Nonlinearity Compensation Technique for Common Band Satellite Channel

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***Abstract*—For effective use of frequency band, carrier superposing (common band) technique has been introduced to satellite communication systems. Meanwhile the satellite's Traveling Wave Tube Amplifier (TWTA) is preferred to be operated near saturation level for power efficiency. However nonlinearity characteristics of TWTA around that level become the cause of interference for carrier superposing systems. Therefore, in this paper, a post compensation technique for TWTA nonlinear distortion is introduced and verified for practical use of carrier superposed Point to Point satellite communication system which adopts interference canceller. Result of the simulation shows it is possible to drastically reduce the BER degradation at all range, specially at nonlinear operating point. This paper also reveals the effect of operating point mismatch that can be caused by rainfall and other environmental changes.**

***Index Terms*—satellite, common band, nonlinearity compensation, TWTA**

I. Introduction

Recently, larger transmission capacity for satellite communication is demanded due to the growing usage like digital broadcasting and internet. From this, common band technique, where two carriers are superposed is becoming a considerable technique as a solution to this problem. In carrier superposing communication system, outbound and inbound signals that are sent on two different frequency bands are superposed and sent in the same frequency band. It is possible to retrieve wanted signals by cancelling out the unwanted signals, signals sent from itself, by subtracting replica signals before demodulating superposed signals. From this, frequency utilization efficiency of two way communication channel composed of outbound and inbound signals can be twice as before at maximum. Thus, many researchers, including authors, have investigated possibilities of carrier superposing technique and is now being in practical use [1]–[6].

However, carrier superposing technique is highly affected by channel nonlinearity. From our previous work it is known that when TWTA (Traveling Wave Tube Amplifier) on satellite is operated near saturation level, signals are degraded very seriously and effective frequency usage achieved by carrier superposing drops down [7]–[9]. To avoid this, authors have proposed a scheme which adds a nonlinear distortion to replica signal to emulate TWTA's nonlinear characteristics for compensation [8], [10], [11]. The methods shown in these references were proposed to give same nonlinearity on the replica signal by digital signal processing at the canceller as the interference signal is received by the satellite TWTA. Though this method can only be used in point to multi-point VSAT system which has an obvious level difference between outbound and inbound signals, and cannot adopt to more general type of channel.

Therefore, in this paper, a scheme which linearizes the received signal by reversely distort received signal based on AM/AM and AM/PM characteristics of satellite's TWTA is proposed. By using this scheme, this paper also proposes a nonlinearity compensation scheme which is adoptable to general type bidirectional satellite communication systems with any kind of level difference between inbound and outbound signals. For nonlinearity compensation of satellite TWTA, there are other types of method like pre-compensation by adding reverse nonlinear distortion at transmitter. However this could cause spectrum spreading in outbound signal and occupies extra band regions. Moreover, it is quite meanless in the common band network to pre-compensate two individual signals at the transmitter side of each earth station because nonlinear distortion is affected to superposed signal. In the case of nonlinearity compensation at modulator for earth station HPA, the pre-compensation method is valid [12].

From these reasons, we adopt post-compensation of satellite TWTA nonlinearity at receiver. Post-compensation method has not been researched by others. In this research, a case of adopting carrier superpose technique to Point to Point bidirectional channel using QPSK modulation is concerned. A simulation model that is close to the actual system is built to evaluate the performance of interference canceller and demodulator.

Our research reveals the effectiveness of proposed post-compensation scheme. This paper also reveals the effect on the post compensation when rain fall occurs in down path of the link or other environment changes since the proposed scheme may be affected by the change of relation of signal operating level (power) between satellite nonlinearity and its compensator in the receiver. This paper has improved our previous paper [13] by adding detail investigations and simulating in more realistic transmission path model which includes filters between satellite TWTA and receiver.

This paper is organized as follows. Section II explains the detail of nonlinearity compensation algorithm and simulation model of carrier superposed Point to Point satellite communication system. Section III describes the simulation result,

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evaluate those results, and shows the effectiveness of proposed scheme. Finally Section IV concludes this paper.

II. Carrier Superposed Network with Nonlinearity Compensation

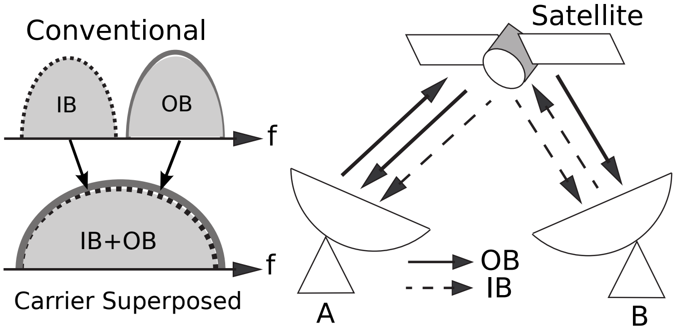

Fig. 1. P to P equal level carrier superposed satellite network

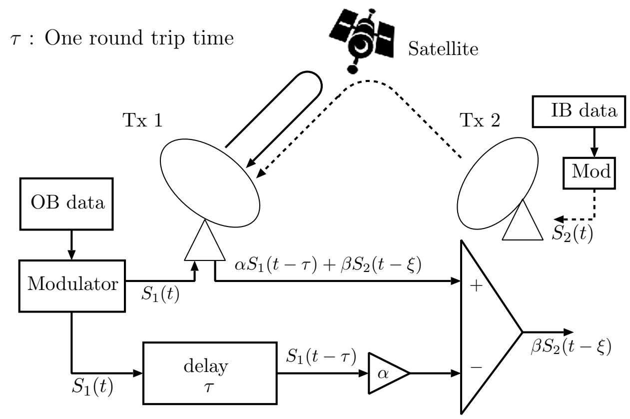

Fig. 2. Concept of interference canceller for superposed transmission.

Figure 1 shows P-to-P satellite communication system model used in this research which two opposite carriers have the same level. In this figure, the channel is setup between two earth station A and B. Here, we state the signal carrier from station A to station B an outbound (OB) signal and signal carrier from station B to station A an inbound (IB) signal.

In conventional satellite communication systems, OB and IB signals are transmitted on different frequency band. In contrary, in carrier superposed system, those signals are superposed and transmitted on same frequency band. From this, either the outbound or inbound signal's frequency band will be free and both carrier frequency can be twice as wide as before, which means doubling the frequency band usage efficiency. To retrieve wanted signal from received signal, unwanted signal, in this case self transmitted signal, which is superposed on wanted signal must be cancelled out. This is done by subtracting the replica of self transmitted signal from received signal.

A. Interference Canceller

Interference is cancelled by generating replica of unwanted signal [4], [6]. In Figure 2, two earth stations transmit the signals, and the signals to the left and right are denoted by $S_1(t)$ and $S_2(t)$ respectively.

Let us assume that the cancellation is performed at the earth station to the left in the figure. Since both earth stations transmit the signal at the same frequency, the received signal is the sum of $S_1(t)$ and $S_2(t)$. The received signal at the station is given by:

$$r(t) = \alpha S_1(t-\tau) + \beta S_2(t-\zeta) + z(t) \tag{1}$$

where α and τ are the round-trip propagation path loss and round-trip delay between the station and the satellite, and β and ζ are the propagation path loss and trip time between two earth stations via satellite. Further, $z(t)$ is an additive Gaussian noise (AWGN) component.

At the canceller, the transmitted signal, $S_1(t)$, is applied to the delay block whose delay time is set to be the same as the round-trip delay, τ. The output of the delay block $S_1(t-\tau)$ is then fed to the variable gain amplifier to adjust amplitude of the replica and the interference signal. If the adjustment is perfect, the gain of the variable gain amplifier is set to be α. The output of the variable gain amplifier is then subtracted from the received signal. The output of the interference canceller is given by

$$u(t) = r(t) - \alpha S_1(t-\tau) = \beta S_2(t-\zeta) + z(t). \tag{2}$$

From this equation, we can find that the interference signal $S_1(t)$ is successfully cancelled. However, to cancel the interference from the received signal, it is necessary to estimate the round-trip delay of the received signal. Here the accuracy of the delay estimation affects interference suppression performance of the canceller [4], [6].

It is also required to adjust the phase and amplitude of both OB signal and its replica signal. Our previous paper handles the solution to these requirements and has shown that they are performed by applying extended matched filter with phaser locked loop.

B. Nonlinearity Compensation Algorithm

In satellite communications, transponder TWTA is preferable to be operated near the saturated region in order to use its power efficiently. However if used in the saturated region, the signals amplified there suffer from the effects of intermodulation and distortion due to AM/AM and AM/PM properties. Figure 3 shows a typical nonlinear characteristics of the TWTA used in ordinary communication satellite. In the case of carrier superposed system, two or more carriers are amplified together. Figure 4 shows an example of vector diagram of input and output signals through TWTA. Composite signal (a) of outbound (OB) and inbound (IB) is provided to TWTA and converted to TWTA output signal (b).

If the power of OB is large enough compared with IB, the output of TWTA will be almost the same as the TWTA output when only OB signal is input so to cancel the interference, nonlinear distorted OB must be fed to the canceller. On the

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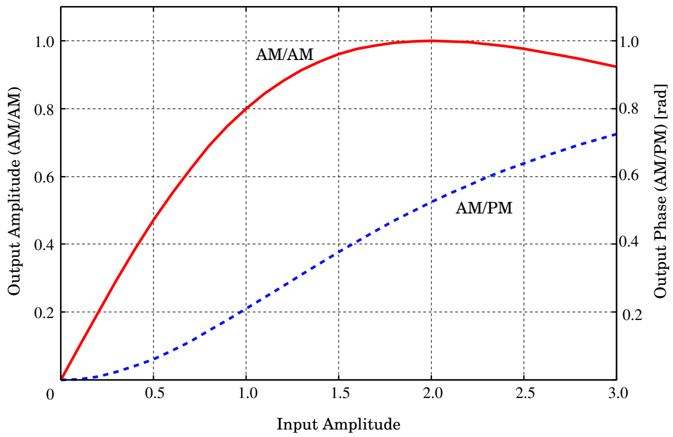

Fig. 3. Nonlinear characteristics of TWTA

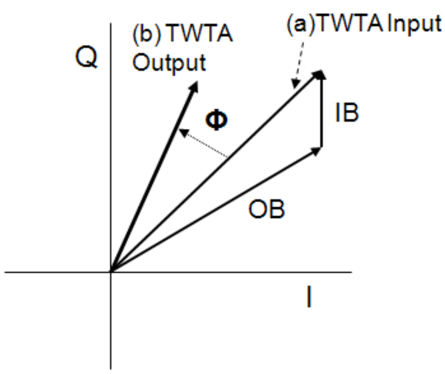

Fig. 4. Signal vectors of TWTA input and output

other hand, if the power of IB is not negligible compared with OB, TWTA output will be different from nonlinear distorted OB signal and this difference causes interference if simply fed to the canceller. To avoid this interference, we adopt post-compensation scheme to compensate nonlinear effects of TWTA when operated in saturated region.

Amplitude of input vector is distorted according to AM/AM characteristics [14]

$$f(r) = \frac{\alpha_x r}{1 + \beta_x r^2} \tag{3}$$

and phase of input vector is distorted according to AM/PM characteristics

$$g(r) = \frac{\alpha_\phi r^2}{1 + \beta_\phi r^2} \tag{4}$$

where r is the amplitude of input vector and α, β are TWTA parameters.

In post-compensation, first, the original TWTA input signal is calculated by the following equation

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

where y is the amplitude of received signal vector. This equation can be derived from above equation 3. After received signal's amplitude is fixed with equation 5, the signal's phase is rotated inversely according to equation 4. These processes of nonlinear compensator are shown in Figure 5. z in the figure represents input signal of nonlinear compensator. Linearization by these methods is actually performed by digital signal processing at receiver side.

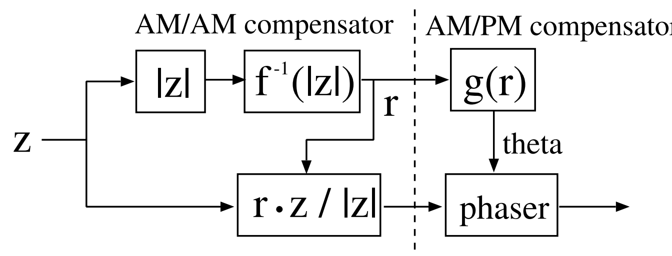

Fig. 5. Block diagram of nonlinear compensator.

Because of the thermal noise added to the receiver's input signal and filters before nonlinearity compensation, the theory of linearization mentioned above will not be satisfied and thus the signals output from compensator does not exactly match to the satellite's input signal. Therefore, overcompensation and undercompensation might occur and this causes remaining interference after passing the canceller. The simulator explained next is used to explore the effect of thermal noise and filter on nonlinearity compensation.

C. *Simulation Model*

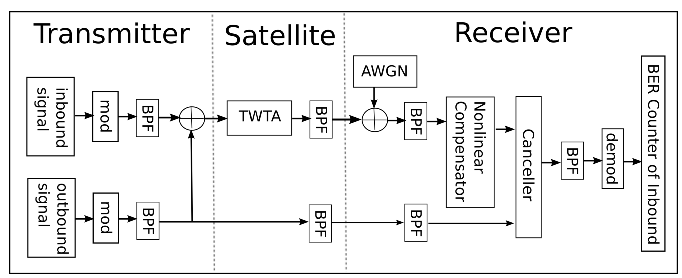

Fig. 6. Block diagram of the simulator

Figure 6 shows the block diagram of simulator used in this research. The purpose of this simulator is to verify the performance of nonlinearity compensator. Therefore the synchronization mechanism is not implemented in this simulation model. The upper path in the figure represents satellite signal path and lower path represents the replica signal path inside the earth station. To make the transfer function of two paths equal, filters used in satellite path are also inserted in replica path. Nonlinearity compensator is inserted before the interference canceller to fix the distortion that signal receives in TWTA. Root cosine roll-off filter is inserted after transmitter's modulator, TWTA, and before nonlinearity compensator, receiver's demodulator. These filters are for suppression of sideband signal and noises, and also for timing adjustment that is in replica signal path.

III. Simulation results and Considerations

Simulation is done using software simulator, based on the model described in previous section. The parameters for this simulation is shown in Table I and the parameters for TWTA nonlinearity is shown in Table II.

TABLE I
Simulation Parameters

System Parameter	Modulation Method	QPSK
	Modulator Transmit Filter	BW $= 1.0$, $\alpha = 0.35$
	Satellite Transmit Filter	BW $= 1.2$, $\alpha = 0.35$
	Earth Station Receive Filter	BW $= 1.2$, $\alpha = 0.35$
	Demodulator Receive Filter	BW $= 1.0$, $\alpha = 0.35$
	Number of Symbol	$200,000$
	Over Sampling Factor	4
Transmission Channel	DUR (IB/OB ratio)	0dB
	Channel	AWGN

TABLE II
Nonlinearity Parameters

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

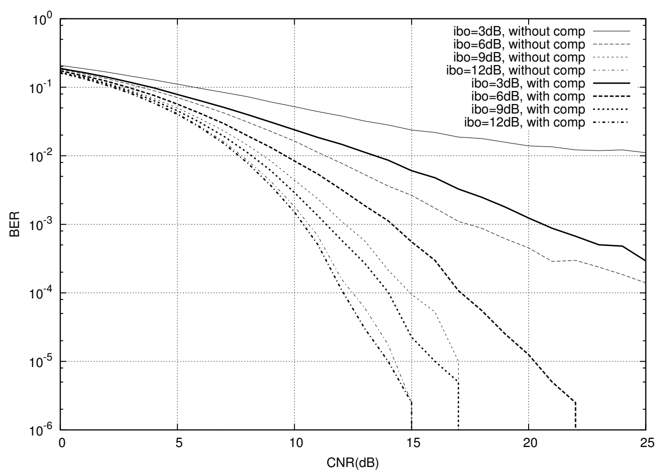

Fig. 7. Effect of changing input back-off on bit error rate

Figure 7 shows bit error rate (BER) curve when changing backoff. Eight lines on the figure represents the BER at input back-off (IBO) = 3,6,9,12dB each with compensation and without compensation. It is shown on the figure that when IBO is small, which means TWTA operation point is more in nonlinear region, the difference of BER between compensated signal and non-compensated signal becomes larger. Moreover, our compensator recovers BER in more linear region like IBO = 12dB. TWTA's property shown in Figure 3 has slight nonlinearity in amplitude gain and certain amount of phase rotation even if large amount of input back-off is taken. Therefore the compensator is valid on linear region.

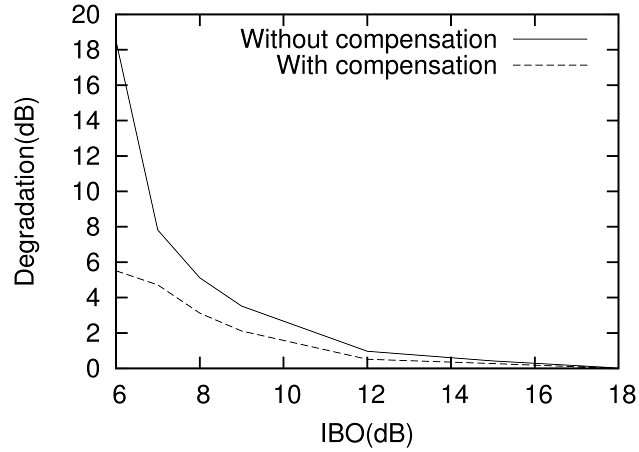

Fig. 8. Degradation due to TWTA nonlinearity with and without compensation

Figure 8 shows CNR degradation of BER for each IBO with compensation and without compensation. From this figure it is possible to read the amount of BER improvement at same IBO by using nonlinearity compensator. For example, at IBO = 8dB, CNR improvement will be about 3dB which means signal power can be reduced to half to achieve same BER using compensator. Another thing that can be read from this figure is the IBO difference between when nonlinearity is compensated or not at the same CNR. For example, when degradation is 2dB, IBO difference will be about 1.8dB which means amplitude of TWTA operating point can be shifted to 1.2 times higher. This means the TWTA can be used at higher operating level by 2dB.

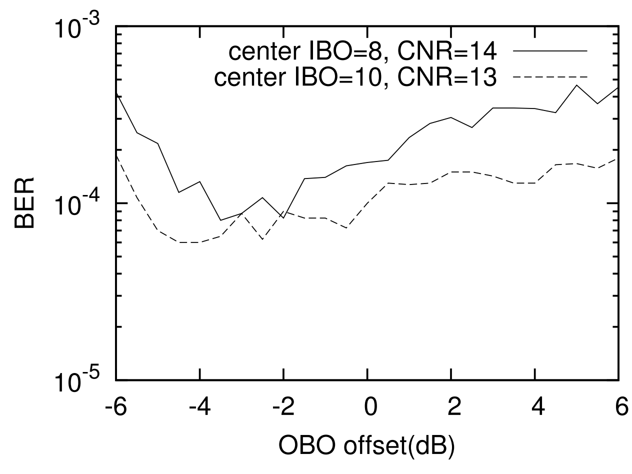

Fig. 9. BER difference when rain attenuation level changes.

Next the effect of rainfall attenuation is evaluated by intentionally simulating attenuation between satellite and receiver. Figure 9 shows the change of BER when OBO is offseted from ideal value. Two lines in the figure represents the BER change when centers are IBO = 8dB, CNR = 14.0dB and IBO = 10dB, CNR = 13.0dB. This result shows that when environment changes and channel attenuation varies for a few dB, BER varies in the order of 10^{-4}. This means that CNR degradation will be within about $1 \sim 2\mathrm{dB}$, even in the rain attenuation of $\pm 6\mathrm{dB}$. If an automatic gain control circuit is used at the receiver input, the change of compensator input level due to the rainfall can be compressed within 1dB or so. Then the value of OBO offset in Figure 9 can be reduced to 1dB order.

IV. Conclusion

In this paper, a nonlinearity compensation scheme for carrier superposed point to point (P-P) satellite communication system using interference canceller is proposed. To show the effectiveness of proposed scheme, a basic software simulation is performed. The result of simulation shows that it is possible to significantly reduce the degradation caused by nonlinearity of satellite TWTA. This scheme reduces the distortion of received signal vector and from this it is adoptable not only to superposed signals but also to single carrier communication systems and conventional broadcasting signals. Previously, it was very challenging to run this scheme, reverse-nonlinear operation of received signal, on real-time with analog circuit but now the digital signal processing technologies have made it much easier. The result also showed that BER degradation due to operating point mismatch when environment condition changes.

For future work, we are planning to verify the performance of proposed nonlinearity compensator with multi-level modulation such as 32APSK (Amplitude Phase Shift Keying) for more practical use in current satellite systems. In general, multi-level modulation is operated in high CNR condition, which means it is more preferable to nonlinearity compensator. When CNR is large, the difference between compensated signal and original signal becomes smaller. Authors are also planning to verify the effect of nonlinearity compensator from other veiw points like signal constellation, not only the BER performance shown here. Moreover, authors are planning hardware experimentation for complete verification of compensator.

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