REPORT 1022-1

MULTI-TRANSMITTER RADIO SYSTEMS USING QUASI-SYNCHRONOUS (SIMULCAST) TRANSMISSION IN THE LAND MOBILE SERVICE

(Question 67/8)

(1986-1990)

This report consists of two parts: A and B. Part A deals with the technical consideration of quasi-synchronous (simulcast) transmission and Part B deals with an application of these techniques for digital transmission in the land mobile service.

PART A

TECHNICAL CONSIDERATIONS OF QUASI-SYNCHRONOUS (SIMULCAST) TRANSMISSION

1. Introduction

Special care must be taken with multi-transmitter systems in which the same message is transmitted at the same time in the same radio channel by two or more transmitters (such systems are known as quasi-synchronous or simulcast). They are used where:

- a large service area must be covered by transmitters of moderate power, in which case there will be a small overlap in the coverage of the transmitters;
- intensive coverage is needed, e.g. in some paging systems. In this case there will be a substantial overlap in the coverage of the transmitters which are used to provide diversity against shadowing (slow fading).

Note. – No diversity advantage is obtained against multipath fading.

Multi-transmitter simulcast transmission can be classified into three categories as follows:

- carrier frequency offset method [Hattori and Hirade, 1978];
- waveform offset method [Hattori and Ogose, 1980; Hattori *et al.*, 1982]; and
- modulation index offset method [Adachi, 1979].

It is necessary to study these methods with respect to transmission performance under fading conditions and their applicability to mobile radio transmission.

The following parameters are important:

- difference between the carrier frequencies of the transmitters;
- relative timing of the modulation at the transmitters caused by different delays in telephone lines and modulation circuits;
- differences in modulation depth and frequency response.

2. Error performance of digital transmission to moving receivers

With a small carrier frequency difference (< 10 Hz) and accurate modulation timing (< 0.2 bit period) the BER at a moving receiver, in Rayleigh fading conditions, in a multi-transmitter system is approximately the same as with a single transmitter, for a given received signal level, as shown in Fig. 1 (for the case of direct frequency modulation of the RF carrier). Typical error distributions are shown in Fig. 2 [French, 1980].

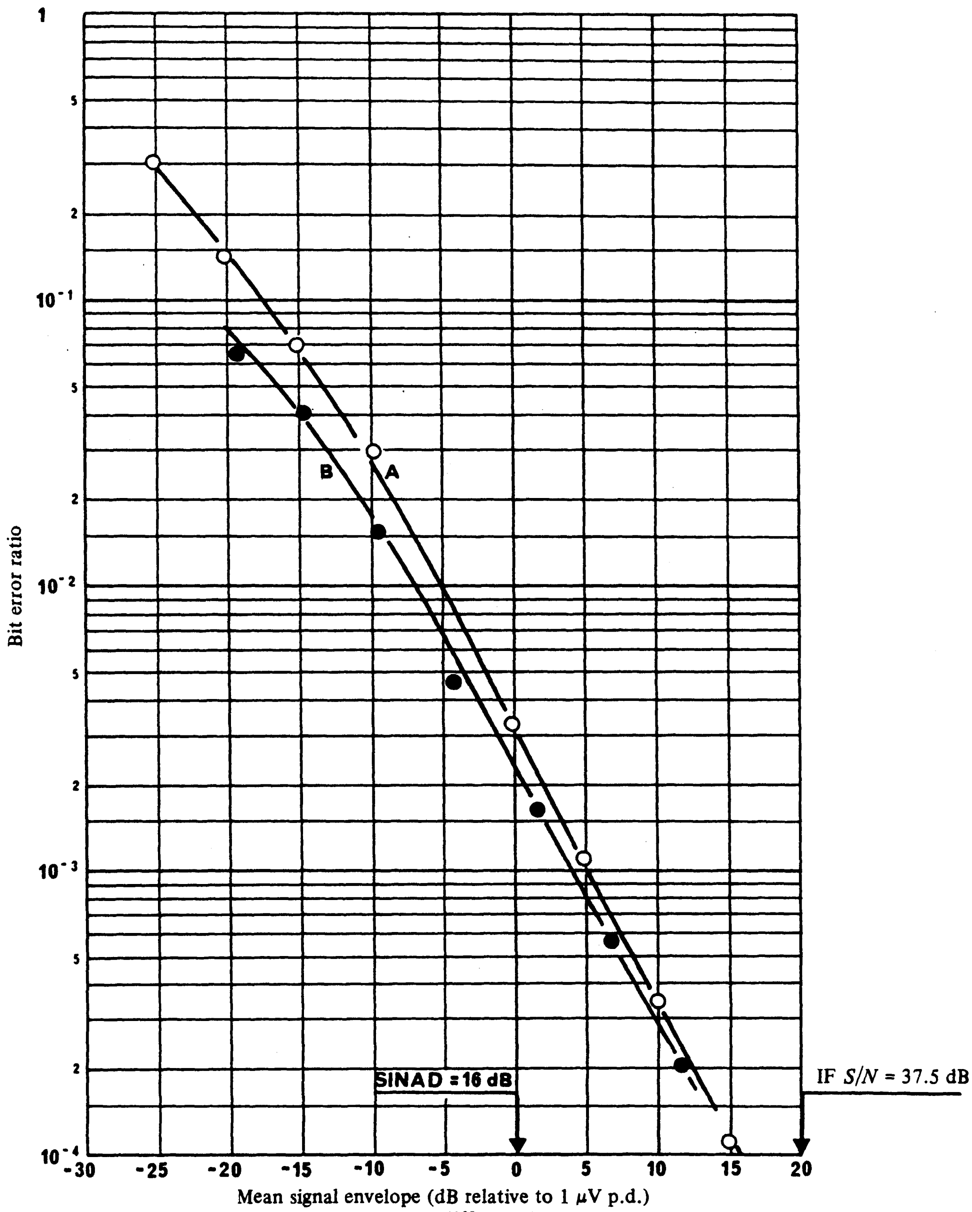

FIGURE 1 – *Error performance, mobile, 1200 bit/s, direct FM*

SINAD: 12 dB at 0.5 μV pd

Curves A : two transmitters

B : single transmitter

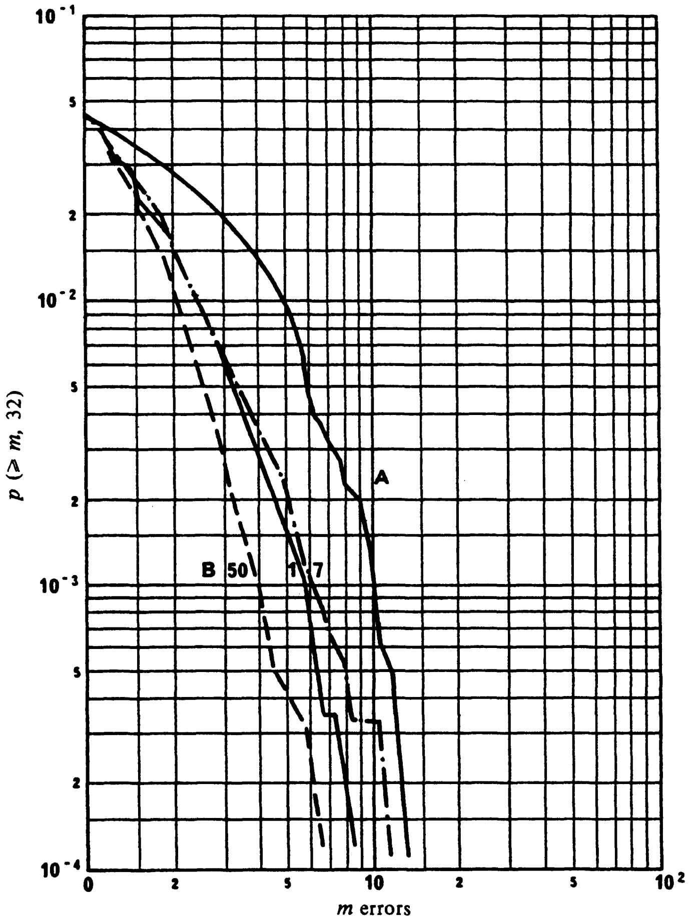

FIGURE 2 – *Error distribution, mobile, 1200 bit/s, direct FM*

BER ≈ 3×10^{-3}

Curves A: one transmitter

B: carrier frequency difference Δf_c

To avoid an excessive BER due to difference in modulation timing, the timing difference should be less than 0.3 bit period for direct frequency modulation of the carrier, as indicated in Fig. 3. With sub-carrier data modulation the timing difference must be small compared to the period of the sub-carrier.

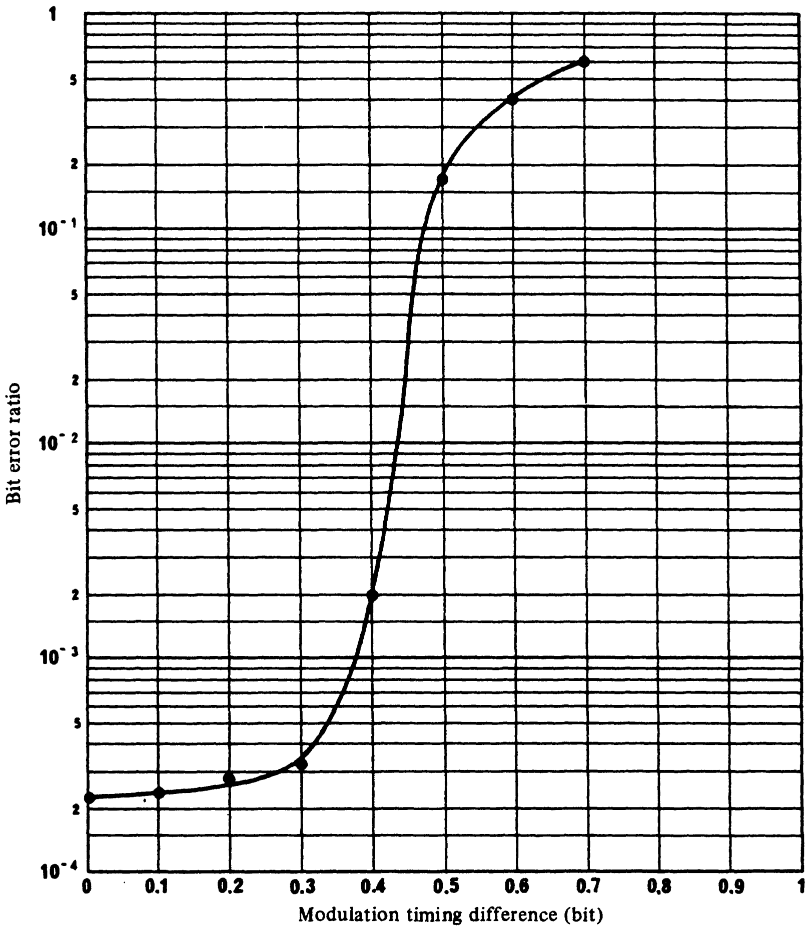

FIGURE 3 – *Bit error ratio modulation timing, mobile, 1200 bit/s, direct FM*

$\Delta f_c = 7$ Hz

Increasing the carrier frequency difference to approximately the bit rate, reduces the BER by two orders of magnitude, as in Fig. 4 [French, 1980]. At higher bit rates this difference in carrier frequency reduces spectrum efficiency.

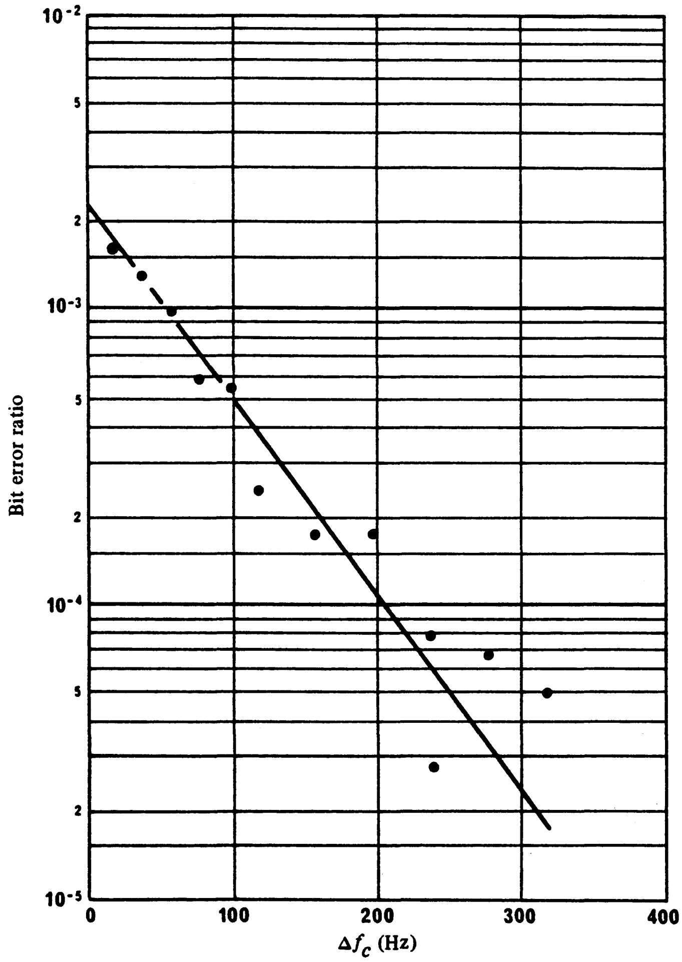

FIGURE 4 – *Bit error ratio against carrier frequency difference, 300 bit/s, direct FM*

Laboratory test results concerning offset methods of carrier frequency, waveform and modulation index are shown in Figs. 5 to 9 inclusive. As shown in Fig. 5, each method results in performance improvement (diversity effect of more than 10 dB) when the average equivalent levels of two received signals are combined.

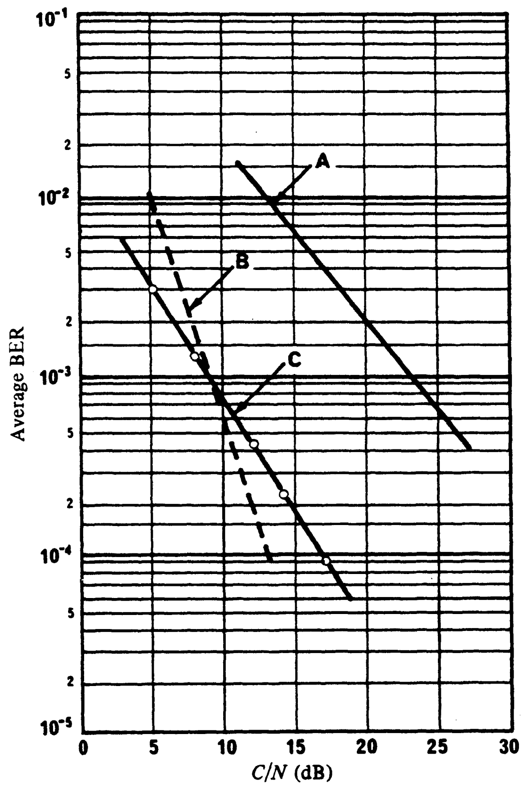

FIGURE 5a – *BER performance versus C/N of carrier frequency offset method and waveform offset method for 300 bit/s Manchester coded signal with direct FM*

Curves A: single transmitter ($\Delta f_D = \pm 3$ kHz)

B: two transmitters with carrier frequency offset ($\Delta f_C = 1$ kHz, $\Delta f_D = \pm 3$ kHz)

C: two transmitters with waveform offset ($\Delta f_d = \pm 3.5$ kHz, $\Delta f_{dh} = \pm 1$ kHz)

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

Δf_C : carrier frequency difference

Δf_D : maximum frequency deviation

Δf_d : average frequency deviation of offset waveform method

Δf_{dh} : frequency deviation corresponding to the peak amplitude of the sinusoidal wave ($= \Delta f_D - \Delta f_d$)

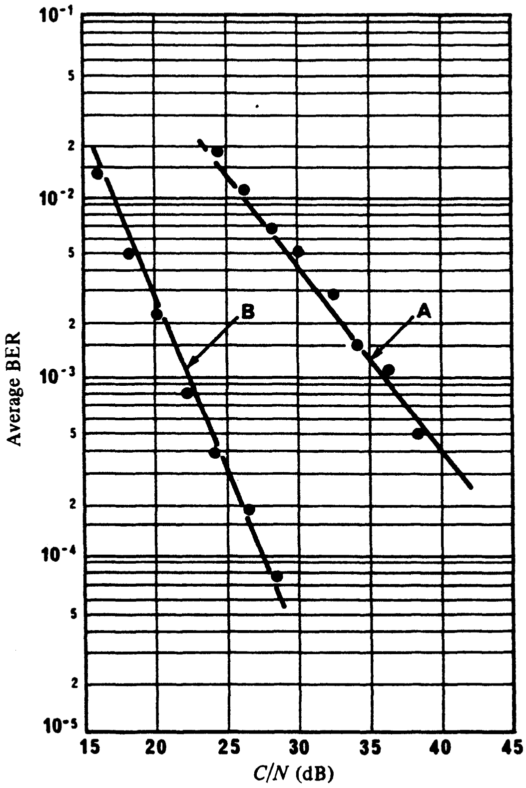

FIGURE 5b – *BER performance versus C/N of modulation index offset method for 600 bit/s differentially encoded Manchester coded signal with direct FM*

Curves A: single transmitter (modulation index $\beta = 9.7$)

B: two transmitters with modulation index offset (modulation index $\beta_1 = 11.7$, $\beta_2 = 9.7$)

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

●: experimental results

If the carrier frequency fluctuates, performance improvement using the frequency offset method changes greatly in the range from 0 to 2 kHz, as shown in Fig. 6 by the broken line. The waveform offset method results in more stable and better performance, as shown in Fig. 6 by the solid line.

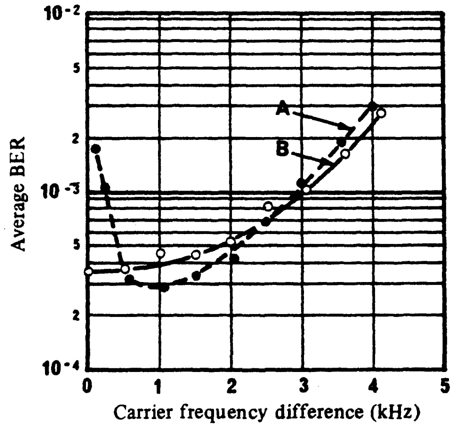

FIGURE 6 – *BER performance versus carrier frequency difference*

Curves A: carrier frequency offset method (Δf_D = ±3.5 kHz)

B: waveform offset method (Δf_d = ±3.5 kHz, Δf_{dh} = ±1 kHz)

Maximum Doppler frequency: 40 Hz

Transmission bit rate: f_b = 300 bit/s

The diversity effect decreases as the modulation signal phase difference increases. The improvement characteristics of the phase difference for the frequency offset and the waveform offset methods are similar. In addition, the allowable value for each method is approximately 60° (0.16 bit duration), as shown in Fig. 7.

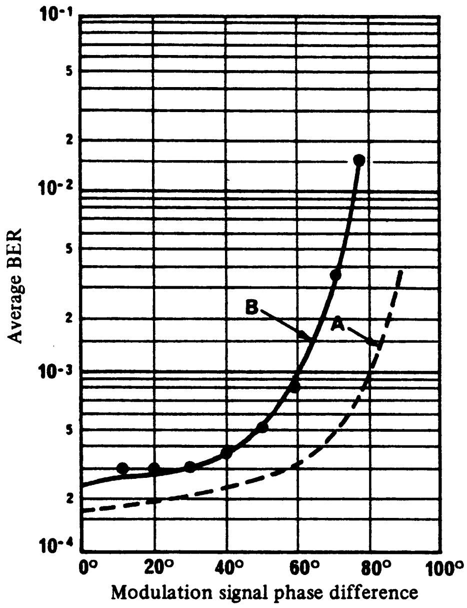

FIGURE 7 – *Effect of modulation signal phase difference on BER performance*

Curves A: carrier frequency offset method (Δf_C = 1 kHz, Δf_D = ±3 kHz)

B: waveform offset method (Δf_d = ±3.5 kHz, Δf_{dh} = ±1 kHz)

Transmission bit rate: f_b = 300 bit/s

Maximum Doppler frequency: 40 Hz

Cross-correlation coefficient: 0

In the modulation index offset method, BER is reduced by an order of magnitude and the optimum index value difference is 2, as shown in Fig. 8.

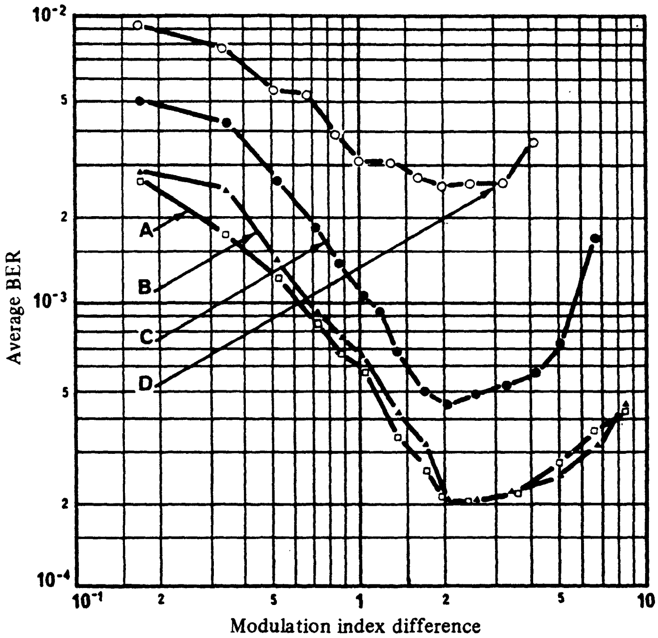

FIGURE 8 – *BER performance in the modulation index offset method for 600 bit/s differentially encoded Manchester coded signal with direct FM*

Modulation index of one transmitter is set as:

Curves A: β_1 = 13.3

B: β_1 = 11.7

C: β_1 = 8.3

D: β_1 = 5

C/N = 26 dB

Modulation index difference: $\Delta\beta = \beta_1 - \beta_2$ $(\beta_1 > \beta_2)$

Cross-correlation coefficient: 0

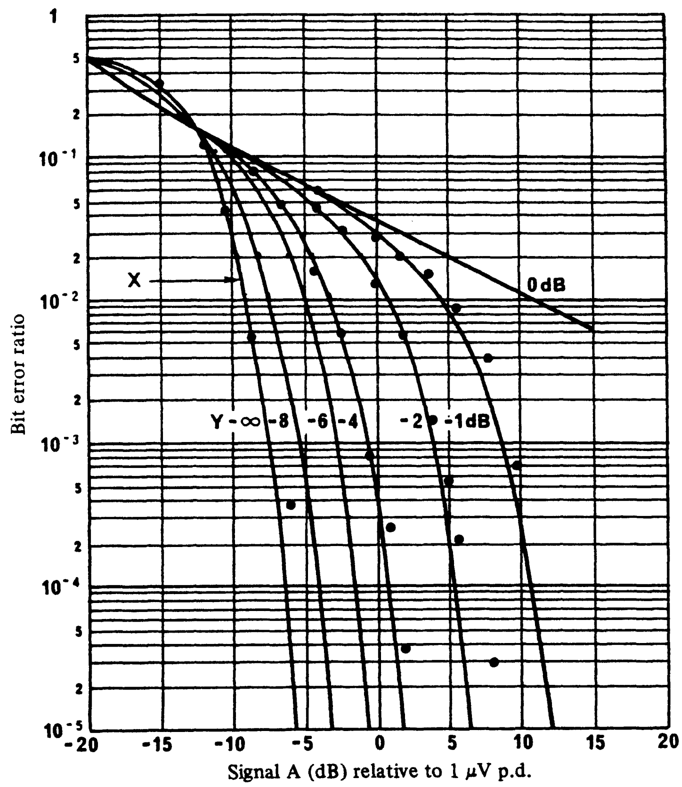

FIGURE 11 – *Stationary FM quasi-synchronous error performance*

12 dB SINAD at –9 dB

Δf_c = 2 Hz

X: A alone

Y: level of signal B relative to A

The mean word error ratio, averaged over a large number of stationary receivers in Rayleigh fading conditions is given in Fig. 12, compared with single transmitter operation, for 64 bit code words and a carrier frequency difference of 1.8 Hz. At lower signal levels (< 12 dB relative 1 μV) performance is improved with the second transmitter (= 2.5 dB) but at high signal levels it is degraded by about 4.5 dB. At higher carrier frequency differences of 18 Hz (see Fig. 13) and 180 Hz, the performance is degraded by between 5 and 10 dB [French, 1982].

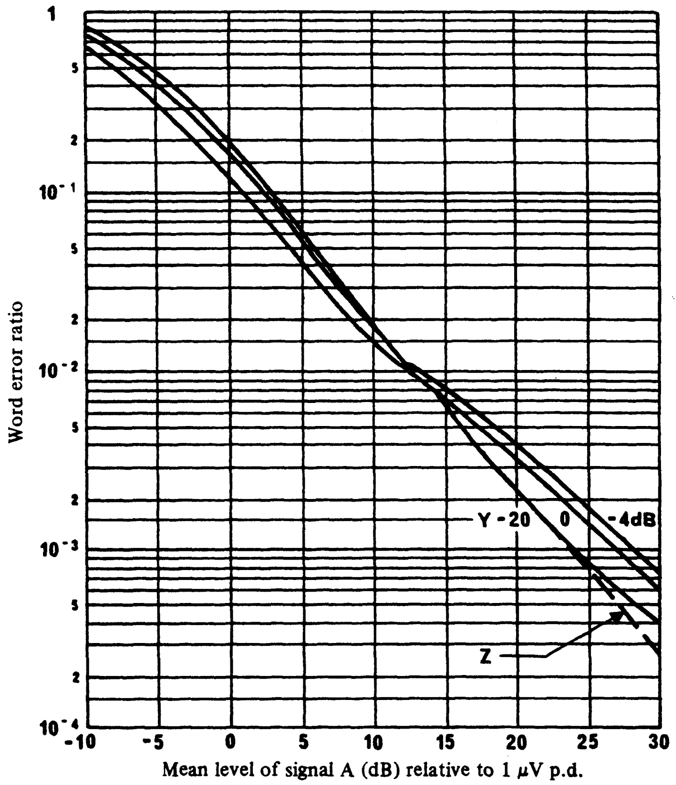

FIGURE 12 – *Mean word error ratio, amplitude modulation*

Δf_c = 1.875 Hz,

f_b = 1200 bit/s,

64-bit words.

Y: relative mean of signal B

Z: A alone

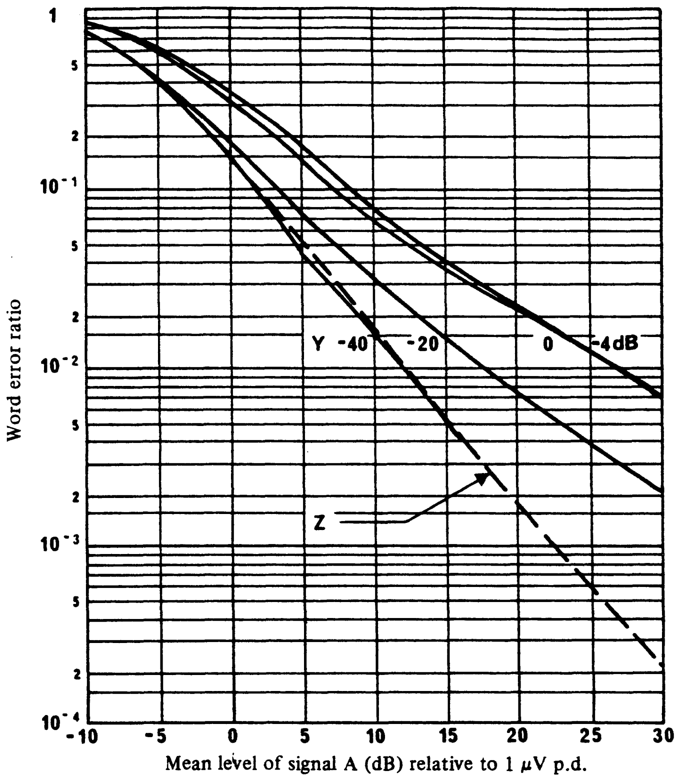

FIGURE 13 – *Mean word error ratio, amplitude modulation*

Δf_c = 18.75 Hz
f_b = 1200 bit/s,
64-bit words
Y: relative mean of signal B
Z: A alone

PART B

APPLICATION OF QUASI-SYNCHRONOUS (SIMULCAST) TRANSMISSION FOR DIGITAL TRANSMISSION

1. Introduction

Land mobile radio telephone systems using analogue cellular technology are either in place or are being deployed in many parts of the world. There is a growing demand for data communications over these cellular systems. Currently, the cellular system providers are investigating new concepts for long and short term solutions to accommodate data application in their networks.

A single frequency system concept is investigated and simulated for the transmission of data over land mobile radio channels. This single frequency system concept operates on a duplex channel dedicated for data applications. The mobile-to-base link is shared by all the data users in the system (Hafez et al., 1987) based on a slotted-ALOHA scheme (Kleinrock and Tobagi, 1975). The base-to-mobile link carries the data packets to the mobiles as well as the timing information needed to regulate the traffic flow on the mobile – to – base link. In the base-to-mobile transmission the same data packet is transmitted simultaneously from all cell sites. This scheme, in its simplest form, will not require hand-offs. One potential application of the single frequency concept is as an overlay over the existing cellular systems through an extended protocol.

2. Conclusions

The performance criterion, as expressed in delay versus throughput with the number of cells as a parameter, is illustrated in Fig. 14. As shown, two observations can be made:

1) There is a strong correlation in the delay throughput between calculated and simulated results. Moreover, better performance is observed in the simulated data.

2) The throughput of the mobile-to-base channel increases approximately linearly with the number of cells in the system provided that saturation has not been reached on the base-to-mobile channel. In the event of saturation, additional base-to-mobile channels or enhanced intelligence can be provided on the system. For example, with an average delay of six (6) time slots, the 37, 61, 91, and 127 cells systems mobile-to-base throughputs are, respectively, 2.7, 4.2, 5.9, and 8.1 times greater than that of an equivalent single cell system.

3. Further Study

Further studies are required to investigate single frequency simulcast systems, including the following:

(a) Optimum bit rate on the base-to-mobile link.
(b) Optimum location and packet routing strategy.

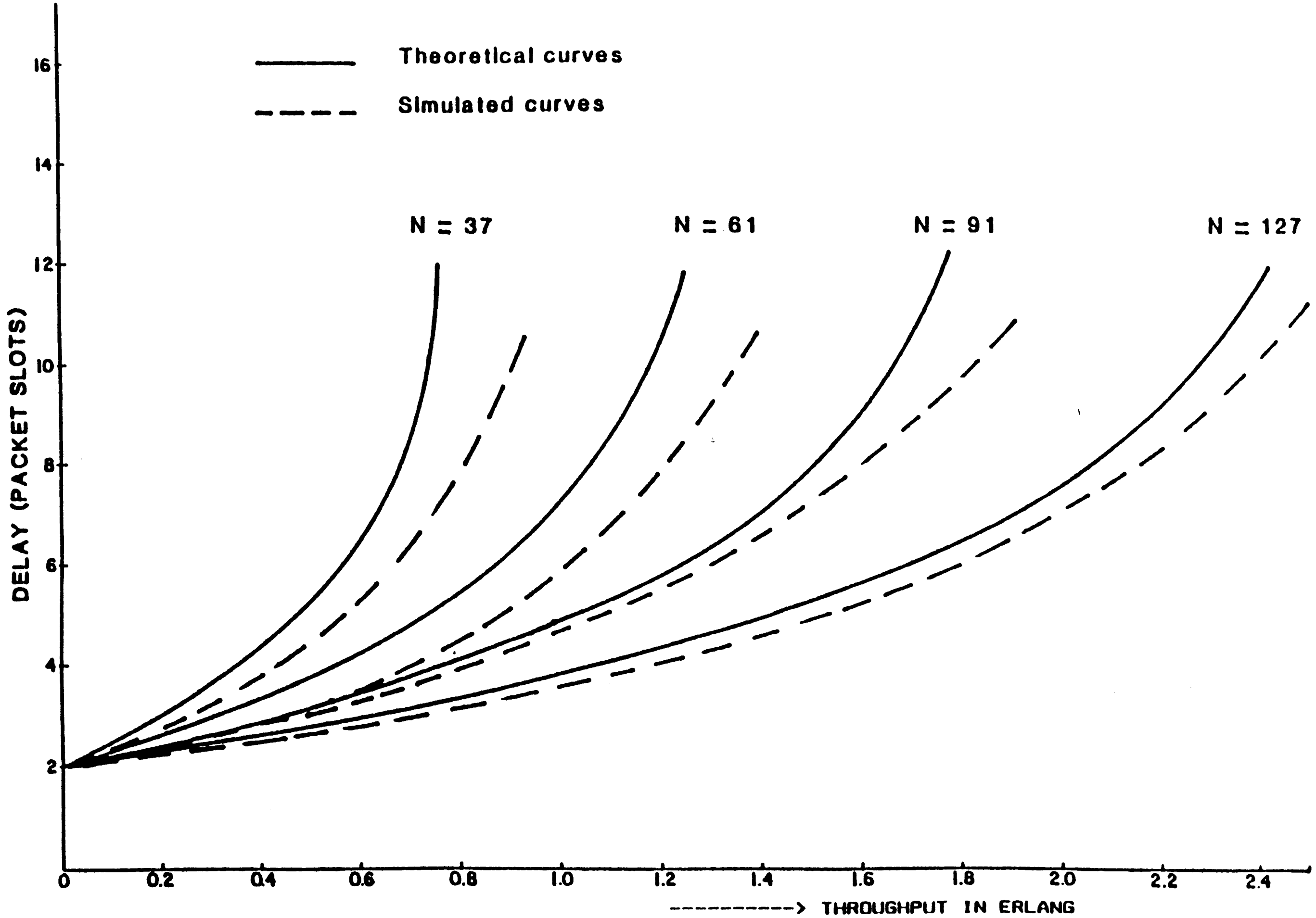

FIGURE 14

<u>Calculated and simulated delays vs throughput as function of number of cells</u>"

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