systems. As part of its developmental program, Mtel will evaluate the integration of NWN with other developing technologies, such as land mobile satellite. For example, NWN will be able to function with the AMSC system so as to provide messaging to vehicles in areas beyond the coverage of NWN base stations.[50]

VI. CONCLUSION

Throughout Mtel's history, it has been a pioneer in the development of new messaging technologies and services because it has been committed to its vision of the future of wireless messaging. NWN was conceived as part of this vision. Mtel's ongoing commitment to NWN, as demonstrated above, will produce valuable public benefits, as have Mtel's prior pioneering efforts. Mtel's technical exhibits, as summarized above, already have demonstrated that Mtel's NWN system is technically feasible, and Mtel is confident that its ongoing validation program will confirm NWN performance in a real world environment. Mtel has provided a significant amount of detailed and comprehensive simulation results that collectively provide a sound

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[50] See Exhibit E at 23-25.

foundation for concluding that its proposed modulation, its proposed channelization, the basic NWN architecture, and the ADFM protocol components will work.

Respectfully submitted,

MOBILE TELECOMMUNICATION
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TAB A

Transmission Parameter Characterization for NWN

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MPR TELTECH LTD.

Transmission Parameter Characterization for NWN

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SUMMARY

This report addresses the modulation described by Mtel in its petition for rulemaking [1]. The petition proposes that transmission of data at a bit rate in the order of 24000 bps in a simulcast environment is achievable. This is an innovative proposal, given that the highest rate proposed in a paging environment to date is 6250 bps with the new European ERMES system [2].

The proposed scheme uses multicarrier modulation (MCM) [3,4] techniques wherein several carriers are each modulated at a low enough rate to avoid serious degradation due to simulcast distortion. By using linear transmitters, enough of these carriers can be placed in the allocated bandwidth to provide the desired capacity.

This report analyses the performance of the individual carriers using the MOOK modulation proposed by Mtel, and also analyses the spectral occupancy of MCM schemes in general using practical amplifiers. The work performed allows the following statements to be made:

I. With 80 microsecond simulcast delay spreads, individual carriers can be modulated at a symbol rate of 3000 baud with acceptable performance.

II. Using conservative assumptions on carrier spacing, MPR was able to show that 5 modulated carriers (3 kbps BPSK) can be placed in a 50 kHz bandwidth with readily available Class A amplifiers using appropriate back-off techniques. Hence 5 carriers each carrying 3 kbaud is demonstrably achievable.

III. MPR's modelling showed that readily available Class A amplifiers using appropriate back-off techniques allow approximately half of the authorized bandwidth to be occupied with modulated signal (e.g. 22.5 kHz out of 50 kHz was modelled). If, instead of the conservative spacing used in the modelling, orthogonal spacing[1] of the carriers were to be used, higher bit rates could be achieved. In this case, 8 carriers with 3 kbps MOOK modulation would be able to carry 24000 bps while falling close to the proposed mask. MPR was unable in the time available to model such a scheme, and cannot comment on its expected performance.

IV. Although MPR only simulated the effect of simulcast delay spreads on two-state non-orthogonal modulation[1] schemes (i.e. schemes where 1 baud = 1 bps), other schemes (such as the 4 level FM scheme used in ERMES, or, alternatively, an orthogonal

[1]This report uses "orthogonal modulation" to signify schenes where a single carrier is modulated with two orthogonal signals - the I (in-phase) and "Q" (quadrature) signal. An example of such orthogonal modulation is QAM. It also uses "orthogonal spacing" to signify carriers modulated at a symbol rate f_s symbols per second and spaced at a frequency f_s Hertz.

modulation scheme) will allow 5 x 3 kbaud carriers to carry more than 15000 bps, at some increase in device complexity. It seems reasonable to conclude that such schemes would support a rate of 24,000 bps.

V. Discussions with vendors of new linearized amplifiers indicate that the number of carriers can be significantly increased if such linear amplifiers are used. Although MPR did not have the data to simulate these amplifiers, it believes that Mtel's claim to place 8 carriers in 50kHz using such linearized amplifiers is reasonable. This would permit operation at 24000 bps while still using simple modulation schemes.

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[3] J.A.C. Bingham, "Multicarrier Modulation for Data Transmission: An Idea Whose Time Has Come", IEEE Comm. Mag., pp 5-14, May 1990.

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PART I

PERFORMANCE SIMULATION OF MULTI-TONE ON-OFF KEYING IN A SIMULCAST TRANSMISSION ENVIRONMENT

Prepared by;

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1 ABSTRACT

Mtel has identified a need for a transmission modulation scheme to support spectrally efficient transmission in a simulcast channel. Earlier studies by Mtel had identified a multi-tone modulation scheme as being a potential candidate for achieving spectral efficiency in the presence of this simulcast delay. Because of the nature of the simulcast channel, it was decided that the channel symbol period should be a minimum of four times the expected simulcast time delay spread for typical simulcast zone sizes. Simulations of a two transmitter simulcast transmission model were performed to verify that the proposed Multitone On-Off Keying (MOOK) is capable of operating at 3000 symbols/second in the simulated simulcast environment with a simulcast time delay spread of ≈ 80 μseconds or less.[1]

Due to the large number of parameters which enter into the performance evaluation of such a system, variation of only a few of the system parameters was investigated. The parameters being varied were limited to (i) the variation in the simulcast time delay with two transmitters, (ii) variation in the levels of the received powers of the two simulcast transmitters, and (iii) the effects of a fixed frequency offset between the two transmitters. The results of the simulation were analyzed using the well known "eye diagram" to evaluate the performance of the simulcast simulation model.

The initial results of the simulation indicate that operation under these conditions is possible. It is recommended that further simulation studies, followed by experimental measurements, be performed to further study the applicability of this modulation scheme for use in the NWN system.

[1] Information transmitted over two or more transmitters operating on the same RF carrier frequency is called **simulcast**[10]. The difference in time delays between the transmitted and received information due to differences in the RF propagation delays is referred to as **simulcast time delay spread** in this document.

2 DESCRIPTION OF SIMULATION TECHNIQUE

The system proposed by Mtel for its Nationwide Wireless Network (NWN) calls for a large number of transmitters to be placed in major metropolitan areas to provide wide area coverage using a single nationwide frequency allocation. Because of the single frequency nature of the system, simulcast zones will exist in various areas of the coverage. The simulcast coverage zones will consist of areas where the received signal at the portable terminal consists of several transmitted waveforms. Each base site uses a store and forward technique to ensure that the transmitted data is synchronous, but due to simulcast time delay spread of the radio frequency transmissions they can be received at the subscriber device with a considerable time delay. This time delay spread results in time delayed replicas of the modulation being received by the portable terminal demodulator, and "intersymbol interference" (ISI) which degrades the performance of the portable terminal compared to a system in which there was no simulcast time delay spread (and hence no ISI introduced by the propagation delay). The goal for the Mtel NWN is to find a modulation scheme which will support high data rates in a single nationwide simulcast channel in which simulcast delay spreads of up to 80μsec can be tolerated.

In this report, one of the candidate modulation schemes is analyzed using simulation to determine its suitability to this particular application. Due to the limited time available, the simulation has focussed on only a few of the possible variables. The parameters addressed at this time were limited to;

- use of the Multi-tone On-Off Keying (MOOK) modulation scheme.
- a two transmitter simulcast zone.
- effect of offsets in the carrier frequencies of the two transmitters.
- effect of the simulcast time delay on the eye closure.

The decision to investigate only the MOOK modulation scheme was based on the desire to test the original concept proposed by Mtel, plus the fact that it appears to represent a good practical tradeoff between bandwidth efficiency and implementation complexity (and therefore cost) of the portable terminal modem. Only two simulcast transmitters were used in the simulation instead of three or more, as well as a fixed frequency offset between the two simulcast transmitters as opposed to more complex techniques such as "random phase dithering". This resulted in both a simpler simulation implementation and a much more direct interpretation of the simulation results. Together, these simplifications allowed the simulation to focus on the issue of the ability of the MOOK modulation scheme to operate in a simulcast environment with sizeable time delay spreads.

2.1 SIMULCAST MODEL

The two key issues addressed by the simulation are those of simulcast transmission and the MOOK modulation. Accurate modelling of the transmission environment is a very complex task, since it involves such things as the RF propagation path loss, intermodulation, co-channel and adjacent channel interference, multipath, receiver filter group delay, etc [10]. Most simulation models attempt to consider only a few of the issues arising in the real world RF environment. The key issue addressed in this report is that of simulcast time delay spread and its effect on the performance of a MOOK modem.

A software simulcast MOOK modulation performance simulation was written to model the received signal in a two transmitter simulcast system. The model is meant to be an approximate representation of a real world simulcast transmission system. The modulation used was classic On-Off Keyed Frequency division multiplexing. In order to simulate the simulcast delay spread between the two signals received at the portable terminal as well as the power difference between the two received signals, a time delay and scaling of the signal from the second transmitter was provided. The simulation model was simplified by using a lowpass representation of the channel rather than a bandpass representation, however these two models are equivalent [1, pp. 130 - 134]. The overall architecture of the simulation is provided in figure 1.

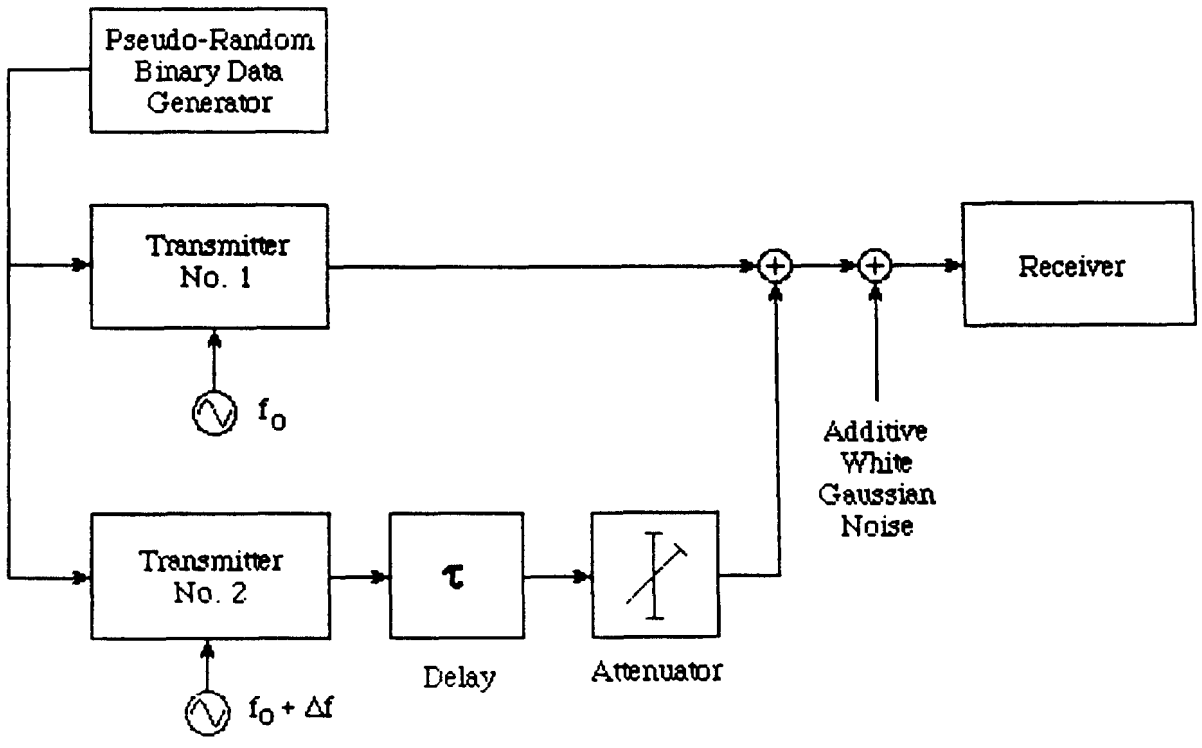

Figure 1 Model of the two transmitter simulcast system.

2.2 SIMULATION MODEL

Each transmitter was capable of generating On-Off Keyed carriers at eight separate frequencies. The processing for each of the carriers was identical, other than the frequency used to generate the baseband sub-carrier. The FDM channel gating pulse was shaped with a 50% square root raised cosine pulse shaping filter ($\alpha = 0.5$), and this was in turn used to amplitude modulate the baseband subcarrier. The gating pulses were generated by a pseudo-random binary sequence generator for each of the channels, thus providing an independent random data sequence in each of the sub-channels. The pseudo-random data stream was used to modulate both of the transmitters. Each of the individually generated modulated subcarriers were added, with this composite signal representing the transmitted signal for that transmitter.

A second transmitter was used to represent the simulcast source. This was identical to transmitter number 1, and transmitted exactly the same random data sequence. At the output of transmitter 2, a delay of between 0 μseconds and 333.3 μseconds in steps of 20.83 μseconds was provided as well as the ability to attenuate the level of the delayed signal from transmitter 2 by any desired amount. The signal from transmitter number 1 was added to the delayed and attenuated signal from transmitter number 2, forming the received signal at the receiver demodulator. A facility to offset the carrier frequency of the second transmitter relative to transmitter number 1 by an amount Δf was also included. Gaussian noise could be added to the received signal, with this facility only being used for qualitative performance evaluation at this time. This signal was then processed by the demodulator.

There are a number of ways to perform the FDM signal demodulation, ranging from very simple implementations to very complex. The more complex methods, such as those proposed in [2] and [3], can achieve higher spectral efficiency than the "classic FDM" technique in which the pulse shaping filters are separated by $f_s(1 + \alpha)$ where f_s is the symbol rate and α is the raised cosine filter roll-off factor, but concerns to be noted are;

- the complexity requires an increased amount of hardware which impacts the portable terminal cost
- the large amount of hardware would require additional battery power, substantially reducing the operational lifetime of the portable terminal on a single battery charge.
- if orthogonal signalling[2] is used, then the orthogonality conditions must be preserved in the real world simulcast environment.

[2] The term **orthogonal** is used in the context of "**orthogonal signal sets**" [5, p. 62, p. 262]. By, this definition, two signals are said to be othogonal if they obey the condition that $\int \psi_i \psi^*_k dt = 1$ for $i = k$, and $\int \psi_i \psi^*_k dt$ [illegible] $\neq k$.

Since these aspects of the demodulator are not well known at this time, the simplest possible demodulator using a classic FDM approach was elected. This will also serve as a baseline for comparison with the other possible schemes in future simulation work. This requires that the signal generated at the transmitters have a symbol rate of 3000 symbols per second, with the individual FDM channel spaced 4500 Hertz apart for a 50% raised cosine pulse shaping filter. A plot of the spectrum for MOOK modulation with eight subcarriers is provided in figure 2.

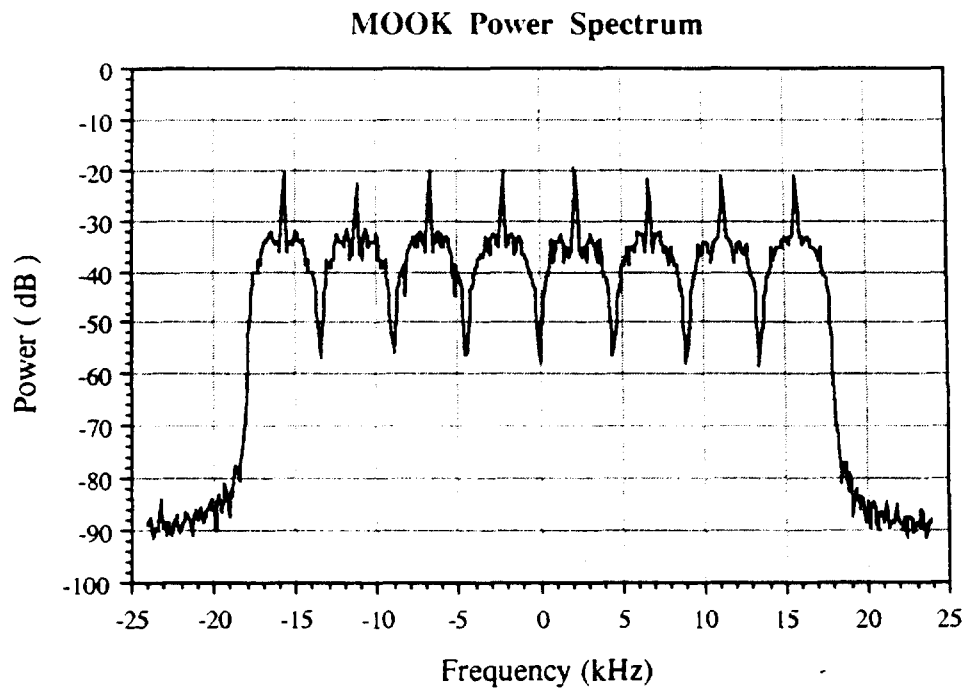

Figure 2 Plot of the power spectrum for the MOOK modulation using a symbol rate of 3000 symbols/second, 50% square root raised cosine pulse shaping, and a sub-carrier separation of 4500 Hz.

The receiver was implemented with an eight channel matched filter envelope detector, again with a square root raised cosine pulse shaping filter with $\alpha = 0.5$. The baseband eye of a single channel was acquired and used to generate "eye diagrams". To reduce the processing time required to generate most of the eye diagrams, only three adjacent sub-channels were generated. Channel number 2 of the eight was used for this purpose, which placed one adjacent sub-channel carrier on either side of sub-channel number 2. A number of tests were performed with all eight sub-channels being generated, and the eye pattern for subcarrier 2 was compared with that generated for the three sub-channel case. No difference

in the two cases could be observed as far as the eye patterns were concerned. The eye pattern for channel 2 was recorded for various combination of simulcast delay and attenuation levels of the signal for transmitter number 2. Data decisions are made using a simple threshold detector, assigning a binary one to the symbol if the decision threshold is exceeded and a binary zero if the decision threshold is not exceeded.

The eye pattern is frequently used for evaluating the level of impairment in system performance. Of interest here are the eye closure and the clock jitter. An eye pattern for a MOOK signalling scheme is shown in figure 3, with elements of the eye diagram noted on it.

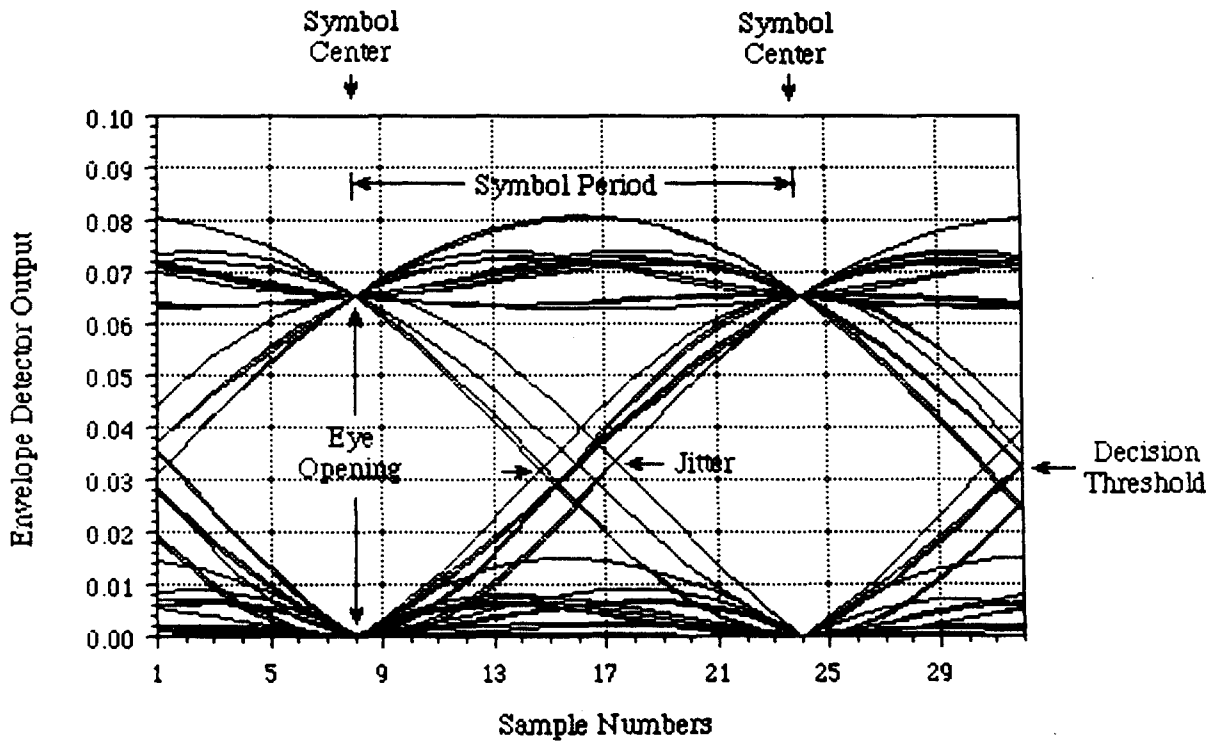

Figure 3 Eye diagram for one of the the MOOK modulation subcarriers using a symbol rate of 3000 symbols/second, 50% square root raised cosine pulse shaping, and a sub-carrier separation of 4500 Hz.

Normally, the demodulator samples the envelope detector output at the symbol centers and compares the value of the detector output with the "decision threshold". If the output is greater than the decision threshold, the symbol is declared to a binary "1". Otherwise, it is declared to be a binary "0".

The eye closure is a measure of the loss in performance due to variations in the signal level presented to the threshold detector, resulting from distortions in the baseband waveform or the addition of noise to the signal. This degradation generally results in a degradation of the modem bit error rate performance.

The clock jitter is a measure of the peak-to-peak time difference of the threshold level crossings D_{jpp}, often expressed as D_{jpp}/T_s where T_s is the symbol period. The receiver demodulator must recover the symbol clock from the received data, and any jitter in this recovered clock results in time shifts of the samples taken of the envelope detector output. Again, distortions in the baseband waveform or the addition of noise to the signal generally increase the amount of clock jitter and reduce the performance of the demodulator.

Eye diagrams were generated for all of the simulations performed, with the eye opening and clock jitter being measured from the resulting plots. The eye opening was plotted as a function of the transmitter power difference and the simulcast time delay.

Since the transmitted data sequence is known, it is possible to make detect and count bit errors during the simulation runs. This was done for all trials, but perfect symbol timing was used in generating this data. For this reason, the bit error count data is representative of an ideal timing recovery situation. However, this is acceptable for the purposes of these simulations. The performance of a deployed system will ultimately depend on the exact symbol timing recovery algorithm chosen.

3 RESULTS

Two separate trials were performed to evaluate the performance of MOOK in a simulcast environment, these being;

- only the relative received signal power and simulcast delay of the two received signals was varied. There was no frequency offset or phase offset between the two signals. A qualitative evaluation of the effect of simulcast delay effect on the performance in additive white Gaussian noise was also performed.
- the relative received signal power and simulcast delay of the two received signals was fixed and a frequency offset was introduced between the two transmitters.

The simulcast simulation program generated eye diagrams and bit error rate measurement results for time delays ranging form 0.0 μsec to 333.3 μsec in steps of 20.83 μsec and for attenuator levels of 0.0 dB, 10 dB, and 20 dB. For both sets of results, only three of eight FDM channels were enabled, and the data was measured for the center of the three channels. In this way, any effects of the adjacent channels on the single channel performance could be observed.

3.1 RESULTS FOR NO TRANSMITTER CARRIER OFFSET

For the eye diagram measurements, the eye opening relative to that with 0.0 µsec delay was measured as a function of the simulcast time delay. Using the definition of eye opening given in figure 3, the worst case closure of the eye at the symbol center was measured as a time function of simulcast delay. The percentage closure in percent was defined as the ratio of the eye opening with simulcast delay present to that with 0.0 µsec simulcast delay. In this way, the eye closure as a function of this simulcast delay can be obtained. This was done with attenuation of transmitter number 2 power levels of 0.0 db, 10.0 dB., and 20.0 dB. The results are plotted in figure 4.

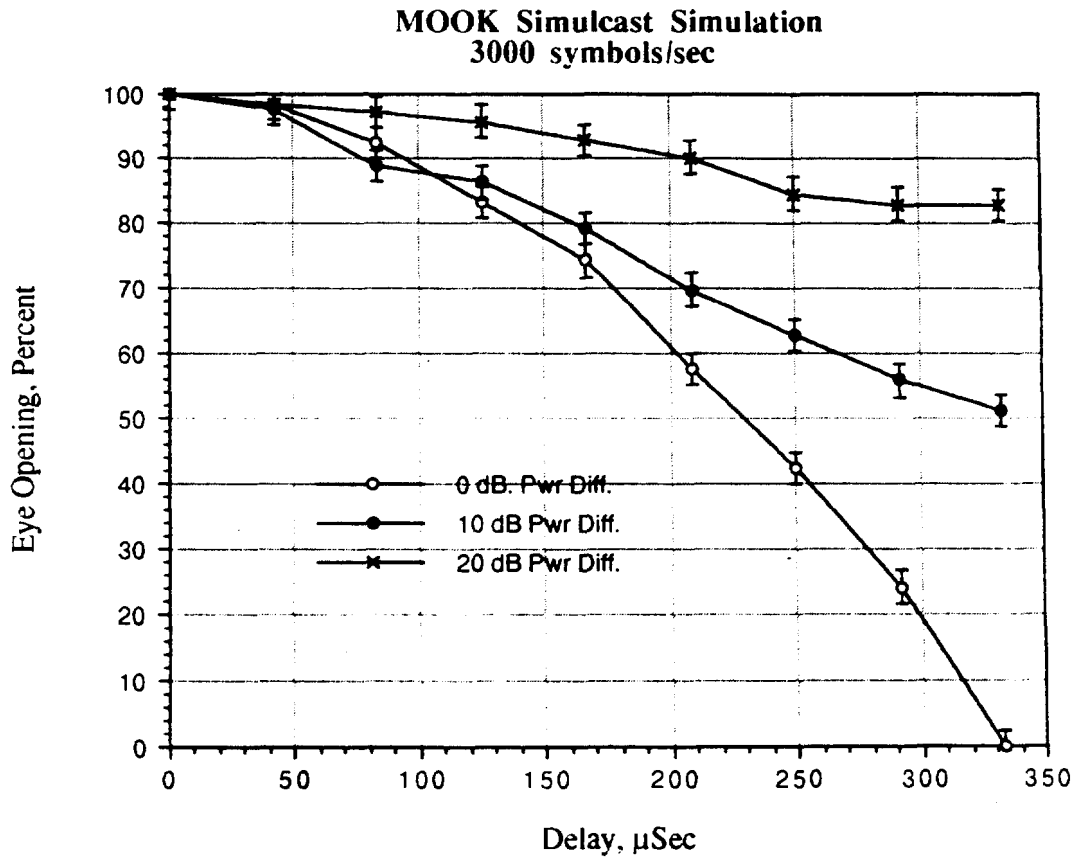

Figure 4 Plot of the eye opening in percent for three received signal power ratios as a function of simulcast delay for MOOK modulation using a symbol rate of 3000 symbols/second, 50% square root raised cosine pulse shaping, and a sub-carrier separation of 4500 Hz.

The data transition jitter in the case of 0.0 μsec delay and 0.0 dB attenuation was measured to be 18.6 ± 2.5 %. This value was not exceeded in all of the simulation trials performed. This number is consistent with the peak-to-peak jitter to be expected for a 50% raised cosine pulse shaping filter [1, pp. 93-110].

Only a qualitative statement about the bit error rate performance can be made at this time. Bit error rate measurements were taken in all tests for 390 symbols. No errors were observed in the single FDM channel being measured until the simulcast delay was 333.3 μsec, or a full symbol period delay.

To demonstrate the effect of simulcast delay on the received signal, a fixed level of additive white Gaussian noise was added to the received signal. This level was held fixed for a simulation trial in which there 0.0 dB difference between the two transmitted signals and the simulcast delay was set at 0.0 μsec for one trial and 166.7 μsec for the second trial run.

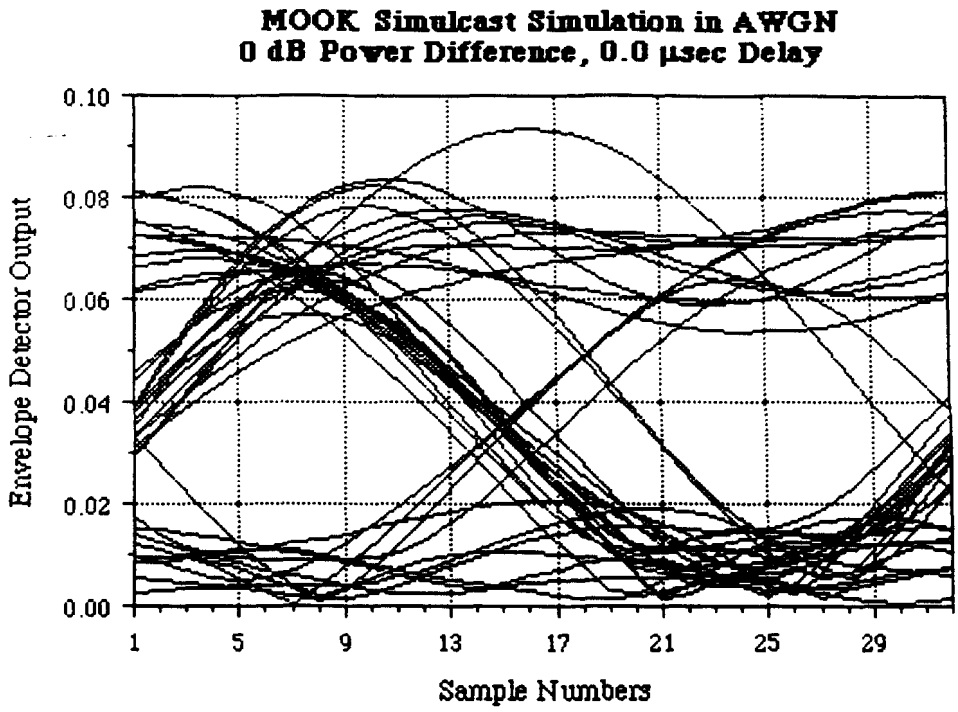

Figure 5 Plot of the envelope detector output for the MOOK modulation with additive white Gaussian noise, 0 dB power difference in the two transmitters, and 0 µsec simulcast delay.

Figure 5 shows the eye pattern for the case where there was 0 dB power difference in the two transmitters and 0 µsec simulcast delay with additive white Gaussian noise (AWGN). Significant closure of the eye is apparent, with the eye opening being only about 60 %. In this particular case, the bit error rate for desired sub-channel had no errors out of the 390 bits sent. The signal to noise ratio of the signal shown in figure 5 was estimated to be about 13 to 15 dB.

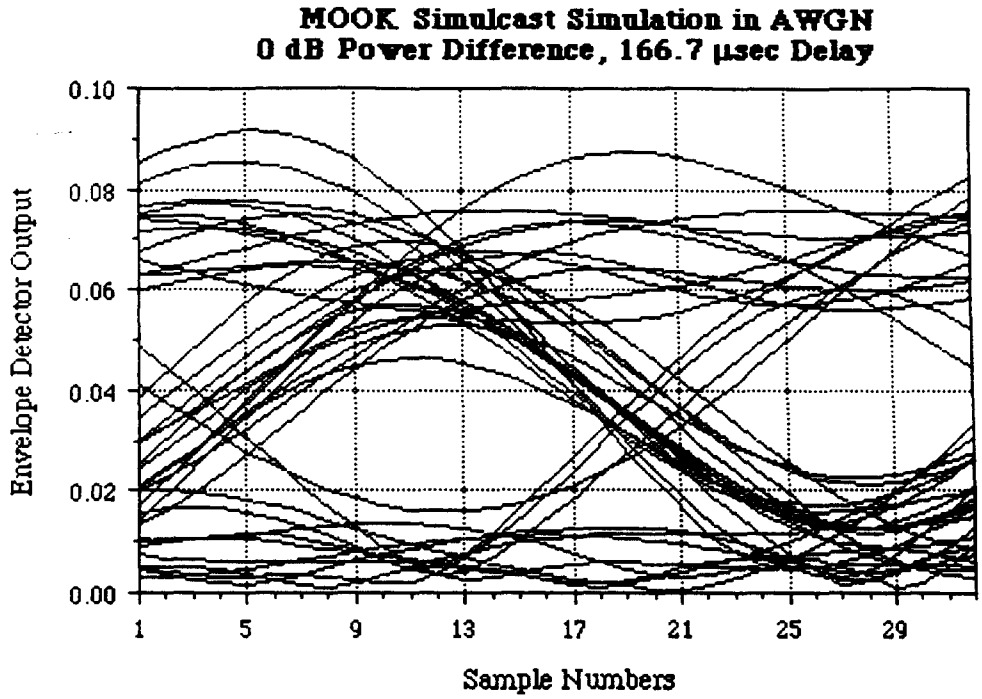

Figure 6 Plot of the envelope detector output for the MOOK modulation with additive white Gaussian noise, 0 dB power difference in the two transmitters, and 166.7 µsec simulcast delay.

Figure 6 shows the eye pattern for the case where there was 0 dB power difference in the two transmitters and 166.7 µsec simulcast delay with AWGN. Significant closure of the eye is apparent, with the eye opening being only about 35 %. In this particular case, the bit error rate for desired sub-channel had 5 errors out of the 390 bits sent. This demonstrates that a loss in receiver sensitivity can be expected in the case of large amounts of simulcast delay. The signal to noise ratio of the signal shown in figure 6 was estimated to be about 13 to 15 dB.

3.2 RESULTS FOR 40 HZ TRANSMITTER CARRIER OFFSET

In the second set of simulations, the power difference between the signals from the two transmitter sites was 0.0 dB, and the simulcast time delay was 0.0 μseconds. This situation essentially simulates the case where the portable terminal is located at the equal signal boundary of simulcast zone. The carrier frequencies of the two transmitters were offset by 40.0 Hz to avoid the situation where receivers would be located in signal null or stationary "fade". This procedure is similar to what is already done in present day simulcast systems. It should be noted that in a typical field installation, the transmitter frequency offsets are never exact because of the phase noise in the oscillators. By forcing the received signal to fade at some low frequency, the order of a few Hertz to tens of Hertz, one ensures that the portable is never in a constant signal null or fade and unable to receive the broadcast transmission. Channel errors arising from the self induced fading caused by the carrier frequency offset are dealt with by the radio channel protocol.

The effect of the frequency offset on the MOOK signal is to cause the envelope magnitude to vary or fade in magnitude over time, with the fade rate being equal to the difference in frequency between the two interfering signal sources. Figure 7 shows this effect for one of the MOOK subcarriers. In this case, the time between the signal fades is 25.0 msec (1/(40.0 Hz)). This simulation represents a worst case example, since the signal strength of the two received signals is the same.

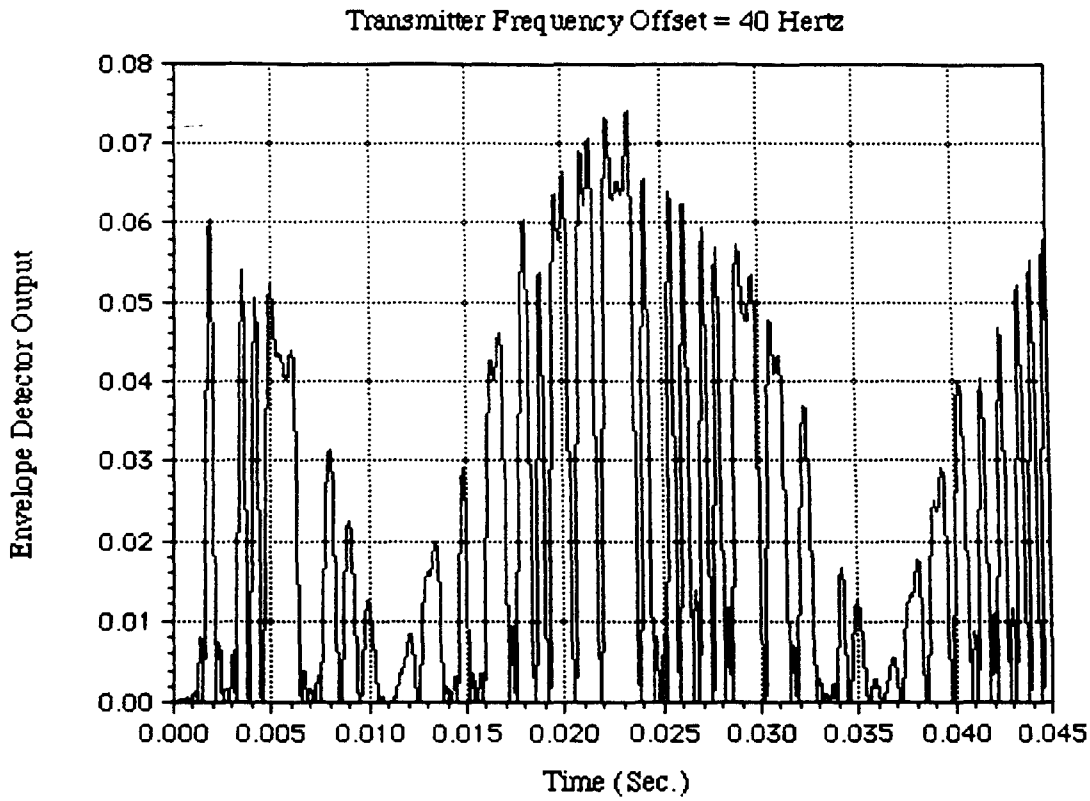

Figure 7 Plot of the envelope detector output for the MOOK modulation using a symbol rate of 3000 symbols/second, 50% square root raised cosine pulse shaping, and a sub-carrier separation of 4500 Hz with the difference in the carrier frequency of the two transmitters being 40 Hz and 0 dB difference in the received signal powers.

The implication of this variation in the envelope detector output to the portable terminal is that the decision threshold for the modem must adapt to the changes in the signal level, or the portable terminal must implement an AGC operation for each of the MOOK subcarriers. To further illustrate this point, eye diagrams were plotted for two portions of the envelope detector output given in figure 7. These portions were taken from 16.7 msec to 27.4 msec where the cancellation of the two carriers is at its least, and from 34.0 to 39.4 msec where the cancellation of the two carriers is at it greatest.

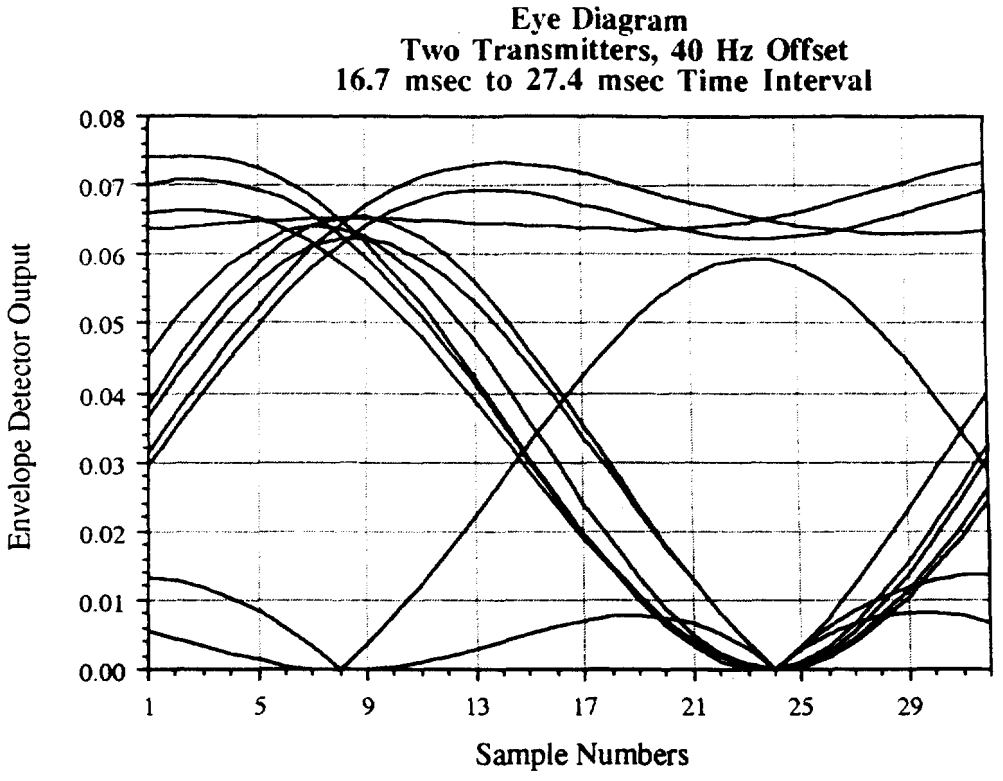

Figure 8 Eye diagram for a 10.7 millisecond portion of data taken from the envelope detector output shown in figure 7. The two carriers are more or less in-phase, and therefore little cancellation of the envelope results.

In figure 8, the eye opening is fairly constant over the 10.7 msec duration of the data set, although some closure can be observed (about 10 %). This situation represents the case where the received carriers from the two transmitters are in phase and little cancelation results.