Optik 125 (2014) 2148–2153

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Performance investigation on harmonic distortion and inter-modulation distortion induced degradation for a single- and two-tone IM-DD SCM optical link

Gausia Qazi [a,*], Ajay K. Sharma [b], H. Najeeb-ud-din Shah [c], Moin-ud-din [d]

[a] Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar 190006, India
[b] Director, National Institute of Technology, New Delhi, India
[c] Department of Electronics and Communication Engineering, National Institute of Technology, Srinagar 190006, India
[d] Dean FMIT, Jamia Hamdard University, New Delhi, India

ARTICLE INFO

Article history:
Received 13 May 2013
Accepted 11 October 2013

Keywords:
Cable television (CATV)
Clipping
Harmonic Distortion (HD)
Intermodulation distortion (IMD)
Subcarrier multiplexing (SCM)

ABSTRACT

Subcarrier multiplexing (SCM) has been utilized for data transmission in high performance broadband in access networks which requires high transport capacity and throughput with guaranteed quality of service. In a transmitter employing SCM technique in an Intensity Modulation Direct Detection (IM-DD) system, laser source nonlinearity is an important issue of concern. This work investigates the sensitivity of resulting harmonic distortion (HD) and inter-modulation distortion (IMD) to changes in subcarrier amplitude, laser bias current operational parameters and laser quantum efficiency, laser active layer volume and laser carrier life time design parameters. Results show that IMD impairment mechanism is more dominant than HD mechanism. The spectrum analyser shows distinct difference in the frequency domain display of HD and IMD dominated systems. HD and IMD mechanisms show high sensitivity to carrier amplitude and active layer volume with a positively increasing slope gradient and high sensitivity to bias current and carrier life time with negatively decreasing slope gradients. Also these impairments are moderately sensitive to laser quantum efficiency. The investigations will help in identification of the most influencing operational and design parameters and their suitable values to be used to effectively reduce the influence of the source nonlinearity of SCM links.

1. Introduction

With the introduction of the Internet and broadband access, the telecommunication industries, worldwide have come up with various broadband solutions and architectural upgrades to keep pace with the fast changes in broadband traffic demands and the data rates [1,2]. The use of a light wave carrier in such networks addresses the bandwidth constraints existent in other type of networks such as wireless and satellite communication systems. Subcarrier multiplexing (SCM) is a preferred multiplexing approach to explore new opportunities for broadband distribution of services in optical access networks [3]. It represents a proven convenient, versatile, simple and a cost effective solution where there is no requirement of sophisticated optics or any source wavelength specifications [1,2,4]. It allows flexible allocation of many GHZ of bandwidth over the available optical spectrum [5].

Two important applications that utilize SCM as the signalling format is the Radio-over-Fiber (RoF) and Hybrid Fiber Coaxial (HFC) based Cable TV (CATV) networks. RoF system integrates the complementary transmission media of radio and light waves [6]. It is one of the potential schemes for future broadband wireless communications systems [7,8] primarily because data from many mobile users can be sent directly through a single optical fibre. The detected RF subcarriers can be distributed to home subscribers or radiated to mobile or fixed terminals like in cellular communication networks. SCM has also been extensively used for CATV distribution over a hybrid fibre-coaxial network evolving from simple one way broadcasts to two-way simultaneous analogue and digital broadband service delivery [9,10]. Direct modulation of laser source is a much simpler and economical solution than implementing external modulation in SCM systems [11]. But the most serious disadvantage of direct modulation technique are limited bandwidth (about 10 GHz) and SNR by high chirp, inherent nonlinearities, Inter-Modulation Distortion (IMD), Random Intensity Noise (RIN), Harmonic Distortion (HD) and clipping [7,12,13].

In this paper emphasis has been laid on investigating and understanding the constraints imposed by laser source originating IMD and HD mechanisms in SCM based IM-DD system where clipping and RIN mechanisms are disabled. The extended study of resulting noise and nonlinearities has been carried out in frequency and time

* Corresponding author.
E-mail address: gausia.qazi@yahoo.com (G. Qazi).

0030-4026/$ – see front matter © 2013 Elsevier GmbH. All rights reserved.
http://dx.doi.org/10.1016/j.ijleo.2013.10.048

domain. This would help to identity various corrective measures that can be implemented at the component level to obtain high signal quality. Section 2 discusses the laser non-ideal diode behaviour and the resulting IMD and HD mechanisms. It also refers to various solutions implemented subsequently to overcome the performance degrading factors. Section 3 gives the description of a single- and two-tone IM-DD SCM which is predominately influenced by HD and IMD induced distortions respectively while it is clipping as well as RIN disabled. The results and discussion is highlighted in Section 4 while the conclusion and future scope is presented in Section 5.

2. HD and IMD induced performance degradation

In IM-DD systems using SCM format, up conversion from RF to optical domain is realized by the direct intensity modulation of a laser or an external modulator by the composite electronically multiplexed RF subcarriers [6–9]. At the receiver direct detection, represents the most practical down conversion of received SCM carriers from optical to RF domain using broadband photo-detection [6]. The IM-DD systems in general represent a simplified, convenient and economical solution in terms of component selection and their manufacturing both on the transmitter and the receiver side [7,11]. However laser source nonlinearity is an issue of concern especially in broadcast environment [3–5,11,14–16] in which there will be mixing between different subcarriers in the laser source producing IMD and HD. Source nonlinearity, which has been attributed to carrier heating effect [17], is dominant at low frequencies [4]. Another major factor responsible for distortion is intrinsic dynamic distortion due to interaction of electrons and photons during stimulated recombination process [18]. This factor results in generation of IMD induced IMPs and HD components even in laser sources which exhibit fairly linear light output versus bias current characteristics [15].

Any two signals w_i and w_j are accompanied by second-order harmonics at $2w_i$ and $2w_j$; second-order IMPs at $w_i \pm w_j$; third-order harmonics at $3w_i$ and $3w_j$; third order two-tone IMP at $2w_i \pm w_j$ and $2w_j \pm w_i$. Three adjacent subcarriers w_i, w_j and w_k mix to produce third-order triple beat IMP of form $w_i \pm w_j \pm w_k$ [4,15]. In a multichannel application, the IMPs and HDs which fall within a certain pass band dedicated to another service, create a negative influence. Two tone IMPs are of special interest because of their proximity to original signal [15].

There are various factors that influence the IMD and HD mechanism generation in the laser which can be exploited to reduce the performance degradation caused by them. Their magnitude depends on the optical modulation depth (OMD) and frequency of each participating subcarrier, imposing constraints on the permissible values and their suitable spectral positions of the subcarriers [4,11,14,15]. Since carrier to IMD ratio reduces as OMD increases the noise due to IMD and HD can be reduced below the internally generated laser diode noise levels by keeping OMD low [17]. A balance has to be sought between the allowable modulation depth and resulting signal power. Low RF power levels leads to reduced receiver sensitivity [14]. On the other hand large RF power levels and hence large modulation depths may be preferred to increase the number of subscribers being served by a single transmitter in a distribution system but at the cost of excessive HD and IMD resulting from joule heating of laser chip [19].

The operation of the system can be limited to the linear region of laser, if all the subcarriers lie within an octave of bandwidth. This arrangement shifts the second order IMPs outside the transmission band [5,11,19,20] thus improving system performance. The octave transmission band, however, implies increase in the frequencies at which all the components must operate, thereby increasing receiver noise levels [11]. An alternative to one octave transmission band restriction for performance improvement is a carefully designed frequency arrangement for carriers to allow the IMPs placement in between the frequency grid. But this solution cannot be implemented in FM systems [16].

An alternative to direct modulation of laser for SCM performance improvement is the use of external modulators which reflects robustness against second- and higher even-order impairments when biased at the point of inflection [8,10,14,18]. In any intensity modulator this allows the operation of SCM over multiple octaves. However the main limitation is that at this point the third- and higher-order odd distortions assume significance. Insertion loss is another severe problem of external modulators [11]. Since these modulators have several attractive properties for SCM applications, therefore much effort has been made to improve their nonlinearities, more so for analogue applications. These include several linearization techniques like feed forward compensation or predistortion circuitry [8,10,11,14].

In this paper a single- and a two-tone IM-DD system has been used to investigate the relative sensitivity of HD and IMD induced distortion components to changes in carrier amplitude, laser bias currents and key laser device parameters like quantum efficiency, active layer volume and carrier lifetime while clipping as well as RIN mechanisms are disabled. The salient features so revealed from the results, thereby can be exploited in the direction of seeking reasonable suppression of IMD and HD and hence promising better system performance.

3. Design of an HD and IMD dominated IM-DD system

A back-to-back arrangement of an IM-DD SCM system was designed based on laser rate equation component [21,22] of the simulator [23] as shown in Fig. 1. The RIN disabled laser rate equation component has been used to simulate the modulation dynamics of a directly modulated laser. The system is made clipping disabled as well by maintaining product of carrier amplitude and modulation peak current lesser than the offset of laser bias current over the laser threshold current. The observation of HD components exclusively is possible in a single-tone IM-DD system. Subsequently, observation of most dominant HD components from single-tone system is done relative to IMD components from a two-tone IM-DD SCM system. The modelling and the simulation results will be used to identify appropriate solutions that can reduce reasonably the sensitivity of the SCM system to these performance degrading mechanisms. The main difference between a single- and a two-tone IM-DD system is that in the former a single subcarrier f_1 while in the latter two closely spaced subcarriers f_1 and f_2 are used to intensity modulate the nonlinear laser device respectively. At the receiver the optical signal is detected by a PIN detector. The spectral content of detected signal, as dispalyed by the spectral

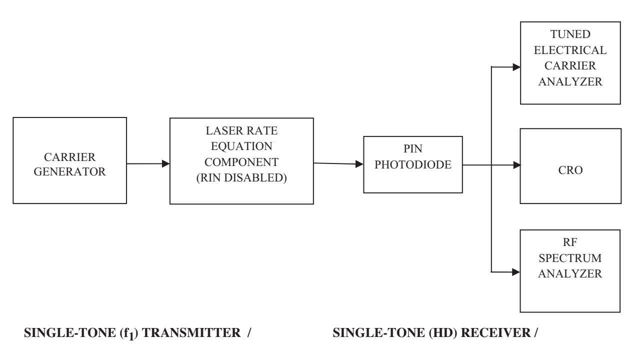

Fig. 1. Measurement setup used to simulate a single-tone IM-DD system and a two-tone IM-DD. SCM system with Clipping as well as RIN disabled.

Table 1
Signal and device parameters used in the one- and two-tone Clipping Disabled–RIN Disabled IM-DD system.

Component name	Parameter name	Parameter value
Carrier generator	Single-tone subcarrier amplitude (A)	1.5 a.u.
	Two-tone subcarrier amplitude (A)	0.5, 1.5 a.u.
	Subcarrier frequency (f_1)	500 MHz
	Subcarrier frequency (f_2)	525 MHz
Laser rate equation component	Laser power	0 dBm
	Threshold current (I_{th})	33.46 mA
	Threshold power	0.028 mW
	Modulation peak current (I_{pk})	3.8 mA
	Bias current (I_{bias})	40, 50 mA
	Quantum efficiency	0.4
	Active layer volume	1.5 E−10 cm^3
	Carrier life time	1 E−009 scs
	Clipping mechanism disabled	$(A)(I_{pk}) < (I_{bias} - I_{th})$
	RIN mechanism	Disabled

analyzer, shows only the original subcarrier at f_1 and HD induced harmonic components in the former case while it shows both harmonics well as IMD induced IMPs in the latter case. The electrical carrier analyzer is tuned to the observed spectral position of the harmonics and the IMPs to record their respective powers. The influence of HD and IMD mechanism is reflected as distortion which is seen in the detected signal onthe CRO display. These investigations enable to identify the most influencing signal, operational and device parameters which can be used to effectively suppress the source non-linearity induced impairments. Table 1 indicates the various parameter values used to realize the system design.

4. Results and discussion

This section presents the results based on the previously described single-and two-tone IM-DD systems shown in Fig. 1. The sensitivity and response of laser induced IMD and HD impairments has been observed with respect to carrier amplitude or modulation current, laser bias current, laser quantum efficiency, laser active volume and carrier life time.

4.1. RF Spectrum of HD and IMD dominated system

A RIN disabled laser source is operated above the clipping threshold with a large bias current of 50 mA. The resulting spectral display in case of single- and two-tone IM-DD systems are shown in Fig. 2(a and b) respectively. The RF spectrum shown in Fig. 2(a) is a result of harmonics produced when a single carrier of 1.5 a.u. at 500 MHz is fed to the nonlinear device. The power of these harmonics becomes insignificant at higher spectral position on the spectrum. On the contrary, when two subcarriers at 500 and 525 MHz frequencies mix in the nonlinear laser source, the detected signal at the receiver shows the original carriers accompanied by clustered groups of IMPs and harmonics of subcarriers. The display of Fig. 2(b) shows suppression of these harmonics at reduced carrier amplitude of 0.5 a.u. The IMD-induced components seen are the second-order IMD components at 1000, 1025 and 1050 MHz; two-tone third-order IMD components at 1525 and 1550 MHz; triple-beat third-order IMD components at 2025, 2050, and 2075 GHz; and harmonics of 500 and 525 MHz. Both the spectrums are observed to be devoid of any clipping induced distortions because the laser is biased well above its threshold current limit and HD suppression in IMD systems is possible at low carrier amplitude.

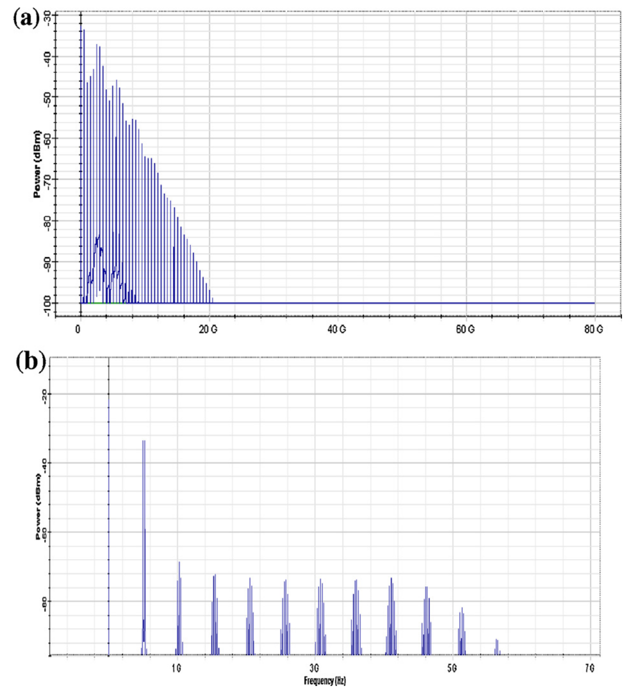

Fig. 2. RF spectrum display of Clipping Disabled-RIN Disabled system where I_{bias} = 50 mA. (a) HD induced spectrum showing f_1 and its harmonics generated in single-tone IM-DD system; carrier amplitude is 1.5 a.u. (b) IMD induced spectrum showing f_1, f_2 and distinct clustered groups of IMPs generated in two-tone IM-DD SCM system; carrier amplitude is 0.5 a.u.

4.2. HD and IMD response to carrier amplitude

A single carrier with amplitude ranging from 0.001 to 1.5 a.u. is fed to the RIN disabled laser biased at 38 mA. Corresponding modulation current given by the product of carrier amplitude and I_{pk}, ranges from 0.0038 mA to 5.7 mA. Thus the system remains clipping disabled as well till carrier amplitude of 1.195 a.u. corresponding to modulation current of 4.54 mA. The RF spectrum will display HD induced harmonics, from single-tone system, similar to Fig. 2(a). The powers of most significant of these harmonics, HD-2f_1 to HD-8f_1 are plotted against carrier amplitude in Fig. 3(a). Here it is observed that all the HD components increase with rise in carrier amplitudes with varying slopes. Although the HD-6f_1 assume significance above 0.19 a.u., however it increases more steeply in comparison to other harmonics till it assumes comparable power levels as that of detected carrier around 1.5 a.u. In Fig. 3(b) slopes of HD-2f_1 and HD-6f_1 from single-tone system is compared to slope of most significant IMD induced IMP-1025 MHz from the two-tone IM-DD system. It is observed that HD-2f_1 and IMP-1025 MHz increase gradually as compared to more rapidly increasing HD-6f_1 till the latter overtakes HD-2f_1 and IMP-1025 MHz at 0.835 and 1.0871 a.u., respectively. Performance of such a system would additionally be degraded by clipping induced distortion above 1.195 a.u. In a two-tone system both IMD and HD are issues of serious concern. IMD is the dominant mechanism till carrier amplitude of 1.0871 a.u. Lower carrier amplitude may be preferred where the power level difference between various distortion components and the detected carriers is large. In the present case, at modulating current of 1.25 mA corresponding to carrier amplitude of 0.33 a.u. this power level difference is large and with higher carrier amplitude the gap goes on reducing. These results reveal a direct relationship between power of HD and IMD distortion components with respect to the carrier amplitude with positive slope gradients.

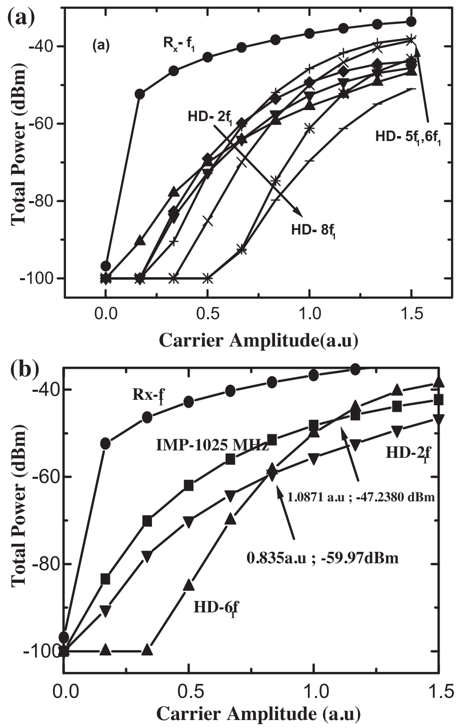

Fig. 3. (a) Measurement of power of HD-$2f_1$ to HD-$8f_1$ from single-tone system against carrier amplitude; RIN is disabled while Clipping is reinforced above 1.195 a.u. (b) Measurement of significant HD-$2f_1$ and HD-$6f_1$ power relative to IMP-1025 MHz from two-tone system, against carrier amplitude; RIN is disabled while Clipping is reinforced above 1.195 a.u.

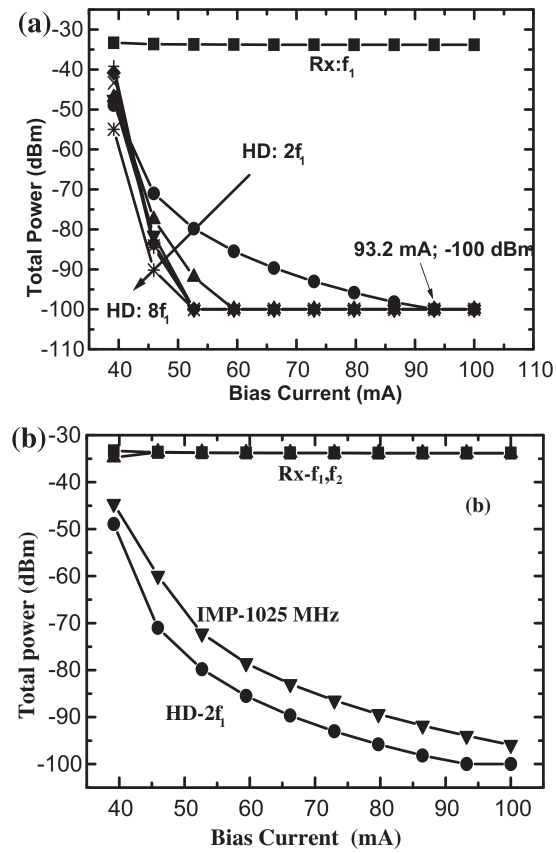

Fig. 4. (a) Measurement of power of HD-$2f_1$ to HD-$8f_1$ from single-tone system against bias current with clipping and RIN mechanisms disabled. (b) Measurement of power of HD-$2f_1$ relative to IMP-1025 MHz from two-tone system against bias current with clipping and RIN mechanisms disabled.

4.3. HD and IMD response to laser bias current

The HD induced harmonics of the single-tone IM-DD system are monitored with respect to laser bias current, I_{bias} over a range 39.16 mA to 100 mA. With carrier amplitude fixed at 1.5 a.u. a clipping disabled operation of the laser is ensured over this bias current range. There is no deterioration observed in the detected carrier power in this range. Results of single-tone system are shown in Fig. 4(a) whereas HD-$2f_1$ is monitored relative to most significant IMP-1025 MHz of the two-tone system in Fig. 4(b). In the HD dominated single-tone system, HD-$2f_1$ remains dominant over other harmonics till it diminishes to negligible level around 93.2 mA. In two-tone system, the IMP-1025 MHz remains dominant over HD throughout the range of operation and both decreasing with same slope. Thus for the IM-DD system to acquire more immunity to HD and IMD, large bias currents must be used although this adversely results in more heating effect restricting the choice to some appropriate lower bias current where HD or IMD influence would be reasonably tolerable. These results reveal an inverse relationship between HD and IMD mechanism and the bias current with negative slope gradients.

4.4. HD and IMD response to laser quantum efficiency

With I_{bias} of 40 mA and carrier amplitude equal to 1.5 a.u. the HD and IMD influence is significantly high as observed in previous results while both clipping and RIN mechanisms are disabled. Fig. 5(a) shows the response of HD induced harmonics to laser quantum efficiency over range 0–1. All the harmonics and detected carrier are observed to increase gradually with increase in quantum efficiency. It is the harmonic HD-$2f_1$which is dominant through out this range of quantum efficiency. In Fig. 5(b), comparing the dominant harmonic HD-$2f_1$ of single-tone system to dominant IMP-1025 MHz of two-tone system it is observed that IMD mechanism is dominant over HD mechanism over the entire range of observation. A proportionate rise in HDand IMD power levels is observed with increase in the laser quantum efficiency. It is clear that these mechanisms remain active maintaing almost a constant power level difference relative to the detected carriers over the entire range. This implies that laser quantum efficiency parameter itself does not offer any means to exercise control over these mechnisms. Conversely this reflects a flexibity in selection of lasers where laser quantum efficiency parameter is concerned.

4.5. HD and IMD response to active layer volume

Active layer volume of the laser device is varied over the range 7E−11 to 1.766E−10 cm^3, while the Quantum efficiency is fixed at 0.4, carrier amplitude is 1.5 a.u. and I_{bias} is set at 40 mA where HD is high and both clipping and RIN are disabled. Fig. 6(a and b) is based on observation of a single-tone and two-tone IM-DD systems respectively. In one carrier system of HD-$2f_1$ relative to IMP-1025 MHz from two-tone system harmonic HD-$2f_1$ remains dominant till an active layer volume of 1.4E−10 cm^3 and thereby higher order harmonics assume dominance. In the two carrier systems the IMD is dominant in comparison to HD-$2f_1$ over the active layer volume range under observation. Lasers with small values of active layer volume show much depleted power levels of HD and IMD components till these become comparable to the detected carrier power levels at active layer volume of1.585E−10 cm^3 while detected carrier power is maintained constant at about −33 dBm. Higher active layer volume than this value shows degradation in detected subcarrier along with the HD and IMD components. This indicates a direct relationship of IMD and HD component power

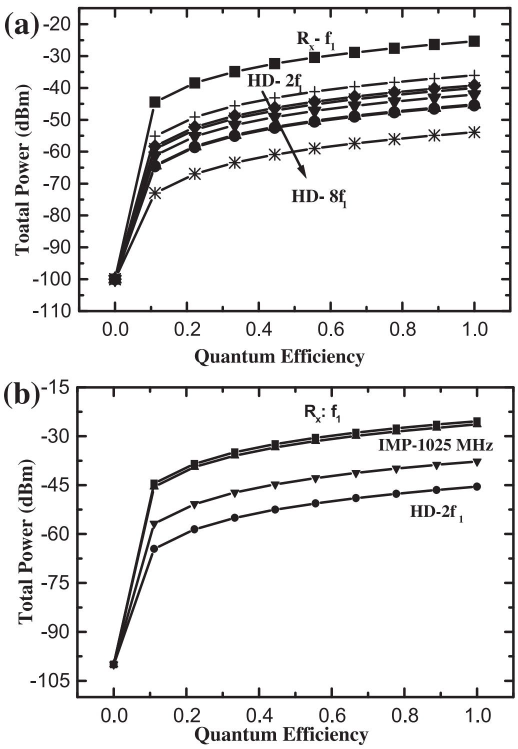

Fig. 5. (a) Measurement of power of HD-$2f_1$ to HD-$8f_1$ from single-tone system against laser quantum efficiency with clipping and RIN mechanisms disabled; I_{bias} = 40 mA. (b) Measurement of power of HD-$2f_1$ relative to IMP-1025 MHz from two-tone system against laser quantum efficiency with clipping and RIN mechanisms disabled; I_{bias} = 40 mA.

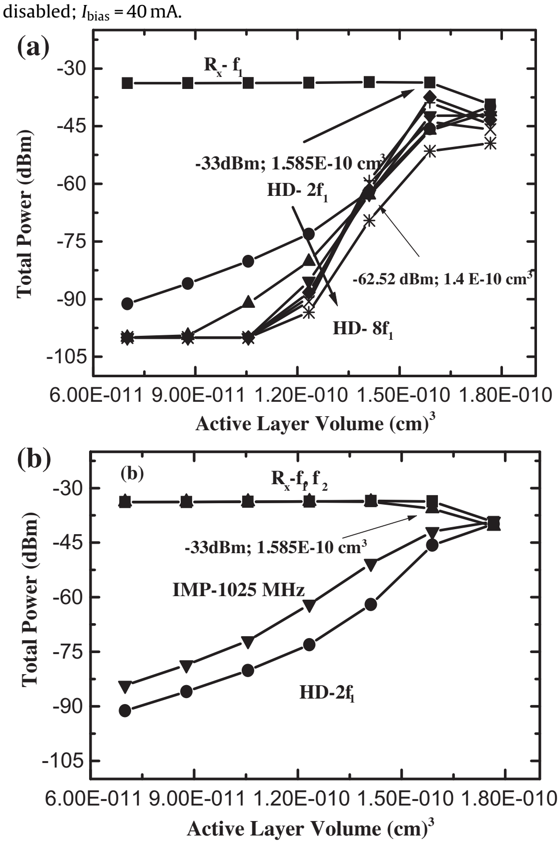

Fig. 6. (a) Measurement of power of HD-$2f_1$ to HD-$8f_1$ from single-tone system against laser active layer volume with clipping and RIN mechanisms disabled; I_{bias} = 40 mA. (b) Measurement of power of HD-$2f_1$ relative to IMP-1025 MHz from two-tone system against Laser active layer volume with clipping and RIN mechanisms disabled; I_{bias} = 40 mA.

with respect to active layer volume with positive slope. For this reason small active layer volumes are preferred. Additionally lasers with small values of active layer volume helps in producing high radiance optical output and reduction in the number of longitudinal modes emitted. To overcome the fabrication complexity involved in designing lasers with small active regions, these can be realized by using stripe geometry or circular metallic contacts. On the contrary, lasers with large active layer volume will offer an ease in fabrication complexity but will be producing low radiance optical power and will be suffer from heavy influence of HD and IMD mechanism at the receiver.

4.6. HD and IMD response to carrier lifetime

Here the laser physical parameter of carrier lifetime is changed from 8.889E−10 to 1.778E−09 seconds while carrier amplitude equal to 1.5 a.u. and I_{bias} is 40 mA in a clipping and RIN disabled system. For the single-tone system the response of HD components is observed against carrier lifetime in Fig. 7(a and b) we observe the response of most dominating harmonic of single-tone system relative to most dominating IMP from two-tone system against changes in carrier lifetime. Both these figures reflect an inverse dependency of HD and IMD with respect to carrier life time. For HD dominated single-tone system there is a greater performance degrading influence of harmonics at low carrier life-time and it is the harmonic $2f_1$ that remains dominant throughout this range while detected carrier remains stable at −33.19 dBm. Likewise in the two-tone system, it is observed that the detected carriers are maintained at stable power levels while IMD is dominant over HD mechanism. Thus to avoid the maximum influence of harmonics and the IMPs in IM-DD systems, it is favourable to choose laser material with large value

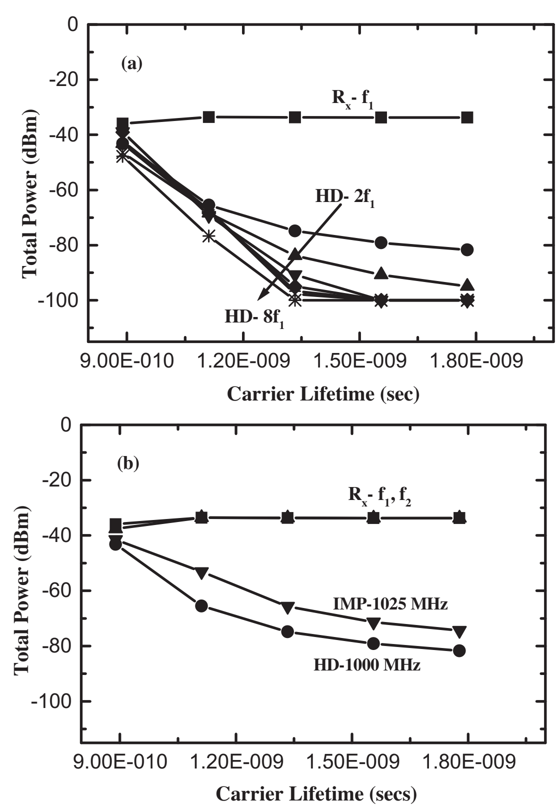

Fig. 7. (a) Measurement of power of HD-$2f_1$ to HD-$8f_1$ from one-tone system against laser carrier life time with clipping and RIN mechanisms disabled; I_{bias} = 40 mA. (b) Measurement of power of HD-$2f_1$ relative to IMP-1025 MHz from two-tone system against laser carrier life time with clipping and RIN mechanisms disabled; I_{bias} = 40 mA.

of carrier lifetime. However, such a choice will have to consider various factors that are influenced by carrier lifetime such as the recombination coefficients and carrier diffusion length.

5. Conclusion and future scope

This paper deals with investigation of HD and IMD induced performance degradation mechanisms resulting from the intensity modulation of an inherent nonlinear laser device in an analogue single- and two-tone IM-DD SCM system while both clipping and RIN mechanisms are disabled. The response of the HD and IMD mechanism to changes in laser device and operational characteristics were compared so that various constraints and limitations imposed by these mechanisms can be understood.

The HD induced spectrum of single-tone systems shows discrete equally spaced spectral components whereas an IMD induced spectrum of two-tone system shows discrete and clustered groups of spectral components. Spectral observation of the IMPs indicates possible performance degradation due to large inter-channel interference when subcarriers are closely spaced and large inter-group interference when these are widely spaced. The performance of multi-channel systems, which are influenced by both HD and IMD mechanisms, can be improved by using receivers which are highly selective with narrow pass band.

In all the case studies it was revealed that harmonic $2f_1$ is the most dominant harmonic in a single-tone system while a two-tone system will be more prone to the negative influence of IMD than HD. However as an exception, it is the harmonic $6f_1$ that showed highest sensitivity among all observed HD and IMD distortion components to changes in carrier amplitude till it exceeds even the most dominant IMD power level. Both HD and IMD component power increase with a rise in carrier amplitude with varying slopes. Low carrier amplitude and hence low modulating currents are preferred to enforce suppression of HD and IMD influence. There is an inverse dependence of HD and IMD mechanism with respect to laser bias current while detected carrier remains reasonably constant. The IM-DD system will experience more immunity to HD and IMD influence at high bias current, although this adversely results in more heating effect. Choice of some appropriate lower bias current is advised where HD and IMD influence would be reasonably tolerable.

At the component level all the HD and IMD components show a proportionate but very gradual increase in their power with the laser quantum efficiency rise. This implies that laser quantum efficiency parameter itself does not offer any means to exercise control over these mechanisms. In case of laser active layer volume, these mechanisms bear a direct relationship to changes in this parameter while detected subcarrier power remains constant over the range of observation. Thus HD and IMD can be suppressed in lasers with small active layer volume which also reportedly results in high radiance optical output and reduced longitudinal modes, but at the cost of fabrication complexity. An ease in fabrication complexity can be realized with large active layer volume but at the cost of low radiance optical power and heavy influence of HD and IMD mechanism at the receiver. The inverse and steep relationship between HD and IMD mechanism and the carrier life time, while detected subcarrier power level remains constant, prompts to select lasers with high carrier life time. However the final selection of a particular carrier life time has to take into account other factors dependent on this parameter like the laser radiation recombination coefficient and carrier diffusion lengths.

The system operational parameters like carrier amplitude and bias current giving rise to reasonably steep response to HD and IMD mechanism thus exhibiting instability in system performance with fluctuations in their values. The steep response in case of device parameters like active layer volume and carrier life time indicates high dependence of the system performance to the proper selection of the parameter. The parameter like laser quantum efficiency, that offers gradual response to these impairments promises flexibility in the choice of this parameter selection.

In this paper extended study of HD and IMD induced IMPs and their comparison was carried out in absence of clipping and RIN mechanism. These observations allowed us to identity various corrective measures that can be implemented at the system signal and component level to effectively reduce the influence of the source nonlinearity of SCM optical links. This work can be further extended to investigate HD and IMD induced distortion in Clipping Enabled and RIN Enabled systems in addition to reveal salient features of frequency domain and time domain characteristics of clipping and RIN mechanism.

References

[1] T. Koonen, Fiber to the home/fiber to the premises: what, where, and when? Proc. IEEE (2006) 911–934.
[2] P.W. Shumate, Fiber-to-the-home: 1977–2007, J. Lightwave Technol. 26 (2008) 1093–1103.
[3] T.E. Darcie, M.E. Dixon, B.L. Kasper, C.A. Burrus, Lightwave system using microwave subcarrier multiplexing, Electron. Lett. 22 (1986) 774–775.
[4] E. Bravi, F. Casella, E. Iannone, R. Sabella, F. UgoBordoni, Transmission of Analog SCM Signals through the transport network, in: IEE (ECOC), 22–25 September, 1997.
[5] R. Olshanky, V.A. Lanzisera, P.M. Hill, Subcarrier multiplexed lightwave systems for broadband distribution, J. Lightwave Technol. 7 (1989) 1329–1340.
[6] T. Yuichi, A study on optical wireless communication system and their applications, PhD thesis, Keio University, Japan, 2002.
[7] M. Kumar, S. Singh, J. Singh, R. Saxena, Performance analysis of WDM/SCM system using EDFA, IJARCSSE 2 (2012) 112–116.
[8] L. Roselli, V. Borgioni, F. Zepparelli, M. Ambrosi, M. Comez, P. Faccin, A. Casini, Analog laser predistortion for multiservice Radio-Over-Fiber systems, J. Lightwave Technol. 21 (2003) 1211–1223.
[9] Optical Data Communication, PRIME Faraday Partnership, Loughborough University, Loughborough, 2004, pp. 1–42.
[10] R. Papaannareddy, G. Bodeep, HFC/CATV transmission system (Invited Paper), Purdue University, Westville, USA, 2002.
[11] T.E. Darcie, Subcarrier multiplexing for lightwave networks and video distribution systems, IEEE J. Sel. Areas Commun. 8 (1990) 1240–1248.
[12] G.P. Agrawal, Fiber-Optic Communication System, third ed., Wiley-Interscience, John Wiley & Sons, Inc., Singapore, 2002.
[13] G.P. Agrawal, Applications of Nonlinear Fiber Optics, Academic Press, California, USA, 2001.
[14] V. Sharma, Simulative investigation of nonlinear distortion in single- and two-tone RoF systems using direct- and external-modulation techniques, Optik 121 (2010) 1545–1549.
[15] L. Su, UWB Radio-over-Fiber system using directly modulated VCSEL, Thesis for Master of Applied Science in Electrical and Computer Engineering, University of Waterloo, Canada, 2007.
[16] M. Maeda, M. Yamamoto, FM-FDM optical CATV transmission experiment and system design for MUSE HDTV signals, IEEE J. Sel. Areas Commun. 8 (1990) 1257–1267.
[17] A.J. Rainal, Limiting distortion of CATV Lasers, J. Lightwave Technol. 14 (1996) 474–479.
[18] S. Betti, E. Bravi, M. Giaconi, Analysis of the performance of subcarrier multiplexed (SCM) optical systems, Comp. Netw. 32 (2000) 563–569.
[19] T.E. Darcie, P.P. Iannone, B.L. Kasper, J.R. Talman, C.A. Burrus, T.A. Baker, Wide-Band lightwave distribution system using subcarrier multiplexing, J. Lightwave Technol. 7 (1989) 997–1004.
[20] P.A. Rocher, S.C. Fenning, Multichannel video transmission over 100 km of step index single mode fibre using a directly modulated 1537 nm distributed feedback laser, Electron. Lett. 26 (1990) 534–536.
[21] M. John Senior, Optical Fiber Communication, Principles and Practice, assisted by M. Y. Jamro, third ed., Pearson Prentice Hall, USA, 2009.
[22] G. Keiser, Optical Fiber Communication, third ed., Mc Graw-Hill International Edition, Singapore, 2000.
[23] OptiSystem Simulator. **V9**, Canada.