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DISTORTION OF W-CDMA SIGNALS OVER OPTICAL FIBRE LINKS

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Abstract: This paper presents first measurement results for the transmission of W-CDMA signals over optical fibre. Using a combination of measurements and simulation, we have evaluated the distortion performance of direct and externally modulated optical links.

Introduction

Radio over fibre systems are now being used extensively for enhanced cellular coverage inside buildings such as office blocks, shopping malls and airport terminals. Distributed antenna systems (DAS) using radio over fibre give clear advantages over other solutions, such as better coverage, higher capacity and easier installation. DAS products are available from a number of manufacturers for current second generation cellular systems. Third generation cellular systems such as UMTS will be deployed within the next few years using W-CDMA radio access. These systems will make extensive use of microcells and picocells in order to deliver high bandwidth services to customers. The benefits of using radio over fibre for these new DAS systems is expected to be even more important, partly because of their higher frequency and bandwidth requirements.

The purpose of this paper is to assess the distortion performance of radio over fibre links for W-CDMA by measurement and simulation of third order intermodulation distortion (IM3). We believe this to be the first reported experimental data for W-CDMA signals transmitted over optical fibre. Two types of intensity modulated direct detection (IMDD) optical links are considered: a) direct modulation of a laser diode, and b) external modulation of an electroabsorption modulator (EAM). IM3 causes power leakage into adjacent channels in W-CDMA and is characterised by the Adjacent Channel Leakage power Ratio (ACLR). The maximum allowed value for ACLR in UMTS is given as -45dBc for the downlink (DL) /1/ and -33dBc for the uplink (UL) /2/ and this paper explores the input power and fibre length limitations for the two types of optical link.

Experiment

Figure 1 shows the experimental setup for measuring ACLR. A vector signal generator (SMIQ from Rohde & Schwarz) was used to generate W-CDMA signals at a carrier frequency of 2GHz with bandwidth of around 4MHz. A single 32ksps channel was used which gave a peak to average power ratio of 6dB. This signal was fed into the optical links. After transmission through various lengths of standard single mode fibre (S-SMF), the received signal was analysed using a vector signal analyser (FSIQ from Rohde & Schwarz). Recommended settings were used for the two instruments which gave an ACLR of less than -63dBc for the back-to-back measurement.

We have also performed standard two-tone intermodulation measurements (with a frequency spacing of 100MHz) in order to provide a relatively straightforward system for trend prediction using simulation.

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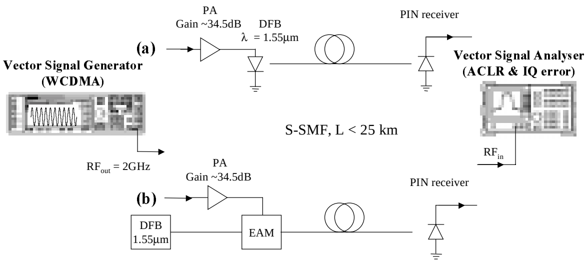

Figure 1: Setup for measuring ACLR
(a) using direct laser modulation
(b) using external EAM modulation

The laser used in these experiments was the Ortel model 10370A (1550nm DFB, output power = 7dBm) which was specially developed for analogue applications. The EAM was produced at BT Adastral Park /3/ and had a fibre to fibre insertion loss of around 6dB at 0V. For these experiments the EAM was biased at -1V. The optical receiver for both links was the Ortel model 10450B.

Results and discussion

Figure 2 shows how the W-CDMA signal is distorted using the case of the directly modulated optical link at an input power of 12dBm as an example. The distortion (spectral regrowth) is seen to increase markedly as the fibre length increases.

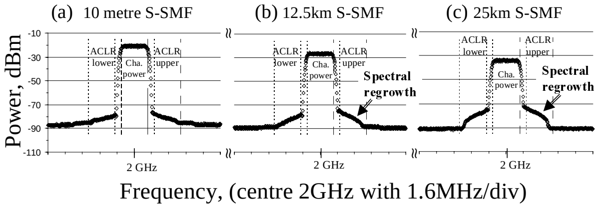

Figure 2: Spectral regrowth for direct laser modulation at P_{in} = 12dBm
(a) fibre span = ~10 metre
(b) fibre span = 12.5km
(c) fibre span = 25km.

Figure 3 shows how this spectral regrowth (in terms of ACLR) varies with input power, fibre length and link type. The following general observations can be made from this figure:

- the EAM link gives higher distortion than the laser
- the distortion in the directly modulated laser link is greatly enhanced by long fibre spans
- at very high input power the distortion tends to converge to a single value

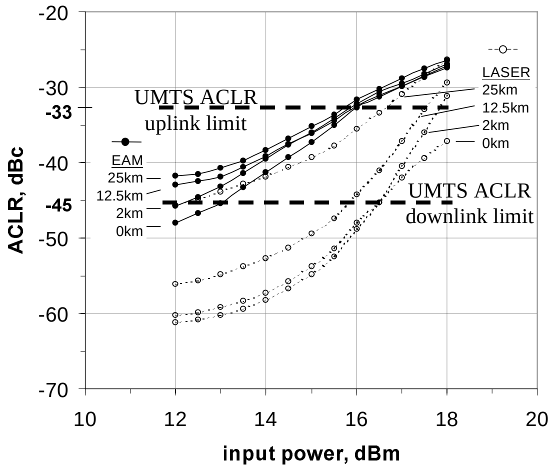

Figure 3: ACLR versus input power and fibre length for direct and indirect modulation.

Several factors are responsible for these observations. Each of the modulation devices has inherent nonlinearity; the laser from gain compression, clipping and power output saturation and the EAM from its complex transfer characteristic. The EAM can be biased to remove IM3 by careful control of bias voltage and input polarisation, but in general it will give more distortion than an analogue laser.

In addition, the laser has significant frequency modulation (chirp) compared to the EAM. It is well documented that chirp can cause additional distortion in combination with chromatic dispersion /4/, which may explain why the distortion increases significantly with fibre span for the case of the directly modulated laser.

In order to understand these effects and to be able to predict trends, we simulated two-tone intermodulation distortion and compared the simulated results with results of the two-tone measurements. The simulation was performed using the OptSim package. Some of the parameters used in the simulation are given in Table 1.

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Nonlinearities caused by the light-current curve have not been included in the simulation. Measured values of loss and chirp as a function of bias voltage were used for the EAM simulation.

Parameter	*Value*
Laser bias current	80mA
Laser gain coefficient	2.5 10^{-16} cm^2
Laser alpha factor	6
Static frequency chirp	0.203 GHz/mA
Threshold current	24mA
EAM bias	-1V
Fibre loss (λ = 1.55μm)	0.2dB/km
Fibre dispersion constant	17 ps/nm/km

Table 1: Simulation parameters

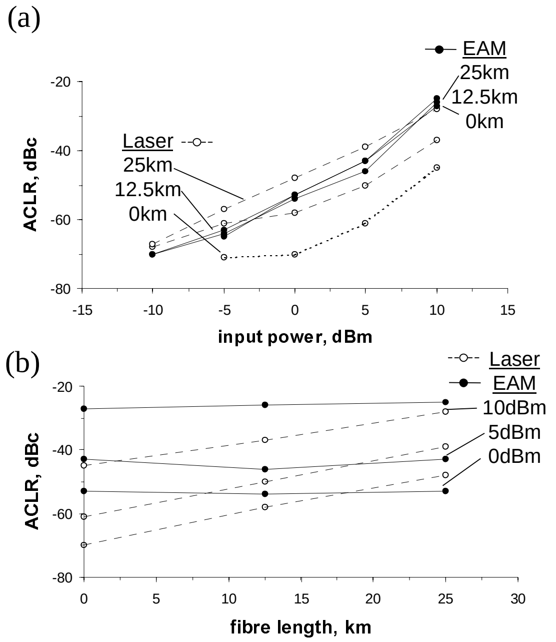

Figure 4: Two-tone measurement results
(a) ACLR versus input power
(b) ACLR versus fibre length

Figure 4 shows the measured two-tone results and figure 5 shows the simulated two-tone results. Points to note from these figures are:

- both sets of measurements (two-tone and W-CDMA) show the same trends. The EAM has higher distortion than the laser but is not further degraded by long fibre spans
- there is good agreement between two-tone simulation and measurement
- the simulation results show that ACLR for the directly modulated laser is fairly constant for the first few km of fibre.

The difference in the input power scales of the W-CDMA and two-tone measurements arises from a combination of factors. The W-CDMA signal used in this work had a peak to average power ratio of 6dB whereas the power in the two-tone case was constant. The two-tone input power used in the figures refers to the power in a single tone. Also, there is an effective difference due to the relatively high frequency separation used for the two-tone measurements /4/. Finally, some of the W-CDMA distortion is removed by the measurement filter. All of these factors combine to give a shift of around 10dB in the input power scale.

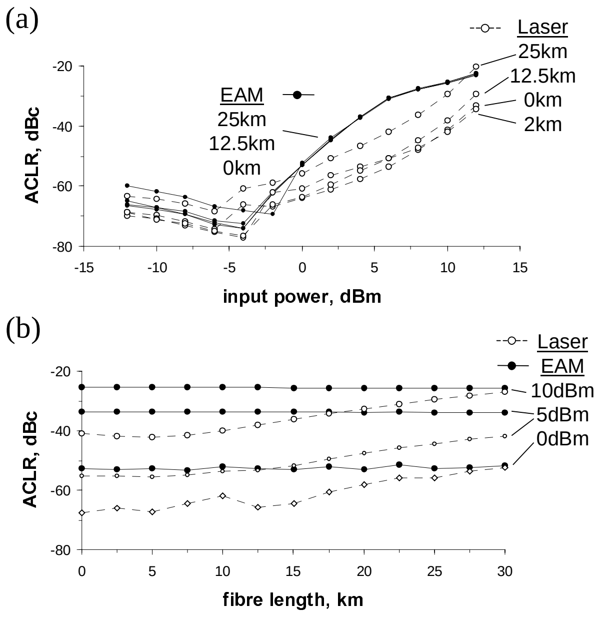

Figure 5: Two-tone simulation results
(a) ACLR versus input power
(b) ACLR versus fibre length

There are two distinct regions in the ACLR versus fibre length plot for the directly modulated laser. At low fibre spans, the distortion caused by the laser nonlinearity is

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dominant. At higher fibre spans however, the distortion caused by the chirp/dispersion effect becomes dominant. For the case of the EAM the distortion caused by the transfer characteristic is always dominant, partly because the levels of distortion are relatively high for this device and partly because the chirp is significantly lower than for the laser.

The main outcome of this work is to evaluate the input power and fibre span limits to meet the UMTS draft specifications for ACLR. Table 2 shows the maximum input power that may be applied to the optical link for a variety of fibre spans for both downlink and uplink.

Fibre span, km	Max. input power, dBm			
	Laser		EAM	
	DL	UL	DL	UL
0	16.5	>18	13	15
2	16.5	17.5	12	15
12.5	15.5	17	---	15
25	12	16.5	---	15

Table 2: Maximum input power to meet ACLR specification for UMTS

For long fibre spans the EAM will not meet the downlink specification. This may be remedied by operating the device at a higher bias voltage where the linewidth enhancement (alpha) factor will be lower or by modifying the design to give a more linear transfer characteristic. The EAM link comfortably meets the uplink specification, which is where the EAM is regarded as being particularly suitable (as a modulator at the remote antenna site) /5/.

Conclusions

To the author's knowledge, this paper has presented first measurement results for the transmission of W-CDMA signals over optical fibre. Using a combination of measurements (W-CDMA and two-tone) and simulation (two-tone), we have made a number of observations regarding the effects of inherent device nonlinearity, frequency chirp and fibre dispersion on the distortion performance of direct (analogue laser) and externally modulated (EAM) optical links. Specifically, we have determined the maximum input power that can be applied to the optical link in order to meet the draft UMTS specification for adjacent channel leakage power ratio. This work will help in the design of suitable optical links for future UMTS microcells and picocells.

Acknowledgement

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