The Joint Effects of Group Delay and AM/PM Distortion of Satellite Transponder on DVB-S2 Based Services

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ABSTRACT:
In satellite transponder design, both the group delay of demultiplexer and multiplexer filters and the AM/PM distortion due to the high power amplifier (HPA) nonlinearity are critical specifications, which should be in an appropriate range to ensure the required BER for having acceptable satellite service quality. Practical problems that inevitably arise in the manufacturing process of a transponder lead to a slight deviation in the fulfillment of the maximum allowable group delay and AM/PM distortion. In this paper, the acceptable range of the group delay and AM/PM distortion is investigated simultaneously so that the required BER of DVB-S2 service is guaranteed. Since there are no proper analytical relations to achieve this goal, these nonlinear effects are simulated in MATLAB SIMULINK for both the QPSK and 8PSK modulation schemes. It is inferred from the achieved results that the acceptable phase shift and the group delay of the 8PSK modulation is less than those of the QPSK modulation.

KEYWORDS: AM/PM, Phase shift, Group delay, DVB-S2, Satellite.

1. INTRODUCTION

The past two decades have seen a quiet revolution in satellite-based services [1]. Geostationary (GEO) satellites operating in the orbit 22,000 miles above the earth can cover approximately one-third of the earth surface. This makes GEO communications satellites extremely potent for broadcasting content such as digital and analog TV, digital and analog audio, and data [2].

The standard for digital video transmission on the satellite communication is DVB-S. DVB-S uses the QPSK modulation and the concatenated error protection based on a convolutional code and a Reed-Solomon (RS) code. It is compatible with the MPEG 2 TV services [3].

DVB-S2 standard, the improved version of the first generation DVB-S, has been developed in 2004 to increase the custom data rate in the same channel bandwidth [4]-[6]. The significant improvements of DVB-S2 in comparison with DVB-S include a new channel coding and higher order modulations. Instead of the concatenation of Reed-Solomon codes with conventional codes, DVB-S2 uses the second generation BCH (Bose Chaudhuri Hocquenghem) and LDPC (Low Density Parity Check) codes as FEC (Forward Error Correction). These features allow the employment of the higher modulation schemes under the same conditions, i.e. the same channel, the same existing earth segment, and the same gain to noise temperature, G/T [7]. DVB-S2 enables all modulation schemes including, QPSK, 8PSK, 16APSK, and 32APSK. DVB-S2 is a very flexible standard, covering a variety of satellite applications as described in [3]. The performance of the DVB-S2 standard under the realistic high data rate telemetry channel conditions is investigated in [8]. In addition, [9] presents the performance of the optimized constellation over a nonlinear satellite channel under the additive white Gaussian noise.

The development of an efficient transmission scheme specified in DVB-S2 is highly related to the group delay of the demultiplexer and multiplexer

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filters of a satellite transponder and to the AM/AM, AM/PM distortions due to the nonlinearity of high power amplifiers (HPA) [2]. Both the phase shift and group delay affect the phase of the DVB-S2 signal and consequently, change the signal constellation and lead to the BER degradation [10].

In [11], the transponder distortions are estimated and cancelled in the forward link of a satellite, and a practical realization of a non-linear equalizer with distortion cancellation at the satellite receiver is introduced using a memory polynomial model for the channel estimation. In [12], an iterative receiver equipped with non-linear distortion noise cancellation is proposed for the user terminal in the DVB-S2X satellite forward link. Furthermore, a low-complexity symbol-based equalizer that performs non-linear distortion cancellation is proposed in [13] for application at the user terminal in the DVB-S2X satellite forward link. In this work, the channel is comprehensively modelled, including the non-linear characteristics of the travelling wave tube amplifier (TWTA) and spectral responses of the input-multiplexing (IMUX) and output-multiplexing (OMUX) filters of the satellite transponder. Additionally, [14] presents the design, simulation, and implementation of a digital pre-distorter for linearization of high power amplifiers used in satellite communication systems.

According to the previously mentioned studies, it is clear that many investigations have been devoted to estimate and cancel the non-linear effects of TWTAs, IMUXs and OMUXs. However, in [15] the effects of the non-linearity of the TWTA are simulated using two QPSK carriers and it is shown that there is an optimum OBO (output back off) value to reach the maximum carrier to noise ratio, C/N. Since there is not an analytical solution to this problem, [15] exploits a Simulink model based on the Saleh model for the TWTA nonlinearity.

Group delay and AM/PM distortion are the two critical specifications determined in the technical requirements of a satellite transponder design. Consequently, in this paper, we investigate the joint effects of the group delay and AM/PM distortion on the DVB-S2 performance. It is obvious that the technical requirements of the satellite transponder design are to ensure the acceptable quality of the received satellite services [2]. In most of the digital communication services, BER denotes the quality of digital services [16]. Practical problems that inevitably arise in the manufacturing process of a transponder lead to a slight deviation in the fulfillment of the maximum allowable group delay and AM/PM distortion. In this paper, the acceptable range of the simultaneous group delay and AM/PM distortion is investigated so that the required BER of DVB-S2 service is guaranteed. Since there are no proper analytical relations to achieve this goal [17], these nonlinear effects are simulated in MATLAB SIMULINK. In section II, a DVB-S2 transmitter and receiver are introduced. In section III, the Amplitude to Phase Modulation conversion (AM/PM) model is studied and a few modifications on Saleh model of MATLAB/SIMULINK are performed. In section IV, the parabolic model for group delay characteristic in the satellite is studied. The simulation results are given in section V. Finally, the paper is concluded in section VI.

2. DVB-S2 TRANSMITTER AND RECEIVEER MODEL

The DVB-S2 transmitter and receiver are modeled in Fig.1 [3], [9]. As seen in the Fig.1, the last section of a DVB-S2 transmitter is the phase modulation. After the phase modulation part, the signals shall be square root raised cosine filtered, to shape the signal spectrum. Baseband shaping filtering prevents from the interferences of the pulses. The baseband square root raised cosine filter shall have a theoretical function defined by the following expression:

$$\begin{cases} H(f)=1 \quad for \quad |f|<f_N(1-\alpha) \\ H(f)=\{\frac{1}{2}+\frac{1}{2}sin\frac{\pi}{2f_N}[\frac{f_N-|f|}{\alpha}]\}^{1/2} \\ for \quad f_N(1-\alpha)<|f|<f_N(1+\alpha) \\ H(f)=0 \quad for \quad |f|>f_N(1+\alpha) \end{cases} \quad (1)$$

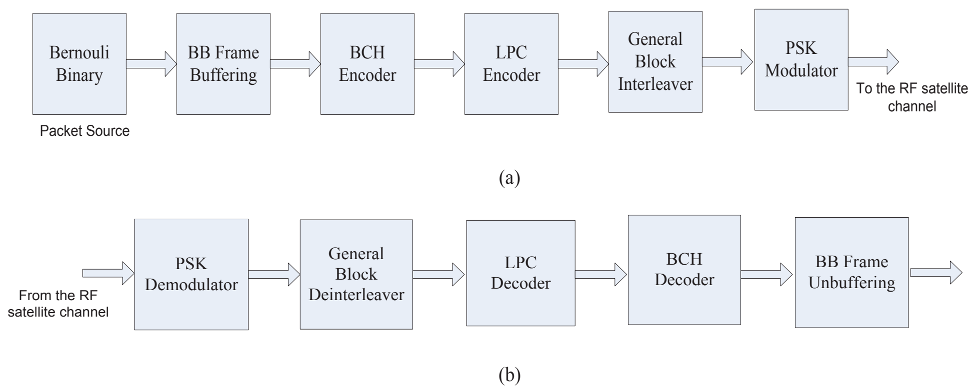


Fig.1.(a) Transmitter and (b) receiver of DVB-S2 [3],[9].

where $f_N=\frac{1}{2T_s}=\frac{R_S}{2}$ is the Nyquist frequency and α is the roll-off factor[3]. The cut off frequency ω_c and α are related as follows:

$$(1+\alpha)\,\omega_c \leq \frac{\omega_S}{2} \quad (2)$$

where T_s is the sampling period and $R_s=\frac{\omega_S}{2\pi}$ is the sampling frequency. $|f|$ denotes absolute value of f. The baseband shaping filter is simulated by MATLAB FDA Tools in this paper. As mentioned in [3], ω_c and α are set to 0.8 and 0.25, respectively.

3. AM/PM CHARACTERISTICS OF THE SATELLITE

The output phase shift of a satellite transceiver varies with input power level of HPAs. AM-to-PM conversion is usually defined as the variation of the output phase for a 1-dB increment in the power-sweep applied to the amplifier input (i.e. at the 1 dB gain compression point). It is expressed in degrees-per-dB (°/dB) [18]. In [19], a complex baseband model for a wideband power amplifier is presented. The model incorporates the carrier frequency dependent AM/AM and AM/PM characteristics in the design process.

In MATLAB/SIMULINK, the AM/PM distortion is represented based on Saleh model [20]-[22] as follows:

$$Fs_{AM/PSh}(u)=\frac{\alpha.u^2}{1+\beta.u^2} \quad (3)$$

$$Fs_{AM/PM}(u)=d(Fs_{AM/PSh}(u))/d(u) \quad (4)$$

where u is the input power level in dB and $Fs_{AM/PSh}(u)$ is its related phase shift. Indices "*s*" and "*AM/PSh"* respectively denote the Saleh model and the amount of undesired phase deviation caused by amplitude variations of the input power. By choosing proper values for parameters α and β, the appropriate AM/PM curve can be fitted to experimental data. $Fs_{AM/PM}(u)$ is the slope of the phase shift characteristic that gives the phase modulation coefficient, in degree per decibel. Assuming that at an input power level of -30 dB, the output phase shift of the power amplifier will be equal to 0 degree, the relation (3) is rewritten as follows:

$$Fs_{AM/PSh}(u)=\frac{\alpha.(1+\frac{u}{30})^2}{1+\beta.(1+\frac{u}{30})^2} \quad (5)$$

For instance, the curve of $Fs_{AM/PSh}(u)$ is plotted in Fig.2 for $\alpha=5.5$ and $\beta=9$. In this Figure, the input power is swept from -30dB to 5dB, which causes the output phase shift to vary from 0 to 32 degrees. This is consistent with the values reported in [19] and the ETSI standard [23]. In [19], [23], by sweeping the input power from -30dB to 0dB, the HPA output phase shift approximately varies from 0 to 40 degrees.

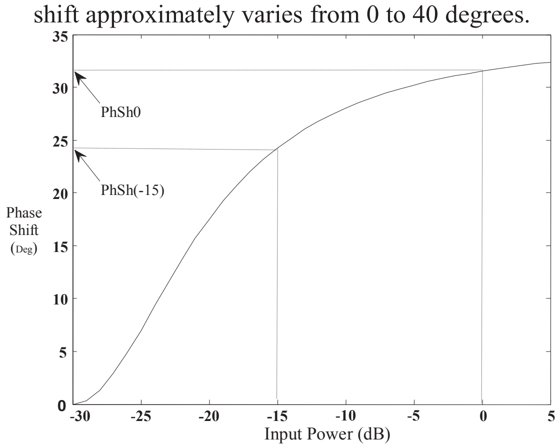


Fig.2. AM/PM conversion curve modeled by the Saleh model ($Fs_{AM/PSh}(u)$), for $\alpha=5.5$ and $\beta=9$.

4. GROUP DELAY CHARACTERISTICS OF THE SATELLITE

A hazardous factor in the satellite communication is the group delay variation over the frequency. This factor increases the BER at a specific *Eb/N0* which is the ratio of the energy per bit to the noise power spectral density. Since the data transmission based on the phase modulation scheme resides in phase, the group delay changes the signal constellation and causes BER degradation. The group delay variation over the frequency may have ripple, linear, or parabolic shapes [24]. In our simulation, we consider a parabolic shape over the frequency. The equation of the group delay is expressed as follows:

$$y=a(x-x_0)^2+b(x-x_0)+c \quad (6)$$

where "a" determines the breadth factor of parabola. The values of b and c do not have important effects on the results. In the simulation, x_0 is set to 0.5. It should be noted that the experimental data can be fitted to this curve by fine tuning of the modeling parameters. In fact, the models are the simplified versions of the reality. The parabolic curves for $a=0.5, 2, 4$, $b=0$, and $c=0.1$ are shown in Fig.3.

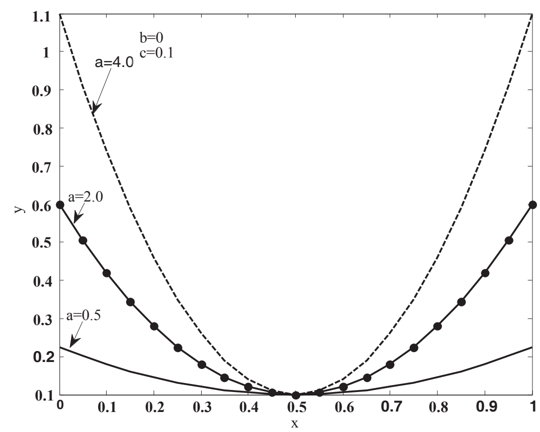
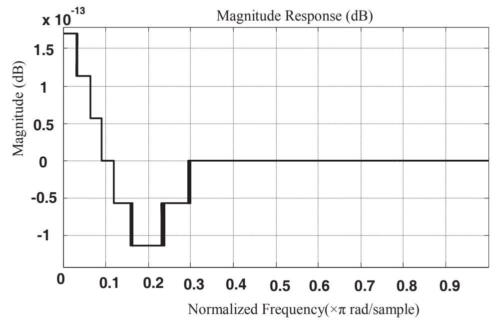


Fig.3. Parabolic curves for different values of "a".

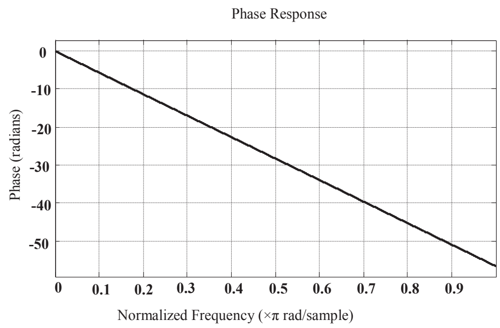
In this paper, several filters with different values of group delay are designed. The magnitude response, the phase response and the group delay curve of the digital filter designed for $a=0.5$, $b=0$ and $c=0.1$, are depicted in Fig.4. It is noteworthy that the effect of the satellite group delay is modeled by using the digital all-pass filters in MATLAB\SIMULINK.

In the following study, the BER of a DVB-S2 based satellite service worsened by a parabola group delay is evaluated for various values of the breadth factor "a". In Table 1, the values of the maximum group delay (GD_{max}) of the satellite transponder in 36MHz bandwidth versus various breadth factors, "a", are shown. According to (6), GD_{max} for $x=1$ is equal to $a\times(1-0.5)^2$ in sample where x_0 is set to 0.5. As a result, for the channel bandwidth of 36MHz and the sampling frequency of 18 MHz GD_{max} is obtained in second as follows:

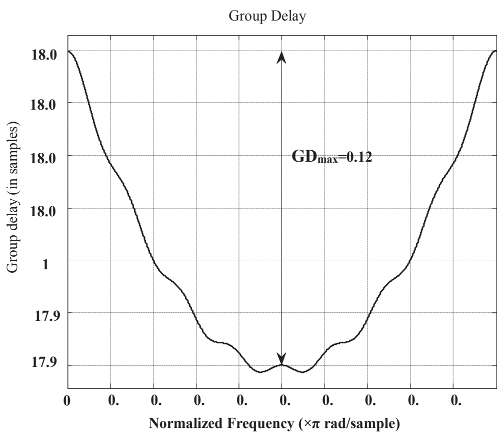
$$GDmax=\frac{a\times(1-0.5)^2}{18MHz}\ (sec) \quad (7)$$



(a)



(b)



(c)

Fig.4. (a) Magnitude response, (b) phase response and (c) group delay curve of the digital filter for *a=0.5*, *b=0* and *c=0.1*.

Table 1. The values of the maximum group delay (GD_{max}) of the satellite transponder in 36MHz bandwidth for various breadth factors "*a*".

breadth factor "*a*"	GD_{max}(ns)
0.5	6.6
1	13.8
1.7	23.6
1.9	26.4
2	27.8
2.3	31.9
2.6	36.1
3.2	44.4
4	55.5
6	83.2
7	97.1

In the ETSI standard [23], the parabola group delay of the satellite transponder is given, in which GD_{max} in a transponder with the bandwidth of 36MHz is reported equal to 40nsec. According to the data shown in Table 1, the typical value of the group delay given in [23] is within the range of the group delay investigated in this paper.

5. SIMULATION RESULTS

In this section, the BER of a satellite DVB-S2 based service disturbed by the phase shift and group delay has been evaluated, separately and jointly. The block diagram used in the simulation is depicted in Fig.5, where the satellite channel is modeled by cascading the AWGN channel, the AM/PM block and the parabolic group delay block. Each of these blocks are simulated in the previous sections. Using the MATLAB/SIMULINK, DVB-S2 is simulated for both QPSK and 8PSK modulations, separately. In the first step, it is assumed that the group delay is equal to zero. In order to study the AM/PM effect, the simulation is done for various AM/PM curves based on Saleh model ($Fs_{AM/PSh}(u)$). These curves are obtained for different values of α and β. Each curve has unique values for *PhSh0* and *PhSh*(-15) (See Fig.2). *PhSh0* and *PhSh*(-15) shown in Table 2 are obtained by replacing u with 0 and -15 in equation (5) for various values of α and β. In addition, the BER is calculated for each phase shift curve ($Fs_{AM/PSh}(u)$) and for the QPSK and 8PSK modulations, which are depicted in Fig.6. In this figure, each phase shift curve is determined by its relevant *PhSh0*.

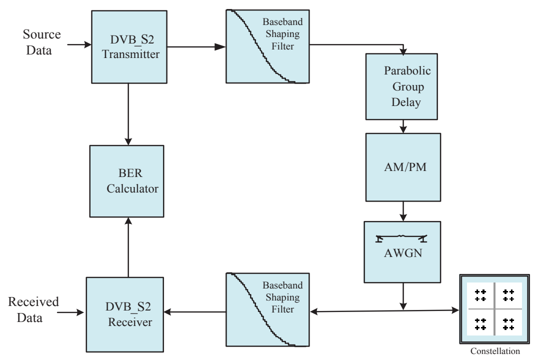


Fig.5. Simulation block diagram.

Making use of Fig.6, the maximum allowable *phsh0* of the satellite channel is obtained. For instance, if the maximum acceptable BER is equal to 10^{-4}, the *PhSh0* of the satellite channel must be less than 31^{Deg} and 16^{Deg} for the QPSK and 8PSK, respectively. In addition, it is easily understood that the enhancement of E_b/N_0 does not improve the BER.

Table 2. *PhSh*0 and *PhSh* (-15) for various α and β

α	β	*PhSh0*(Deg)	*PhSh*(-15)(Deg)
1	10	5.2	4.1
3	9	17.2	13.2
4	10	20.8	16.4
4	9.1	23	17.5
5.5	9	31.5	24.2
6.5	9	37.2	28.6
7.5	9	43	33

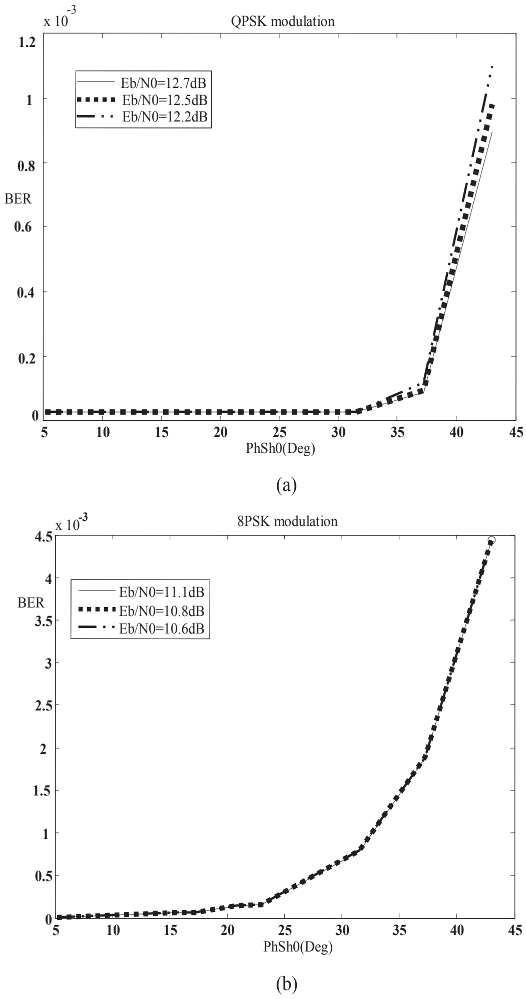


Fig.6. BER versus *PhSh0* for (a)QPSK and (b)8PSK modulations in DVB-S2

Then, for investigation of the group delay effects, the simulations have been done for various parabolic group delays. In this step, it is assumed that the AM/PM effect is equal to zero. Fig7 presents the BER versus "a" for the QPSK and 8PSK modulation schemes, in which the maximum acceptable breadth factor "a" of the satellite channel is obtained. For example, if the maximum acceptable BER is equal to 10^{-4}, the breadth factor "a" must be less than 2.5 for E_b/N_0=12.7dB in the QPSK modulation. This value is equal to 1.5 for E_b/N_0=10.6, in the 8PSK modulation. Moreover, from the simulation results, it is understood that the enhancement of E_b/N_0 improves the BER.

The displacement of symbols caused by the AM/PM effect and the parabolic group delay are shown in Fig.8 and Fig.9, respectively.

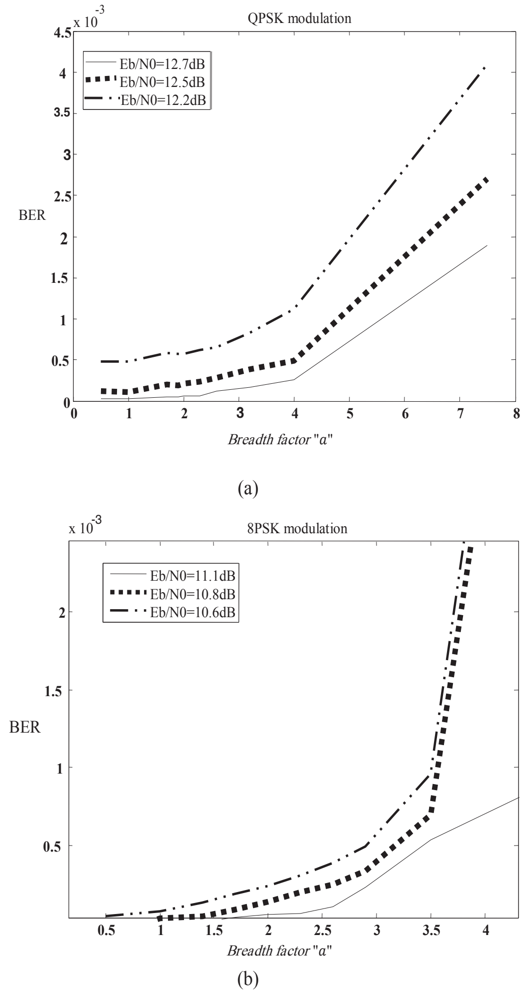
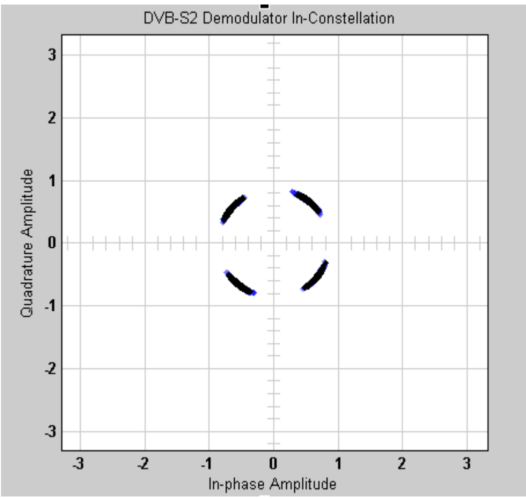


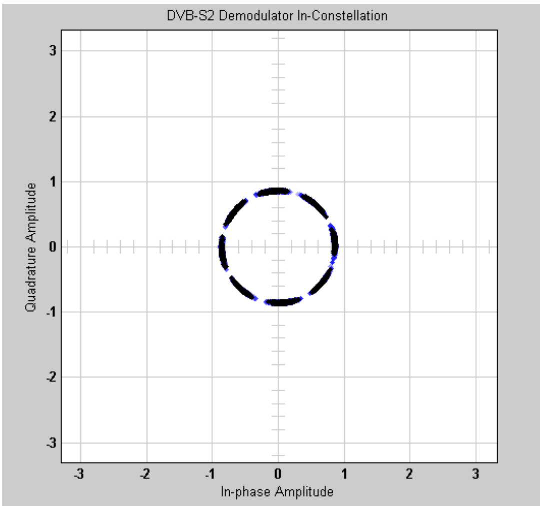
Fig.7. BER versus "a" for (a)QPSK, and (b)8PSK modulations in DVB-S2.

In order to study the joint effects of AM/PM and group delay, the simulations have been performed for the various AM/PM conversion ($Fs_{AM/PSh}(u)$) and group delay curves, simultaneously. The results are presented in Table 3 to Table 8 for different values of E_b/N_0. The allowable range of *PhSh0* and breadth factor "a" at the satellite channel is obtained from Table 3 to Table 8. For example if the maximum acceptable BER is equal to 10^{-4}, the acceptable range of *PhSh0* and "a" should be identical to the values highlighted in Table 3 to Table 8. If the BER of the received signal is less than 10^{-4}, it will have an acceptable quality. In Table 3 to Table 8, the BERs less than 10^{-4} are highlighted. Therefore, the appropriate values of "a" and *Phsh0* for which the BER is less than 10^{-4} are achieved. In this way, the acceptable ranges of the phase shift and group delay meeting the transponder technical requirements are obtained. In addition, the allowable range of AM/PM and "a" in the 8PSK modulation are less than the allowable range of AM/PM and "a" in the QPSK modulation. In other words, as expected, the 8PSK modulation is more sensitive to the phase shift and group delay than its QPSK counterpart.

The displacement of symbols caused by the joint effects of AM/PM and group delay is shown in Fig.10.



(a)

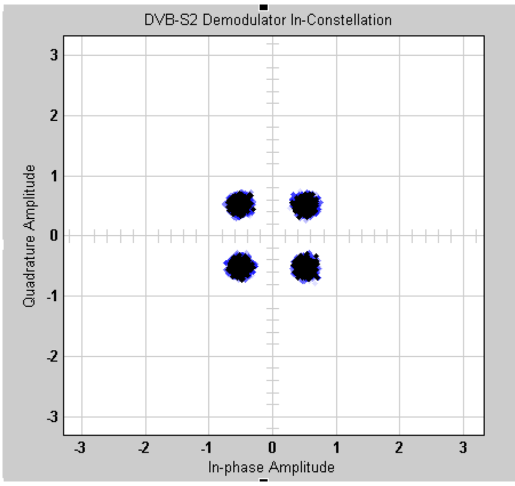


(b)

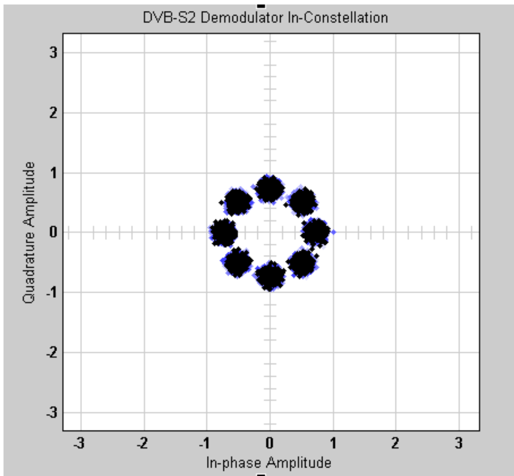
Fig.8. Symbols displacement caused by the AM/PM effect for (a) QPSK, (b)8PSK modulation schemes in DVB-S2.

6. CONCLUSION

In the design of a transponder, practical problems that inevitably arise in the manufacturing process lead to a slight error and change in the fulfillment of the transponder technical requirements. Therefore, it is useful to know the maximum allowable values of these errors in the transponder implementation. For this purpose, the influence of phase shift on BER is simulated in a DVB-S2 based satellite service. Then, the effect of group delay on BER is simulated separately. Finally, the joint effects of group delay and phase shift on BER are inspected, and consequently the acceptable range of the simultaneous group delay AM/PM distortion are determined to guarantee the required BER in DVB-S2 service. In the simulation, both the QPSK and 8PSK modulations are examined separately.

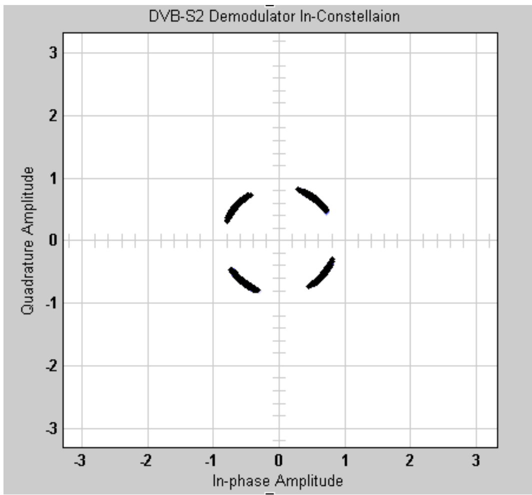


(a)

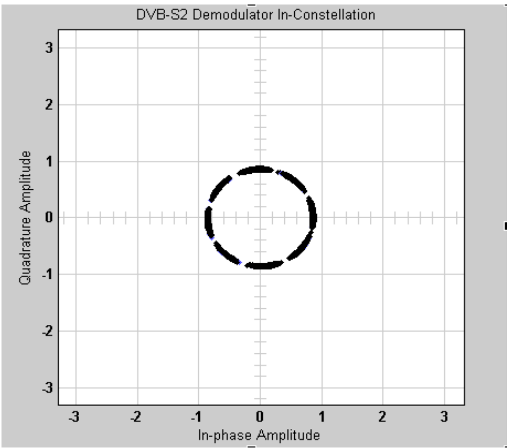


(b)

Fig.9. Symbol displacement caused by the parabolic group delay effect for (a)QPSK and (b)8PSK modulations in DVB-S2.



(a)



(b)

Fig.10. symbol displacement caused by the joint effects of AM/PM and parabolic group delay for (a)QPSK, (b)8PSK in DVB-S2.

7. ACKNOWLEDGMENT

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Table 3. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for QPSK modulation and $Eb/N0=12.7\ dB$

*PhSh*0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	3.086
15.6	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	27.16
17.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	38.89
20.8	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	3.086	139.5
23	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	4.321	201.2
31.5	2.469	2.469	4.321	4.321	4.938	8.642	9.877	22.84	48.770	1402
37.2	8.642	13.58	26.54	33.95	36.42	50.00	62.96	125.9	304.3	3042
43	105.6	142.6	230.9	258.6	279.00	356.8	468.5	743.2	1303.00	5463

Table 4. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for QPSK modulation and $Eb/N0=12.5\ dB$

PhSh 0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	3.086
15.6	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	27.78
17.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	41.36
20.8	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	3.086	143.2
23	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	4.321	209.9
31.5	2.469	2.469	4.321	4.321	4.938	8.642	10.49	24.69	51.23	1419
37.2	9.259	14.81	29.01	35.19	38.27	51.85	64.2	134	311.7	3059
43	112.3	152.5	236.4	269.1	290.1	369.1	475.9	755.6	1325	5470

Table 5. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for QPSK modulation and $Eb/N0=12.2\ dB$

*PhSh*0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	3.704
15.6	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	31.48
17.2	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	43.21
20.8	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	4.321	152.5
23	2.469	2.469	2.469	2.469	2.469	2.469	2.469	2.469	4.321	222.2
31.5	2.469	2.469	4.321	4.321	4.938	8.025	11.73	25.31	53.09	1430
37.2	10.49	17.9	31.48	38.27	41.36	55.56	72.84	137	324.7	3065
43	127.8	169.8	254.3	285.8	306.8	388.3	498.1	779.6	1346	5503

Table 6. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for 8PSK modulation and $Eb/N0=11.1\ dB$

*PhSh*0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	1.543	2.058	3.601	3.858	4.372	7.202	10.03	24.43	67.9	1811
15.6	8.745	12.86	24.69	29.58	32.41	43.98	59.16	109.1	233.5	2281
17.2	9.259	14.15	25.98	31.38	33.69	48.1	63.79	115	247.7	2314
20.8	27.01	34.21	60.96	72.02	78.96	97.99	129.6	217.6	427.7	2705
23	31.64	40.12	68.42	80.76	86.93	109.8	144.8	239.5	460.6	2755
31.5	154.8	178.2	253.9	284	306.3	377.3	460.1	673.4	1062	3598

Table 7. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for 8PSK modulation and $Eb/N0=10.8\ dB$

*PhSh*0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	1.543	2.058	3.601	3.858	4.372	7.202	10.03	24.43	67.9	1811
15.6	9.002	12.86	24.69	29.58	32.41	44.24	59.41	109.8	233.8	2283
17.2	9.259	14.15	25.98	31.38	33.69	48.1	63.79	115	247.7	2314
20.8	27.01	34.21	60.96	72.02	78.96	97.99	129.6	217.6	427.7	2705
23	31.64	40.12	68.42	80.76	86.93	109.8	144.8	239.5	461.2	2756
31.5	154.8	178.2	253.9	284	306.3	377.3	460.1	673.4	1062	3599

Table 8. BER($\times 10^{-5}$) versus $PhSh0$ and breadth factor " a", for 8PSK modulation and $Eb/N0=10.6\ dB$

*PhSh*0(Deg)	breadth factor of parabolic curve of group delay(a)									
	0.5	1	1.7	1.9	2	2.3	2.6	3.2	4	7.5
5.2	1.543	2.058	3.601	3.858	4.372	7.459	10.29	26.49	69.96	1814
15.6	9.002	12.86	24.69	29.58	32.41	44.24	63.79	109.8	233.8	2283
17.2	9.259	14.15	25.98	31.38	33.69	48.1	63.79	115	248.7	2318
20.8	27.01	34.21	60.96	72.02	78.96	100.1	132.5	220.9	430	2708
23	31.64	40.12	68.67	81.53	87.71	110.6	146.9	240.5	461.2	2761
31.5	157.7	178.8	261.1	289.6	681.3	379.9	466	676.4	1070	4267