"THE INCOHERENT-CARRIER COMMUNICATION SYSTEMS".

S Y N O P S I S.

Possibilities of the use of incoherent carriers for transmission of analogue and digital signals have been established. It has been shown that for analogue signals a message SNR of 60-70 db, can be obtained by using compound pulse modulation and carrier clipping. The use of incoherent carriers eliminates the fading distortion, normally very disturbing with the coherent carrier systems.

For ON-OFF, digital transmission through noisy fading channels, an error rate of 1×10^{-5} has been obtained with incoherent carriers for a CNR of 17 db; the sinewave carriers under similar conditions require 53 db CNR for the single channel reception. Thus in effect, the noise-carrier provides a signal gain of 36 db. Minimum noise-carrier bandwidth required to obtain fading protection has been obtained, and it was found to depend on the method of noise-carrier generation. Different methods of noise-carrier generation have been studied. The diversity effectiveness of noise-carrier systems have been evaluated and it has been shown to be equivalent to five-fold equal-gain ~~prediction~~ predetection combining system with independent fading channels. The results of the noise-carrier system have been extended to laser communication in general and semiconductor lasers in particular.

With certain optical masers and microwave signal sources, it is difficult to maintain absolute coherency of the carrier. Also in most of the laser applications, such as in communications and timing, it is generally thought that the coherence of laser emission is essential. The semiconductor lasers have a minimum spectral bandwidth of 7,500 Gc/s (2.5Å) and below the threshold the intensity fluctuations are similar to RF black-body radiations. Thus semiconductor lasers, inspite of their ease of fabrication, high efficiency of operation and modulation, have generally been considered unfit for use in communication systems. It has therefore been of recent interest[30] to evaluate the different modulation systems using narrow-band incoherent-carriers and optimise them if possible.

The present day communication systems use mainly sinusoidal i.e. coherent-carriers for the transmission of intelligence. The use of coherent-carriers through fading transmission medium, leads to a fluctuating envelope at the receiver, called "fading". To combat deterioration of a signal quality due to fading, various modulation techniques and diversity methods have been suggested. However in practice, even with the most sophisticated modulation techniques, a complete protection against fading has not been achieved, because of the practical limitation of the number of diversity channels that may be used economically. For the transmission of computer data, the allowable error rate is of the order of 10^{-10} to 10^{-5}; this stringent condition requires a new approach to the transmission and reception of signals. It has been envisaged that by the use of an incoherent-carrier communication, a complete protection against fading can be obtained in practice by the use of a single receiving system.

The use of incoherent or quasi-coherent carriers introduces additional noise at the output of the detector, since incoherent-carriers or noise-carriers have random phase and amplitude variations. On detection, the noise-carrier components will combine with the modulation signal, thereby producing noise components. Rowe[1,2] has theoretically evaluated AM and FM types of modulation for narrow-band incoherent-carriers. He has shown that tolerable message to noise ratio (M) is obtained only if the message bandwidth f_m is very small compared to the noise-carrier bandwidth B_n and the base-band is shifted to a higher frequency, thus making the useful information bandwidth only a fraction of the available spectrum. No suitable practical methods of frequency modulation of noise-carriers have been evolved yet. With simple amplitude modulation, the best possible message SNR is only 12 db, a very low figure, to be of any practical interest.

The purpose of the present investigation in this thesis has been to obtain an improvement of the message SNR through the use of compound modulation systems (e.g. PLM-AM, PPM-AM, PFM-AM, PCM-AM and DM-AM) with incoherent carriers, and the message SNR's for above modulation system have been evaluated. It has been shown[30] that by the use of clipped noise-carrier, a message SNR of 60-70 db is obtainable under practical conditions with PLM-AM and PFM-AM systems. These investigations have led to the development of practical noise-carrier systems both for analogue and digital signals. It was also found that noise-carriers provide complete protection against fading[29] and the incoherent carrier systems have a built-in frequency diversity effect.

Minimum noise-carrier bandwidth required for complete protection depends upon the frequency of operation f_o of the system. At 10 Mc/s it was found to be 100 cps[29,31]. The diversity improvement due to noise-carrier has been shown to be similar to the equal-gain predetection combining system, using correlated fading channels. Techniques have been developed along the lines suggested by Pierce and Stein[67], to calculate the approximate diversity effectiveness of the K-fold correlated fading channel using predetection equal-gain combining. Detailed studies of the incoherent-carrier systems, their message SNR's and the diversity effectiveness have been made, often by taking the help of theories developed by Rice[33], Mideleton[34] and Bennett[48] for random noise detection.

1. Transmission over a non-fading channel:

For the transmission of signals in a non-fading medium, consider a noise-carrier that is fully modulated by pulses. The RF signal thus produced is received and detected in a envelope detector. Assuming that the narrow-band noise-carrier has a Gaussian or rectangular distribution, the video SNR at output of the envelope detector has been found to be

$$V = 2\pi\psi_o \frac{\int_0^\infty P_s(f)\,df}{\int_0^\infty P_s(f) \odot P_n(f)\,df} \qquad \ldots (1)$$

where ψ_o = Total RF noise power.

$P_s(f)$ = The spectral density of the modulating signal.

$P_n(f)$ = The spectral density at the detector output for RF noise only.

$\odot$ = Denotes the convolution operator.

For $B_n << f_r$, where f_r is the pulse repetition frequency, it has been found that the best video SNR for both types of modulation systems, is given by

$$V_1 = \frac{2\pi\psi_0}{\int_0^\infty P_n(f)\,df} \qquad \ldots (2)$$

The total low frequency noise for Gaussian noise-carrier at the output of an envelope detector is given by[28]

$$\int_0^\infty P_n(f)\,df = \left(\frac{4-\pi}{2}\right)\psi_0 \qquad \ldots (3)$$

Thus it is found that the best video SNR is only 11.7 db. The video SNR's for larger B_n have been evaluated and they are found to be lower than 11 db depending on the modulation system, unmodulated pulse width, modulation index (or deviation ratio) of the primary modulation system and also on message frequency.

For any wide-band demodulation system (e.g. PLM, PPM, PFM, FM etc.) the input and output SNR's are proportional, when input SNR is above the threshold value of a particular modulation system. The video SNR of 11.7 db is much below the threshold (20 db approx.) for pulse modulation systems. Knudtzon[36] has shown that below the threshold level, due to the presence of noise, the pulse length (in PLM) will be altered due to both noise pulses and signal holes, This causes a loss of signal after demodulation which he has termed as modulation suppression factor 'm', and the range of 'm' is 0.2 to 0.3 for 11 db video SNR. Hence further improvement of video SNR is necessary.

Middleton[34] has shown that the low frequency noise output of a detector can be reduced considerably by preclipping the input noise. It was found that clipping of noise-carrier at the transmitter before modulation or at the input to the receiver, improves the video SNR considerably. The video SNR with clipped noise-carrier for $B_n << f_r$ was found to be

$$V_c = \frac{2\psi_0}{\int_0^\infty P_{n_1}(f)\,df} \qquad \ldots (4)$$

where,

$$\int_0^\infty P_{n_1}(f)\,df = \sum_{2,4\ldots}^{\infty} \frac{\psi_0^n h_{on}^2}{2^n \left(\frac{n}{2}\right)^2!} \qquad \ldots (5)$$

and,

$$h_{on} = \eta(-1)^{\frac{n+2}{2}} \psi_0^{\frac{1-n}{2}} \bar{\epsilon}\, \phi_{b_0}^{(n-1)}, \quad n = 2,4,6\ldots \qquad \ldots (6)$$

η = dynamic transconductance of the tube taken as one for linear rectifier.

$\bar{\epsilon}$ = transmission (window) width.

b_0 = clipping level.

$$\phi_{b_0}^{(n)} = (-1)^n H_n\left(\frac{b_0}{\sqrt{\psi_0}}\right) \exp\left(-\frac{b_0^2}{2\psi_0}\right) \Big/ (2\pi)^{1/2}$$

$H_n\left(\frac{b_0}{\sqrt{\psi_0}}\right)$ being the Hermitian polynomial of the nth order. Equation (6) indicates that low frequency noise at the output of the detector will depend upon the clipping level b_0 and transmission width $\bar{\epsilon}$. Equation (6) has been numerically evaluated for various clipping levels b_0. It has been found that by suitably choosing the clipping level b_0 and transmission width $\bar{\epsilon}$, any desired video SNR can be obtained for clipped carrier.

Considering that the PLM receiver consists of a detector, a slicer, a differentiator, a flip-flop and a lowpass filter, the effective noise at the output of the filter (for Video SNR above threshold) will be due to the PPM[38] of both the leading and lagging edges of the video pulses. The message SNR for PLM-AM system with noise-carrier was found to be

$$M_L = \frac{1}{4}\mu^2 L^2 B_c^3 \times m_1 \times \text{Video SNR} \qquad \dots (7)$$

where μ is the index of modulation for PLM.

L is the pulse width without modulation.

m_1 is the modulation suppression factor for PLM-AM

B_c is the channel bandwidth.

PPM is essentially the same as PLM except that the variable width is now replaced by the shift of the position of a narrow pulse. The message SNR for PPM-AM system with noise-carrier was found to be

$$M_P = \frac{1}{2} t_0^2 B_c^3 L\, m_2 \times \text{Video SNR} \qquad \dots (8)$$

where t_0 is the time shift of the pulse due to modulation, m_2 is the modulation suppression factor for PPM-AM.

The PFM receiver consists of a detector, a slicer, a differentiator, a pulse lengthener and a lowpass filter, the message SNR for PFM-AM system was found to be

$$M_F = \frac{3}{16}\frac{D^2}{\pi^2}\left(\frac{B_c^3}{f_r^2 \cdot f_{mx}}\right) m_2 \times \text{Video SNR} \dots (9)$$

where D is the deviation ratio.

f_{mx} is the maximum message frequency and f_r is the pulse repetition frequency.

TABLE NO.I.

Variation of Message SNR with noise-carrier bandwidth B_n for noise-carrier with and without clipping.

Pulse repetition frequency f_r = 100 Kc/s; Message bandwidth f_m = 30 Kc/s;

PLM modulation Index μ=0.5; PFM Deviation Ratio D = 2;

Mean Pulse width τ = $1/2f_r$; channel Bandwidth B_c = 2.5 Mc/s.

Noise-Carrier Bandwidth B_n in Kc/s	Message SNR in db.								
	Noise-carrier without clipping.				Clipped Noise-Carrier.				
	PLM-AM		PFM-AM		PLM-AM		PFM-AM		
	Experi-mental.	Theore-tical.	Experimental.	Theore-tical.	Experi-mental.	Theore-tical.	Experi-mental.	Theore-tical.	Characteristics of the RF clipper.
2	27	28.8	42	41	57	57	67	69.5	$\bar{\epsilon} = 0{\cdot}2\sqrt{\psi_0}$; $\frac{b_0}{\sqrt{\psi_0}} = 0{\cdot}5$
50	22	21.5	37	33	50	49	55	62	$\bar{\epsilon} = 0{\cdot}5\sqrt{\psi_0}$; $\frac{b_0}{\sqrt{\psi_0}} = 0{\cdot}5$
200	17	21.5	28	-	37	38	47	50.5	$\bar{\epsilon} = \sqrt{\psi_0}$; $\frac{b_0}{\sqrt{\psi_0}} = 1{\cdot}0$

The message SNR for PCM-AM with uniform quantization and ON-OFF binary system is given by[39]

$$M_c = 1.3 \exp\left[\frac{1}{4} \cdot \text{Video SNR}\right] \text{ for } n > 1 \qquad \ldots (10)$$

where the number of quantizing levels is given by 2^n.
The message SNR for DM-AM and ON-OFF binary system is given by[40]

$$M_D = \frac{1}{32} \cdot \frac{1}{P_e} \cdot \frac{f_r}{2f_m} \qquad \ldots (11)$$

where P_e is the error rate at the input of the DM modulator.

The theoretical and experimental message SNR for PLM-AM a nd PFM-AM modulation systems for noise-carrier with and - without clipping are given in Table No.I. The effect of channel noise was also measured and it was found that for CNR $<$ 20 db, the message SNR deteriorates as in sinewave-carrier systems. For CNR $\geq$ 20 db, no measurable deterioration of message SNR was found.

2. <u>Transmission over a Fading Medium</u>:

An incoherent carrier can be considered to consist of an infinite number of randomly phased components distributed over the noise-carrier bandwidth. Thus a noise-carrier communication system may be considered to have a built-in frequency diversity. The equivalent number of channels will depend on the noise-carrier bandwidth B_n, but even with a very narrow-band noise-carrier, the number of diversity channels available are very much larger than those with any existing practical diversity system.

The probability density function (PDF) of the envelope of a narrow-band noise-carrier received through a fading channel have been obtained through the extension of the results of the joint PDF for two Rayleigh-distributed fluctuating envelopes R_1 and R_2, each belonging to narrow-band Gaussian Signals (with zero mean and the variance σ_e^2), and the same is given by[41]

$$p(R_1, R_2) = \left(\frac{R_1}{\sigma_e^2} e^{-R_1^2/2\sigma_e^2}\right)\left(\frac{R_2}{\sigma_e^2} e^{-R_2^2/2\sigma_e^2}\right) \qquad \ldots (12)$$

Assuming, that the narrow-band noise-carrier consists of an infinite number of randomly phased independently-fading carriers distributed over the noise-carrier bandwidth, the PDF of the resultant envelope of the composite received signal is given by

$$\underset{n \to \infty}{p}(R_1, R_2, \ldots R_n) = \prod^{n} \left[\frac{2R_n}{R_o^2} \exp\left(-\frac{R_n^2}{R_o^2}\right)\right] \qquad \ldots (13)$$

which tends to a delta function at the average value of the resultant envelope ($\simeq \sqrt{n R_o^2}$), where $R_o^2 = \langle |R|^2 \rangle = 2\sigma_e^2$. The above equation shows that the received envelope will remain virtually constant over the Rayleigh fading cycles.

To verify the above results experimentally, the noise-carrier system was tested with an interference-type Rice fading simulator. The simulator consisted of three RF channels operating at 10 Mc/s with a channel bandwidth of 2.5 Mc/s. The delay in two channels were varied by two independent low frequency random-noise generators, giving a total delay variation of 4 μs approximately. The PDF of the envelope record of a sinewave-carrier received through the simulator was found to be given by

$$p(Q) = \frac{2Q}{S_Q^2} \exp\left(2 - \frac{Q^2}{S_Q^2}\right) I_0 \left(2\sqrt{2}\, Q/S_Q\right) \qquad \ldots (14)$$

with $H/S_Q = 2$,

where Q = resultant amplitude of the envelope of the composite signal.

S_Q^2 = mean square value of the fading component.

H = amplitude of the specular component.

Experimental results with noise-carriers without clipping (gaussian noise-carrier) did not show any deterioration with fading. The noise-carrier with clipping was found to have very little deterioration due to fading.

For digital transmission, the error rate of a sine-wave-carrier, with ON-OFF modulation in a noisy fading channel (following the Rayleigh fading law), is given by[28]

$$P_{es} \simeq \frac{1.63}{\gamma_0} \text{ for } \gamma_0 \gg 1 \qquad \ldots (15)$$

where γ_0 is the mean channel SNR(CNR) at the input of the receiver. Since with noise-carrier, it has been shown that there is practically no fluctuation of the received envelope due to fading, then the error rate in a fading channel with clipped noise-carrier and ON-OFF modulation, will be the same as that for the non-fading channel with sinewave-carrier and it can be taken as

$$P_{eN} \simeq \frac{1}{2} \exp\left(-\frac{\gamma}{4}\right) \text{ for } \gamma \gg 1 \qquad \ldots \ldots (16)$$

where γ is the CNR,
assuming that the power for the clipped noise-carrier is same as for the sinewave-carrier.

For a sinewave-carrier system with an input power P, the voltage at the output of the envelope detector is $\sqrt{2P}$, whereas for a gaussian noise-carrier, the envelope detector output voltage is $\sqrt{2\pi\psi_0}$ where ψ_0 is the input noise power. Thus for the same input power, the envelope voltage for the gaussian noise-carrier was found to be higher, thereby providing a lower error rate for the same CNR. This was also borne out in the experimental observation.

Assuming that FSK modulation is possible with clipped noise-carrier, the error rate of such a system with FSK for the noisy fading channel was found to be

$$P_{eNf} = \frac{1}{2} \exp\left(-\frac{\gamma}{2}\right) \qquad \ldots (17)$$

Comparing equations (16) and (17) it is seen that the same error rate is achieved at half the value of γ for the FSK system as compared to the ON-OFF case. Since in ON-OFF modulation with envelope detector, γ is defined in terms of the power transmitted only during the Marks (zero power is transmitted during spaces), then the average power used in ON-OFF is only half the value used in defining γ. Thus at low error rates the ON-OFF and the FSK system will achieve equivalent error rates at the same average CNR. The only significant disadvantage of the ON-OFF modulation with sinewave-carrier is the need of optimizing the detection threshold under fading condition at each CNR; no such problem exists for the ON-OFF modulation with noise-carrier. Thus the incoherent-carrier system, under fading channel condition, provides the same error rate for ON-OFF and FSK with same average CNR (at low error rates).

3. Diversity Effectiveness of Narrow-band Noise-Carrier:

The noise-carrier consists of an infinite number of randomly phased frequencies distributed over the noise-carrier bandwidth. Among these frequencies, the adjacent ones will have correlation in their fading, due to the passage through the fading medium. Thus the effectiveness of the noise-carrier can be considered to be similar to that for large number of carriers having partial correlation in fading. Since with noise-carrier, all the components linearly add up at the input of the receiver, similar to predetection equal-gain combining systems, the diversity effectiveness of the noise-carrier will be similar to the K-fold diversity with pre-detection equal-gain combining system with correlated fading channels. The effect of non-independent fading upon the performance of K-fold equal-gain combining ($K \geqslant 2$) has not yet been determined analytically even for jointly gaussian fading signals.

Pierce and Stein[67] have, however, solved the problem for the K-fold diversity (with correlated fading) using maximal-ratio combining for the case of jointly gaussian fading signals. It was found that the diversity dffectiveness of the equal-gain system under similar condition is approximately the same as that for maximal-ratio combining. Stein has suggested that the effective order of diversity in correlated fading with maximal-ratio combining is determined by the number of Eigen values of the covariance matrix (of the K signals) which are essentially above the threshold to which the diversity performance is being referred. The technique has been used to determine the diversity effectiveness for K-channels with correlated fading as applicable for the noise-carrier systems. To obtain numerical results, the values of the envelope correlation coefficient ρ_{env} of two carriers as a funmtion of their frequency separation was taken from the published results[63,64,65]. It was also found that the minimum frequency separation (diversity spacing) between different carriers required to obtain a correlation coefficient of 1/e, follows an approximate law given by

$$f_s \simeq 0.9 f_c^2 \text{ cycles} \qquad \ldots (18)$$

where f_c is the carrier frequency in Mc/s.

The CNR requirement has been calculated for different error rates with predetection equal-gain combining system for the ON-OFF modulation system, with 2 to 10 correlated fading channels. Assuming that the noise-carrier can be considered to consist of discrete bands, say at 0.01 f_s spacing, and also that each of the discrete noise bands do not interfere with each other, it was found that the diversity effectiveness of the noise-carrier system is equal to the 5-fold independent diversity system. The experimental results show that the noise-carrier system requires a CNR of 17 db (approx.) to provide an error rate of 1×10^{-5} with one physical receiving system under noisy fading channel conditions. Sinewave-carrier under similar conditions with one receiver requires a CNR of 53 db (approx.). Thus in effect the noise-carrier provides a signal gain of about 36 db. It has been shown that with noise-carrier, no further improvement will be obtained, if additional physical space/frequency diversity is used at the receiving end. With a CNR better than 20 db, no error was noticed with noise-carrier under noisy fading channel conditions.

In a digital communication system, the maximum data rate is limited by the pulse spread due to the medium. The fading channel introduces a pulse spread d_r at the receiver output a nd the maximum data rate is thereby limited to $1/d_r$ approximately. The consequent adjacent channel cross-talk, as will be found in a multiplexed digital system, was experimentally determined and it was found that for $P_{eN} = 10^{-5}$, the noise-carrier requires 0.25 - 0.4 µs more separation at 10 Mc/s than that required for the sinusoidal carrier. This is due to the incoherency of the incohe-rency of the carrier and is much smaller than the pulse spread due to the dispersion of the signal in the medium. Thus, although the noise-carrier does not provide any protection against the pulse-spread in the medium, the overall channel bandwidth required would be approximately the same for both sinusoidal and noise-carrier systems.

4. Minimum Noise-Carrier Bandwidth Requirement:

For the design of practical communication system with noise-carrier, the minimum noise-carrier bandwidth required to provide the complete protection against fading, has to be known. It was found that this minimum bandwidth is dependent on the type of the noise-carrier used, since the PDF and number of zero crossings of the noise-carrier depend on the mode of its generation. To determine the optimum method of noise-carrier generation different methods of noise-carrier generation (random and pseudo random) and their characteristics were studied. It was found that the RF noise-carrier generated by frequency translation of a low frequency bandpass, random-noise of desired bandwidth B_n (by balanced modulation and filtering SSB method) requires the minimum noise-carrier bandwidth to provide the necessary protection against fading. In this SSB method of noise-carrier generation, the noise-carrier amplitude is proportional directly to the modulating noise envelope. Since the number of maxima of the noise-carrier envelope is equal to the bandwidth in cycles per seconds, it is felt that the noise-carrier produced by the SSB method will fail if the bandwidth of the low frequency noise is reduced considerably. It was experimentally found that the noise-carrier generated by SSB fails if the noise-carrier bandwidth is reduced below 78 cps at 10 Mc/s. If the pseudo-noise is used for generation of the noise-carrier by SSB, then the pseudo-noise should not only have a bandwidth more than 78 cps, but also the p-n sequence used should be of sufficient length. The other method of noise-carrier generation is by frequency modulation of a sinewave-carrier by low frequency narrow-band noise. The deviation ratio (D) of FM has to be kept very much less than one to avoid variation of noise-carrier bandwidth B_n with input modulating noise amplitude. For $D < 1$, the output of the modulator consists of two identically phase modulated, constant amplitude sidebands alongwith a varying amplitude sinewave component. Thus the FM method neigher provides a true noise-carrier nor has the resultant amplitude of the three components a gaussian PDF. As a result, the equation (10) is no longer valid. It was experimentally verified that this FM noise-carrier requires about three to six times more bandwidth to provide a complete protection against fading as compared to the SSB type of noise-carrier.

The minimum noise-carrier bandwidth B_n required, to provide protection against fading in terms of error rates, was determined experimentally with the Rice Fading Simulator, for the noise-carriers generated by different methods, and the same

TABLE NO. II.

Minimum Noise-Carrier Bandwidth B_n required for complete protection against fading for noise-carriers generated by different methods.

Mean noise-carrier frequency f_o = 10 Mc/s. Rice Fading Simulator was used.

Sl. No.	Type of Noise-Carrier Generation. Method of modulation.	Types of noise generator.	Minimum noise-carrier bandwidth required to provide fading protection; order of fading protection given in terms of error rate. 10^{-4}	10^{-5}	0
1.	Frequency translation by balanced modulation of sinewave-carrier with video freq.narrowband noise and filtering to obtain SSB.	(i) Video frequency random noise.	80 cps.	90 cps.	100 cps.
2.	Frequency Translation by frequency modulation of sinewave-carrier with low freq. narrowband noise.	(i) 480 cps wide random noise.	500 cps.	900 cps.	1000 cps.
		(ii) 78 cps wide random noise.	1800 cps.	2000 cps.	-
		(iii) Pseudo noise generated in multi-level p-n sequence gen. clock freq. 400 cps.	600 cps.	1000 cps.	3500 cps.
		(iv) Pseudo noise generated in constant level p-n sequence generator, clock freq. 400 cps and lowpass filtering.	2000 cps.	3500 cps.	-

is given in Table No.II. Experimental results show that no error is ~~even~~ introduced even if $f_r < B_n$ for clipped noise-carrier ($\bar{\epsilon} = 0.5\sqrt{\psi_0}$ $b_0/\sqrt{\psi_0} = 0.5$), where B_n is sufficiently large. With partially clipped noise-carrier ($\bar{\epsilon} = 2\sqrt{\psi_0}$; $b_0/\sqrt{\psi_0} = 1.0$) the minimum data rate must be greater than 2 B_n to keep the error rate below 10^{-5}.

5. <u>Laser Communication</u>:

With gas lasers operating well above threshold the amplitude fluctuation is very small, but the frequency fluctuation is only of the order of 1 to 10 Mc/s. Modulating frequency for a gas laser can be much higher than 10 Mc/s[5]. Thus the emission for gas lasers can be considered similar to clipped noise-carrier and the results for $B_n \leqslant 2$ Kc/s in Table I can be directly applied to gas laser system. On the other hand emission from semiconductor lasers have large amplitude fluctuation and the frequency fluctuation is of the order of 15,000 Gc/s[4]. The maximum modulating frequency of semiconductor lasers is at present restricted to 40 Gcps (approx.). Thus semiconductor laser system can be considered similar to gaussian noise-carrier system and all the results of noise-carrier system for $B_n > f_r$ in Table I can be directly applied to semiconductor laser system.

6. <u>Conclusion</u>:

A summary of important results of noise-carrier and sine-wave-carrier systems is shown in Table III where a relative comparison in terms of CNR can be made. It is seen that the noise-carrier system completely alleviates the fading effects due to amplitude and selective fading. For analogue modulation systems, the channel bandwidth requirement for noise-carrier system is about ten times more than the sinewave-carrier system;

TABLE NO.III.

Summary of the Experimental Results with Incoherent and Coherent Carrier Systems with noisy Rice Fading Channels.

Frequency of transmission f_o = 10 Mc/s; Channel bandwidth = 2.5 Mc/s; Pulse repetition frequency f_r = 100 Kc/s; Noise-Carrier Bandwidth $B_n \ll f_r$; RF noise clipper characteristics - Window width $\bar{\epsilon} = 0.2\sqrt{\psi_o}$; clipping level $b_o/\sqrt{\psi_o} = 0.5$; Analogue modulation characteristics - Deviation Ratio for PFM D = 2.0; PLM modulation index $\mu = 0.5$; Mean pulse width $L = 1/2f_r$; Message bandwidth f_m = 30 Kc/s; Pulse width for digital modulation is 1 μs.

Channel signal to noise ratio in db.	Digital Signal Transmission (ON-OFF)			Analogue Signal Transmission using Pulse Modulati			
	Clipped Incoherent carrier.	Coherent Carrier.		Clipped Incoherent Carrier.		Coherent Carrier (PFM-AM)	
	Error rate.	Error rate.		Message SNR in db with/without fading.		Av. Message SNR in db.	
	With/without fading.	Without fading.	With fading.	PFM-AM	PLM-AM	Without fading.	With fading.
>20	0	0	10^{-3}	67	57	-	-
17	Better than 10^{-5}	Better than 10^{-5}	1.2×10^{-2}	67	57	Better than 70	60
16	2.2×10^{-4}	2.1×10^{-4}	2.1×10^{-2}	60	50	60	50 - 45
14.5	2.3×10^{-3}	4.6×10^{-3}	4.8×10^{-2}	35	25	35	20
12.0	2×10^{-2}	5×10^{-2}	1.3×10^{-1}	20	less than 20	20	less than 10

however, for pulse and digital modulation, the RF channel-bandwidth requirement is practically the same for both types of carrier systems. Thus it is felt that the noise-carrier system will be more useful in the transmission of information through disturbed fading medium and may do away with the physical diversity systems.