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Analysis of CNR Penalty in Radio over Fiber System Including the Effect of Phase Noise & RF Oscillator

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Abstract---To analysis of the system performance based on photocurrent at the photo detector. A carrier to noise i.e. CNR is used, for the evaluation of the performance of the Radio over fiber system, because it is a good & simple parameter for measuring of system performance using the ratio between the carrier power and the noise power. Also evaluate the CNR penalty, including the effect of phase noise from laser and RF oscillator line width. CNR penalty is defined the ratio of CNR value & the reference CNR value. The CNR of photocurrent is calculating by using an autocorrelation (AC) function and a power spectral density (PSD) function. The large data traffic services, video and voice communication, wireless & optical communication work capacity on photonic technology Most Radio over fiber techniques utilize (single mode fiber) SMF to feed the BSs, because the bandwidth of (multi mode fiber) MMFs is severely limited by modal dispersion. Many current and future Radio over fiber techniques may be used only for outdoor (SMF dominates) applications, but not indoor coverage (over MMFs). In This paper analysis the Transmission performance measure optical Single side band. Radio over fiber system is based on phase noise from the laser and RF oscillator line width. In this measure the effects of Power decrement due to dispersion effect on CNR & fiber chromatic dispersion effects on various length of the fiber.

Keywords—carrier to noise ratio, radio over fiber, single mode fiber, multi mode fiber, dispersion effect

I. INTRODUCTION

In ninety century, Radio over fiber technology was first demonstrated for cordless or mobile telephone service, a large number of research that investigate its limitation and develop new high performance Radio over fiber technologies. To be specific, the Radio over fiber network typically comprises a central control station (CS), where all routing, switching and frequency management functions to be performed & an optical fiber network, which interconnects a large number of functionally simple and compact base stations (BSs) for wireless signal distribution. Because of simple base station structure cost can be deploying infrastructure can be dramatically reduced compared to other wire line alternatives. Radio over fiber technology further has a benefit of transferring the RF (Radio Frequency) signal and from a CS that can allow flexible network resource management and rapid response to variations in traffic demand due to its centralized network architecture. The benefits can be translated into system installation likely in wide coverage broadband process and operational saving process in wireless communication systems, where a high density of BSs is necessary. The technique of modulating the radio frequency sub carrier onto an optical carrier for distribution over a fiber network is known as the radio over fiber Radio over fiber system [8]. A Radio over fiber system entails the use of optical fiber links to distribute RF signals from a central CS to BS. The centralization of RF signal processing functions enables equipment sharing, dynamic allocation of resources, and simplified system operation and maintenance [8]. Doing this, BSs are simplified significantly, as they only need to perform amplification process and optoelectric conversion. Narrowband communication systems and WLANs, RF signal processing such as frequency, multiplexing, carrier modulation, up-conversion are performed at the BS, and immediately after fed into the antenna. Its perform to functions in control station to centralize RF signal processing by radio over fiber system, and then use to optical fiber, which provided low signal loss (0.3 dB/km for 1550 nm) to distribute the RF signals to the BSs, as shown in Fig.1.

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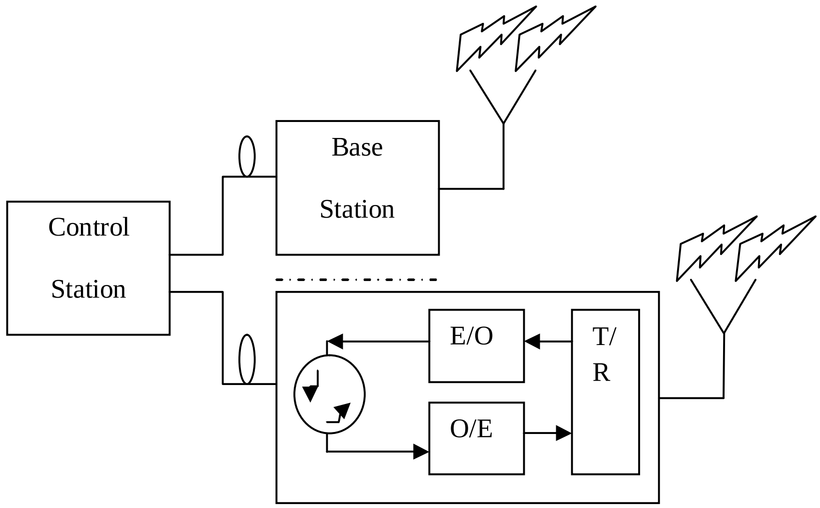
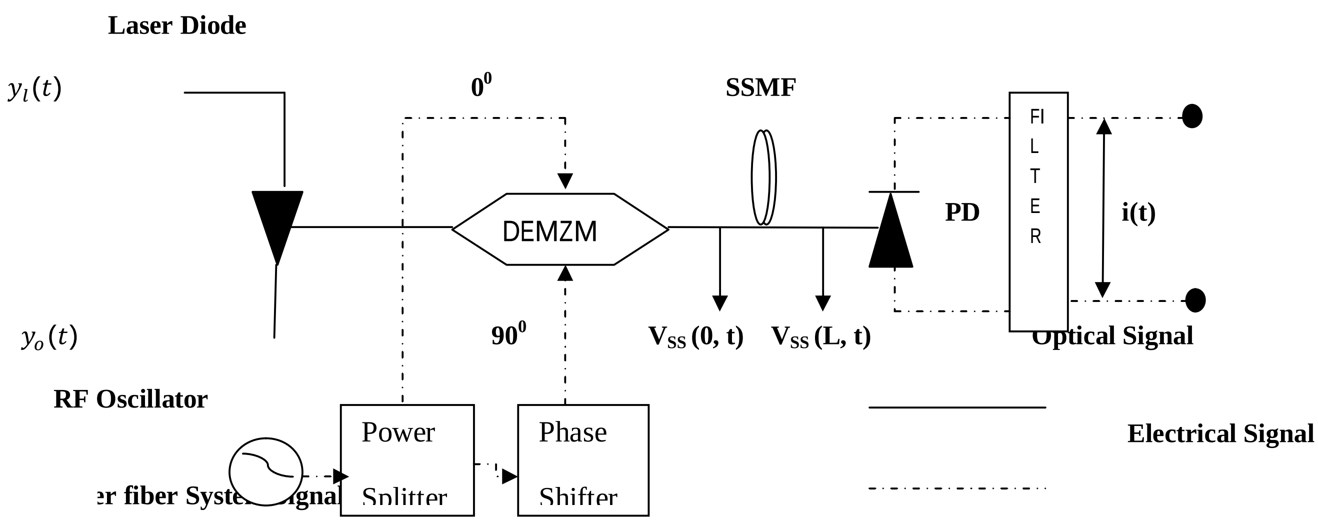


Where **E/O:** Electric to optic converter, **O/E:** Optic to Electric Converter, **T/R:** Transmitter/Receiver

Fig.1. General Radio over Fiber System

II. RADIO OVER FIBER MODEL

Radio over fiber system is that where light is modulated by a radio signal and transmitted over an optical link. As shown in fig.2 The output signal of the MZM is transmitted by a standard SMF and detected by a photodiode (PD) to generate the photocurrent i(t) at a Base station. The wireless channel makes the signals at its amplitude and phase distortion. MS amplifies and filters the received signal to detect the transmitted RF signal. LD [6] with an DEMZM (Dual Electrode Mach Zehnder Modulator) [18] in a central CS. Here RF signal from an oscillator is split by both power splitter & a 90^o phase shifter. Now this RF signal is optically modulated by the LD with an MZM. This optically modulated signal is transmitted to the PD & the photocurrent i(t) across to the transmitted RF signal is carried out by the filter. At the result, Data are extracted through RF demodulation process at MS.



$$y_l(t) = a_l \, exp \, j(w_l t + \varphi_l(t)) \; ....(1)$$

$$y_o(t) = v_o . \cos(w_o t + \varphi_o(t)) \; ....(2)$$

Where $\boldsymbol{a_l}$ and $\boldsymbol{v_o}$ define as amplitudes from the optical source and the RF oscillator signal, $\boldsymbol{w_l}$ and $\boldsymbol{w_o}$ represent angular frequencies of the signals from the LD and the RF oscillator, and $\boldsymbol{\varphi_l(t)}$ and $\boldsymbol{\varphi_o(t)}$ are phase-noise processes. Here optically modulating $\boldsymbol{y_o(t)}$ by $\boldsymbol{y_l(t)}$ with a DEMZM, the output signal of the DEMZM [18] is found as

$$V_{ss}(0,t) = \frac{l_{MZM}.y_l(t)}{\sqrt{2}}\left\{\exp j\left[\gamma\pi + \frac{\pi}{v_\pi}.\frac{y_o(t)}{\sqrt{2}}\right] + \exp j\left[\frac{\pi}{v_\pi}.\frac{y_o(t)}{\sqrt{2}}\right]\right\} \ldots\ldots \textbf{(3)}$$

$$V_{ss}(0,t) = \left[\frac{l_{MZM}}{\sqrt{2}}\{a_L.\exp j(w_L t + \varphi_L t)\}\ \left\{\exp j\left[\gamma_\pi + \frac{\pi}{v_\pi}.\frac{v_o}{\sqrt{2}}\cos(w_o t + \varphi_o(t))\right] + \exp j\left[\frac{\pi}{v_\pi}.\frac{v_o}{\sqrt{2}}\alpha\pi\cos(w_o t + \varphi_o(t) + \theta)\right]\right\}\right] \ldots\ldots \textbf{(4)}$$

Here yo(t) represent the phase-shift version of yo(t) that provided by DEMZM,

$\gamma(=v\mathrm{dc}/v_\pi)$ and $\alpha(=v_o/\sqrt{2}v_\pi)$ define a normalized dc and ac value, v_π is represent the switching voltage of DEMZM, LMZM is the insertion loss of DEMZM, also θ is phase shift provided by phase shifter. Now generating the OSSB signal, θ and γ are set to $\pi/2$ and 1/2, respectively. By using **(4)** and the represented conditions, At DEMZM can be modeled by the OSSB signal as following:

$$V_{ss}(0,t) = \frac{a_L.l_{MZM}}{\sqrt{2}}\left\{\exp j\left[\frac{\pi}{2} + w_L t + \varphi_L(t) + \alpha\pi\cos(w_o t + \varphi_o(t))\right] + \exp j[w_L t + \varphi_L(t) + \alpha\pi\cos(w_o t + \varphi_o(t) + 90°)]\right\} \ldots\ldots \textbf{(5)}$$

$$V_{ss}(0,t) = \frac{a_L.l_{MZM}}{\sqrt{2}}\left\{\exp j\left[\frac{\pi}{2} + w_L t + \varphi_L(t) + \alpha\pi\cos(w_o t + \varphi_o(t))\right] + \exp j[w_L t + \varphi_L(t) - \alpha\pi\sin(w_o t + \varphi_o(t))]\right\} \ldots\ldots \textbf{(6)}$$

$$V_{ss}(0,t) = \left[\frac{a_L.l_{MZM}}{\sqrt{2}}\exp j(w_L t + \varphi_L t)\left\{\begin{matrix}\cos\{\alpha\pi\sin(w_o t + \varphi_o t)\} - \sin\{\alpha\pi\cos(w_o t + \varphi_o t)\} \\ +j[\cos\{\alpha\pi\sin(w_o t + \varphi_o t)\} - \sin\{\alpha\pi\sin(w_o t + \varphi_o t)\}]\end{matrix}\right\}\right] \ldots\ldots \textbf{(7)}$$

By using Bessel functions [31] in equation (7), we get

$$V_{ss}(0,t) = \left[\frac{a_L.l_{MZM}}{\sqrt{2}}\exp j(w_o t + \varphi_o t)\ \{J_0(\alpha\pi) - J_1(\alpha\pi)\exp j(w_o t + \varphi_o t) - \exp(-j)\cos(w_o t + \varphi_o t) + j[J_0(\alpha\pi) - J_1(\alpha\pi)\exp j(w_o t + \varphi_o t)\} - \exp(-j)\cos(w_o t + \varphi_o t)\}\right] \ldots\ldots \textbf{(8)}$$

$$V_{ss}(0,t) \cong a_L.l_{MZM}\left\{\begin{matrix}J_0(\alpha\pi)\exp j\left[w_L t + \varphi_L(t) + \frac{\pi}{4}\right] - \sqrt{2}J_1(\alpha\pi) \\ \exp j[w_L t + \varphi_L(t) + w_o t + \varphi_o(t)]\end{matrix}\right\} \ldots\ldots \textbf{(9)}$$

there can be negligible high-order components of Bessel function, then the value of $\alpha\pi$ in the Bessel function gets very small order due to the fact of $v_\pi << v_o$. The output signal from DE MZM is transmitted by the standard single mode fiber represented various different group delays, because of fiber chromatic dispersion, and at different wavelength. After that transmission of l_{fiber} in kilometer on SSMF, Then the at the end signal become as following relation

$$V_{ss}(l,t) \cong \left[\begin{matrix} a_L.l_{MZM}.l_{add}.10^{\frac{\alpha_{fiber}l_{fiber}}{20}}J_0(\alpha\pi) \\ \left\{\begin{matrix}\exp j\left[w_L t + \varphi_L(t-\tau_0) - \varphi_1 + \frac{\pi}{4}\right] - \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)} \\ \exp j[w_L t + \varphi_L(t-\tau_+) + w_o t + \varphi_o(t-\tau_+) - \varphi_2]\end{matrix}\right\}\end{matrix}\right] \ldots\ldots \textbf{(10)}$$

III. EVALUATION OF CNR PENALTY

Evaluation of Carrier to noise ratio penalty by using a square law model, the photocurrent i(t) can be obtain by(10) as

$$i(t) \cong n|V_{ss}(l,t)|^2 \ \ldots\ldots \textbf{(11)}$$

where $|\,.|^2$ is the square-law detection and η define as the responsively of the Photo diode.

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$$i(t) \cong \eta |a_{L1}|^2 \left\{ D + 2 \propto_1 \begin{bmatrix} cos\left\{w_L t + \varphi_L(t-\tau_o) - \emptyset_1 + \frac{\pi}{4}\right\} \\ +j\sin\left\{w_L t + \varphi_L(t-\tau_o) - \emptyset_1 + \frac{\pi}{4}\right\} \\ \cos\{w_L t + \varphi_L(t-\tau_+) + w_o t + \varphi_o(t-\tau_+) - \varphi_2\} \\ +j sin\{w_L t + \varphi_L(t-\tau_+) + w_o t + \varphi_o(t-\tau_+) - \varphi_2\} \end{bmatrix} \right\} \ldots.. \mathbf{(12)}$$

Here

$$a_{L1} = a_L . l_{MZM} . l_{add} . 10^{\frac{\alpha_{fiber} l_{fiber}}{20}} J_0(\alpha\pi) \text{a}$$

$$\alpha_1 = \frac{\sqrt{2} J_1(\alpha\pi)}{J_0(\alpha\pi)}$$

$$D = 1 + \alpha_1^2$$

From (12), the autocorrelation function $r_1(\tau)$ [25], [26] is obtained as

$$r_1(\tau) = i(t). i(t+\tau) \ldots.. \mathbf{(13)}$$

$$\frac{r_1(\tau)}{\eta^2 . a_{L1}{}^4} = D^2 + \begin{Bmatrix} 2\,\alpha_1^2 \cos(w_o t) \exp\left(-2\gamma_t|\tau|\right), |\tau| \le |\tau_1| \\ 2\,\alpha_1^2 \cos(w_o t) \exp\left(-2\gamma_d|\tau|\right) - \gamma_d|\tau|), |\tau| \ge |\tau_1| \end{Bmatrix} \ldots.. \mathbf{(14)}$$

Now written the PSD function $S_1(f)$ as

$$S_1(f) = F . r_1(\tau)$$

$$S_1(f) = r_1(\tau) \int_{-\infty}^{\infty} r_1(\tau) d\tau * \exp(-j\tau w) \quad \ldots.. \mathbf{(15)}$$

The first term of equation (16) shown a dc component, the second and third term is the broadening effects because of reason to the fiber chromatic dispersion and RF oscillator and. linewidth of the laser.

$$\frac{r_1(\tau)}{\eta^2 . a_{L1}{}^4} = \begin{bmatrix} D^2\delta(f) + \frac{2\gamma_o\alpha_1^2 . \exp(-2\gamma_t|\tau|) . \cos[2\pi(f-f_o)\tau]}{\gamma_o^2 + [2\pi(f-f_o)]^2} \\ + \frac{4\alpha_1^2 . \exp(-2\gamma_t|\tau|)}{(2\gamma_t)^2 + [2\pi(f-f_o)]^2} . \{\gamma_t . \exp(-2\gamma_t|\tau|) - \gamma_t \cos[2\pi(f-f_o)\tau \\ - \frac{4\pi\gamma_L(\gamma_L+\gamma_o)(f-f_o)}{\gamma_o^2+[2\pi(f-f_o)]^2} . \sin[2\pi(f-f_o)\tau]\} + p(f+f_o) \end{bmatrix} \ldots\ldots \mathbf{(16)}$$

$$p(f+f_o) = \begin{bmatrix} \frac{2\gamma_o\alpha_1^2 . \exp(-2\gamma_t|\tau|) . \cos[2\pi(f+f_o)\tau]}{\gamma_o^2 + [2\pi(f+f_o)]^2} + \frac{4\alpha_1^2 . \exp(-2\gamma_t|\tau|)}{(2\gamma_t)^2 + [2\pi(f+f_o)]^2} \\ . \{\gamma_t . \exp(-2\gamma_t|\tau|) - \gamma_t \cos[2\pi(f-f_o)\tau - \frac{4\pi\gamma_L(\gamma_L+\gamma_o)(f+f_o)}{\gamma_o^2 + [2\pi(f+f_o)]^2} \\ . \sin[2\pi(f+f_o)\tau]\} \end{bmatrix}$$

The received RF carrier power p_1 is following as shown:

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$$p_1 = 2\int_{f_o-\frac{D_o}{2}}^{f_o+\frac{D_o}{2}} S_1(f)df \text{ ….. } \mathbf{(17)}$$

The evaluating for total RF power excluding dc power, utilizing (14) and total power can calculate as:

$$p_t = r_1(0) - \eta^2 a_{L1}^4 . D_o^2 = 2a_{L1}^4 \eta^2 \alpha_1^2$$

Calculate the ratio P between the total carrier power and the required power as followings:

$$P = \frac{p_1}{p_t}$$

$$P \cong \frac{2}{\pi}\left\{\exp(-2\gamma_t|\tau|)\tan^{-1}\left(\frac{\pi . D_o}{2\gamma_o}\right)\right\} \text{…. . } \mathbf{(18)}$$

The fiber chromatic dispersion, because to the differential delay represented by CNR penalty. RF oscillator and linewidths from the laser is found as following:

$$CNR \cong \frac{p_1}{2D_{o.}\left(\frac{N_o}{2}\right)}$$

$$\mathrm{CNR} \cong \frac{2\eta^2 a_{L1}^4 \alpha_1^2 P}{N_o . \left(\frac{\gamma_o}{\pi}\right)\tan\left(\frac{\pi . P\exp(-2\gamma_t|\tau|)}{2}\right)}$$

….. **(19)**

$$\Delta\mathrm{CNR} = 10\log_{10}\left[\frac{P_o . \gamma_o\tan\left(\frac{\pi P}{2} . \exp(2\gamma_t|\tau|)\right)}{P . \gamma_{oo}\tan\left(\frac{\pi P_o}{2} . \exp(2\gamma_{oo}|\tau|)\right)}\right]$$

….. **(20)**

IV. SIMULATION AND RESULT

A. Results Obtained By MATLAB Simulations

Determine the CNR Penalty due to differential delay & linewidth and what type of fiber used. Here CNR_0 is represented a reference CNR. The CNR penalty ΔCNR is represented as

$$\Delta\mathrm{CNR} = 10\log_{10}\left[\frac{P_o . \gamma_o\tan\left(\frac{\pi P}{2} . \exp(2\gamma_t|\tau|)\right)}{P . \gamma_{oo}\tan\left(\frac{\pi P_o}{2} . \exp(2\gamma_{oo}|\tau|)\right)}\right]$$

Determine the $CNR_{0,}$ firstly half power bandwidth filter P, Set to 0.5value. γ_o to π, RF Oscillator linewidth is 1-Hz.ΔCNR dependable on percentage of received power (P), differential delay & linewidth. The first result shown in Fig. 1 with Table 1 represents CNR penalty with respect to two important parameters:

1) RF oscillator linewidth (Y_o) in Hz
2) Percentage of received power (P)

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TABLE 1
THE PARAMETERS FOR CNR PENALTY AS FUNCTION OF RF OSCILLATOR AND PERCENTAGE OF RECEIVED POWER

Sr.no.	Parameters	Values
1	Optical transmission distance	10 km
2	Fiber dispersion	17 ps/nm-km
3	Half power bandwidth filter	0.5
4	Wavelength of LD	1550 nm
5	RF carrier frequency	30 GHz
6	RF oscillator linewidth	0.1 to 20 Hz
7	Percentage of received power	0.1 to 0.99

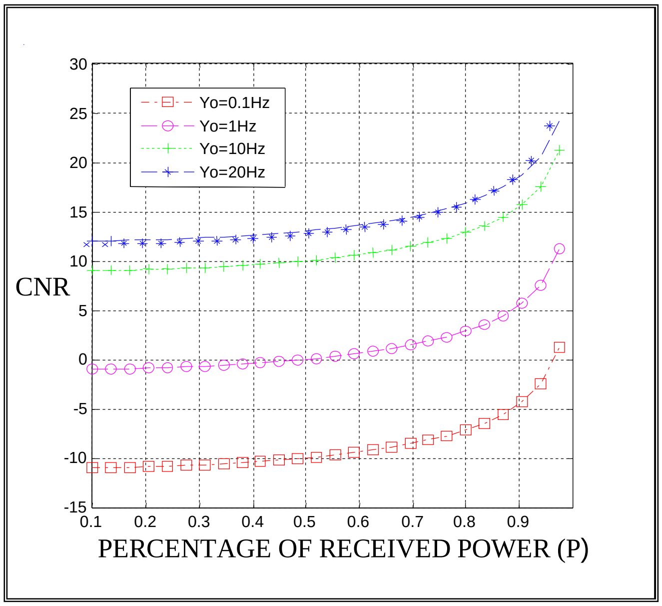

Fig.3. ΔCNR as a function of the percentage of received power and RF oscillator linewidth

Here RF oscillator linewidth (Y_o) values 0.1 to 20 Hz. Generally, RF Oscillator linewidth (Y_o) takes range less than 1 Hz. Because determine 1 Hz RF oscillator linewidth (Y_o), gets cost-aware RF oscillator.

As shown in fig 1found the two steps:-

As result shows that, carrier to noise ratio penalty increases as well as RF oscillator linewidth (Y_o) also increases. This represented that Y_o is linearly proportional to ΔCNR. e.g. if ΔCNR increase 20 db its means which is equivalent of 20 time increases of RF oscillator linewidth $Y_{o..}$ In fig 1 represented that CNR penalty around 22 db as well as RF Oscillator linewidth from 0.1 to 20 Hz range.

The ΔCNR increases, percentage of received power P became larger. As the increase of noise power is more then received power signal. So CNR penalty increases & bandwidth also increases. Here ΔCNR is around 12.1 db increases from .1 to .99.

CNR penalty increase at the point of result when bandwidth will be considered at situation of P>90%

The Second result shown in Fig. 2 & Table 2 represents CNR Penalty with respect to two importent parameters:

Laser Linewidth (Y_d) in MHz
Length of Fiber (L) in Km

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TABLE 2

THE PARAMETERS FOR CNR PENALTY AS FUNCTION OF LASER LINEWIDTH AND LENGTH OF FIBER

Sr.no	Parameters	Values
1	Optical transmission distance	1 km to 40 km
2	Wavelength of LD	1550 nm
3	RF carrier frequency	30 GHz
4	Fiber dispersion	17 ps/nm-km
5	Half power bandwidth filter	0.5
6	Laser linewidth	10 to 624 MHz
7	Percentage of received power	0.5

In fiber parameter range of laser linewidth is 10 to 625 MHz. This is typical linewidth values of Distributed feed back laser & Fabry-Perot laser.

As well as ΔCNR increases as the laser linewidth (Y_d) exponentially increases. At the CNR penalty due to laser linewidth from range of 10 to 624 MHz are .22, 1.2, 4.8, and 8 dB in range of 2, 10, 30, and 40 km in standard single mode fibers.

As the CNR penalty increases around 8 dB, then fiber length from 1 km to 40 km. In the Radio over fiber system represented from ΔCNR at the long transmission like 40 km, where ΔCNR is not changed in =0.22 dB the short transmission =2 km for Fabry-Perot laser.. Practical microcell boundary of Fabry-Perot laser, where the radius of microcells from .2 to 1 km. So CNR Penalty depends upon specifically in the distance of laser linewidth

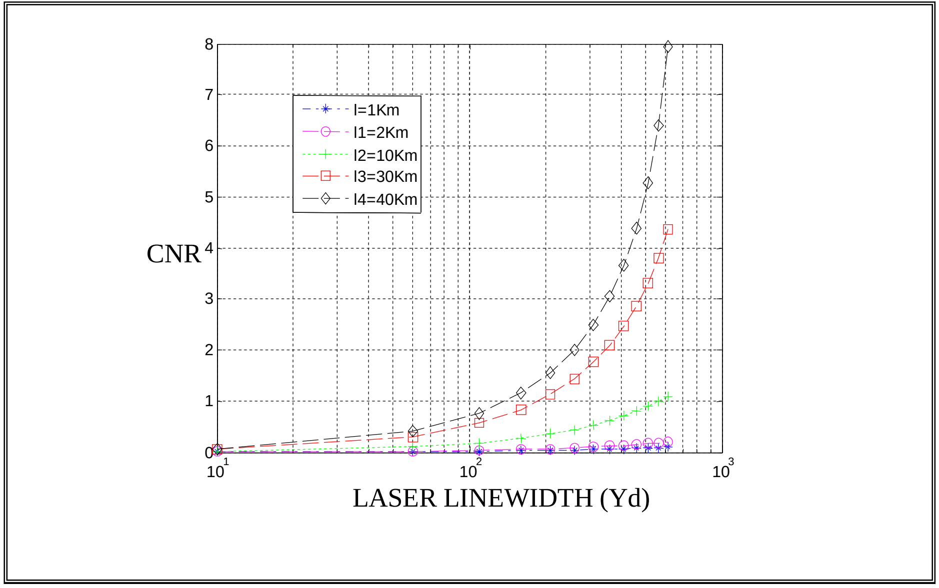

Fig.4. ΔCNR as a function of the laser linewidth and length of fiber

Major CNR penalty causes when the laser linewidth selected for long transmission due to large differential delay. But in case of short distance the phase noise from the RF oscillator is negligible factor for CNR penalty. Measure the CNR penalty RF oscillator linewidth 0.1 to 20 Hz is approximately around of 23 dB for any of the cases, But measure the CNR penalties at the range of 624 MHz are .22, 1.2, 4.8 and 8m dB in 2, 10, 30 and 40 km Standard single mode fiber. This means that we can employ a cheap laser such as the FP laser in the Radio over fiber system in picocell, microcell and macrocell boundary to CNR penalty to be observed at this situation.

V. CONCLUSION

Carrier to noise ratio penalty is linearly proportional to RF Oscillator linewidth. Also, it is concluded that before select the filter bandwidth we should be very careful about the minimum power required to detect the signal. From simulation result we observed that as the laser linewidth increases, carrier to noise ratio penalty also exponentially increases. As distance of optical fiber increases CNR also increases.

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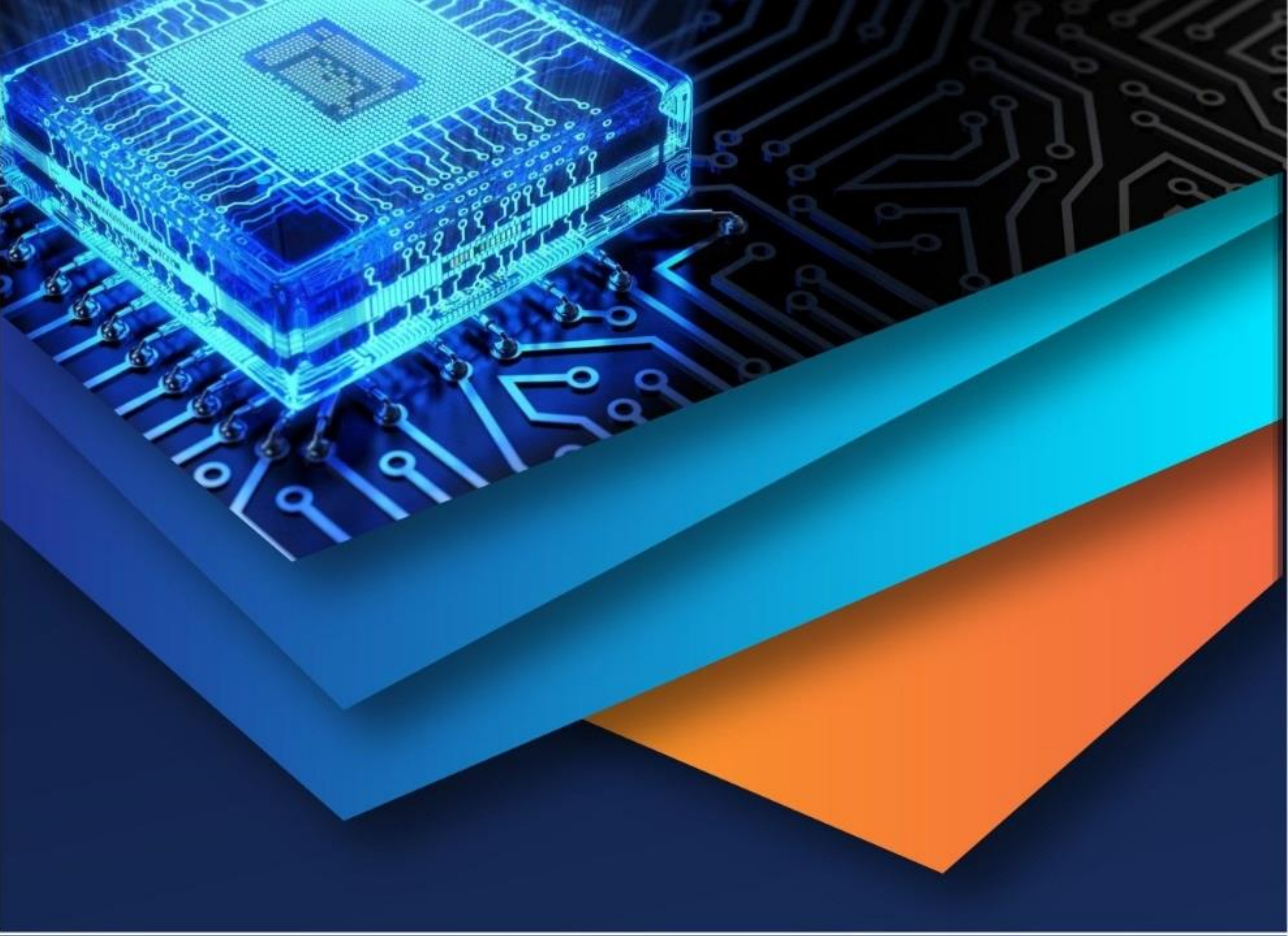

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