFFECTS OF NONLINEARITY

In the satellite communications, the transponder TWTA is preferably operated in the region of saturation in order to use power effectively. Then, the signals amplified there suffer from the effects of inter-modulation and distortion due to the AM/AM and AM/PM conversion. Figure 2 shows a typical nonlinear characteristics of the TWTA used in the conventional communications satellite. In the case of a carrier superposed system, two or more carriers are commonly amplified. Figure 3 shows a vector diagram of input and output signals through the TWTA. Composite signal (a) of outbound(OB) and inbound(IB) is provided to TWTA and converted to the TWTA output signal (b). If the power of OB is large enough in comparison with IB, the conversion which the composite signal(a) is received by the nonlinearity is the same as that by which OB is received. On the other hand, it is not true in such system that the power of IB is not smaller enough than OB like point-to-point network.

As mentioned, the difference between received OB and its replica becomes interference. And if the received OB is distorted by the nonlinearity of TWTA, it causes the difference between received OB and its replica.

III. NONLINEARITY COMPENSATION

As described above, interference power is generated due to the nonlinear distortion of unwanted signal (OB). Our purpose in this study is to compensate the distortion. We take different approaches for two types of networks. First, it is for the VSAT system in which the power level of OB is much higher than those of IBs. In this system, the distortion which the composite signal suffers from the nonlinearity is almost the same as the distortion which OB signal suffers from. In this case, therefore, major part of the difference between received unwanted signal and its replica is removed by intentionally giving the same nonlinearity to the replica[9][12]. Secondly, the approach took for point-to-point network is, as shown in Figure4, to put the compensator which has inverse nonlinear characteristics of the TWTA in front of the canceller since we can not apply same approach to P-P system as in the VSAT system where we give nonlinearity to the replica. Here we call replica compensation for the P-MP system and post compensation for the P-P system. The detailed configurations and the effects of both approaches are then discussed.

A. Replica compensation

Here, we refer the method and the effect of replica compensation shown in the reference [9] and [12]. This approach is to compensate the distortion by intentionally giving the same distortion to the replica. Figure 4 shows the conceptual block diagram of replica compensation. The upper side of this block diagram is the path where the received signals (OB+IB) are provided to the canceller. The lower path is to generate the replica of OB by demodulating received signal. The output of the demodulator is then fed to the nonlinearity. This function is achieved not by adding actual non-linear devices such as a Sohottky diode but by a numerical approach of signal processing in a degital filter and does therefore not impact significantly on the hardware size. Here the issue is how to estimate the nonlinear characteristics of satellite TWTA in the replica generator of the canceller unit. It is not difficult to know the satellite TWTA nonlinearity itself by getting the data of the transponder from the satellite operator. Also, there are not so many variations in the nonlinear characteristics in the same class of TWTA. However, even though it is possible to know nonlinear characteristics, we still have to know the operating point (back off) of the satellite TWTA in order to give the same nonlinearity to the replica because the effects of nonlinearity on to the signals depends greatly on the operating level (back off) of the amplifier. Furthermore, the uplink power to the satellite frequently deviates due to the rain attenuation or other reasons. It is therefore mandatory for the nonlinearity compensation to have a function which automatically tracks the operating level of the transponder.

Namely adaptive back off function is mandatory. Figure 5 and 6 show the effects of replica compensation. The extrated carrier to interference ratio is improved by about 10 dB(Figure 5) and half of the BER degradation is improved in dB as shown in Figure 6.

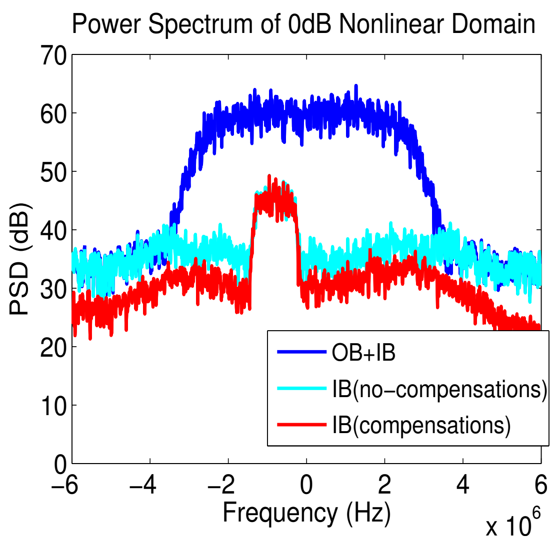

Figure 5. Power spectrum of canceller input and output,IBO=0[dB](refer to [9])

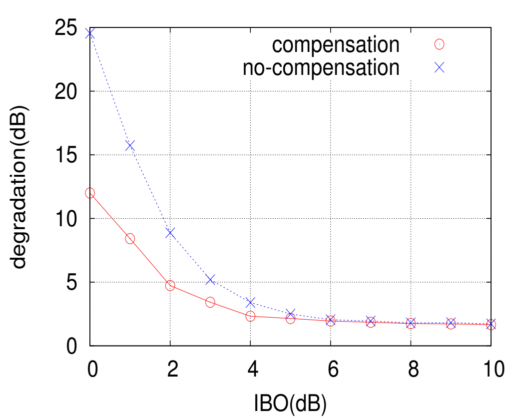

Figure 6. BER degradation at 10^{-4} and its improvement by replica compensation(refer to [9])

In this method, it is assumed that the nonlinear characteristics given to the replica is the same as that of satellite TWTA for both amplitude and phase. However, it is important to investigate the effects of the difference between two nonlinearities. We think it is not difficult to adopt same amplitude nonlinearity of the replica as that of the satellite TWTA since it is not difficult to get precise data of the amplitude nonlinearity of the TWTA Then, we have investigated the effects in case some difference exists between two phase nonlinearities. As shown in these figures,

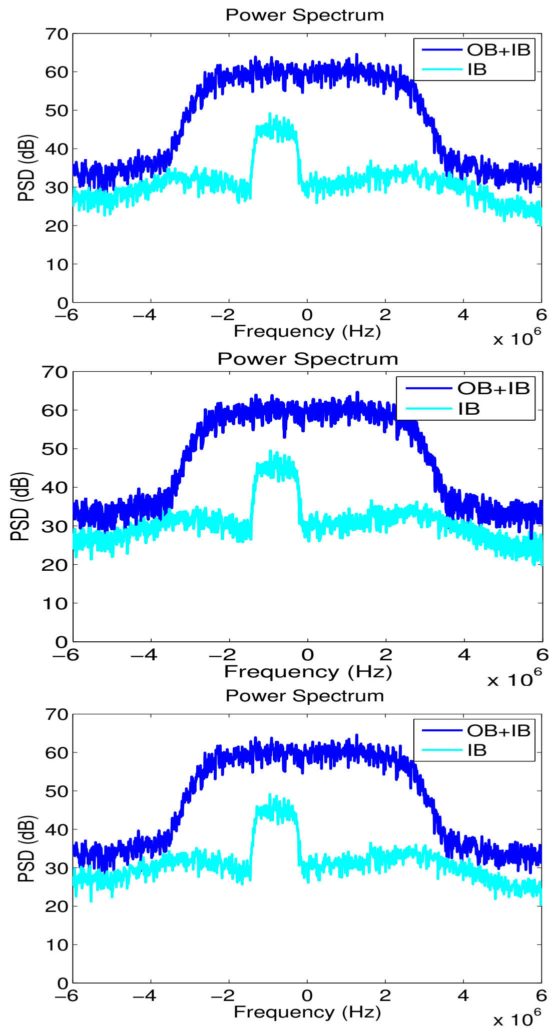

Figure 7. Power spectrum for three cases of phase nonlinearity
Upper : $+20\%$of satellite AM/PM
Middle: $\pm 0\%$ of satellite AM/PM
Lower : $-15\%$of satellite AM/PM

(refer to [12])

it can be said that the change of phase nonlinearity up to +20 and -15 % does not give significant degradation to the performance of nonlinearity compensator.

B. Post compensation

As mentioned, the replica compensation is useful only when the unwanted OB signal level is much higher than wanted IB signals. We propose here another method to compensate distortion which the received signals (composite of both OB and IBs) suffer from the satellite nonlinearity. By this approach, the distortion should be basically removed from the received signal regardless the relation between OB and IB levels.

Figure 8 shows the vector diagram distorted by the nonlinearity. Phase and amplitude of a vector is converted

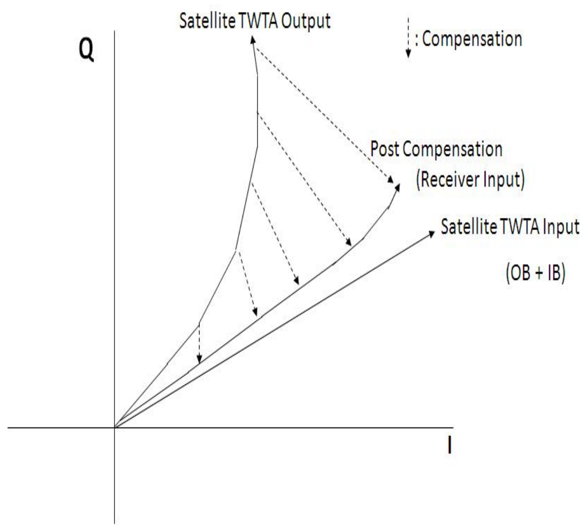

Figure 8. Vector diagram of TWTA input/output and receiver input by post compensation

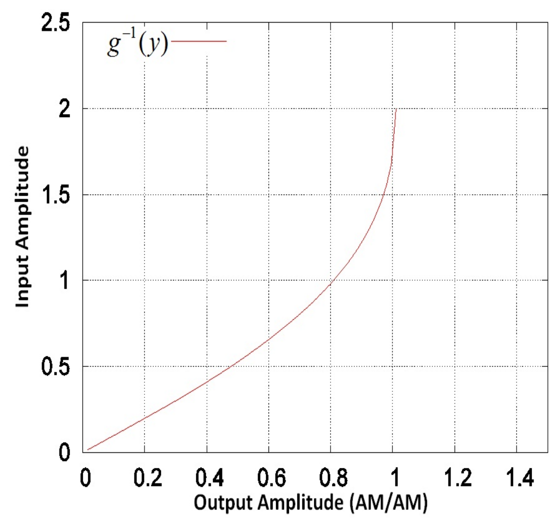

Figure 9. Inverse Nonlinear Characteristics of TWTA

(twisted) according to the AM/PM and AM/AM conversion characteristics of TWTA respectively. Our method is to put the inverse characteristics of the nonlinearity at the canceller input. It is theoretically expected that large part of the distortion can be removed from the received signal before it is provided to the canceller. By this operation, the twisted vector should be stretched as shown in Figure 8. But it shall be notified, in this case, that the inverse operation for the amplitude conversion (AM/AM) increases the noise since this operation is to expand larger portion of amplitude of the received signals which contain thermal noise.

1) Theory of post compensation: Lets assume the non-linear characteristics of the TWTA as , where r is the input signal of TWTA, then the output of TWTA can be expressed by,

$$g(r) = \frac{\alpha_x r}{1+\beta_x r^2} \tag{1}$$

for AM/AM

$$f(r) = \frac{\alpha_\phi r^2}{1+\beta_\phi r^2} \tag{2}$$

for AM/PM

Table I
PARAMETERS OF TWTA CHARACTERISTICS

α_x	1.0
β_x	0.25
α_ϕ	$\pi/12$
β_ϕ	0.25

In the carrier superposed network, the satellite input signal is the summation of outbound signal (A) and inbound signal (B). Therefore the satellite output signal is obtained by,

$$y = g(A+B) \tag{3}$$

Our proposal is to put inverse nonlinear characteristics $g^{-1}(y)$ at the receiver input, then the original signal A+B can be principally attained by

$$A+B = g^{-1}(y) \tag{4}$$

$$g^{-1}(y) = -\sqrt{\frac{\alpha_x^2}{4\beta_x^2 y^2} - \frac{1}{\beta_x^2}} + \frac{\alpha_x}{2\beta_x y} \tag{5}$$

The input-output characteristics of the path is shown in Figure 10 which is compensated by inverse nonlinearity shown in Figure 9.

2) Simulation results: Figure 11 and 12 show the results of computer simulation. The post compensation improves BER by about 1 $\sim$ 1.5 dB as shown these figures. Figure 13 shows the effects of post compensation for two case of TWTA operation points. As shown in Figure 13, large improved can be expected for small input back off.

IV. CONCLUSION

This paper proposes a new nonlinearity compensation method for the interference canceller used in carrier super-positioning point to point(P-P) satellite system. In this system, both inbound and outbound signals are transmitted in the same frequency band and therefore the interference canceller that subtracts the unwanted signal from received signal is required. However, the amplifier used at satellite,

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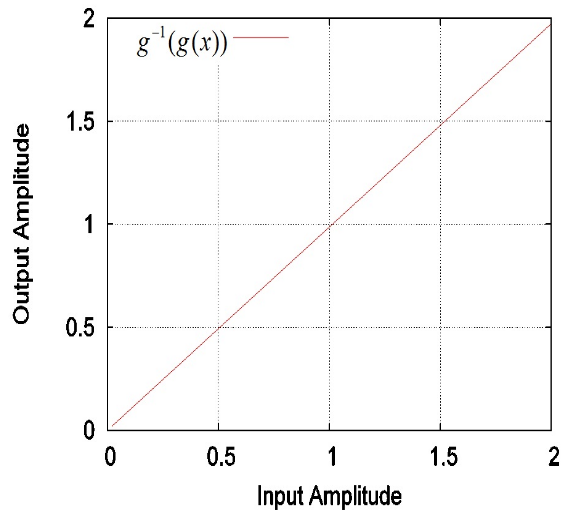

Figure 10. Path Characteristics Compensated by Inverse Nonlinearity

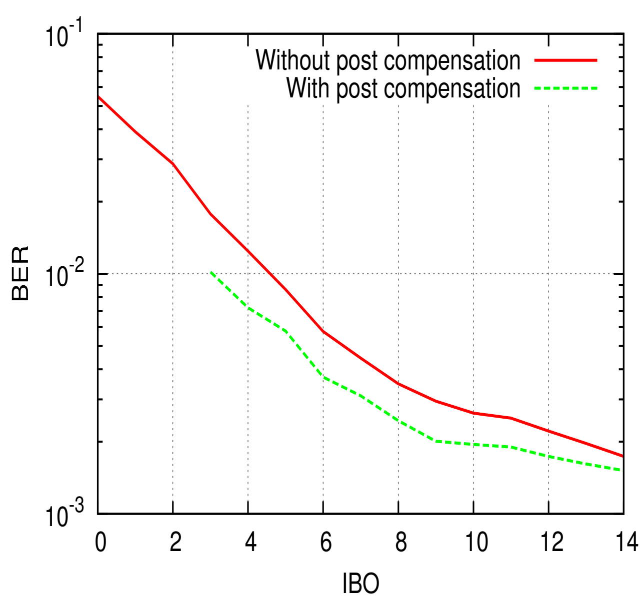

Figure 11. BER Performance vs input back off of TWTA for with and without post compensation, CN = 10[db]

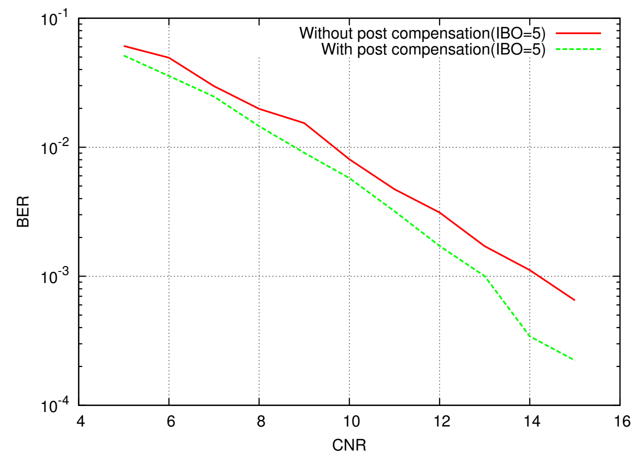

Figure 12. BER Performance vs CNR for with and without post compensation, IBO = 5[dB]

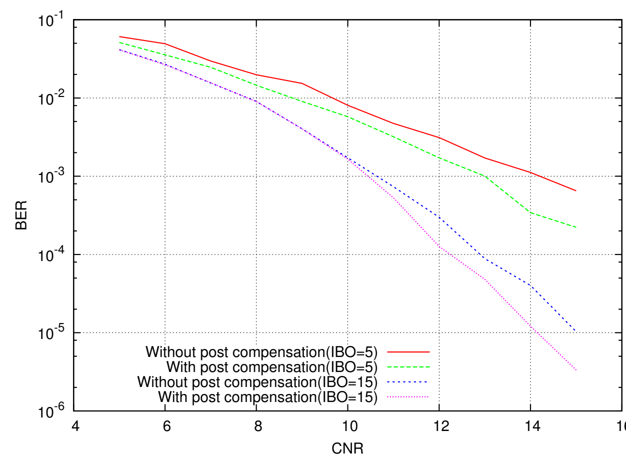

Figure 13. BER Performance for two cases of operating point of TWTA

TWTA, shows nonlinear characteristics when it is used at high input level. To compensate this nonlinear distortion, received signal is deformed with reverse characteristics of TWTA to achieve nondistorted signal. Also, the method which is applicable to P-MP VSAT can not be applied to this case. Therefore we proposed here post compensation method. In this paper, this method is evaluated with computer-based simulation and the result shows that it is able to decrease the effect of nonlinearity which is distorted at satellite's TWTA. For future work, we must check if this method is useful in such conditions that the received signal is attenuated by rain. We also must check if this method does not make worse in the heavier noisy conditions due to the inverse nonlinear operation.

The BER data shown here are now under the further study since these are the case in the simplified transmission path which does not include filters in the down link. (satellite output filter and receiver input filter)

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