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PREDISTORTION TO MITIGATE NON-LINEARITY AND Q FACTOR IMPROVEMENT IN 16 APSK SATELLITE COMMUNICATIONS

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Abstract

In this project, an optimal 4 + 12 amplitude and phase shift keying (APSK) modulated orthogonal frequency-division-multiplexing (OFDM) system is proposed (the numbers 4 and 12 represent the constellation points located in the inner ring and the outer ring, respectively). Although the 4 + 12APSK modulation format has smaller average Euclidean distance than 16 quadrature amplitude modulation (QAM), the 4 + 12APSK modulated OFDM system has the best transmission performance, with increased tolerance towards both amplified spontaneous emission noise and channel nonlinearities compared with 16QAM and 8 + 8APSK modulated OFDM systems. The maximum reach at *Q* factor = 8.2 dB (when bit-error rate (BER) equals $5 \times 10{-}3$) is evaluated to assess the system performance based on a single channel OFDM system, and illustrates that the transmission performance of 4 + 12APSK modulated OFDM outperforms 8 + 8APSK modulated OFDM and 16QAM modulated OFDM by approximately 10.5%.

Index Terms—Amplitude and phase-shift keying (APSK), Nonlinearities, Orthogonal Frequency-Division-Multiplexing (OFDM), Quadrature Amplitude Modulation (QAM).

Introduction

From commercial point of view, low quality of audio or video is not always liked by the people. Much Entertainment multimedia transmission depends on Fiber optic and satellite based Communications. There are commercial risks while a low quality of audio or video is transmitted. This low quality transmission is the result of a basic metric, BER. (Bit Error rate) performance. High BER leads to low quality communication system. As it is a well known fact, that high data rate is needed to transmit the larger amount of data at less time. This is very essential when audio or video data is considered. The commercially available fiber optic transmitters and receivers are based on QPSK modulation. This type of modulation supports only two bits per symbol. Based on business aspects, better quality of video is expected from the users. Whatever the need of fiber optic, whether launched for broad casting or for research purpose, they need to be operated at high data rate. The data rate is purely dependent on the type of modulation and the code rate of the convolutional coding [1] process done in the physical layer of

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the communication systems. In addition to the commercial point of view, many fiber optics launched for weather forecasting or for spying etc. need to transmit video or images, which has to be done at faster rate. Usage of fiber optic communication systems lies in their ability to efficiently broadcast digital multimedia information over very large areas [2]. Best example is the so-called direct-to-home (DTH) digital television broadcasting. Fiber optic systems also provide a unique way to complement the terrestrial telecommunication infrastructure in scarcely populated regions. The introduction of multi beam fiber optic antennas with adaptive coding and modulation (ACM) schemes will allow an important efficiency increase for fiber optic systems operating at Ku- or Ka-band [3]. The main idea behind this work is to address the problems while using a modulation technique other than QPSK. In QPSK, as it has only one ring which consists of only 4 constellation points, it is not affected by the non linearity of the fiber optic amplifier. TWTA (Travelling Wave Tube Amplifier) is used for such purposes in order to obtain the gains in the order of 1000. As higher modulation schemes are approached like 32 APSK, it involves three concentric circles, each circle with different amplitude levels. So when the modulated signal is amplified, naturally the output will be non linear. This non linearity distorts both the amplitude and phase at the output. Our work is to analyze the performance of a communication system with 32 APSK under non linearity and in the presence of AWGN.

Quadrature amplitude modulation (QAM). This is also a multilevel modulation method in which the amplitude and the phase of the carrier are modulated. In the following discussions only BPSK and QPSK considered, since many of the general properties can be explained with the help of these two methods, and more over they are widely used [4].

APSK

Amplitude phase shift keying (APSK) is a higher-order modulation scheme designed for efficient transmission over fiber optic channels owing to its intrinsic robustness against nonlinear amplifier distortions, as well as spectral efficiency. The second generation standard for digital video broadcasting via fiber optic (DVB-S2) adopts the APSK scheme in conjunction with other features [5]. A union bound for the error performance of M-ary modulations in additive white Gaussian noise (AWGN) has been presented in [6]. This bound acts as an upper limit for the symbol error rate of APSK modulations. In [7], the error performances of 16- and 32-APSK schemes were analyzed and tight error rate expressions were proposed. The expressions were derived based on symmetry and by including only the necessary error terms associated with the pair-wise probabilities of the symbols in the first quadrant of the constellations.

Amplitude phase-shift keying (APSK) is a modulation consisting of several concentric rings of signals, with each ring containing signals that are separated by a constant phase offset. APSK has recently become widely adopted, due primarily to its inclusion in the second generation of the Digital Video Broadcasting Fiber optic standard, DVB-S2 [8], as well as some other standards such as DVB-SH, IPoS, GMR-2 3G, and ABSS. APSK is known to be both spectral and energy efficient, and is especially well suited for nonlinear channels. For a given modulation order *M*,

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an APSK constellation is characterized by the number of rings, the number of signals in each ring, the relative radii of the rings, and the phase offset of the rings relative to each other. In [9] and [10] these parameters were optimized using a technique based on information theory. In particular, the achievable *information rate* was computed for each choice of APSK parameters, and from these information rates, the optimal parameters were identified.

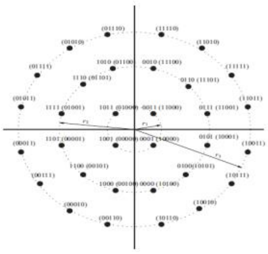

Fig 1: Constellation diagram of APSK

Constellation Diagrams for Various Modulations

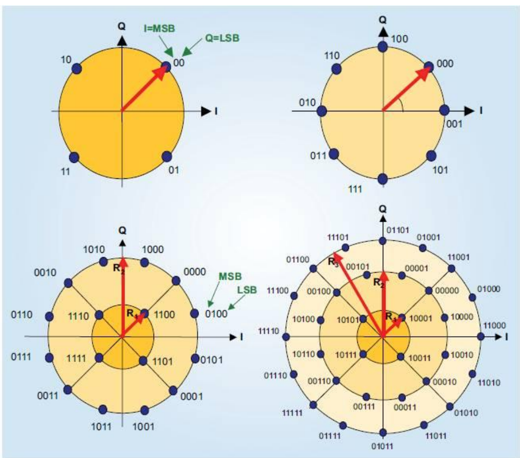

Fig 2: **Constellation Diagrams for Various Modulations**

Differences between 32APSK and Earlier Modulations

The figure shown below gives an idea of the arrangement of constellation points for various modulation schemes. In case of BPSK, there do not exist any quadrature component. Both the constellation points lie in the real axis of the polar plane. As BPSK is the low end modulation, it has not been shown in the figure. As the need of the higher data rate comes into picture, higher modulation schemes are proposed. The main idea is to utilize the channel effectively at a particular span of time.

As shown in figure, 4QAM carries 2 bits per symbol, 8 PSK carries, 3 bits per symbol, 16 APSK carries 4 bits per symbol, whereas, 32 APSK carries 5 bits per symbol.

Amplitude and Phase-shift keying or Asymmetric Phase-shift keying, (APSK), is a digital method of modulation that transmits data by varying, or modulating, both the amplitude and the phase of a carrier. In other words to day, it combines both ASK and PSK to increase the symbol set. It can be considered as a super class of QAM. The advantage over conventional QAM, for example 16-QAM, is lower number of possible amplitude levels, resulting in fewer problems with non-linear amplifiers. In 16 QAM, it is possible to transmit 4 bits per symbol. But the same is possible with 16 APSK also. But the effects of non linearity are less with 16 APSK. The arrangement of constellation points is in such way the amplitude levels are less.

Modulation/Properties	BPSK	QPSK	8PSK	16QAM	16APSK	32APSK
Bits/symbol	1	2	3	4	4	5
No of	0	1	1	-	2	3

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rings							

Table 1: **Comparison of various modulation types**

Constellation Design

The following is the mathematical formula for calculating the constellation points in a polar graph. The points are arranged in a such a way that the angles in the inner most circle has 4 different angles but with same amplitude determined by the radius r(1). The radius of the other two circles are determined by the following formula,

r(2)=gamma(1) * r(1)

r(3)=gamma(2) * r(1)

where gamma(1)=2.84 and gamma(2)=5.27

The points are calculated with the help of table values obtained from a fiber optic amplifier as shown below. The radius is calculated as

r(1) = input amplitude / sqrt(2

Need of Higher Data Requirement

Data transmitted to and from fiber optic travels about 36000 km (in case of broad casting fiber optics kept in Geo synchronous orbits), which takes a total of 1ms time as round trip delay. As the distance involved is high, we need higher data rate. Not only based on distance, but based on various commercial and technical aspects, higher data rate is required, so that the channel is utilized effectively. More over video streaming is dependent on bulk amount of data. Hence the buffering of the video should be very faster. To do this higher data rate is needed. As we know the lower end modulations are carrying minimum 1 bit per symbol. This gives a very lowest possible data rate. But this is not sufficient for video buffering. Hence high data rate is preferred like 32 APSK so that 5 bits are carried out for each symbol.

Amplifier Parameters

Input backoff

To maximize the efficient use of the scarce on-board available power, the fiber optic high power amplifier (HPA) must be operated close to saturation, creating a highly nonlinear environment, in which efficient transmission of more than 3 bps/Hz is a challenging task. [11]. Number of carriers are present simultaneously in a TWTA, and more over the amplifier characteristics are not linear as shown in fig.. the operating point cant be taken at non linear region. So the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of intermodulation distortion. Such multiple carrier operation occurs with *frequency division multiple access* (FDMA). The point to be made here is that *backoff* (BO) must be allowed for in the link budget calculations. Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single-carrier saturation level. The earth-station EIRP will have to be reduced by the specified BO, resulting in an uplink value of

$$[\mathrm{EIRP}]_U = [\mathrm{EIRP}_S]_U - [\mathrm{BO}]_i$$

Although some control of the input to the optical fiber power amplifier is possible through the ground TT&C station, input BO is normally achieved through reduction of the [EIRP] of the earth stations actually accessing the optical fiber. [4]

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Output Back off

Where input BO is employed, a corresponding output BO must be allowed for in the fiber optic EIRP. As the curve shows, output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion, as shown in Fig.

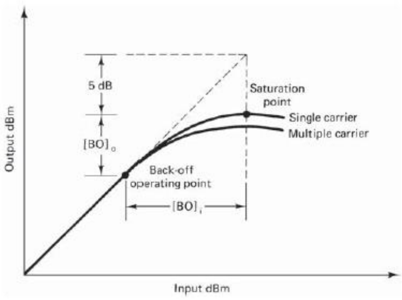

Fig 3. **Amplifier Characteristics [4]**

Non linear characteristics of amplifier

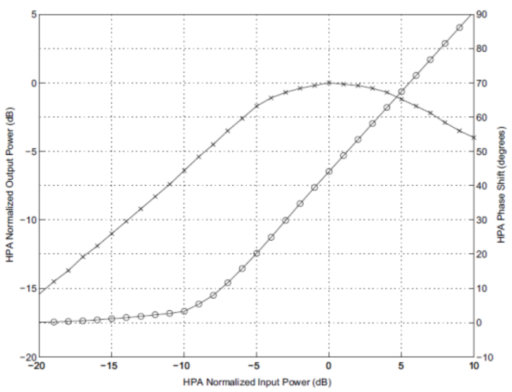

Fig 4. **HPA output amplitude and phase characteristics [11]**

From the graph shown in fig. it is observed that the output power in db exihibits a non linear performance. Similarly the output phase shift also varies in non linearly. So adjusting the operating point at very less IBO is also not advisable, because, a sufficient amount of amplification may not be reached. The fiber optic amplifier gain at 4Ghz is shown in the table

Methods to compensate non linear effects All amplifiers are usually characterized by a specific amount of bandwidth, in which it will operate in linear region. It is always suggested to use the amplifier in that particular bandwidth of operation. Non linear output from an amplifier or any system is basically a fault at the system. But, practically, it is not possible to discard that process just because of non linearity. So the intension of fiber optic users aims at how to compensate such non linearity. Most generally speaking, the amplifier non-linearity has two major effects. First effect is that, the constellation points location at the transmitted side is distorted, because, the constellation points are mapped by the HPA nonlinear characteristic to a different point (amplitude, phase). Furthermore, the relative positions of the constellation points change. This impairment can be reduced by ad-hoc static pre-compensation at the transmitter, or post-compensation at the receiver. Second, inter symbol interference (ISI) appears at the receiver as the HPA, although memory less, is driven by a signal with controlled ISI due to the presence of the modulator SRRC filter. This ISI is basically, by means of AWGN as well as the shift or rotation introduced by the non linearity. This leads to an overall nonlinear channel with memory. As a consequence, the demodulator SRRC is not matched anymore to the incoming signal. This issue is to be tackled mainly with a pre-equalization at the modulator [12], or equalization at the demodulator or a combination of the two techniques

Pre-compensation at the Transmitter

Although slight superiority of 6+10-APSK, for nonlinear transmission over an

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amplifier, 4+12-APSK is preferable to 6+10-APSK because the presence of more points in the outer ring allows to maximize the HPA DC power conversion efficiency. It is better to reduce the number of inner points, as they are transmitted at a lower power, which corresponds a lower DC efficiency, the HPA power conversion efficiency is monotonic with the input power drive up to its saturation point. Fig.-- shows the distribution of the transmitted signal envelope for 16- QAM, 4+12-APSK, 6+10-APSK, 5+11-APSK, and 16-PSK; the shaping filter is a square-root raised cosine (SRRC) with roll-off factor $\alpha = 0.35$. As we observe, the 4+12-APSK envelope is more concentrated around the outer ring amplitude than 16-QAM and 6+10-PSK, being remarkably close to the 16- PSK case. This shows that the selected constellation represents a good trade-off between 16-QAM and 16-PSK, with error performance close to 16-QAM, and resilience to nonlinearity close to 16-PSK. Therefore, 4+12+APSK is preferable to the rest of 16-ary modulations considered. Similar advantages have been observed for 32-APSK compared to 32-QAM [11].

Static Distortion Compensation: The simplest approach for counteracting the HPA nonlinear characteristic is to modify the complex-valued constellation points at the modulator side. Because of the multiple-ring nature of the APSK constellation, pre-compensation is easily done by a simple modification of the parameters ρ_l and φ_l. The known AM/AM and AM/PM HPA characteristics are exploited in order to obtain a good replica of the desired signal constellation geometry after the HPA, as if it had not suffered any distortion. This can be simply obtained by artificially increasing the relative radii ρ_l and modifying the relative phases φ_l. at the modulator side. The calculation of the pre-distorted constellation parameters can be made with the technique described in [13] for the computation of the distorted constellation center of mass (centroids) seen at the demodulator matched filter output. Measurements showed that the HPA characteristic sensitivity to temperature or aging results in a limited change of gain but not in a modification of the AM/AM, AM/PM characteristics shape. The limited gain variations are compensated by the fiber optic optical fiber automatic level control (ALC) device, thus off-line pre-compensation has a long term value. If required, the compensated parameters can be adapted to track larger slow variations in HPA characteristic due to aging.

5.1.2) Dynamic Distortion Compensation: The dynamic pre compensation approach by Sari [12] considers not only the current constellation symbol, as done in the case of static pre compensation, but also for Q symbols before and after. In general for M-QAM modulation the possible pre-distortions are now M^{2Q+1}. Similar to the static pre-compensation described before, the pre-distorter complex values can be obtained offline minimizing the minimum squared error (MSE) between the ideal constellation and the noiseless points measured after the demodulator symbol matched filter. This can be achieved through an extension of the methodology described for the static approach. In this case, the number of updating equations for M-QAM is M^{2Q+1} which can be reduced to $M^{2Q+1}/4$ exploiting the M-QAM quadrant symmetry [12]. For APSK the memory requirement can be further reduced to $3M^Q/16$. The main drawback of this technique is the amount of time required to compute the pre-distortion coefficients and the memory required which grows rapidly with the constellation and memory parameters (M, Q). It should also remarked that the dynamic pre-compensation is less

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effective than the static one when more than one carrier is passing through the same HPA. This is because the uncorrelated inter modulation noise among carriers will dominate over the ISI thus making the dynamic pre-compensation ineffective. [11]

Existing system

- The concept implemented in base paper takes 16APSK.
- Symbol error rate and bit error rate has been analysed
- SER of 10e-7 and BER of 10e-7 at 50DB has been achieved.

Proposed system

- The Subcarrier intensity modulation is implemented M-QAM.
- Symbol error rate and bit error rate has been analysed
- SER and BER should be analysed with existing system

1. Higher modulations are considered 16 APSK with sub carrier intensity modulations.

2.Bit error rate can be achieved lesser than 10e-4 at 30db itself.

3. Less effect by non linearity.

Q-factor

The performance of back-to-back Q factor, which is derived from BER and calculated as

$$Q = 20 \times \log10 (\sqrt{2} \times \text{erfcinv}(2 \times BER)),$$

Implementation

Built in functions of Matlab communication tool box had been used to implement the above shown block diagram. The simulation had been done with three options to be chosen by the user namely 1.With AWGN, 2. With Non linearity +AWGN and 3. With Non linearity +AWGN(Scaled). In addition to this, the user may evaluate the performance by giving both the IBO in dB as well as input voltage in milli volts.

Steps

Step1 : Front end menu designed with disp function

Step 2: Options are obtained from user to simulate the system

Step 3: If the input values are available in tablular column, missing values are calculated using interp1 function

Step 4: Based on the given input values, the radius of innermost circle R1 is calculated (if the option is to use input voltage in mV). On the other hand if the input is chosen in the form of IBO in dB, the radius of the outter most circle R3 is calculated. Based on these values the radii of remaining circles are calculated. (R2, R3 in case on input mV and R1, R2 in case of input in the form of IBO)

Step 5: Random data of length 30000 bits generated and converted into integers using bi2de function.

Step 6: The symbols are now plotted using scatterplot function, which is nothing but input constellation.

Step 7:The symbols are now amplified with the help of table values shown in Table 3.

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Step 8: The performance is analyzed based on different values of E_b/N_o

Step 9: The received constellation is also plotted as well.

Step 10: Bit error rate is calculated using biterr function and plotted for each value of SNR. The simulation may be repeated in the similar way, after scaling is done.

Modulation	Q factor (db)	Distance (km) (when distance kept as reference)
4+12APSK	10.5	1040
	11	1200
	11.5	1360
8+8 APSK	10	1040
	9.5	1200
	9	1360
16 QAM	9	1040
	8.7	1200
	8.5	1360
Q factor (db)	Modulation	Distance (km) (when distance kept as reference)
9	4+12APSK	1300
	8+8 APSK	1200
	16 QAM	1050
8.5	4+12APSK	1450
	8+8 APSK	1350
	16 QAM	1200
8.2	4+12APSK	1500
	8+8 APSK	1450
	16 QAM	1300

Results

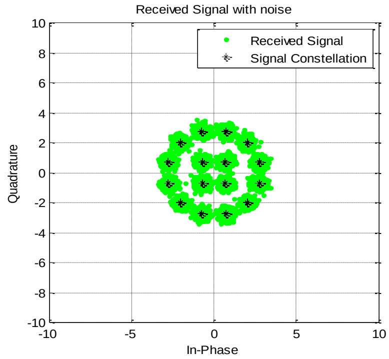

Fig 5. Received constellation points

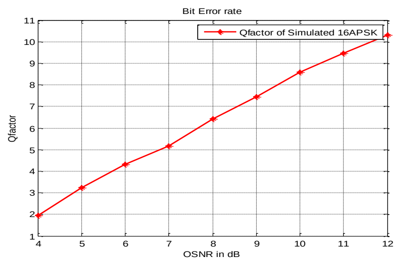

Fig 6. BER graph of 16APSK

Conclusions

A communication system had been implemented through matlab simulations under various options to consider with non linear channel. This project is aimed at a high data rate which is a basic necessity in the video broadcasting. This new modulation technique is highly immune to noise and hence a conventional 16QAM performs worse than the 16APSK. So this method of modulation is very useful for the less noise and high data rate system. In conventional broadcasting standards like DVB S2, 16APSK is used. Our research work, reveals that Q factor is better in case of 32QPSK too. So, this method of modulation will be very ideal to the video broadcasting and hence this may be useful to the high definition satellite based video broad casting. This work is very useful even in fiber optic long distance

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communications, because, the Q factor gives a very long communication profile without any repeaters.

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