Journal of Engineering and Applied Sciences 1 (1) : 60-65, 2006

Equal and Unequal Spacing Analogue Fibre Optic System Carrier Position CTBs

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Abstract: The analogue fibre optic system can be limited by the carrier position Composite Triple Beat (CTB), which is the sum of all the third order Inter-Modulation Distortions (IMD_3) that appear at a channel accommodating a carrier as a result of the optical portions nonlinearity. The carrier position CTB might not be filtered off and is therefore liable of interfering destructively with the carrier. As a result, the carrier's magnitude might appear to be lowered. An experiment was performed to determine the carrier position CTB for an analogue fibre optic link fed with 14 equal and unequal frequency spacings RF carriers with the presence of distortions in unused channels. The Golomb Ruler's marks were referred to for obtaining the unequal frequency spacing carriers. The CTB appearing at carrier positions for the unequal frequency spacing case was found to be lower than when the equal frequency spacing was employed. In addition, the unequally spaced carrier-to-noise ratios were higher than the equally spaced carriers though some of the unequally carriers were lower in magnitude.

Key words: Composite triple beat, equal frequency spacing, golomb ruler

INTRODUCTION

The composite triple beat (CTB) appearing at RF carrier positions is a limitation encountered in an analogue fiber optic system such as the radio-over-fiber or hybrid radio fiber system, used to transport the second and third generations mobile communication signals, as they interfere destructively with the carrier. As the CTB falls directly on the channels used, it might not be filtered off. The RF carrier in that channel would seem to be lower in magnitude. The CTB is actually composed of two-tone and three-tone third order intermodulation distortions appearing at a channel. These third order intermodulation distortions (IMD_3) are beat products generated when signals of two or three different frequencies are fed to a non-linear device or system.

The number and level of CTB at a carrier position are affected by the frequency plan or channel placing used. Chan and Chen introduced the Multiple Delete Insert (MDI) algorithm to come up with a frequency plan to reduce the number of IMD_3 in three links. The resulting frequency plan indicated that the frequency separation between the successive used channels were different[1]. According to Hunziker, the frequency plan based on Golomb Ruler could be used to reduce the IMD_3 of low cost fiber optic links intended to serve as cellular remote antenna feeding[2]. The Golomb Ruler is made up of marks that are positioned in a way the distances between any pair of the marks are different[3,4]. The Golomb Ruler for five marks is given in Fig. 1.

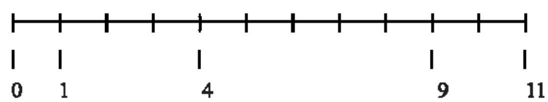

Fig. 1: The OGR for five marks

The first mark is placed at the leftmost and referred to as integer value 0[3]. The goal of the Golomb Ruler is to have as many marks as possible for a given length or achieve the shortest ruler possible known as the Optimum Golomb Ruler (OGR)[3,4]. The Golomb Ruler in Fig. 1 is also the OGR for 5 marks. The total number of channels that the bandwidth can accommodate relates to the length of the Golomb Ruler. The number of channels designated for use in a frequency plan corresponds to the number of marks on the Golomb Ruler.

The objective of this work is to measure and compare the carrier position CTB produced at the output of an analogue fiber optic system that is fed with RF carriers that are equally spaced and spaced unequally according

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to the Golomb Ruler's marks, in the presence of distortions. Then the CTB-to-carrier ratio and CTB reduction factor for both frequency plans are determined. The CTB-to-carrier ratio is the level of carrier position CTB with respect to the carrier magnitude. The CTB reduction factor is the ratio between the carrier position CTB of the original arrangement to the CTB due to the new frequency plan[1]. The equal frequency spacing carriers is assumed to be the original arrangement and referred to as equally spaced channel placing (ESCP). Arranging the channels in accordance to the Golomb Ruler's marks is referred to as the Golomb Ruler channel placing (GRCP).

EQUAL VERSUS UNIQUE CHANNEL SPACING

For the experiment, 14 RF carriers were employed with a minimum channel spacing of 200 kHz and frequency starting from 890MHz. The channels used in the ESCP were the channels numbered 1, 10, 19, 28, 37, 46, 55, 64, 73, 82, 91, 100, 109 and 118. Therefore the carriers in the ESCP was spaced 1.8MHz from each other. The channels used for the GRCP were the channels numbered 1, 7, 19, 20, 24, 40, 50, 65, 72, 74, 101, 109, 112 and 175. The initial 13 channels corresponded with the Golomb Ruler for 13 marks obtained from[4]. The frequency spacings between each pair of carriers are unique in the GRCP. In addition, the bandwidth of the GRCP exceeded that of the ESCP. Before the actual testing was performed, a simulation was carried out to determine the number of CTB appearing from the 1st to the 175th channel for both channel placings. The outcomes of this simulation as well as the locations of the carriers are indicated as in Fig. 2 and 3. No CTB or IMD_3 overlaps the carrier for the GRCP. This implies that arranging the channels to be used according to the Golomb Ruler can avoid IMD_3s from interfering with the channels in use to carry information. Moreover, less than ten IMD_3 are found in the unused channels of the GRCP.

On the contrary, the CTB for the ESCP appeared directly at the carrier positions and equally spaced. The carrier position CTB for the ESCP are higher than any of the CTB in the GRCP's unused channels. The CTB number maximizes at the middle occupied channels. This suggests that the middle occupied channels will the most distorted by the CTB. Decrease in the CTB number is observed at the end occupied channels as well as unused channels from the 127th to the 175th channels.

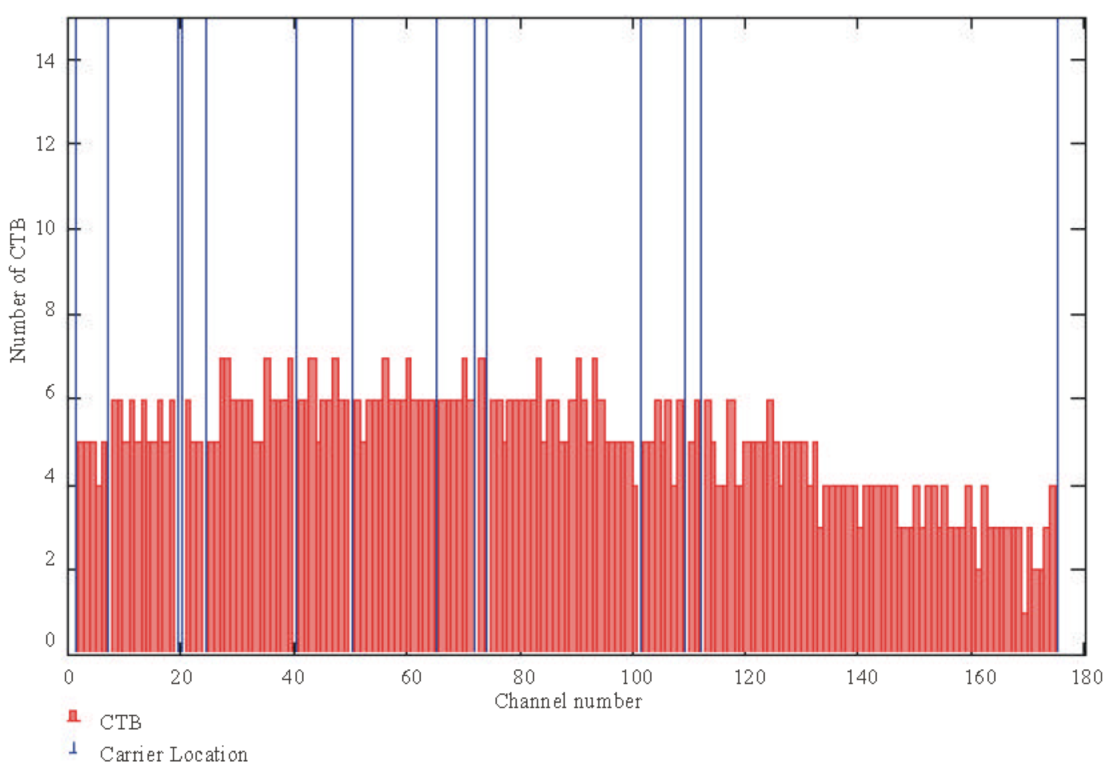

Fig. 2: The number of CTB generated and location of carrier for the GRCP

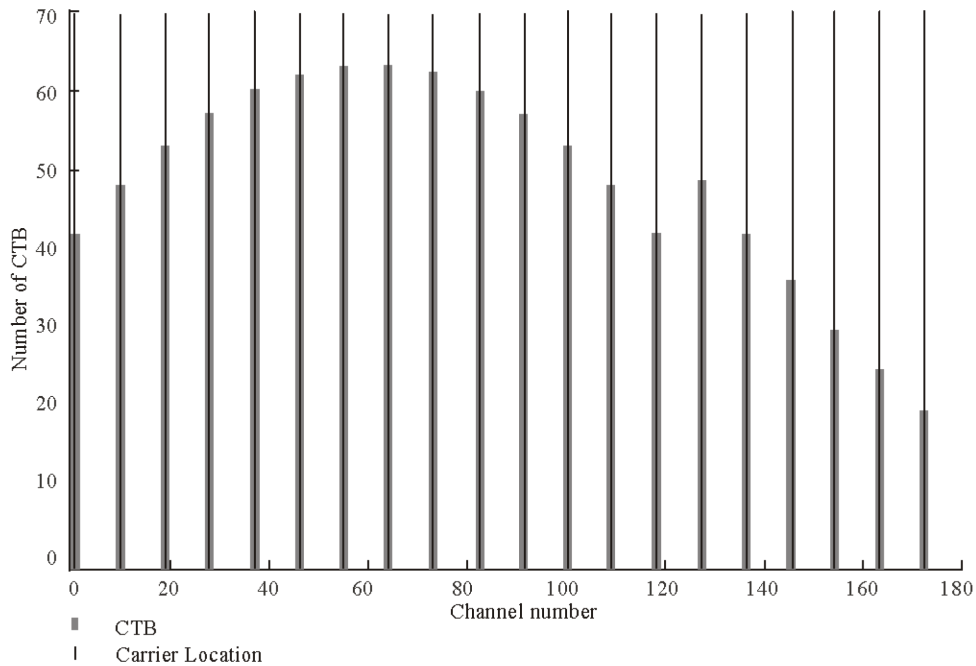

Fig. 3: The number of CTB generated and location of carriers for the ESCP

The comparison between the CTB distributions for both the GRCP and ESCP indicates that GRCP might be preferred over the ESCP in overcoming the carrier position CTB problem. However the levels of CTB to be observed are dependent on the nature of the actual input fed to the optical link, such as the magnitude of the carriers and the presence of distortions in the unused channels. The behavior or characteristics of the optical link itself might also influence the levels of CTB produced.

EXPERIMENT SETUP

The experiment set-up for measuring the carrier position CTB is given in Fig. 4. The pattern for the equal and unequal frequency spacing RF carriers are created using the IQCreator and supplied to the IFR 3413 digital RF signal generator. The IQCreator, a software associated with the digital RF signal generator, is employed to create the signal patterns. The GRCP and ESCP patterns produced using the IQCreator software are given in Fig. 5. The output of the digital RF signal generator is fed to the optical link that is made up of an electrical to optical converter (E/O), fiber optic patch cord with 15 to 16 dB attenuation and an optical to electrical converter (O/E). The E/O light output power is approximately -5dBm while the O/E converter accepts light power of less than -20dBm.

The E/O converter employs intensity modulation of the laser diode. Direct detection of the Ge-APD takes place in the O/E converter. Both converters support RF

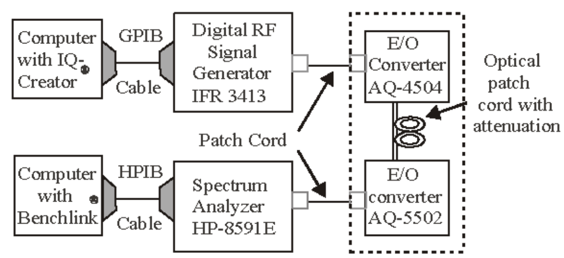

Fig. 4: The experiment set-up to measure CTB appearing at carrier position

frequencies of less than 1GHz. The maximum allowable RF input power to the E/O converter is -15dBm. The O/E converter would provide RF output power of approximately -40dBm or greater if its received light power was -20dBm. The output of the O/E converter was fed to the spectrum analyser. The computer, installed with the BenchLink software, was employed to retrieve the display of the spectrum analyser and its related data through the HPIB cable.

The ESCP and GRCP signals generated by the signal generator are indicated in Fig. 6 and 7. Though the carriers are intended to have the same magnitude as indicated in Fig. 5, the RF levels for the ESCP signal ranged between -18.26 to -15.21 dBm while GRCP signals varied from -18.27 to -15.59 dBm. The carriers in Fig. 6 are easily differentiated in comparison to some in Fig 7. The third peak in Fig. 7 is actually composed of the third and fourth carriers of the GRCP.

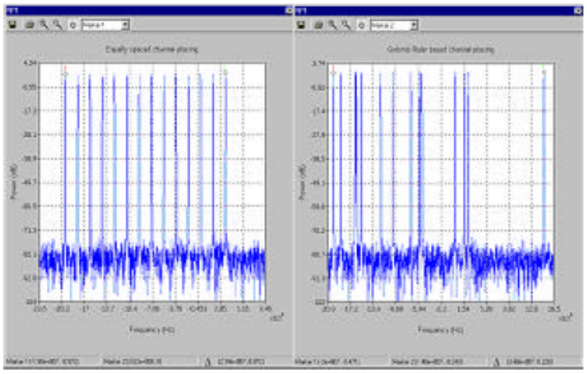

Fig. 5: Equally and unequally spaced spaced carriers generated using IQCreator

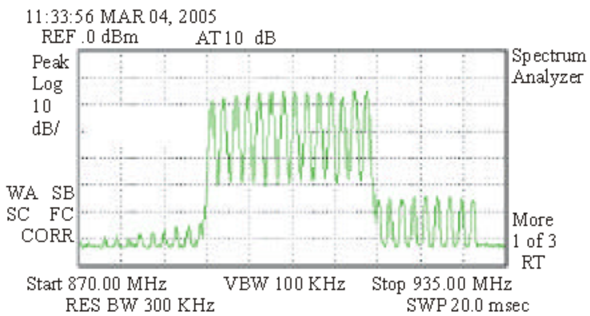

Fig. 6: The ESCP signal as seen at the IFR 3413 output

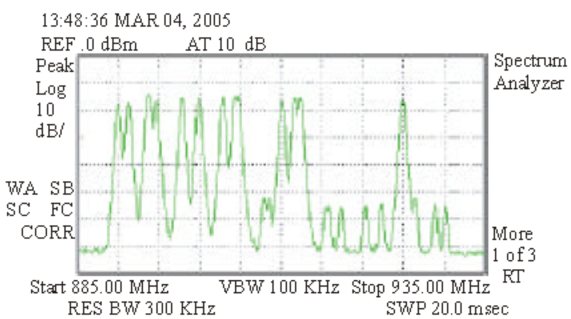

Fig. 7: The GRCP signal as seen at the IFR 3413 output

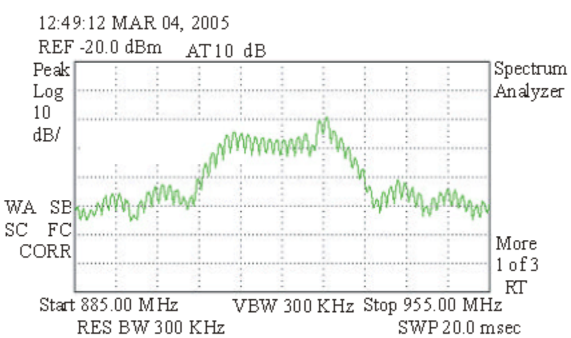

Fig. 8: The ESCP signal as seen at the O/E converter putput

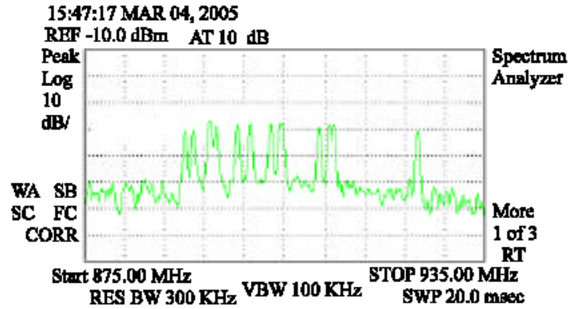

Fig. 9: The GRCP signal as seen at the O/E converter output

The individual carriers in both Figures reveal spreading, whereby each carrier occupies a small bandwidth of about 20.8kHz. Therefore the measurements are based on the average powers of the narrow band carriers or 'channel powers' rather than their peak powers. Some distortions are visibly present in the unused channels of both signals, indicating that the actual input to the optical link will not only be the intended carriers only. These distortions are peaks with magnitudes less than -50dBm. The distortions in unused channels could interact with the existing carrier to produce additional carrier positions IMD_3 that were not accounted for in the simulation results in Fig. 2 and 3.

The O/E converter outputs due to both channel placings are shown in Fig. 8 and 9. The O/E converter output for the GRCP signal resembles that of its E/O converter input. However the envelope of the O/E converter output for the ESCP signal varies greatly from its E/O input. The distortions appearing in unused channels of the GRCP O/E converter output are found to be less than -55dBm. The distortions in some of the unused channels of the ESCP signals are extremely high and easily mistaken for the actual carriers themselves, especially those residing close to 890 and 914MHz.

In order to measure the CTB that appears at the carrier position, the magnitude of the individual carrier in both ESCP and GRCP are fed to the optical system and their RF levels at the O/E converter output are recorded and noted as the expected channel power. When only one carrier is fed to the optical system, no IMD_3 is assumed to be produced at or around this carrier position or distortion free. The channel powers associated with each carrier in both Fig. 8 and 9 will be noted as the observed channel powers. They would be different from the distortion free carriers if IMD_3s fall onto them. In short, the carrier position CTB is the difference between the expected and the observed channel powers.

This method of determining the carrier position is different from that used in[5]. The CTB measurement method stated in[5] required the desired channel to be notched out and the CTB falling onto it due to other channels would be measured. However, the IMD_3 or CTB produced by the interaction between the desired channel and other channels that fell back onto the desired channel might not be detected. Let the carrier frequency f_1, f_2 and f_3 be 891.8, 893.6 and 895.4MHz. The IMD_3 at $f_1+f_3-f_2$ would appear at 893.6MHz. If the CTB at 893.6MHz is to be measured using common method, this IMD_3 might be neglected.

RESULTS AND DISCUSSION

The gap between the expected and observed channel powers at the 14 carrier positions for both the ESCP and GRCP can be seen in Fig. 10. The difference between the expected and observed channel power for the ESCP is higher than that for the GRCP, which leads to greater CTB appearing at carrier positions as shown in Fig. 11. Therefore, employing unequal frequency spacing based on the Golomb Ruler's marks leads to lower levels of CTBs to appear at carrier positions even in the presence of distortions in unused channels as compared to utilizing equal frequency spacing.

Figure 12 indicates that the CTB-to-carrier ratios for the respective the carrier positions in the ESCP are higher than the GRCP. Lower CTB-to-carrier ratios are preferred as they indicate that the CTB distorts the carrier less severely. Therefore, the carrier positions CTBs for the GRCP distort their carriers more than the ESCP. The 13th and 14th carriers of the ESCP curve in Figure 12 are found to be lower than the other carriers though their CTB level are significantly high, as their carrier magnitudes that are indicated in Fig. 10 are high.

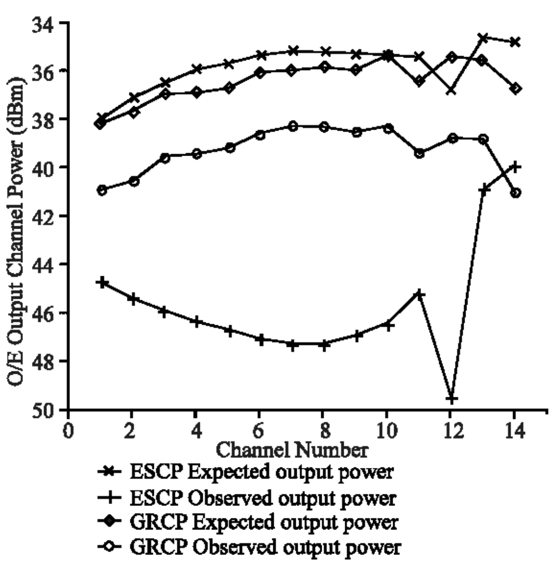

Fig. 10: The expected and observed output channel powers for the ESCP and GRCP signals at the 14 carrier positions.

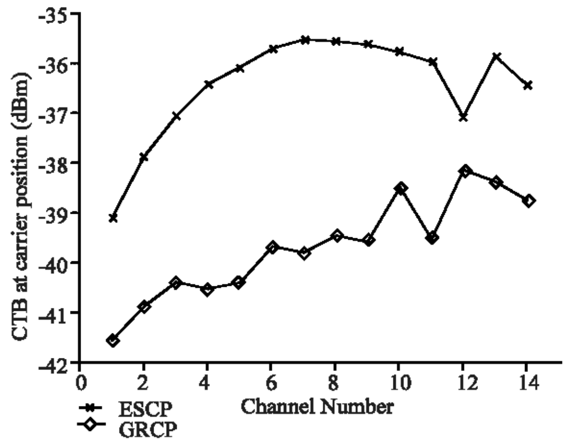

Fig. 11: The CTB levels at carrier positions

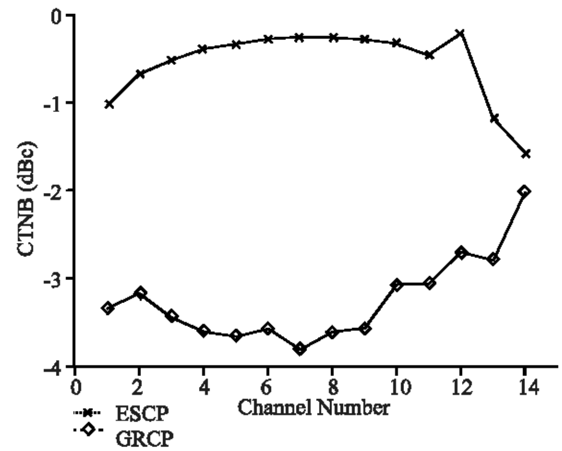

Fig. 12: The CTB-to-carrier ratios at the 14 carrier positions

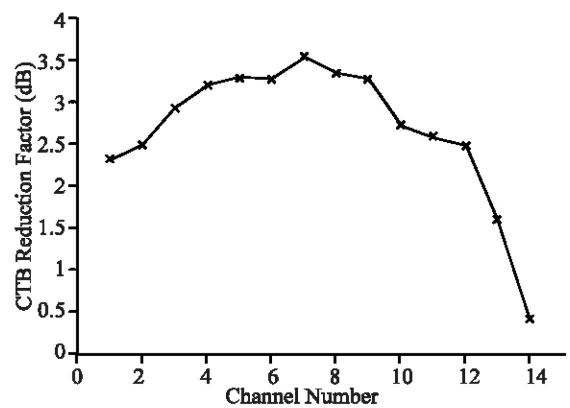

Fig. 13: The CTB reduction factor (dB)

The CTB reduction factor in Fig. 13 is actually the difference between the ESCP and GRCP CTB-to-carrier ratios for the respective carrier positions. This is to incorporate the effects of the carrier magnitudes that are varied or altered when different frequency plans are implemented. The CTB reduction factors for all the carrier positions are greater than 0dB, which manifest that the unequal frequency spacing as a better frequency plan to be employed. The unequal frequency spacing leads to lower carrier position CTB and the resultant carrier position CTB impose less distortions to the carrier even in the presence of additional distortions introduced by the interaction between the existing carriers and distortions in unused channels.

CONCLUSION

The CTB at the output of the analogue fibre optic system that appear at carrier positions when the carriers fed were equally and unequally frequency spaced were looked into. The unequally frequency spacing or Golomb Ruler carriers led to less carrier position CTB than when the equal frequency spacing carriers were employed though distortions were present in unused channels. This also resulted in CTB reduction factor of greater than 0dB. In addition the CTB-to-carrier ratios were lower when the Golomb Ruler based unequal frequency spacing was implemented. The disadvantage of arranging the carriers using the Golomb Ruler based unequal frequency spacing consumes greater bandwidth than the equal frequency spacing. However, the Golomb Ruler based unequal frequency spacing can still be implemented with the signal extraction with frequency arrangement (SEFA) technique proposed by the ITU[6], which can also cater for the large bandwidth consumption.

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