BENNO FRIEDMAN

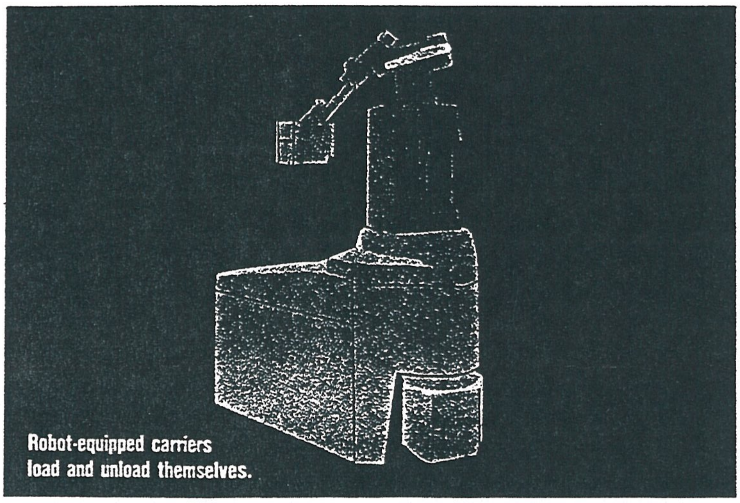
tec (Lisle, Ill.)—guidepaths consist of wires embedded in the factory floor. Each carrier has an antenna that detects the magnetic fields surrounding the guide wires when the wires are energized at low voltages. The antenna generates an output signal corresponding to its location within the guidepath's magnetic field. To keep the antenna (and thus the carrier) centered over the path, a microprocessor on the carrier reads antenna signal strength and adjusts the carrier's steering mechanism to maintain a constant signal.

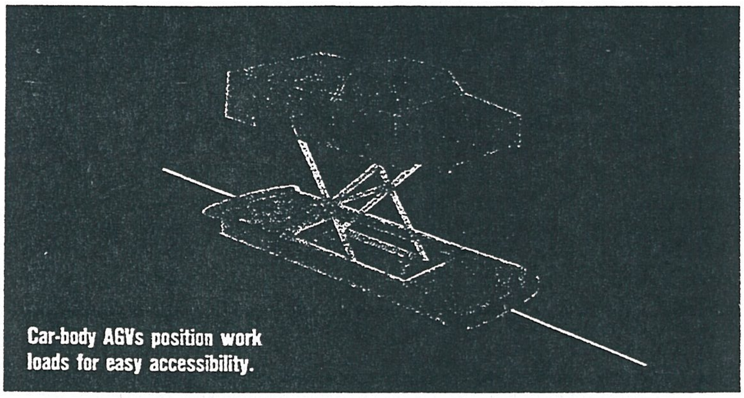
An alternate guidance method employed by Litton Industrial Automation Systems (Zeeland, Mich.) relies on transparent guidelines painted onto the floor. As a Litton carrier passes · the transparent strip, fluorescent particles . he guidepath are energized by an ultraviolet light beneath the vehicle. A photosensor detects the energized guidepath, feeding the on-board microprocessor the signal it needs to control steering. A big advantage is that the lines can be applied to any surface, even carpeting, says Litton; embedded wires generally require a concrete floor. However, the strip needs periodic reapplication, especially in high-traffic areas, where it wears more quickly.

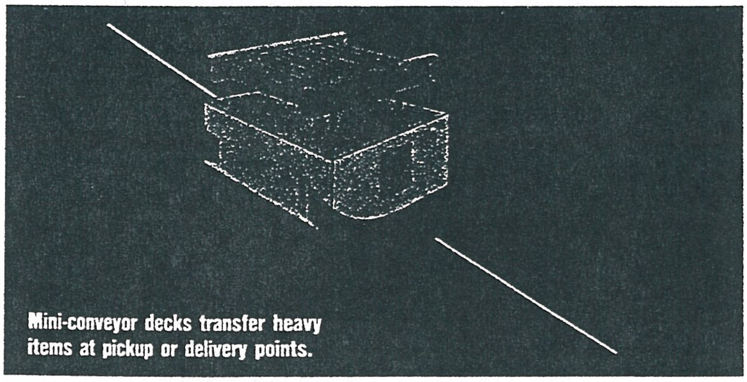
In all but the simplest AGV systems, a central control computer dispatches carriers, tracks them, and governs their movements on the various guidepath loops. Communications networks, usually dedicated wiring in the floor, permit the transmission of encoded messages like status reports from carriers or commands from the controllers. Large AGV systems often use a control hierarchy that divides the total system into zones, each with a lower-level controller that reports to the central computer and

Volvo's Anglewicz, aboard a carrier in a car-seat assembly line, says AGV systems are growing rapidly because they complement the manufacturing trend toward flexibility.

GETTING JOBS DONE


Robot-equipped carriers load and unload themselves.


Car-body AGVs position work loads for easy accessibility.


Mini-conveyor decks transfer heavy items at pickup or delivery points.

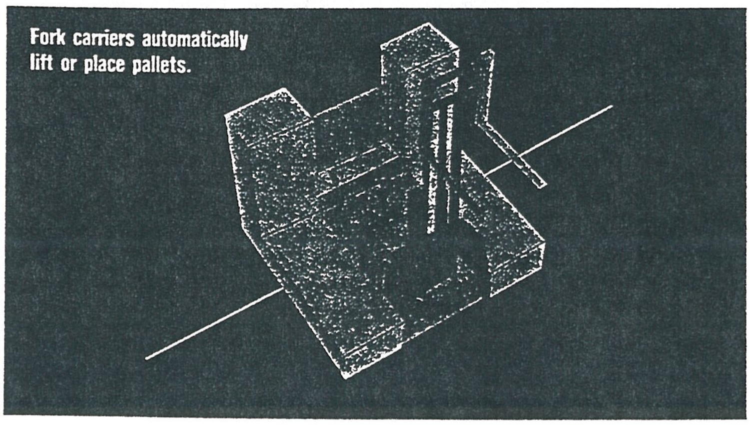

Fork carriers automatically lift or place pallets.

IMAGE BUILDERS

the frequencies of the alternating current in each loop. Since each loop is energized at a different ac frequency, carriers stay on the correct path—rather than wandering onto another one at intersections within their zone—by following a designated frequency.

Since AGVs are electrically powered, recharging is another important control priority. In some cases, carriers are temporarily removed from the system and sent to recharging areas, where they plug themselves in. Less disruptive, however, is "opportunity charging," carried out when a vehicle is in use. If a vehicle will be stopping at a specific station for a long enough span, the central computer instructs the carrier to engage the automatic charging terminal at that station. With Volvo systems, for example, a carrier parks over receptacles embedded in the floor at workstations. When instructed, it lowers its charging arm, which engages the receptacle and absorbs the charge into its battery power system. Thus the carrier receives many short boosts during the production period, keeping its batteries at least 80% charged.

The AGV concept was first applied on a large scale to manufacturing in 1974, when Volvo (the automaker) installed a 260-carrier system at its plant in Kalmar, Sweden. Since then the AGV population has grown to more than 15,000 vehicles, making up about 3300 systems worldwide. President Clifford T. Anglewicz of Volvo Automated Systems claims industry sales will grow to $1 billion by the early 1990s, from current levels of below $200 million. Most of the growth will take place in assembly AGV systems, since they are so large, according to a report being prepared by Norman W. Jetta for the New York consulting firm Frost & Sullivan. At three Oshawa plants alone, GM is installing assembly AGV systems that will employ about 1500 carriers.

Because they require so many carriers per system, automobile plants are the largest users of AGVs. But that market is being shaken by GMF Robotics' purchase last spring of wire-guided AGV technology from Eaton-Kenway, a subsidiary of Eaton Corp. (Cleveland). Under the agreement, Kenway will continue to serve the AGV needs of its existing customer base, but GMF gains the right to manufacture the vehicles and sell them under the GMF name to automakers and other industrial segments. Already the world's largest robot maker, GMF is half owned by General Motors, which is expected to give the Troy, Mich., company a large portion of GM's future AGV business.

That will hurt other guided vehicle suppliers, since GM is their largest single customer by a wide margin. To regain sales that may be lost in the automotive sector, major AGV suppliers are launching marketing campaigns to introduce the AGV concept to other industries. Volvo, for instance, which currently claims to have 25–30% of the U.S. market (thanks to the recent sale of some large automobile assembly systems), is now approaching light appliance companies. Volvo also plans a major marketing push in materials handling, having concentrated until now on assembly systems. And Portec, the company that supplied large AGV systems for automobile engine and chassis assembly to GM's Flint, Mich., plant, is targeting the print- · and papermaking industries, and plans to .d more systems for transporting workpieces between stations in flexible manufacturing systems, says AGV marketing manager Michael Dempsey.

AGVs have already found an eager market in the electronics industry, where small carriers with motorized receiving and unloading devices transport in-process inventory. At NCR's Wichita, Kans., plant, for example, two Litton carriers shuttle printed circuit boards between storage and assembly areas, providing flexibility to meet changes in production demands among the plant's three products: computer data storage devices, business minicomputers, and minis for bank and retail transactions. "If you put in any kind of hard automation like an overhead conveyor, it's there for good and you have to work around it," says Peter Sommerville, plant utomation engineer.

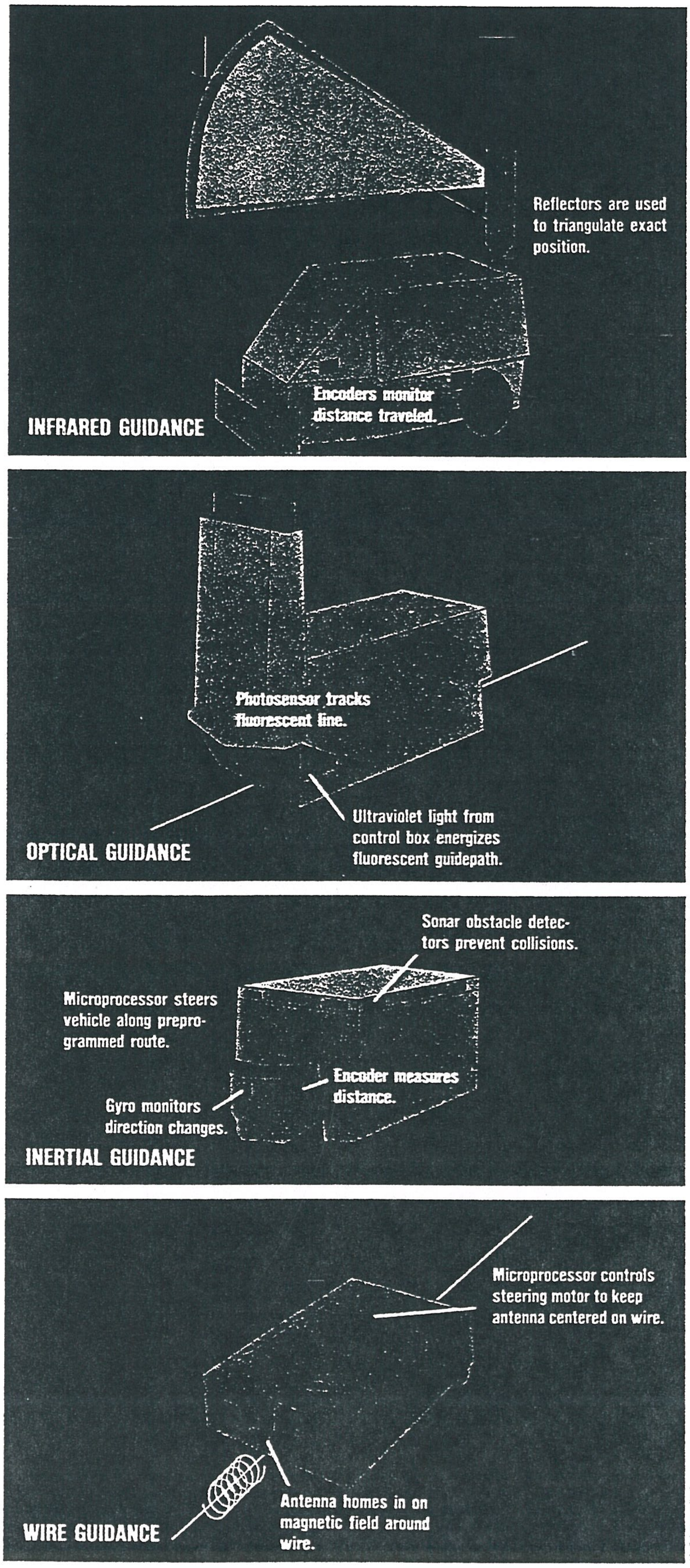
NCR's system is relatively simple as AGV installations go: there is no host computer; instead, the two carriers have keypads for the manual entry of destination codes before each run. Sommerville reports that even this modest system has yielded a significant reduction in inventory. (Since delivery time is faster, fewer parts are needed to fill the pipeline between storage and production areas.) Also, the simplicity of the system allowed it to be integrated smoothly into the Wichita facility; guidepaths were installed . weekend, workers trained in a day.

At Magnetic Peripherals, the Minneapolis manufacturer of hard disk drives, Litton optically guided carriers are used in a cleanroom, where special flooring rules out embedded wires. "We've made a multitude of changes in our assembly process, and the system has been able to accommodate them in a matter of minutes," says Rick Heupel, manager of module production for the Large Disk Division. Now the company is exploring the use of AGVs as cleanroom assembly platforms for manual workstations. (So far, electronics manufacturers have used AGVs largely for material transfer.)

The promise of such expanded applications is driving significant new developments in automated guided vehicles. GMF's longer-term strategy is to merge AGV's with robots, says vice-president Jimmy L. Haugen. Carriers with robot arms that load and unload themselves eliminate the need for separate machines or laborers at each stop where parts must be transferred. Gerald D. Michael, manager of Arthur D. Little's Manufacturing Automation Technologies Unit in Cambridge, Mass., expects to see more ventures between robotic and AGV suppliers like that between GMF and Eaton-Kenway.

Hybrids of AGVs and robots are already on the market. Automation vendor Flexible Manufacturing Systems of Los Gatos, Cal., has sold - of its Mobile Transport Units, consisting of AGV coupled with a six-axis robot from Intelledex (Corvallis, Ore). Although it claims

STAYING ON COURSE



facturing Systems of Los Gatos, Cal., has sold four of its Mobile Transport Units, consisting of an AGV coupled with a six-axis robot from Intelledex (Corvallis, Ore). Although it claims that adaptations for other industries are coming, Flexible Manufacturing so far has targeted electronics companies, pitching its Mobile Transport Unit to microchip makers as part of a computer-integrated manufacturing concept. The carrier is specially designed to transfer silicon wafer cassettes or other cleanroom containers between workstations. It is dispatched and controlled by a central computer that communicates with the carrier via an infrared signal system. According to independent tests conducted for the company, wafers transferred by the robot carrier have one-tenth to one-third the particle contaminants of manually handled wafers.

Positioning accuracy has been a nagging technological hurdle to affixing robots to AGVs: the robot must be in the exact same floor position each time it arrives at a station if it is to accurately carry out its programmed task. Flexible Manufacturing solves this problem with an optical docking method that automatically compensates for minute deviations in carrier position. As the vehicle approaches a station, a laser on its front illuminates a one-inch strip of mirror attached to the dock. Photosensors, also on the front of the carrier, detect the reflection from the mirror's two outside edges, yielding the angle between the center line of the carrier and the edges of the mirror. With these data, the AGV's on-board microprocessor computes the deviation of its center line from its intended position and makes appropriate adjustments.

"Industrial robotics and industrial AGVs are merging," says ADL's Gerald Michael, although extensive use is three to seven years away.

But the coming wave of AGV technology is self-navigating carriers. "There's a big incentive to eliminate those guide wires," says Arthur D. Little's Michael. Laying guide wire is disruptive and costly, and some surfaces, like the wood-block floors of older factories or the floors of machine shops where metal chips accumulate, don't accommodate embedded wires.

Already, some wire-guided systems have limited off-wire capabilities. For instance, the Conco Tellus Tele Carrier system permits off-wire repetition of maneuvers performed on-wire. Carrier wheels are equipped with encoders that store routine distances in the carrier's computer memory. Then, if a carrier is traveling down an aisle and turning right at, say, 12-foot intervals to service pickup-and-delivery zones that are five feet off the aisle, the host computer can instruct the vehicle to repeat the maneuver at the end of the guidepath instead of turning to follow its loop. Off-wire capabilites can reduce system costs substantially when a large number of pickup-and-delivery spurs off the main guidpath are needed, says Portec's Michael Dempsey. For instance, a Portec system for a food-processing plant in the southeastern U.S. has about 1000 off-wire points. "Otherwise we would have had to cut spurs to 1000 stands," says Dempsey.

AGV systems that communicate via in-floor wiring lose touch with carriers that leave the guidepath. However, Barry Timmerman, AGV marketing manager for Conco Tellus, says that the company's system maintains constant contact by radio. To avoid signal interference, he says, data are transmitted over a special FCC-licensed band that is free of other commercial broadcasts and high enough to be isolated from the electromagnetic interference given off by production equipment. The low-power (2-watt) system is largely confined within factory walls.

But wire-guided AGVs can't stray more than about 20 feet from their guidepaths, says Timmerman. Any farther and the carrier's encoder could be fooled by such things as wheel slippage, which could result in an inaccurate distance reading.

The coming wave of autonomous AGV systems will likely compensate for such navigation errors with external reference points for navigation assistance. Flexible Manufacturing, which was the first company on the market with an autonomous carrier, uses each dock as a reference point: after a carrier calculates its docking error with the aid of Flexible's optical method, it computes the minute steering corrections needed to get it back to its true path once it leaves the dock. That path to various workstations, and around obstacles, is taught by an operator who walks it through the route. The carrier actually stores several routes in its memory, and can retrace any of them when instructed by the central host computer.

Caterpillar Industrial, the Mentor, Ohio, subsidiary of the construction equipment giant Caterpillar Tractor, is testing its inertially guided AGV system in its parent's Aurora, Ill., plant, where wood-block floors prohibit wire-guided systems. The AGVs check their positions with infrared laser scanners that read bar-code labels affixed to reference points throughout the factory. Stored in AGV memory are the position coordinates of each reference label, so a carrier's control computer is able to determine its position by triangulation based on the labels within its field of view.

Another approach is the infrared guidance system developed by The TOR Group (Saint Laurent, Quebec) and applied to its own trailer-towing AGV. Atop a mast on the TOR-VEE carrier is an infrared beacon that rapidly sweeps a vertical beam of light back and forth ahead of it. Reflectors suspended from the factory ceiling at regular (usually 25-foot) intervals above every aisle bounce return signals to an optical array in the mast. TOR-VEE navigates by scanning for and following a preprogrammed sequence of reflectors. In its computer memory is the position of the next reflector along its planned route; thus the carrier scans only where it expects to find that reflector, ignoring others that are not in the proper position. Once it's locked onto its target, the carrier can more precisely calculate its distance from that reflector, pinpointing its position within the factory.

Since TOR's database contains a "roadmap" of all the reflectors within the factory, new routes can be made on the fly. A new sequence of reflectors is programmed into a control computınd downloaded via the system's infrared cal communication link. (Research at TOR s to develop artificial intelligence for carrier igation that will permit a vehicle to select its rc once a destination is entered.) One wback to infrared communications, howev- s that it requires line-of-sight positioning veen carrier and data transmitter; com- ıds must wait until TOR-VEE crosses a desig- ed communication point.

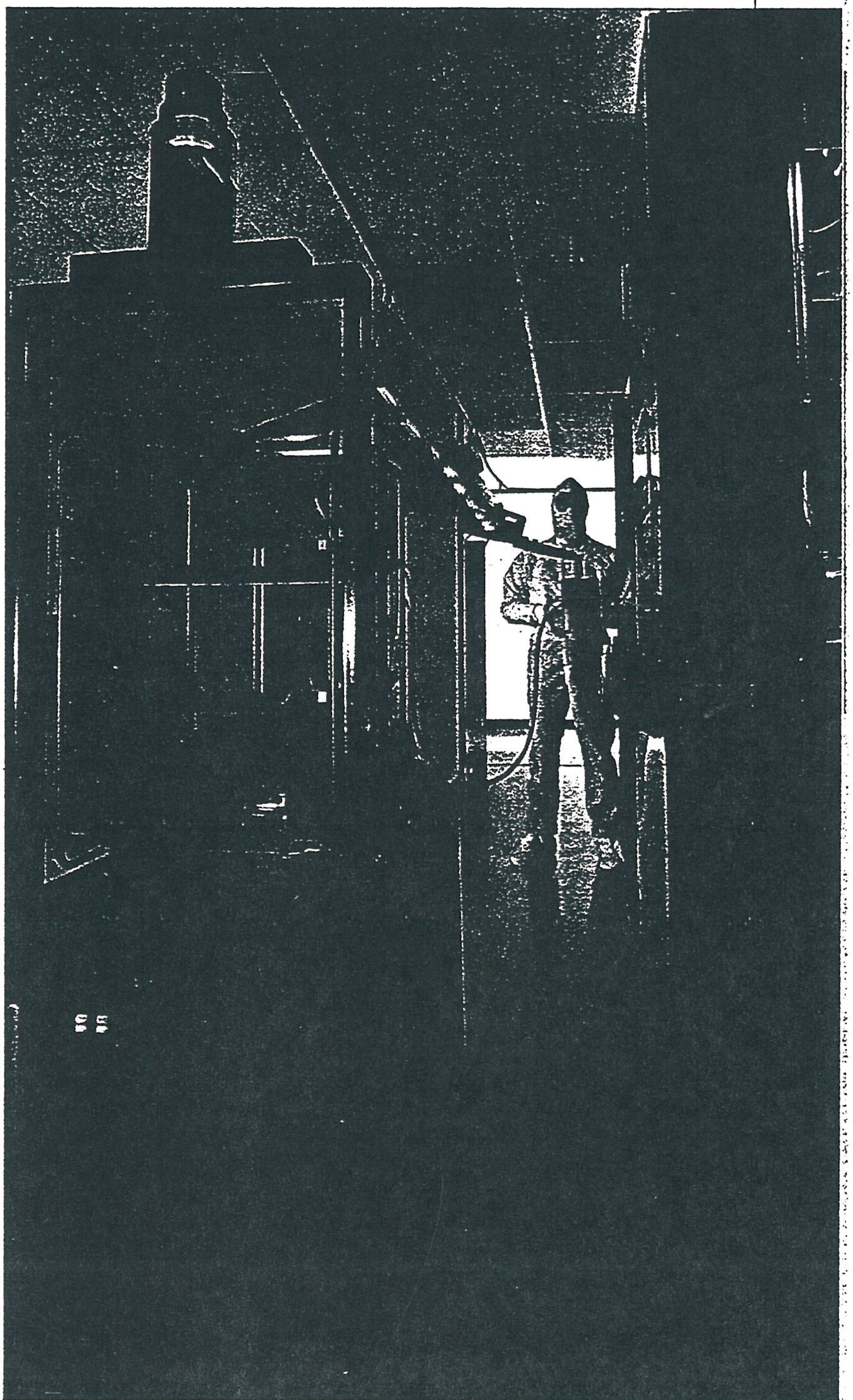
he TOR-VEE system is being well received by ıufacturers who can't use wire guidance, rding to David M. Osborne, manager of 's U.S. operations, in Farmington Hills, h. In one plant, a TOR system crosses a steel vbridge over a sunken railroad track; in her, metal tailings on the floor around ses would interfere with wire guidance. "A of times the reason we get jobs is because e isn't any other way to do it," Osborne says. , for long distances the installed cost of $1 foot of travel for TOR's reflector system pares favorably with the $8–$10-per-foot for re guidepath installation, he says.

ıt AGV assembly systems, the guidepath ıly a small percentage of total system cost. iers, used in such large numbers, represent highest cost. And in individual price per ier, wire-guided vehicles have an advantage self-navigating ones, which require more ıisticated sensing and computing power are still in an emerging stage).

hat's more, self-navigating automated ed vehicles provide more flexibility than is ılly eded in an assembly operation, re, laid out, AGV routes are not likely ıange, since the massive workstation equip- t they service can't be moved and rear- ed anyway.

ıerefore industry analysts and AGV vendors e expect wire-guided systems to continue to inate the AGV assembly-system market. ever, in materials-handling applications— arket considered less mature—the added bility of self-navigating systems has a big- payoff. Storage and retrieval areas, for in- ce, en have a large number of possible es that can be costly and difficult to reach vire. And because materials-handling sys- s generally require far fewer carriers than mbly systems do, cost per carrier is less a or.

oreover, while the market for assembly systems is hot today, it will reach a satura- point, predicts Arthur D. Little's Michael, e only a limited number of products are able for AGV assembly. Anything much er than a car, he says, is unmanageable for iers. And when products are much small- like toasters or dishwashers—their value is too little to justify the additional expense GV assembly systems over a simple, light- conveyor. When this saturation point is hed, says Michael, the market for driverless erials-handling carriers in warehousing, ica and even offices should have ma- d enough to pick up the lost momentum of mbly systems.



EDDIE SHVARTZMAN

By reducing human handling, the self-navigating, self-loading robot AGV of Flexible Manufacturing Systems greatly lessens cleanroom contamination.

Thus, many suppliers of automated guided vehicles are setting future sights on material transfer applications. Says Volvo president Anglewicz, whose company is beginning its first forays into materials handling, "That market is a tremendous opportunity." □

Jeffrey Zygmont is a senior editor of HIGH TECHNOLOGY.

For further information see RESOURCES, *p. 68.*

Time Delay Spread and Signal Level Measurements of 850 MHz Radio Waves in Building Environments

DANIEL M. J. DEVASIRVATHAM, MEMBER, IEEE

Abstract—**Time delay spread and signal level measurements of 850 MHz radio signals were made over inside-to-outside radio paths at two residential locations and an office building. Root mean square time delay spreads of up to 420 ns were encountered in residential environments. However, when a direct path was present, this improved to less than 325 ns overall, and even to 100 ns at one residence. Received power levels were around −40 dB, with respect to levels received at 0.3 m antenna separation, under favorable conditions. In other cases, these relative levels varied from −40 to −80 dB. Median signal levels agreed well with continuous wave measurements made earlier at one site. No significant polarization dependence or floor level dependence were seen in these data.**

Introduction

THE PROPAGATION OF radio waves in and around buildings is characterized by strong multipath effects. The components of the signals reaching the receiver would usually have propagated through walls, floors or other buildings, undergone attenuation, reflection, and diffraction by structural and geographical features, and consequently arrive at slightly different times. The resulting time smear causes intersymbol interference, which limits the usable signaling rate of digital radio communications systems operating in building environments.

Time delay spreads of radio waves inside a large office building have been reported by Devasirvatham [1]. Measurements in a mobile radio setting have been made by Cox [2], [9]. Attenuation studies in houses have been reported by Cox, Murray and others [3]–[7], [10]. Time delay spread measurements in houses are not available, however.

This paper describes time delay spread and signal level measurements made at two residences and an office building, over inside-to-outside radio paths. The experiment is outlined, with examples of received signals, and the results of data analysis are presented. Some implications of the results for the design of communications systems serving buildings are discussed. More diverse measurements are needed before generalized conclusions can be attempted.

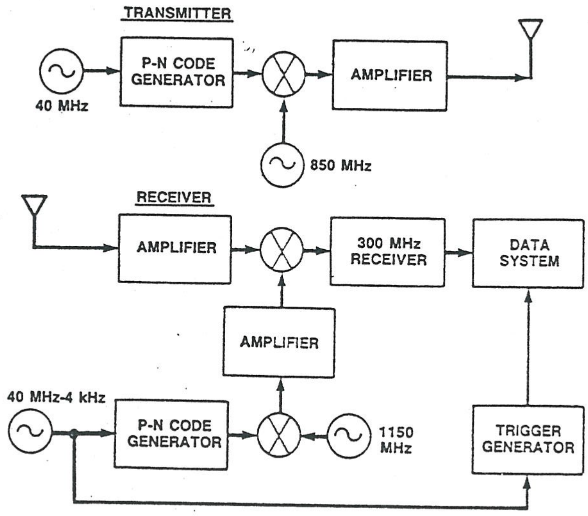


Fig. 1. Block diagram of time delay measuring system.

The Experiment

The experiment follows the method given in [2]. A block diagram is given in Fig. 1. Briefly, a 40 Mbit/s maximal length pseudonoise code generated by a 10 bit feedback shift register is broadcast by a biphase modulated 850 MHz transmitter. After multipath propagation, it is then correlated with the identical code (running 4 kbit/s slower) at the receiver. As the code generated at the receiver sweeps past the time smeared code in the received signal, the receiver output traces the power-delay profile of the received signal.

It can be shown [2] that the system is similar to a bistatic radar transmitting a set of single triangular pulses. Let n be the length of the shift register, f_c be the transmitted code rate, and d be the difference in the code rates generated at the transmitter and receiver. In the ideal case, without multipath propagation or receiver noise, the receiver output of the sliding correlation of the sequences is a triangular pulse. However, unlike a conventional radar system, the output also contains noise caused during the times that the codes were not correlated. If the average value of this noise is taken to be unity, the peak amplitude of the correlated pulse relative to the noise floor is

$$\text{pulse amplitude } p_a = 2^n - 1. \tag{1}$$

Further

$$\text{pulse base width } t_p = 2/f_c. \tag{2}$$

The ambiguity interval is determined by the time taken for the transmitted code to repeat itself, because a section of

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received code that is delayed beyond one code cycle would be indistinguishable from its copy in the current cycle of the code. Since

$$\text{code sequence length } N=2^n-1, \tag{3}$$

$$\text{ambiguitiy interval } t_a=N/f_c. \tag{4}$$

In a conventional bistatic radar system, to record this signal properly, the data acquisition rate would have to be higher than f_c. However, in this method, the effective information rate is only d, the rate at which the codes sweep past each other. This simplifies the data acquisition considerably. Thus, if the data are digitized at an interval of t_s by the data acquisition system, then for the equivalent pulse radar [2],

$$\text{effective sampling interval } t_e=t_s/k, \tag{5}$$

where

$$\text{scale factor } k=f_c/d. \tag{6}$$

The repetition time of the output trace is the time taken for the transmitter and receiver codes to slip past each other, and is given by

$$\text{trace repetition time } t_r=N/d \tag{7a}$$

$$=t_a k. \tag{7b}$$

For the system used in this study,

$$n=10 \tag{8}$$

$$d=4 \text{ kbit/s} \tag{9}$$

$$f_c=40 \text{ Mbit/s}. \tag{10}$$

Hence

$$p_a=1023 \tag{11}$$

$$t_p=50 \text{ ns} \tag{12}$$

$$t_a=25.6 \ \mu s \tag{13}$$

$$k=10\ 000 \tag{14}$$

$$t_r=256 \text{ ms}. \tag{15}$$

The ambiguity distance is about 7.7 km. The root mean square (rms) width of the equivalent pulse is 10 ns, and is a measure of the resolution of the observations.

The bandwidth of the detection filter was 10 kHz. Since the data rate is 4 kHz, any distortion introduced by this filter is minimal.

The transmitter and receiver antennas were sleeve dipoles. The transmitter power was +26 dBm into the antenna. The highest output signal-peak/noise-floor ratio was determined by the correlation noise level of the pseudonoise code, and was better than 40 dB. Due to the presence of receiver front end noise, in a few cases the output signal-peak/noise-floor ratio dropped to about 8 dB in areas of heavy attenuation of the received signal.

A trigger pulse was generated once for each complete slip of the receiver's pseudonoise code sequence past the transmitted sequence, and was used to synchronize a digital data acquisition system. The position of this pulse relative to the code sequence could be changed in order to position the output trace suitably within a chosen recording time window.

All measurements reported in this paper were made with the transmitter located inside the buildings. Its antenna was located about 1.8 m above the floor. The receiver was in the Bellcore radio research van. This vehicle is described in [5]. It has an 8.2 m antenna mast which could be raised and plumbed to be vertical. The receiver sleeve dipole was located at the top of this mast.

The receiver van was parked at locations around the building being studied. The transmitter was designated as the "scanning unit" and was moved to various locations in the building. The receiver output was digitized at an interval t_s of 10 ms per point; i.e., an effective sampling interval t_e of 1 ns per point. Two thousand forty eight points representing a time interval of 2048 ns were digitized and stored for each measurement. Care was taken to verify that no returns were visible beyond this delay.

For a given sample, the scanning unit was moved through eight equally spaced points along the perimeter of a 1.2 m square and a measurement, as defined above, was made at each point. The eight measurements were then power averaged at each time point. These averaged power-delay profiles were obtained for several different transmitter-receiver locations.

Subsequently, averaged data up to 1800 ns after the first arrival of the signal were used for analysis after ascertaining that there was no output signal beyond this point. The rest of the 2048 ns of data were used to estimate the noise floor of the signal.

While most data were taken with both antennas vertically polarized, representative samples of the data at crossed relative antenna polarizations were also taken.

The Data

Brief descriptions of the experimental sites are given below.

A. Residence 1

Residence 1 is an apartment on level 2 of a two-floor condominium complex. The unit is in a longer arm of a group of three buildings built in a U-shape, around a courtyard 40 × 30 m in size. A similar plan is followed throughout the complex. The buildings are constructed of wood, with metal vapor barriers in the walls and aluminum siding. Windows are covered with nonmetallic screens.

The receiver van was positioned, in turn, in three locations. Two were in the courtyard, 8 and 31 m from the unit, with the receiver antenna slightly above roof level; i.e., at level 3. The third was in the courtyard of an adjacent group of buildings, 82 m away, again with the antenna at level 3. However, there was no line of sight to the apartment in this case, since it was obscured by buildings. Six transmitter positions were chosen inside the apartment for each receiver location.

Fig. 2 shows a typical power versus time delay profile,

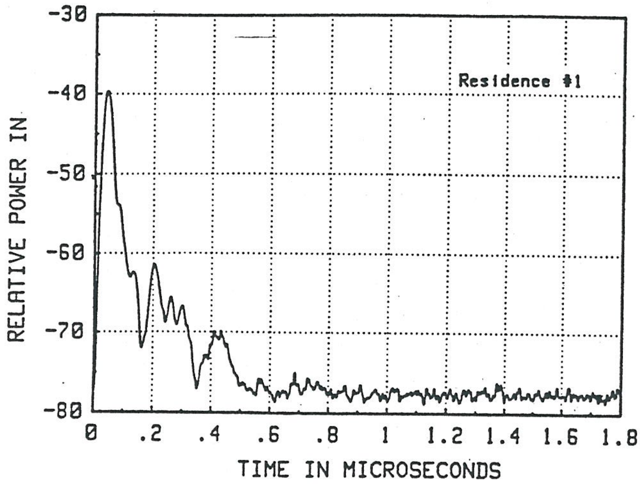

Fig. 2. Residence 1: an averaged power-delay profile with receiver in same courtyard.

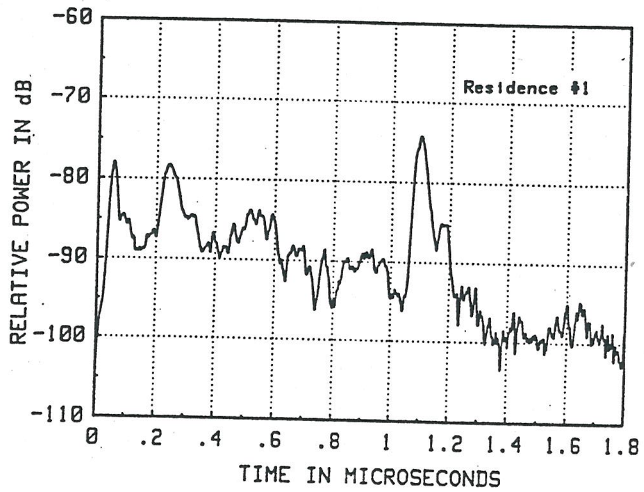

Fig. 3. Residence 1: worst-case averaged power-delay profile recorded with receiver in next courtyard. No line of sight.

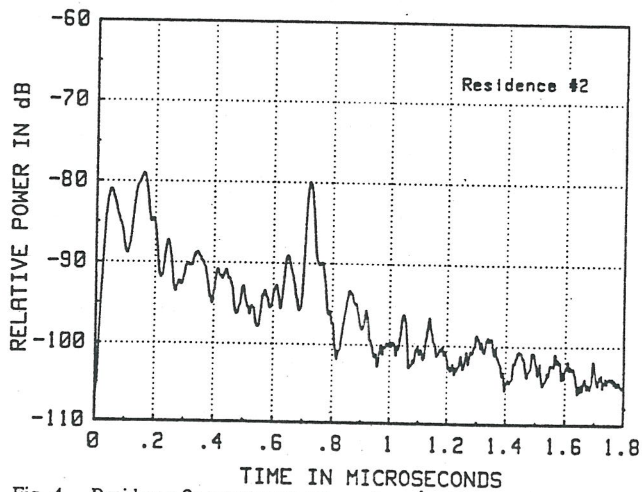

Fig. 4. Residence 2: worst-case averaged power-delay profile recorded.

Here the power levels are normalized to the peak power received when the transmitter and receiver antennas were 0.3 m apart. In the case shown, the receiver was in the same courtyard as the residential unit. A well-defined pulse is seen with very little spread, due to the strong line-of-sight path. Fig. 3, on the other hand, shows a response when the receiver van was in the next courtyard. The absence of a good line-of-sight path together with a strong reflection from another building complex, indicated by a pulse arriving a microsecond [illegible], contribute to a large spread in arrival time. The [illegible] engineering implications of this will be discussed later.

B. Residence 2

Residence 2 is a two-story house at the edge of a one-acre zoned development. It is a wood-framed house with aluminum siding at the sides and back and a nonmetallic composition siding in front. There is full foil backed insulation in the walls and the windows are covered with nonmetallic screens. The inner walls are made of sheet rock.

The receiver van was positioned at three locations, two of which were on the road running parallel to the front of the house. The third position was on a road running past houses located behind this house. There was some obstruction by other houses in the last two locations. The distances from the house were approximately 46, 168, and 114 m, respectively.

The transmitter was moved through six locations on the first level and four locations on level 2 of the house. Approximately half the locations were toward the front of the house and the other half were toward the back.

Fig. 4 shows the worst-case delay profile recorded. This was obtained at the third location, 114 m from the house and facing the rear of the house. Reflections from other houses in the area are seen to be significant.

C. Office Building

The office building studied was the AT&T Bell Laborato- [illegible] Crawford Hill Laboratory, also designated HOH. It is a medium-sized rectangular two-level structure, built against the side of a small hill behind it, in the form of an H with unequal arms. The main portion is 118 × 14 m in plan, with a 20 × 23 m perpendicular projection about 33 m from one side, extending behind it toward the hill. This connects with a 44 × 14 m section on level 2 which is parallel to the main portion. The building is served by a driveway which rises from below its level, and also winds around behind it.

The building has a steel frame and glass outer walls with metal venetian blinds on the windows. Inside, partitions are constructed from sheet rock and wooden cupboards. There is a significant amount of laboratory equipment in the rooms.

The receiver van was positioned in the driveway, both in front of the building and behind it. Due to the change of the level of the road, in the first case the receiver antenna was approximately at level 1 of the building, 69 m away. At the second position, the antenna was at about level 3; i.e., above the roof of the building and 15 m away from the rear section.

Fig. 5 shows the worst averaged power-delay profile seen during these measurements. The second of the two sets of reflections seen in Fig. 5 is delayed 0.6 μs and is believed to be due to reflections from the hill behind the building.

Analysis and Results

The root mean square time delay spread (i.e., the square root of the second central moment) of each of the averaged

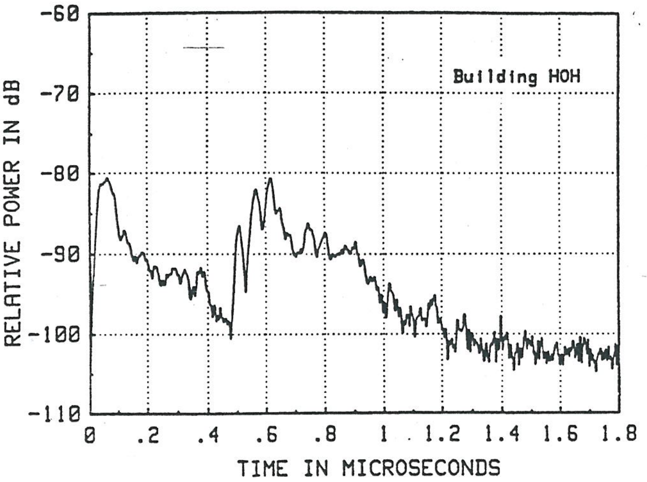

Fig. 5. Office building HOH: worst-case averaged power-delay profile recorded.

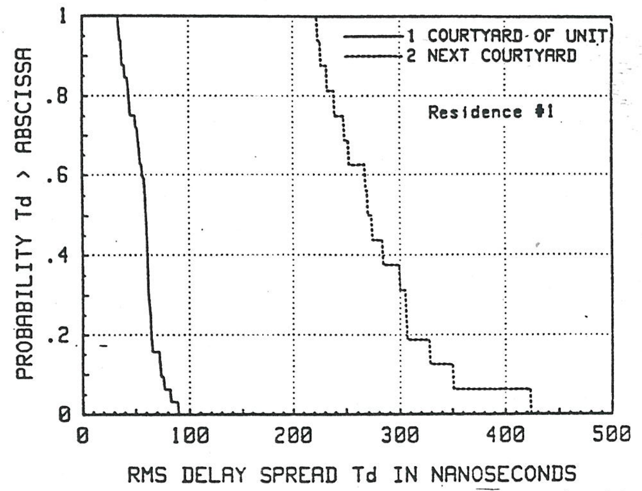

Fig. 6. Residence 1: cumulative distributions of root mean square time delay spreads at the two courtyards.

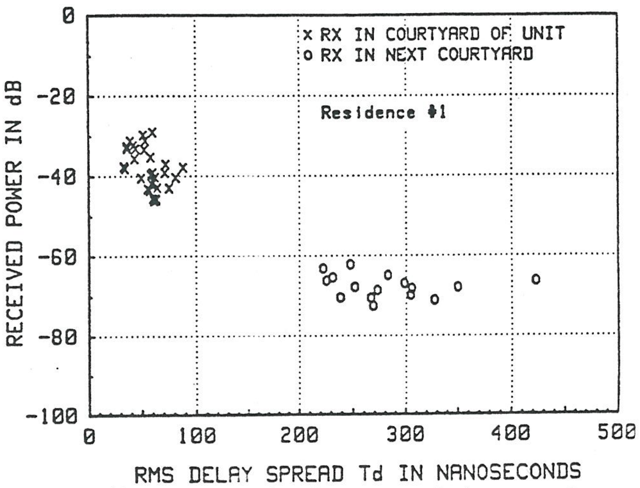

Fig. 7. Residence 1: scatter plot of average received power against root mean square time delay spread.

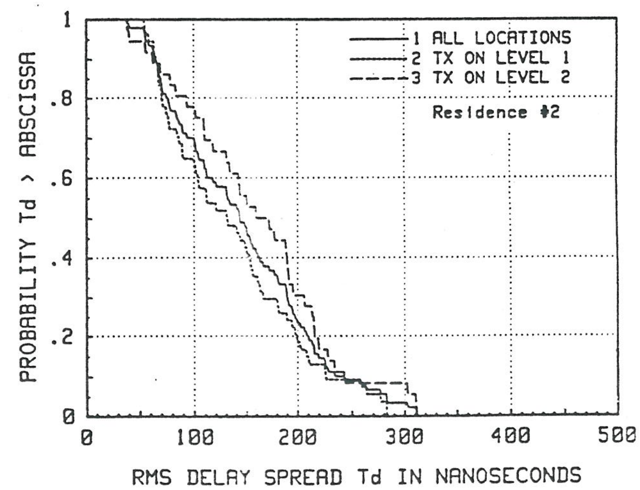

Fig. 8. Residence 2: cumulative distributions of root mean square time delay spread for the two floors of the building.

time delay profiles was calculated. Since the inverse of the rms delay spread can be defined as the correlation bandwidth of the medium, the results may be easily interpreted in the frequency domain as well [9].

The total power in each averaged profile, normalized to the power obtained when the separation between the antennas was 0.3 m, was also calculated. Since this is an average, not only over eight physical locations, but also over an 80 MHz frequency bandwidth which corresponds to many correlation bandwidths, it gives the equivalent average continuous power which would be received from a narrow-band continuous wave (CW) source when moved through the same measurement area.

The solid curve (curve 1) in Fig. 6 shows the distribution of rms delay spread at residence 1 when the receiver was in its courtyard. The maximum rms delay spread is under 100 ns. The dotted curve (curve 2) shows the rms delay spread distribution obtained when the receiver was in the next courtyard. The difference between this and the results of the solid curve is significant. The maximum rms delay spread is now 422 ns. Even the minimum rms value of 220 ns is greater than the maximum of the previous case. The absence of a line of sight, clearly, has a major impact in this location.

Fig. 7 is a scatter plot of average received power against rms time delay spread for these locations. The two sets of data are in clearly defined clusters. An additional 20–30 dB of attenuation is present at the second location.

Results from residence 2 are shown in the next three plots. Fig. 8 shows the rms delay spread distribution for all the receiver locations with the physical level of the transmitter location as a parameter. The maximum rms delay spread is 312 ns and is not significantly affected by the level on which the transmitter was located. No significant received power dependence with transmitter location level was found either. Fig. 9 shows delay spread distributions obtained when both antennas were vertical (co-pol, curve 1), the receiver antenna was horizontal and at right angles to the direction to the house (cross-pol broadside, curve 2), and finally, horizontal and pointing along the direction to the house (cross-pol end-on, curve 3), respectively. It is seen that the delay spread

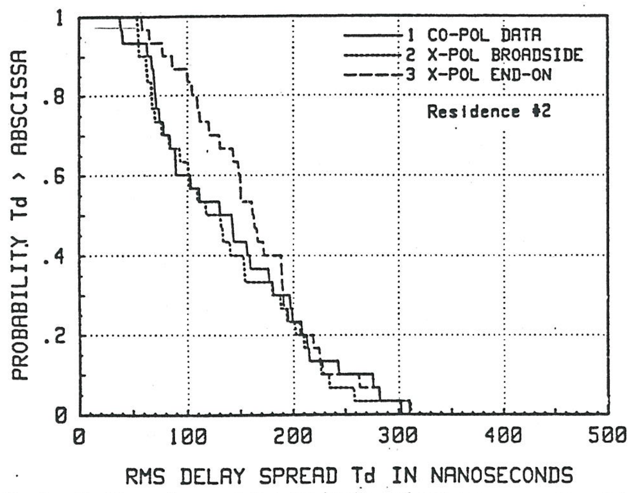

Fig. 9. Residence 2: cumulative distributions of root mean square time delay spread for the three principal relative antenna polarizations.

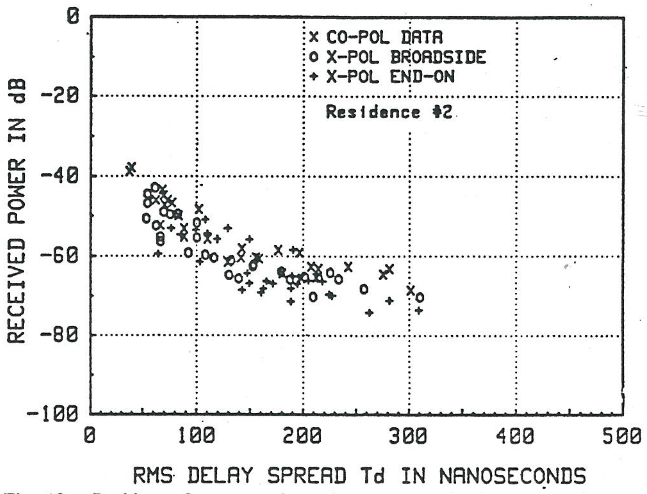

Fig. 10. Residence 2: scatter plots of average received power against root mean square time delay spread for the three principal relative antenna polarizations.

distributions are also independent of these relative antenna polarizations. The power versus delay spread scatter plots for the three polarizations, shown in Fig. 10, confirm that the data are well mixed, both in power levels and in delay spread. This agrees with the results for average power levels in CW measurements [10].

Attenuation studies made at residence 2 at 815 MHz have been reported earlier by Cox *et al.* [5, p. 937, fig. 14]. These studies were made in April 1982, using a continuous wave source. Relative signal levels obtained from the present work were compared with those of the earlier study. The median signal level relative to the level at 0.3 m antenna separation over all transmitter locations at each receiver location was found. These are shown in Table I, together with the distances from the house. The corresponding levels from the earlier study [5, p. 937, fig. 14] for the first floor and the second floor, respectively, corrected to 0.3 m reference distance, are also given. Considering the large uncertainties involved in such measurements, the results from these two different techniques are in good agreement.

The distributions of rms delay spread obtained for the inside-to-outside measurements at the office building are shown in Fig. 11. The maximum rms delay spread is now 321 ns. Both levels of the building give comparable values of delay spread. The power versus delay spread scatter plots for the data at this location, shown in Fig. 12, confirm that the relative received power levels are not significantly different at the two physical building levels.

TABLE I
COMPARISON OF WIDE-BAND AND NARROW-BAND SIGNAL LEVELS RELATIVE TO LEVEL AT 0.3 m ANTENNA SEPARATION

DISTANCE (meters)	RELATIVE SIGNAL LEVEL (dB) WIDEBAND	CW 1ST FLOOR	CW 2ND FLOOR
46	-52	-49	-54
114	-64	-62	-64
168	-68	-69	-69

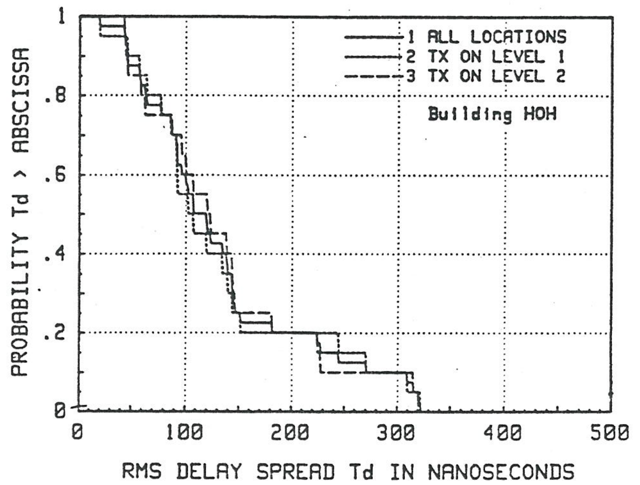

Fig. 11. Office building HOH: cumulative distributions of root mean square time delay spread for the two floors of the building.

Discussion

Some broad generalizations may be drawn from the results given above. If substantiated by further measurements, they could have useful implications for the design of universal personal communications systems [11].

The importance of base station antenna location is well illustrated by the results of residence 1. If the units around a courtyard are served by an antenna placed in that courtyard, then, using a worst-case rms delay spread of 100 ns, it is indicated in [8] that a data rate of 800 kbit/s could be supported at an irreducible error rate of 0.001. This assumes binary DPSK modulation with raised cosine pulses over such a nonequalized channel.

Rms delay spreads of up to 312 ns could support a maximum data rate of 250 kbit/s for 0.001 error probability in residence 2 for the same type of signaling [8].

It is interesting to note that the worst-case rms delay spread obtained at the office building is of the same order as the result from residence 2. It is also greater than the delay spread observed within another, much larger office building [1]. This result would not have been expected from an inspection of the

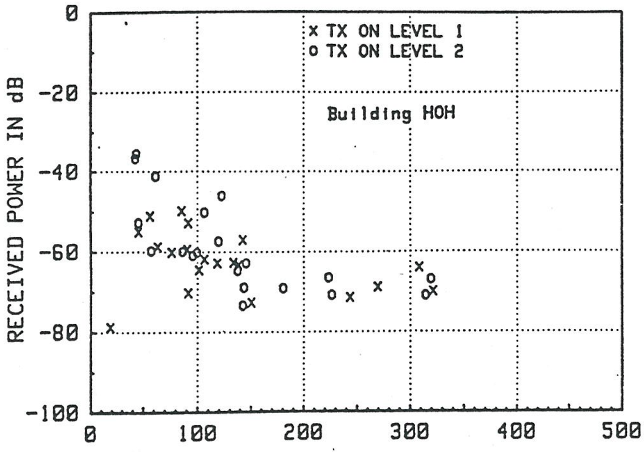

Fig. 12. Office building HOH: scatter plots of average received power against root mean square time delay spread for the two floors of the building.

sites alone. Thus, it would be useful to determine if a worst-case rms delay spread of around 450 ns is a reasonable upper bound for outside coverage of buildings in general. Measurements in the 300 to 500 m range are also needed [11].

Summary

Time delay spreads and signal level measurements were made at two residences and a medium sized office building. In all cases, the propagation paths were from within the building to a simulated base station outside the building. Worst-case rms delay spreads of less than 325 ns were obtained for both the office building and the one-acre zoned house. This could support digital data rates of up to 250 kbit/s for 0.001 error probability, using binary differential phase shift keying (DPSK) modulation. Received signal levels were between 40 and 80 dB below the levels received at 0.3 m antenna separation.

The residence located in a medium-density complex showed a worst-case rms delay spread of under 100 ns when the base station was located to serve its neighborhood with a line-of-sight path to the residence. Received power levels were then 30 to 50 dB below the level at 0.3 m separation. This delay spread could support data rates of 800 kbit/s for 0.001 error probability using binary DPSK. The rms delay spread increased up to 422 ns when there was no line of sight. These measurements demonstrated the importance of an unobstructed path from the base station antenna to the building being served.

Acknowledgment

This work was done with the guidance of H. W. Arnold and D. C. Cox. The measurements were made with the assistance of R. R. Murray and M. J. Krain. The data at Crawford Hill were gathered entirely by them. The permission and patience of the occupants of the buildings studied are gratefully acknowledged.

References

[1] D. M. J. Devasirvatham, "Time delay spread measurements of wideband radio signals within a building," *Electron. Lett.*, vol. 20, no. 238, pp. 950–951, Nov. 1984.

[2] D. C. Cox, "Delay doppler characteristics of multipath propagation at 910 MHz in a suburban mobile radio environment," *IEEE Trans. Antennas Propagat.*, vol. AP-20, no. 5, pp. 625–635, Sept. 1972.

[3] H. H. Hoffman and D. C. Cox, "Attenuation of 900 MHz radio waves propagating into a metal building," *IEEE Trans. Antennas Propagat.*, vol. AP-30, no. 4, pp. 808–811, July 1982.

[4] D. C. Cox, R. R. Murray, and A. W. Norris, "Measurements of 800 MHz radio transmission into buildings with metallic walls," *Bell Syst. Tech. J.*, vol. 62, no. 9, pp. 2695–2717, Nov. 1983.

[5] D. C. Cox, R. R. Murray, and A. W. Norris, "800 MHz attenuations measured in and around suburban houses," *AT&T Bell Lab. Tech. J.*, vol. 63, no. 6, pp. 921–954, July 1984.

[6] S. E. Alexander, "Characterizing buildings for propagation at 900 MHz," *Electron. Lett.*, vol. 18, no. 21, pp. 913–914, Oct. 1982.

[7] ——, "Radio propagation within buildings at 900 MHz," *Electron. Lett.*, vol. 19, no. 20, p. 860, Sept. 1983.

[8] W. C. Jakes, *Microwave Mobile Communications.* New York: Wiley, 1974, pp. 236–240.

[9] D. C. Cox and R. P. Leck, "Correlation bandwidth and delay spread in multipath propagation statistics for 910 MHz urban mobile radio channels," *IEEE Trans. Commun.*, vol. COM-23, no. 11, pp. 1271–1280, Nov. 1975.

[10] D. C. Cox, R. R. Murray, H. W. Arnold, A. W. Norris, and M. F. Wazowicz, "Cross polarization coupling measured for 800 MHz transmission in and around houses and large buildings," *IEEE Trans. Antennas Propagat.*, vol. AP-34, pp. 83–87, Jan. 1986.

[11] D. C. Cox, "Universal portable radio communications," *IEEE Trans. Veh. Technol.*, vol. VT-34, pp. 117–121, Aug. 1985.

Daniel M. J. Devasirvatham (S'77–M'81) was born in Sri Lanka in February 1949. He obtained the B.S.E.E. degree from the University of Sri Lanka, Peradeniya, and the M.S.E.E. and Ph.D degrees while a Fulbright-Hayes Scholar at The Ohio State University, Columbus, OH.

His research included microwave and millimeter wave propagation in turbulence and in rain, on earth-space paths. He also worked on radar/radiometric studies of radio propagation in rain. He returned to teach at the University of Sri Lanka. He was later a Director and Research and Development Manager, of a group of computer companies in Sri Lanka. He is now a Member of Technical Staff in the Radio and Satellite Systems Research Division of Bell Communications Research Inc., Red Bank, NJ. He is currently studying radio propagation in and around buildings. He is also working on the development of multiprocessor based real-time control systems for universal digital personal communications systems of the future.

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October 24, 1986

Second Nordic Seminar on Digital Land Mobile Radio Communication October 14-16, 1986 -- Stockholm

Report to IEEE Standards Committee 802.4L
By C. A. Rypinski

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Second Nordic Seminar on Digital Land Mobile Radio Communication October 14-16, 1986 -- Stockholm

Report to IEEE Standards Committee 802.4L
By C. A. Rypinski

1. SUMMARY

Many technical matters, relevant to radio medium local area network technology, were discussed at this meeting. Most presentations were by major European, Japanese and US companies and by European Telecom administrations. In addition, participants in CEPT, CCIR and CCITT were present. There were 550 attendees including less than 20 from USA.

Of relevance to the 802.4L committee, were a number of papers analyzing multipath propagation and the equalization of its degrading effects, diversity methods and error correcting coding using in the medium kilobaud rates of 250-350 and 1500-2000 at 900 MHz. In addition, one paper addressed the relationship of the protocols to the 7 layer model and related software. Some of the discussion was directed to very high service densities requiring very small cell dimensions.

A surprise was that most authorities were advocating a mixed TDMA/FDM system with a 250-350 kilobaud rate in the medium which was generically called "narrowband TDMA". (There was no advocate for a pure FDM system.) A number of presentations were concerned with adaptive equalizers for this type of system. "Broadband TDMA" characterized systems operating at 1 megabaud and higher rates.

Many papers attempted comparative evaluations of the proposals eventually ending with a conclusion in capacity per square kilometer per MHz of spectrum.

There was no mention whatever of local area network functions or interfaces, however it was commonly assumed that ISDN compatibility inherently provided any necessary capability.

1.1. Discussion of Papers

The discussion in the text portion of this report is a compilation of reported propagation, modulation methods, signal spectrum, channel coding and error rates, and adaptive equalizers arranged by subject. In addition, there is a section on "broadband TDMA" related to megabit rate propagation and processing.

1.2. Attachments

25 selected papers (out of 75) are copied and attached as printed for the proceedings. Certain figures and quotations are taken from these for use in the discussions above. Also, the agenda for the meeting is copied with titles and authors for use as a Table of Contents showing the Paper No. used in the references in the discussion above. The last page in the attachment shows the USA attendees.

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2. DISCUSSION OF PAPERS

Almost all submissions were concerned with high error rates resulting from multipath propagation using conventional modulation and no special coding; and they proposed many methods to overcome this difficulty improving from 10^-1 to 10^-2 BER to 10^-3 to 10^-4 packet error rate.

"It is concluded that powerful means of signal processing are necessary to safeguard digital land mobile radio communication systems operating at transmission rates of several hundred kbits/s." -- **Lorenz, Bundespost, FRG [49]**

"As the transmission is increased beyond the coherence bandwidth of the radio channel, the frequency selective fading becomes apparent with significant impairment in transmission unless it is mitigated by added signal design and receiver processing. It can be viewed as a natural diversity provided by the channel and perhaps harnessed, to improve the radio systems performance." -- **Bajwa, TSCR, UK [46]**

"It was found that the multipath characteristics and the corresponding coherence bandwidth for digital data transmission is extremely dynamic with large variations." -- **Szabo, SEL, FRG [53]**

The primary methods of offsetting multipath errors were coding, diversity and modulation/detection technique. Methods were proposed for making use of multipath to obtain a form of diversity transmission.

2.1. Cellular System Concept

The cellular concept provides a wide area service from whatever number of sites is required. If frequency space is limited, larger capacity is obtained from more sites and more closely spaced reuse of the same frequencies. In the beginning, radio sites with a service radius of 10 km or more is reasonable; but as saturation is approached, the coverage radius of cells may be decreased to 2 km or less. "Small cells" are associated with higher frequencies, interiors of buildings and low transmitter power. Also the absolute magnitude of multipath delay spread is less in "small cells."

A primary consideration in small cell design is the frequency reuse factor in a regular cell pattern system layout. Conventional analog telephone systems use a pattern of 21 groups in conservative designs and 12 in aggressive designs. The speakers arguing for digital technique, which inherently takes more frequency space for the same information, all depend on a lower requirement for desired/undesired signal level ratio with digital than with analog modulation. Reuse factors of 3 to 9 are typical. Some plans depend on a statistical character for interference that is offset by channel coding or diversity.

No. channels per cell = No. channels available / Reuse factor

<u>If the 802.4L group were to settle on small cells (radio context) dimensioned to cover cells (manufacturing context), stock areas, aisles, lines and arteries inside a building, as might be necessary for microwave or very low power operation, a frequency reuse type of plan would be essential.</u>

"The minimum cell radius is limited to 2 km because of nonpredictable propagation characteristics (which) may occur inside buildings etc. To this end it is essential to use a modulation format which is robust against cochannel interference which will determine the no. of adjacent cells in which a particular frequency can only be used once (frequency reuse factor)." -- **T. Maseng, ELAB, Norway [19]**

"If we have to utilize higher frequency bands, for example in a microwave region, radio zone radius may be limited to 100 meters with transmitting power of 1 watt. In such a case, a new concept referred to as 'Tree Radio Zone' may be considered, in which each radio zone looks like a tree instead of a hexagonal cell, as shown in Fig. 4." -- **Ikegami, Kyoto University, Japan [6]**

"On the other hand, the lower powers and lower antenna masts of a dense personal system create an environment with lower delay spread; and in so doing, systems using Time Division Multiplexing become more attractive." -- "For providing universal portable communications, the separate circuits at the ends of the the telephone loops can be provided using low-power digital radio links for the last 300-500 meters." -- **D. C. Cox, H. Arnold, P. Porter; Bell Communications Research, USA [43]**

2.2. Bit Error Rate Comparisons

Bit error rate comparisons must be made on a channel with fast **Rayleigh** fading resulting from changes in position of the order of a radio wavelength (25 cm). For analytical purposes, a two-ray model with worst-case phase relationship and various relative amplitudes is often used. (See **Svensson [19]**) More complex models have been used, and experiments conducted as propagation studies. For laboratory experiments, complex fading simulators have been built.

Because the reflectors causing multipath are not stationary, nor is the dielectric medium through which the signals pass stable, Rayleigh fading occurs when vehicles are stationary. One inducement to use frequency-hopping schemes is to avoid the possibility that a stationary vehicle is at a singular low-signal location.

Most reports on methods of improving BER show a reference level before the improvement. This reference could be the Shannon relation, but it is more often a conventional modulation without benefit of the particular aids described. Reference modulations are commonly a smoothed phase transition form of MSK referred to as GMSK or TFM.

Reference Definitions

MSK is Minimum Shift Frequency Keying invented by M. L. Doelz and described in U.S. Patent 2,977,417. He teaches that the minimum separation of the two frequencies for frequency shift keying is one-half the baud rate. Expressed in another way, the accumulated phase shift during one bit interval must be at least 90 degrees different for the two possible frequencies.

TFM is "tamed FM" disclosed by F. de Jager and C. B. Dekker ("Tamed Frequency Modulation--A Novel Method to Achieve Spectrum Economy in Digital Transmission," IEEE Trans. Commun. vol. CM-20, May 1978) The technique is frequency shift with non-instantaneous, gradual changes in phase under keying and changed always in the direction with the least discontinuity from previous keying transitions.

GMSK is Gaussian-filtered MSK. It is described by K. Murota et al ("GMSK Modulation for Digital Mobile Radio Telephony," IEEE Trans. Commun. CM-29, July 1981). The logical keying signal is passed under a Gaussian shaped lowpass filter before application to a voltage controlled oscillator.

R. J. C. Bultitude, Communications Research Centre, Canada [45]

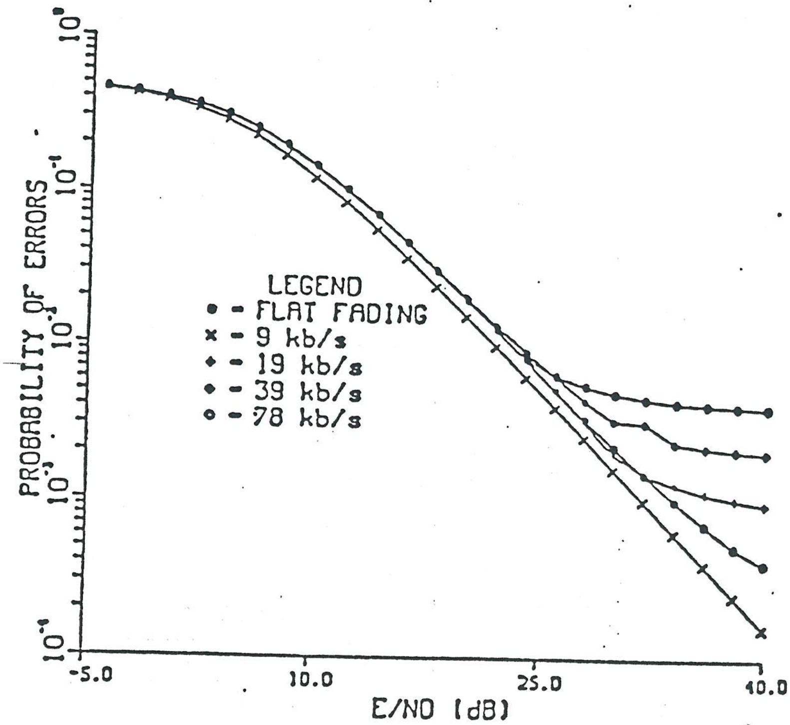

Fig. 7. Probability of error predictions for the experimental DPSK system operating along the first street section.

For each street section the probability of error as a function of average bit energy to noise ratio was calculated using equations derived in this paper for data rates ranging in one octave steps from 9.765 kb/s to 78.125 kb/s. Accepted flat fading equations for DPSK [10] were modified [11] to make use of envelope fading data derived from the impulse response estimates, and flat fading performance characteristics were also computed for comparison purposes. Figure 7 shows results for the first street section. Only small differences from these results were shown in performance curves for the other street sections in the measurement area. The figure shows that the channel can be classified as a flat fading channel for data rates below about 10 kb/s. In addition, there is excellent correspondence between the flat fading curve calculated using well known equations, and the 9.765 kb/s curve. This is considered confirmation of the new techniques for error prediction presented in this paper. Above 10 kb/s the performance characteristics show that the channel is frequency-selective, and intersymbol interference effects rather than noise set the lower boundary for error performance. This lower boundary is seen to be independent of E/N_0, and increases monotonically with increasing data rate, for data rates greater than that for which the channel is frequency-selective. Comparison of computed performance characteristics with the shape of measured spaced frequency correlation functions showed that the flat fading/frequency selective boundary is, on average, at a transmission bandwidth (twice the data rate for the system discussed here) which is about eight percent of the frequency separation from the reference at which the real part of the spaced frequency correlation function decreases to a value of 0.5

T. Naerhi, Telecommunications Laboratory, Finland [21]

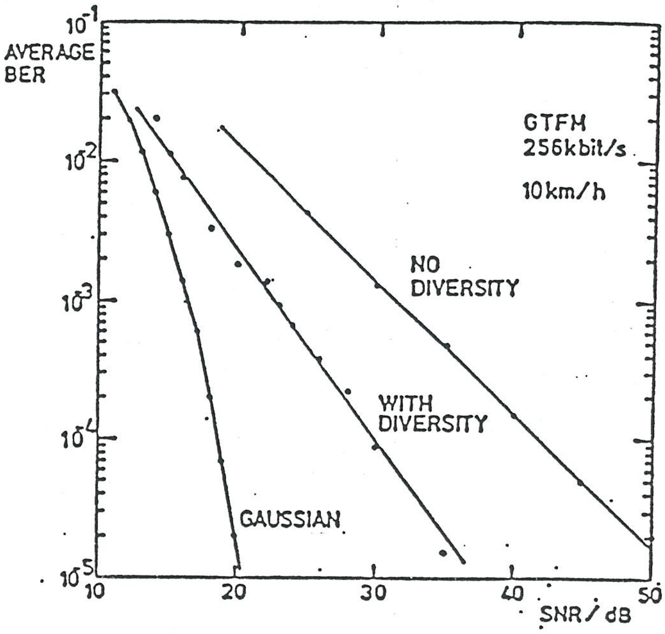

Fig. 13

4 BER MEASUREMENTS AT 256 kbit/s

In the recently started experimental program switched diversity is being implemented in a narrowband TDMA experimental system. Figure 13 shows the first results from these measurements, where GTFM-modulated data at 256 kbit/s (without TDMA structure) is transmitted through the simulated Rayleigh fading channel. In the receiver non-coherent discriminator detection is used together with a bit-by-bit decision method. The figure shows BER vs. signal to noise ratio (SNR) in the Gaussian channel and in the fading channel with and without switched diversity at the vehicle speed 10 km/h. With the switching threshold adjusted to the optimum value, the improvement in the average BER is 5...6 dB at BER = 10^{-2} and 8...9 dB at BER = 10^{-3}.

2.3. Radio Propagation

Enough has been said about bit error rate to establish that a problem exists. Suitable remedies depend upon understanding the nature and dimensions of the distortions in the channel. The studies presented explored short and medium distance and a range of time resolution that would include megabit baud rates.

Correlation in time and frequency is an important matter. There is an indication that if an adaptive equalizer is set at the beginning of a packet, the settings will remain valid for 0.1 to 1 millisecond. It is also known that the transmission is level only over a narrow frequency band. Megabaud bandwidths may be strongly non-uniform across the bandwidth. Depending on the detection method and modulation, this can be advantage or disadvantage.

The main subject of **Bultitude [45]** is dimensioning the correlation of changes in frequency and location as a propagation calculation and experiment. The parameters obtained can be used to calculate BER as a function of symbol rate.

R. W. Lorenz, Bundespost, FRG [49] reports average power delay profiles, frequency correlation function, transfer function/impulse response calculated from the average power delay profiles for New York (Cox) and Berne. His work is related to 100 kbs BPSK and 200 kbs QPSK.

Comparisons of signal level variation in bandwidths of 25 kHz and 8 MHz are given by **L. Szabo, Standard Electric Lorenz, FRG [53]**. His conclusions are show below:

> "The measured maximum width data show that delays beyond 8 microsec are very seldom and there are no substantial differences in the various degrees of urbanization. The observed maximum delays are up to 32 microsec. It seems that values in excess of 8 microsec are comparatively rare. The maximum width has a relatively higher probability between 1 and 5 microsec.
>
> Based on the measurements (more than 6000 impulse response recorded in different German cities and environments) the following statistical weighted results are detected: (The amplitude resolution for the paths is limited to 20 dB.)
>
> * Maximum width caused by multipath is less than 7 microsec for 99% of the records.
> * The strongest path is positioned in the first 2 microsec of the received structure in 90% of the cases.
> * The strongest path is definitely not the first path in about 30% of the records.
> * The main signal energy is concentrated in the first 3 resolvable paths and in the first 5 microsec for 99% of the records.
> * The paths in the first 2 microsec are mainly Rayleigh-fading loaded.
> * The paths more than 4 microsec behind the time of arrival are more stable."

2.4. Diversity

Well known diversity techniques depend upon a second antenna or transmitter to enable selection of the best of more than one propagation path. With a single transmitter and two receiving antennas (with sufficient spacing to have a low level of level correlation) switch selection or linear combining are both possible and used.

As shown on page 5, Naerhi [21] observes considerable advantage for a two-antenna, selection diversity receiver in a handheld unit at 256 kbs. He concludes:

> "With the switching threshold adjusted to the optimum value, the improvement in BER is 5-6 dB at BER 10^-2 and 8-9 dB at BER 10^-3."

The subject of diversity selection is presented in considerable detail by L-F. Chang, H. Arnold, R. Bernhardt and P. Porter of Bell Communications Research [24]. The system they offer uses two-antenna selection at both fixed and mobile terminals, and the selection is based on error detection in the channel coding. They conclude:

> "As has been shown many times before, diversity is a very effective way to mitigate the wide variability in the instantaneous signal in the radio environment; a system with 3-branch macroscopic diversity can be 20 dB or more superior to one with no diversity, and diversity against Rayleigh fading adds even more advantage. Conversely, at the same quality level, a system with diversity can use much larger coverage areas and smaller capital investment. As a result, diversity can be considered a system necessity."

Their Figures are shown below and on the following page.

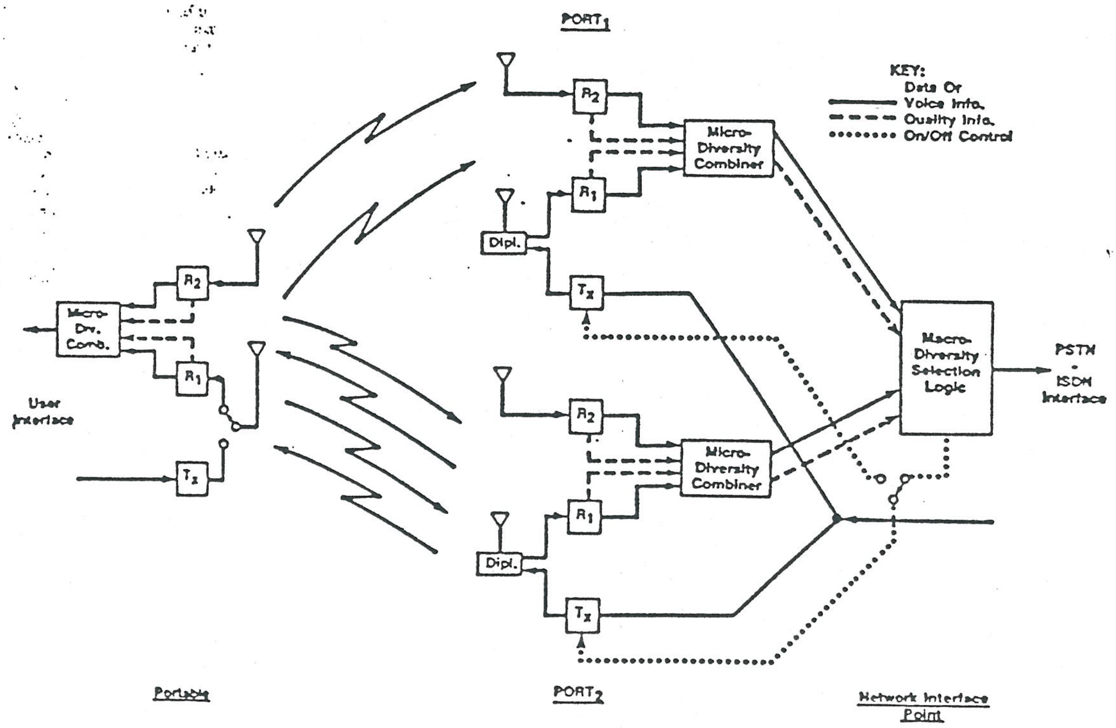

Fig. 1 Functional Block Diagram of the Diversity Selection Process

L-F. Chang, H. Arnold, R. Bernhardt and P. Porter, Bell Communications Research, USA [24]

Figures showing probability of word error vs. average SNR per branch (5 dB/div)

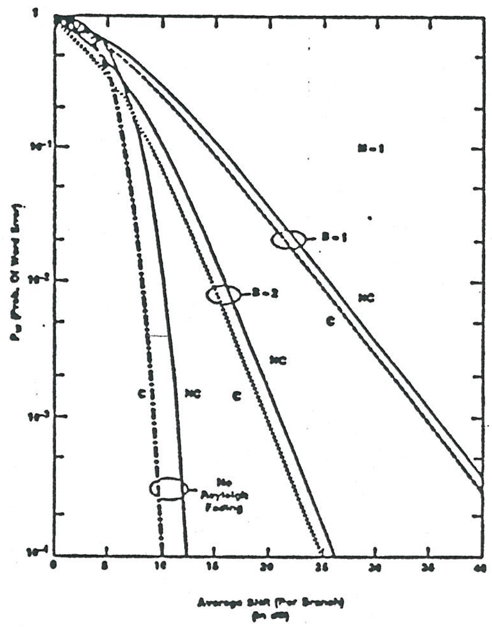

Fig. 2 Performance of a BCH(31, 21, 5) Code -- Selection based on Power

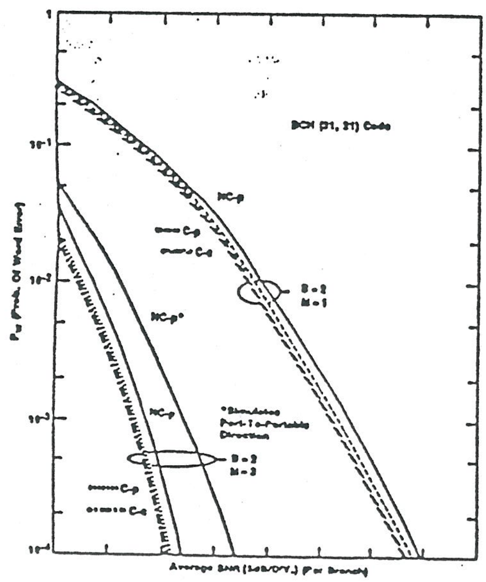

Fig. 3A Performance over a Multipath, Shadowed, AWGN Channel, using a BCH(31, 21, 5) Code

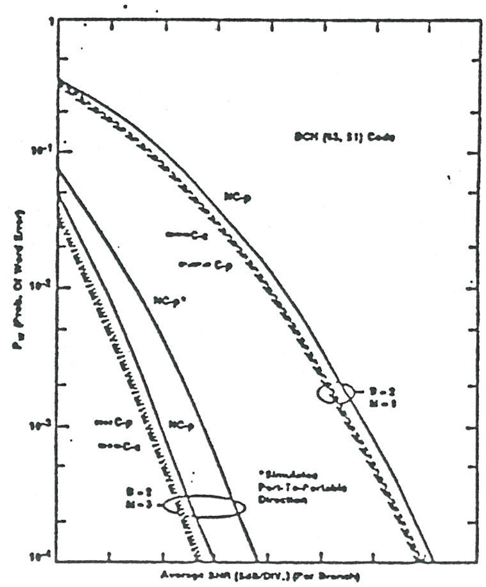

Fig. 3B Performance over a Multipath, Shadowed, AWGN Channel, using a BCH(63, 51, 5) Code

Note: to compare this curve to Fig. 3A, a factor of 21/51 must be applied to P_w.

2.5. Channel Coding

All papers were agreed on the imperative need for channel coding for 1/4 to 1/2 the available baud capacity. **T. Maseng, ELAB, Norway [19]** said from the platform: "The more coding, the less bandwidth." His paper presents details of a combined modulation, coding and adaptive equalizer plan with block diagrams of the implementation.

Most frequently used in system plans, were the Reed-Solomon codes, though BCH and others were suggested. Coding is limited by exhaustion of speed and capacity in the processing stage, a subjective level differently evaluated by various presenters. In most cases, the selection of the channel code is intimately related to other features of the system that control the distribution of error bursts and lost messages from interference.

H. Jokinen, Nokia-Mobira, Finland [22] shows an example using a Reed-Solomon code word of 448 bits in which 400 bits are payload. He shows an implementation using an 8051 microprocessor with additional hardware functions in CMOS that is capable of decoding with 9 errors in 5 milliseconds, 2 errors or less in 1.6 milliseconds.

The Nokia-Mobira proposal presented by **E. Kuisma, Finland [29A]** uses Reed-Solomon (57,39,19), symbol 7 bits for channel coding. Figure 6 (3 graphs) shows BER with and without channel coding and diversity.

"Reed-Solomon codes of length 8 to 25 are used" in the plan described by **J. L. Dornstetter, LCT, France [30]**.

The Ericsson DMS 90 proposal, described by **J. Uddenfeldt [26]** includes a Reed-Solomon (12,8) 4 bits/symbol code with a data transmission rate of 340 kbs. Test results are presented in a companion paper by **Uddenfeldt, Raith and Hedberg, Ericsson Radio Systems, Sweden [27]**. Below is Figure 1 from this paper showing the effect on BER of the channel coding.

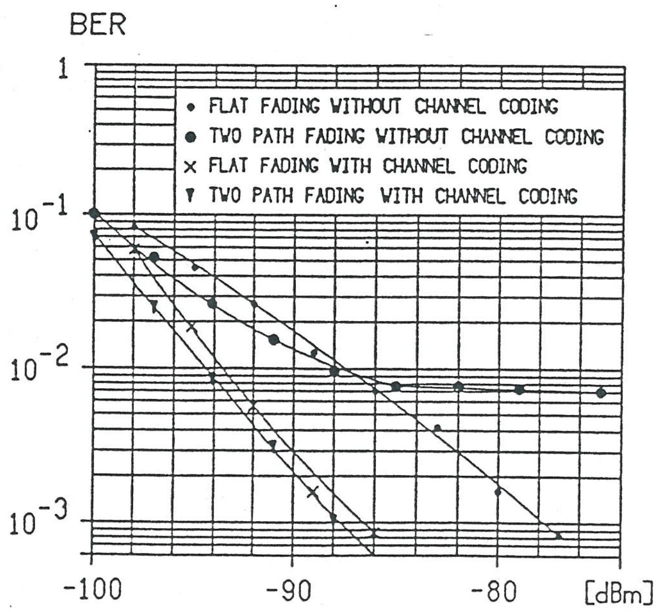

Figure 1. Laboratory measurements.

2.6. Frequency Hopping

Some of the proposals contain frequency hopping as part of the system plan. The main value is that signal level is more consistent among all users and with time for one user. The bad path is not used for more than one packet by any particular mobile. With some interleaving and time displacement of parts of packets, it is possible to distribute error bursts so that the forward error correction is effective. This is well described by **J. Uddenfeldt, Ericsson Radio systems, Sweden [26]**, paragraph 2.3.

In a plan described by **J. L. Dornstetter, LCT, France [30]**, frequency hopping is used in a more complex way where there is no simultaneous use of the same frequency within the same cell, but there is a possibility of collision between cells and the lost packets are overcome with coding. The description of the advantages is:

> "It is often claimed that the only interest of Frequency Hopping (FH) with respect to conventional FDMA lies in a potential benefit for the stationary user experiencing a deep fade on its assigned frequency. While true, this statement nevertheless represents an overwhelming simplification of the situation.
>
> ....
>
> Beside such an advantage for the stationary user, FH provides another advantage: the spectrum efficiency can be increased by introducing simultaneously FH and an adequate channel coding scheme.
>
> ....
>
> The net gain in spectrum efficiency due to FH lies about 50%.
>
> ....
>
> Roughly speaking, the old situation was "20% of the users have a channel that performs poorly 100% of the time" while now we are faced to the new situation "100% of the users have a channel that performs poorly 20% of the time.""

The intimate relationships between coding, frequency hopping, diversity and C/I limits on frequency reuse are fully used in this plan.

2.7. Modulation and Modems

There is much art in the selection of a modulation and the technique of the receiver demodulator. For delays of less than 1 bit interval, **Ikegami [6]** shows a considerable advantage for anti-multipath modulation/demodulation in Figure 3 though he gives no usable explanation of the modulations compared.

There is considerable detail and math given by **S. Mahmoud and M. El-Tanay, Carleton University, Canada [17]**, analyzing TFM, Gaussian MSK, 3RC and duobinary MSK all of which are continuous phase modulation with index 0.5 . Figure 1 compares all of these for BER vs. Eb/No. The emphasis is on carrier recovery from a squaring process which is not necessarily an absolute requirement.

The modulation and modem are a part of the description of adaptive equalization given by **T. Maseng [19]**.

A two-ray model is used as a tool in evaluating details of coherent detection of continuous phase modulated signals by **A. Svensson, University of Lund, Sweden [20]**. He concludes:

> "We have shown that CPM schemes with h=0.5 can be used effectively to combat multipath fading on a two-ray channel, when the impulse response can be measured relatively accurately. The question is how to adaptively adjust the filters in the detector. This seems to be a difficult task for the linear detector but might be possible to overcome for an ML (maximum likelihood) detector."

The modulation chosen by **Kuisma, Nokia-Mobira, Finland [29B]**, is filtered MSK (GTFM or GMSK). He gives considerable detail on size, complexity, power drain of the circuits required to implement the modem, channel coding and radio.

R. Failli and M. Sentinelli, SIP D. G., Italy [37] refer to a block diagram of a flexible modem for

> "transmission rates up to 300 kbit.s, using any phase modulation of the 12PM3 class, which includes MSK, GMSK, TFM, GTFM, CCPSK, etc.; <u>these modulations differ from one another only by the shape of the phase trajectories by which the signal vector shifts from one state to another</u>."

Cox, et al, Bell Communications Research [43] picks QPSK in a plan with short range and no special treatment for multipath adaptive equalization.

H-P. Ketterling and D. E. Pfitzmann, Bosch, FRG [32][33A], as part of the system, S 900 D, describe CP-4FSK (continuous phase 4 frequency shift) modulation and demodulator circuit for a rate of 128 kbs without using an adaptive equalizer.

2.8. Adaptive Equalizers

Adaptive equalization adjusting to the measured impulse response of the channel is used by almost all plans at rates above 100 kbs. The problem is well stated by **T. Maseng, ELAB, Norway [19]**:

> "The input bit stream is not continuously transmitted, but concentrated in bursts which are transmitted at a higher data rate. Each burst has a duration of 0.1 to 1 millisecond, so the channel is assumed to be constant during a burst. At the start of each burst, a known signal is transmitted which is utilized in the receiver to determine the channel characteristics valid for the same burst. The receiver is then "tuned" to receive a signal in such a channel, and the information part of the burst is decoded by the adaptive Viterbi algorithm. During the period of no transmission, other mobiles may use the same frequency band, thus performing Time Division Multiple Access (TDMA)."

Though some assume that the required equalization does not change much during one message (1 millisec), others undertake more frequent adjustments. Those that adjust during a message, include the Ericsson [26][27] and the Philips MATS-D [36].

The same subject is treated by **J. Uddenfeldt, Ericsson Radio systems, Sweden [26]** in the description of the Ericsson DMS 90 system:

> "With TDMA transmission, severe time dispersion occurs. A typical value for the spread of time delay in an urban area is 0.5-2 microseconds. This will make a TDMA system virtually useless at a transmission rate of 340 kb/s.
>
> The experimental system for DMS 90 uses an adaptive decision feedback equalizer (DFE) to eliminate time dispersion. The DFE is an adaptive filter with both a feedforward and a feedback part. The filter coefficients are updated for each new TDMA-burst, and they can be updated during the burst. The equalizer compensates for the channel time response and eliminates the time dispersion.
>
> Furthermore, the adaptive equalizer can make positive use of the multipath propagation in the form of a diversity function. This stems from the fact that, with time dispersion, the same signal travels multiple ways before it reaches the receiver. With independent fading of the rays, it is possible to provide a diversity function.
>
> The adaptive equalizer can perform these functions without any bandwidth expansion."

This equalizer is described in greater detail by **J-E Stjernvall, et al, Ericsson Radio Systems, Sweden [27]** in paragraph 3.5 and attached figures.

Another design for the adaptive equalizer is described by **E. Kuisma, Nokia-Mobira Oy, Finland [29A]**:

> "The equalizer includes a T/2 spaced, 6 tap forward section and a T spaced 3 tap decision feedback section. The sampling rate is four times the bit rate (4/T). The adaptation is based on stochastic gradient update algorithm.
>
> There are two modes of operation. A training mode in the beginning of the subframe (32 bits) is used to make the initial tap setting; and a decision feedback mode during the sub-frame will make the adjustment of tap coefficients according to the varying conditions. Different step sizes are used in different modes. Adaptation is performed once during a symbol (every fourth sample) but equalization is performed for all samples.
>
> In addition to removing intersymbol interference, the equalizer also reduces effects of noise, random FM and non-idealities of the receiver by maximizing the eye opening before decision."

Kurisma [29B] continues to describe this equalizer (for a rate of 28 kbs) in the form of the engineering model intended to eventually result in a design for a hand-held portable:

> "The implementation is based on TMS 32020 signal processors. 6 processors and additional hardware, 4 double Eurocards together, are used to get a flexible system."

2.9. Plans Using Megabaud Rates

The "MATS-D Radio Transmission Plan" proposes wideband transmission from base to mobile at a 1.248 Mbs rate. The plan is described by **R. Beck, U. Wellens, et al, Philips Kommunikations, FRG** [36]. None of the other related papers listed in the references were available at the meeting. Description of the adaptive equalizer is given. The plan is described as suitable for high speed trains at 230 km/hr.

The title **"A Digital TDMA Micro Cell System for Business Cordless Telephones"** describes the context for **D. Aokerberg and B. Persson, Ericsson Radio Systems, Sweden** [44]. The data rate is 1250 kbs in a 1.5 MHz bandwidth with 32 millisecond frames. There is no adaptive equalization, however the system assumes a time dispersion of only 50 nanoseconds with 800 nanosecond bit intervals for a transmission range of 50 meters.

The plan of **F. Ikegami, Kyoto University, Japan** [6] uses 1 Mbs outward rate for 1 kilobit packets with anti-multipath modulation. He estimates a zone radius of about 100 meters with transmitting power of 1 watt at microwave frequencies. Ikegami's Figure 3 (shown below) suggests that suitable modulations may well tolerate average delay spread of up to 0.7 bit period. At 1 Mbs, this point is the difference between 50 and 500 meters range limitation without adaptive equalization.

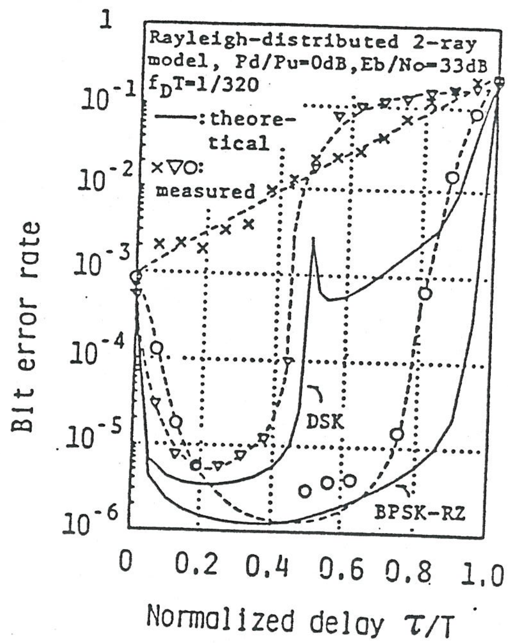

Fig.3 Bit error rate performance of anti-multipath modulation/demodulation systems DSK and BPSK-RZ, compared with conventional BPSK.

2.10. ISO Model and the Access Protocols

Only Madame M. B. Pautet, CNET, France [72] was the only speaker concerned with the ISO model. She gave the following specifics on where a mobile radio system is not accomodated in the 7-layer structrure:

". . . .the radio interface of a digital multiservice PLMN differs from an ISDN user interface, because of three main reasons:

1) The absence of a fixed physical support (the physical channels are taken from a shared pool) implies soe kind of switching at the radio interface; moreover, demand for spectrum efficiency leads to a tight allocation of channels both in time and bit-rate.
2) The mobility of users results in constant changes in their access-point to the network, and this even during communication periods (handover).
3) The non-stationarity of the transmission medium is due to attenuation, masks and Rayleigh fading and results in frequent losses of bit bursts.

For all these reasons, the ISDN user-accesslayer protocol, dscribed in CCITT recommendation Q.931 cannot be used as a basis for part of the signaling protocols as will be explained in section 1.3."

Madame Pautet leaves the data link layer behind and goes on to propose management blocks and structure which resolve these difficulties in a stucture with minimum departure from CCITT recommendations and ISO standards.

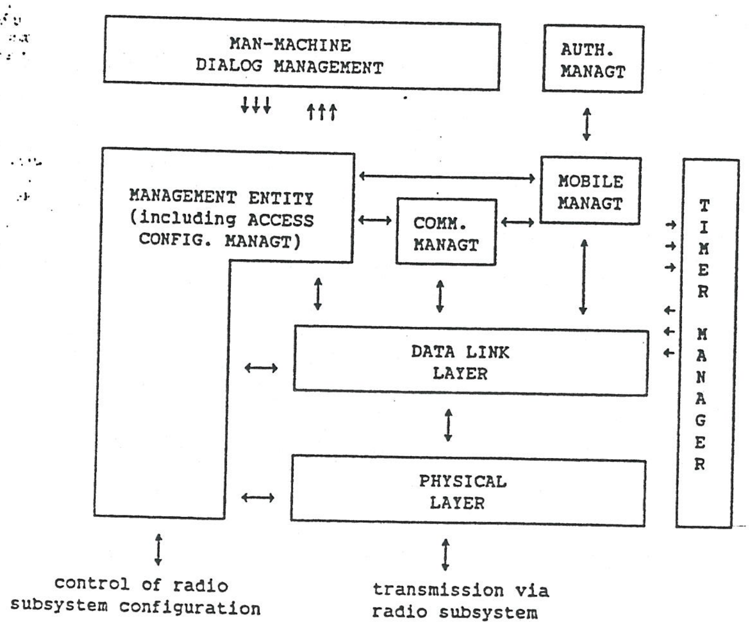

Figure 3 - Mobile Station Modules

3. PAPERS INCLUDED IN ATTACHMENT

Number	Author(s), Title, Affiliation
6	F. Ikegami, **Discussions on the "Ultimate Communication"** Kyoto University, Japan
17	S. Mahmoud & M. El-Tanany, **Design and Performance of Continuous Phase Modems for Mobile and Portable Radios**, Carleton University, Ottawa, Canada
19	T. Maseng & O. Trandem, **Adaptive Digital Phase Modulation**, ELAB, 7034 Trondheim-NTH, Norway
20	A. Svensson, **On Coherent Detection of Continuous Phase Modulation On A Two-Ray Multipath Fading Channel**, University of Lund, Box 118, S-221-00 Lund, Sweden
21	T. Naerhi, **Experimental Results on Diversity in Digital Mobile Radio**, Technical Research Centre of Finland, 02150 Espoo, Finland
22	H. Jokinen, **Channel Coding and Bit Error Measurements in a 900 MHz Digital Mobile Telephone Test System**, Nokia-Mobira Oy, 24101 Salo, Finland
24	L-F Chang, H. Arnold, R. Bernhardt, P. Porter; **Coding as a Means to Implement Diversity Selection in a Frequency Re-Using Portable Radio System**, Bell Communications Research, Red Bank, NJ 07701 USA
26	J. Uddenfeldt & B. Persson, **A Digitial FD/TDMA System for a New Generation Cellular Radio**, Ericsson Radio Systems AB, S-163 80 Stockholm, Sweden
27	J-E Stjernvall, K. Raith, B. Hedberg; **Performance of an Experimental FD/TDMA Digital Radio System**, Ericsson Radio Systems AB, S-163 80 Stockholm
29A	E. Kuisma, **Performance Analysis of a Digital Mobile Radio System Based on Narrowband TDMA**, Nokia-Mobira Oy, 24101 Salo, Finland
29B	E. Kuisma, **Feasibility Study of the Radio Equipment Including Hand Portables in a Narrowband TDMA System**, see 29A
30	J. Dornstetter, **The Digital Cellular SHF 900 System**, Laboratoire Central de Telecommunications (LCT), Villacoublay Cedex, France
32	H-P. Ketterling, **The Digital Mobile Radio Telephone System Proposal S 900 D**, Robert Bosch GmbH, Berlin, FRG
33	D. Pfitzmann, H-P. Ketterling, K-H. Tietgen; **A New CP-4FSK Sampling Demodulator for the FD/TDMA System S 900 D and Numerical Modulation Methods**, Robert Bosch GmbH, Berlin, FRG
36	R. Beck, C. Grauel, K. Stry, U. Wellens; **MATS-D Radio Transmission**, Philips Kommunikations Industrie AG, Nuremberg, FRG
37	R. Faili et al, **Provisional Results of Italian Experiments on Digital Land Mobile Radio**, SIP D. G. & CSELT, Rome & Torino, Italy
43	D. Cox, H. Arnold, P. Porter; **Universal Digital Portable Communications: A System Perspective**, Bell Communications Research, Red Bank, NJ
44	D. Aokerberg, B. Persson; **A Digital TDMA Micro Cell System for Business Cordless Telephones**, Ericsson Radio Systems AB, S-163 80 Stockholm

Number	Author(s), Title, Affiliation
45	R. J. C. Bultitude, **Error Rate Calculations for the Transmission of DPSK on 800/900 MHz Mobile Radio Channels with Measured Characteristics**, Communications Research Centre, Ottawa, Canada K2H 8S2
46	A. Bajwa & O. Kafaru, **900 MHz Wideband Multipath Propagation Measurements and Modelling**, Telecom Securicor Cellular Radio Ltd. & University of Liverpool, London EC1 and Liverpool L69, UK
49	R. Lorenz, **Variation of Multipath Spread in Mobile Radio and its Impact on Digital Transmission**, Forschungsinstitut der Deutschen Bundespost, D-6100 Darmstadt, FRG
53	L. Szabo, **Experimental Investigations on the Time Variations of the Mobile Communication Channel**, Standard Electrik Lorenz AG, Stuttgart, FRG
69	R. Cheeseman, P. Munday, B. West; **An Experimental Test Bed for Digital Cellular Radio**; British Telecom Research Laboratories, Racal Research Ltd., GEC Research Ltd.; UK
71	P. Matthews & B. Rashidzadeh, **A Comparative Study of Wideband TDMA and TD/FDMA Systems for Digital Cellular Mobile Radio**, Univ. of Leeds, UK
72	M. B. Pautet & F. Courau, **Modular Implementation of Signalling Protocols in a Digital Mobile Communications System**, CNET, France

NEC Res. & Develop., Special Issue on "C&C Office System" 1985

Networks UDC 621.316.544:621.395.7:681.3.02:621.391.63

C&C-NET STAR Subsystem

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ABSTRACT The C&C-NET STAR subsystem basically takes the form of a radial linking that connects two or more terminals of various types with nodes via individual wiring system; the central node solely governs the network control and the switching functions. PBX is the oldest and most widely adopted STAR subsystem the details of which would be introduced separately. This paper deals with the packet switching system and the spatial star-link system out of those currently available STAR subsystems of various kinds.

KEYWORDS Star-link, Packet switching system, New media, VAN (value added network), Optical star link, C&C network system

1. INTRODUCTION

The star-like structured system extends its transmission lines towards its terminals from the center equipment in a star-like configuration. Because of the collective control over all the system communications solely by its center equipment and its simple-structure terminals, the STAR subsystem is easy to organize and has been the one most widely used for the last few years.

The C&C Network System embraces a variety of STAR subsystems shown in Table I. The system that handles data and image communications in the extended form of PBX on one hand, in addition, to the current upgraded and diversified telephone-oriented services and that helps create more economic and efficient complex systems is the NEAX2400 IMS (C&C-NET STAR2400) system. Its sister system, NEDIX510F (C&C-NET STAR2600) packet switching system now enjoys a high evaluation as one of the new STAR subsystems that deftly executes the exchange of non-voice data of computers and data terminals and that appears now to be rapidly growing.

As a key system giving an impetus to the so-called new media and VAN (Value Added Network), rapid development and diffusion of this packet switching system can be expected.

Further from the viewpoint of its network components or equipment connection, this system's equipment and installation are much easier to modify and appropriate actions against various types of noise within the office can be more easily. This advantage is quite instrumental in building up a high-level office system.

The spatial optical star link of C&C-NET STAR2800 system certainly satisfies such needs and it can be said to be a new network system, which is capable of interconnecting a number of data terminals via spatial light propagation.

Against its merits of saving the control cost of the terminal trains, which is generally allowed by its integrated control over the entire network, the star system involves certain demerits such as the shutdown of its whole functions in case of a failure of the central equipment, which involves considerable expense. Appropriate consideration should therefore be given to system design in order to overcome such negative effects.

2. NEDIX510F PACKET SWITCHING SYSTEM

2.1 Introduction

The recent advancement of OA (Office Automation) and FA (Factory Automation) expedites the data communications system under which many data

Table I STAR subsystems.

Typical STAR subsystems	Purpose
NEAX2400 IMS	New-age EPABX incorporating complete data processing functions into PBX
NEDIX510F	System that exchanges data in the form of a packet
C&C-NET STAR2800	Star-link system using spatial propagation of light

*Business Communications Division
†Integrated Switching Development Division
‡Business Communications Systems Marketing Promotion Division
§1st Microwave Communications Systems Division

terminals, word processors, personal computers are installed within the offices and plants and within which system data processing is handled jointly by the center computer and those distributed small-sized computers. Diversification and upgrading of the system scale and services the data processing system offer are greatly accelerated as demands for data communications between a number of data terminals and the master data processing facility are increasing more and more.

With the advent of the ARPA network of the U.S. Department of Defense, introduced in the 1960s as a suitable means for data communication, packet switching systems have been implemented and operated in many nations. This data communication system divides a set of data into blocks of about 1,000 bits each, composes a packet adding the address, error control and other information to each block, and exchanges various data in the form of a packet. Satisfying the requirement of higher quality of data communication on one hand, this new system is instrumental in improving the use efficiency of communication lines by its capability for multiplex communications. Because of its ability to process data, which is once stored in the system, this system is more competent to offer the value-added communication services by its functions of speed conversion, code conversion, format conversion, protocol conversion, media conversion, multi-address calling, mail box service and delayed delivery service.

The NEDIX510F Packet Switching System incorporates all such features and becomes a member of out DIANA product group. The system introduced here is a new version that is made more compact and more competent by our latest multi-microprocessing technique when compared with its predecessor "Digital Data Switching System for Overseas Use."

2.2 System Configuration

The NEDIX510F Packet Switching System (PS) consists of network components of Packet Switching Equipment (PS), Packet Multiplexing Equipment (PMX), Message Store and Forward Switching Equipment (MPS) and Network Control Center (NCC), all of which are interconnected via the communication circuits. As shown in Fig. 1, the hardware of NP-series network components can be chosen, depending on the scale and purpose of the individual packet switching system, from five different models of NP10, NP20, NP30, NP40 and NP50. Each model is composed of the hardware components common to all models, and the distributed control on its functions and load is executed by the multi-microprocessor except NP10. Therefore, scale upgrading or functional modification

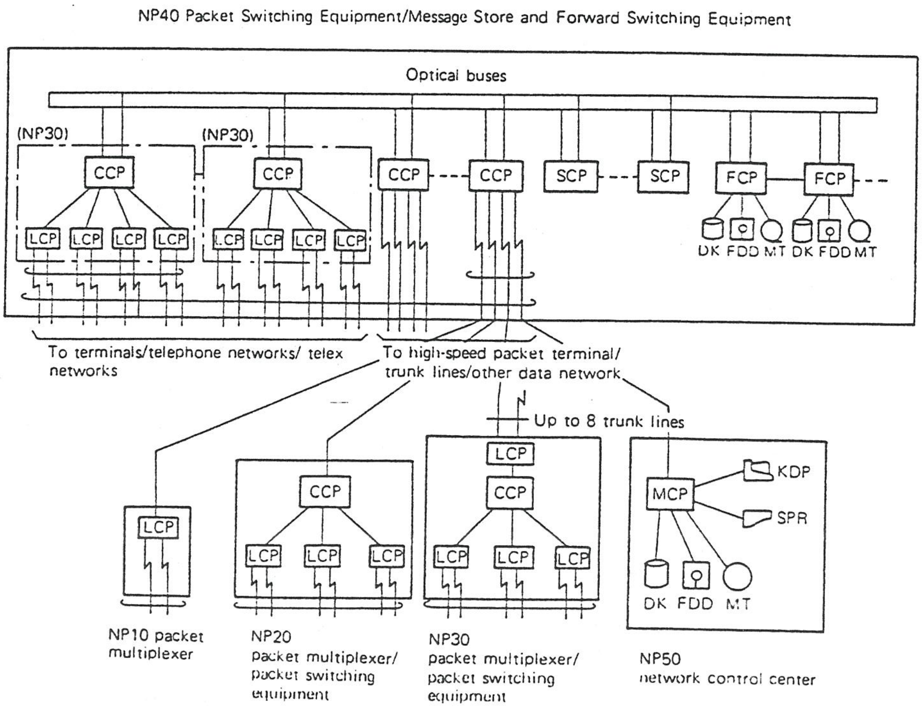

Fig. 1 NEDIX510F System configuration.

of each system can be readily achieved.

The Model NP10 consisting of a single line control processor (LCP) can be connected to a maximum of 16 terminals and it is in most case used as a PMX.

The Model NP20 composed of a communication control processor (CCP) and plural Line Control Processors (LCPs) can be used as a PMX or a PS. CCP generally serves for the protocol control on the packet level and the trunk circuit control while LCP executes the protocol control on the level lower than the packet level such as the transmission control, modem control and packet assembly/disassembly function (PAD), thereby effecting the layered distribution of the system functions.

The Model NP30 composed of one CCP and LCPs has functions as a PMX or a PS. The addition of optical bus interface (OBI) unit to this model turns it to a building block of its higher-ranked NP40.

The Model NP40 is composed of CCPs, the Switching Control Processors (SCPs) for routing control, File Control Processors (FCPs) for controlling Magnetic Disks (DKs), Floppy Disks (FDs), Magnetic Tapes (MTs) and other I/O devices. This model is generally used as a PS or MPS.

The model NP50 consists of a Management Control Processor (MCP) and a set of the I/O devices including Keyboard Display (KDP), Serial Printer (SPR), Magnetic Disks (DKs), Floppy Disks (FDs) and Magnetic Tapes (MTs) and it is generally applicable as NCC.

Photo 1 shows an outer view of the NP10, NP20 and NP40 composed of six units of NP30 units. As apparent from this photo, the NP40 bay consists of the layered NP30 units, it is fully modularized, with both functional configuration and structure.

2.3 Hardware

2.3.1 Hardware Configuration

The hardware of the NEDIX510F Packet Switching System is a combination of functionally divided microprocessor modules of different types, functions

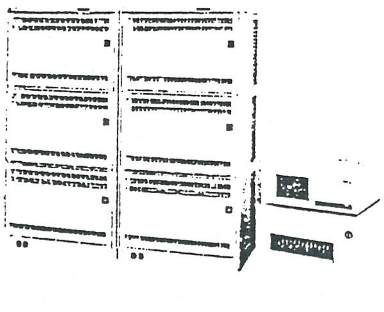

Photo 1 Appearance of C&C-NET STAR2600.

and features as listed in Table II. The configuration of individual microprocessors is also shown in Figs. 2 to 6.

2.3.2 Interprocessor Connection

The system's microprocessors are mutually connected via a high-speed X.25 link and multiprocessor system bus.

1. High-speed X.25 Link:
   This link directly connects the individual microprocessor modules, which are arranged in layered structure, and executes the serial data transfers at a maximum speed of about 1 Mbps according to the CCITT Rec. X.25 LAPB. This link is generally used for the CCP-LCP connection.
2. Multiprocessor System Buses
   The bus is a high-speed optical bus system and jointly used by the distributed microprocessor modules. It is capable of data transfer of a maximum of 32 Mbps, and mostly used to connect CCPs, SCPs and FCPs of NP40.

2.3.3 Other Functions

An inside look at the NP 30 unit mounting one CCP is given in Photo 2. The right half of this unit is a space provided for an extension of CCP and power supply unit. Photo 3 shows the PC board of OBI controller on which four proprietary LSIs are mounted.

2.4 Software

2.4.1 Features

Each piece of software of NEDIX510F is designed to permit the multiprocessor configuration that offers on one hand high reliability to the real-time multiprocessing and the distribution effect of various forms and capability of data processing between a number of multiprocessors. Changes and extensions of hardware and/or services on the other hand can be readily achieved through optimum software modularization. In other words, each module is composed of a functional unit, and the module-to-module interfaces are provided by the transaction memory with the standard formats.

A simpler program structure is successfully designed by containing the program units within each module, which is composed of these program units. To maintain module independence the system structure does not have any common data that are directly accessible by a number of modules. Its competent system functions are thus offered by a combination of mutually independent functional modules.

System maintainability, extendibility, productivity and compatibility are kept extremely high because of the use of high-level programming language (C language).

2.4.2 Software Configuration

A typical software configuration and its main functions are shown respectively in Fig. 7 and Table III. As is obvious in Table III, the system software mainly consists of the operating system (OS), the call processing program (CP) and the administration program (AP).

OS is available in two types, one is for the real-time processing (OS-R) and the other for the administration OS (OS-M) which uses UNIX OS. The former is contained in the processors of CCP and LCP that

Table II Functions and features of microprocessor modules.

Microprocessor module	Main functions	Features
Communication Control Processor (CCP)	· Packet-level communication control	· Allowed to connect multiprocessor system bus · High-speed X.25 link incorporated
Line Control Processor (LCP)	· Communication control on link level/physical level (X.25/X.75) packet level communication control also allowed · PAD function	· Applicable from low speed (50 bps) to high-speed (64 kbps) lines · Various supports to synchronization system (LCP for start-stop line); LCP for synchronous (SYN/F) line · DMA circuit incorporated (LPC for synchronous line) · A maximum of 4 hardware timers per line incorporated · Interrupt function based on detection of changing point of control line on receiving end · High-speed X.25 link ports incorporated
Switching Control Processor (SCP)	· Routing control · Line switcher control	· Allowed to connect multiprocessor system bus
File Control Processor (FCP)	· File control · Store and forward switching control · System restart control	· Duplicated configuration allowed · External bus dual access function · Duplicate write function into file/work memory · ECC-added work memory · Multiprocessor system of main CPU and IOPs · Multiprocessor system bus allowed to connect · High-speed four-port X.25 link incorporated
Management Control Processor (MCP)	· Various I/O device control · Network administration · Software development	· Memory management function (allowing to use UNIX system OS) · RAM up to 512 bytes incorporated · IBM-compatible MT allowed to use · Multiprocessor system of main CPU and IOPs · High-speed X.25 link allowed to connect · 16K byte EPROM incorporated · Hard disk controller LSI used · IEEE 796 buses adopted · Multiprocessor system buses allowed to connect

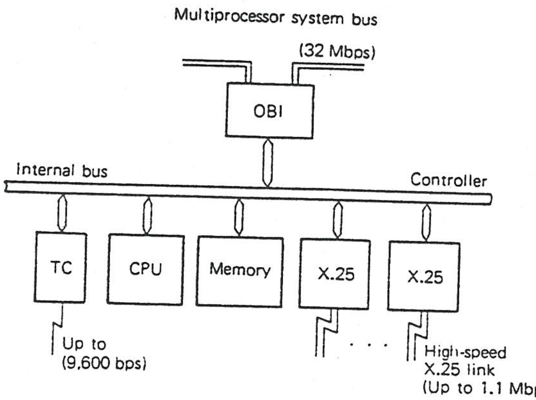

Fig. 2 Block diagram of communication control processor module.

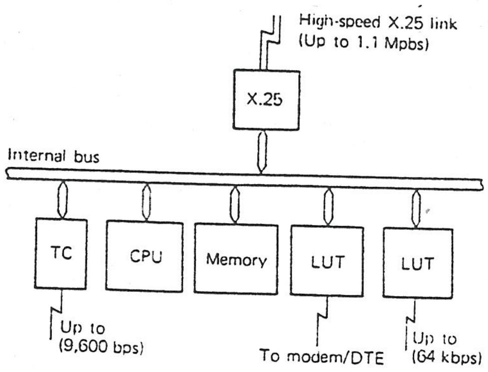

Fig. 3 Block diagram of line control processor module.

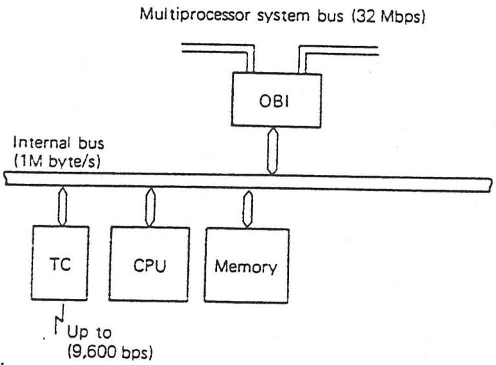

Fig. 4 Block diagram of switching control processor module.

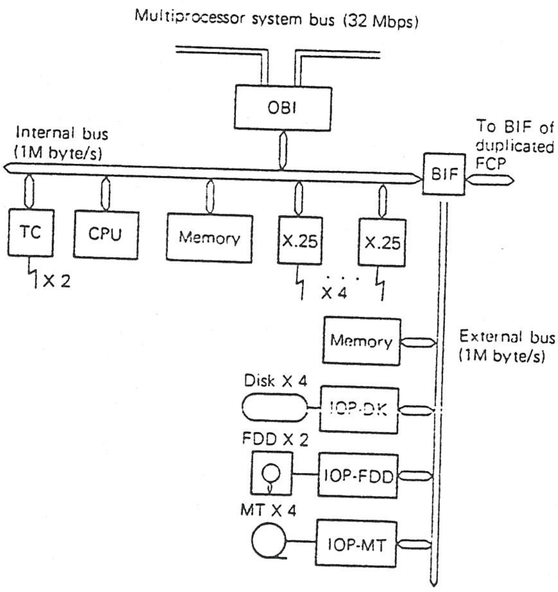

Fig. 5 Block diagram of file control processor module.

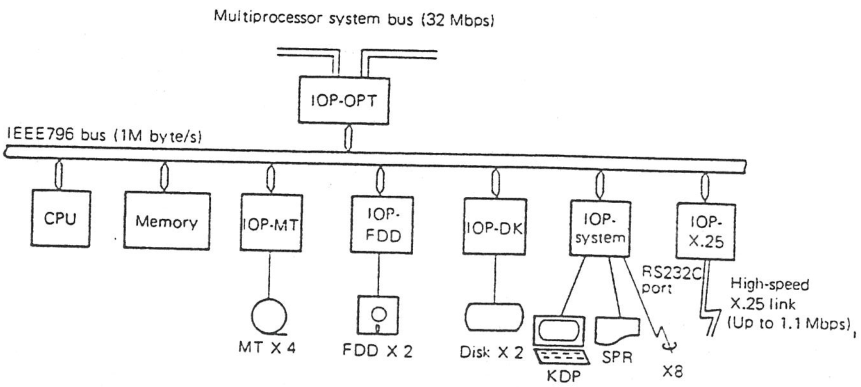

Fig. 6 Block diagram of management control processor module.

handle the switching processing and the latter is stored in MCP that provides the man-machine interface.

CP consists of PSE (packet switching equipment) controlling the packet switching and PAD (packet assemble/disassemble). The former can be subdivided functionally into the call setting and disconnection (X.25/X.75 Level 3 handler) and the routine processing. PAD on the other hand is provided for each protocol and stored in LCP.

AP is composed of the main administration program and the local administration program (AP-L); the former is stored in MCP and the latter in each of the processors other than MCP. AP-M monitors the operating status of the network according to the reports from AP-L as well as executes the processing of data gathered by individual processors, requests of administration processing to AP-L and man-machine interfaces. AP-L likewise monitors the operating status of each processor, gathers various data generated by call processings, reports the information to AP-M and executes the administration processing when so requested by AP-M.

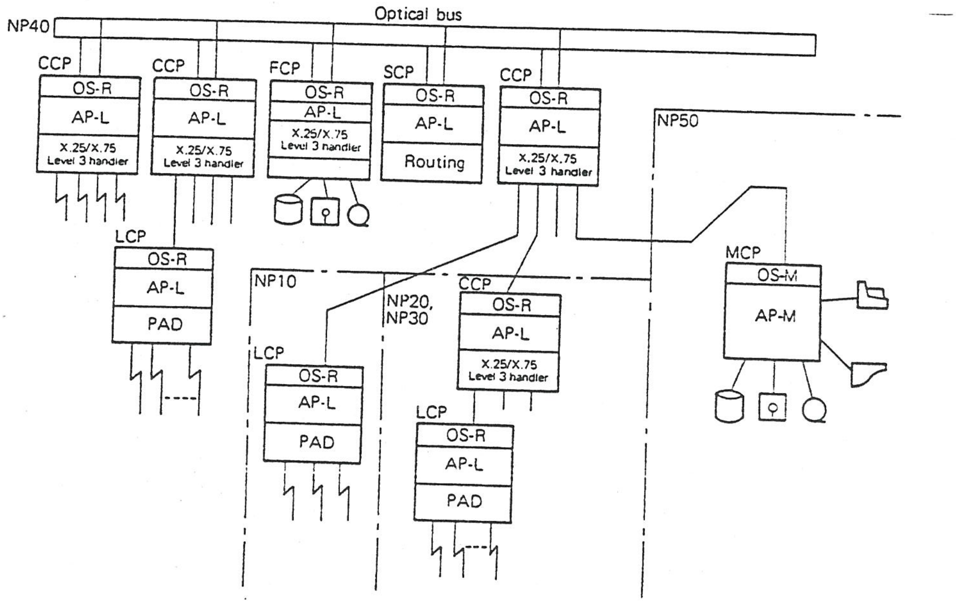

Fig. 7 An example of software configuration.

Table III Software functions.

Program	Functions
Operating System (OS)	· Executional management – Management of individual program execution · I/O control – Control over various I/O devices · Command control – Man-machine interface control · Fault handling – Fault identification and diagnosis control · Inter-processor communication – Communication between other processors
Call Processing Program (CP)	· Packet switching – CCITT X.25/X.75 – based packet switching · PAD processing – Conversion of terminal-generated data format into standard packet formats provided in several kinds for individual terminals and services
Administration Program (AP)	· Charge processing – Creation and registration of source data of charges into files · System extension/modification – Changes and/or extension of subscribers, inter-office routers and services of various kinds · Monitor & measurement – Traffic measurement and other monitors of various kinds

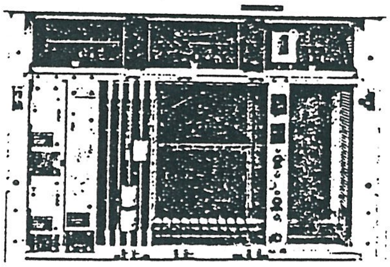

Photo 2

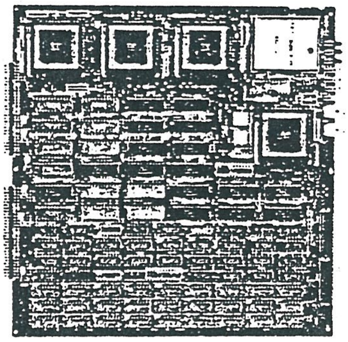

Photo 3

2.4.3 Man-Machine Language

Quite a significant role is played by the man-machine language (MML) in the system operation. In addition to various CCITT recommended commands and messages, other high-level command programming languages (shell languages) are applicable, and any composite commands can be defined by the users for combined execution of two or more basic commands.

3. C&C-NET STAR2800 OPTICAL STAR LINK

3.1 Necessity for Wireless In-House Data Transmission

The amount of communication cable for in-house data communication is steeply rising as the number of data terminals increases. A large quantity of cable has been laid by several methods such as undercarpet laying, free-access flower, etc. Therefore, movement of data terminal for rearrangement of floor layout is complicated and this kind of cost occurs in every layout change. The simple wireless interconnection method may be a good solution for cost-free movement of data terminals.

It will advance personalization of data terminal to push development of office automation and factory automation. The following are the explanations for wireless in-house optical data communication "C&C-NET STAR2800" which has star topology and is free from the above-mentioned disadvantages of cable communication systems.

3.2 System Configuration

C&C-NET STAR2800 is composed of an optical repeater, a controller, optical transceivers, and interface units.

The optical repeater is installed on the ceiling of the central part of the room and has non-directional receiving sensitivity and non-directional transmission pattern of light to communicate with all optical transceivers in the same floor.

The controller receives signal pulses from the optical repeater, retimes the pulses and then feeds them to the optical repeater with the synchronizing pulse. These pulses are transmitted as infrared light by the optical repeater. The optical transceivers transfer the optical signal between the optical repeater and the interface units.

The moderate directivity of an optical transceiver gives a good transfer factor for optical signal from transceiver to repeater, while the directivity of the receiving optics rejects background light such as interior lighting and sun-beam to out of sight.

These expands the maximum transmission distance between optical repeater and transceivers. The degree of directivity of C&C-NET STAR2800 system is designed to achieve 10 meters of service range between the optical repeater and maximum of 37 optical transceivers when the transmission rate is as low as 1200 bps as shown in Table IV.

3.3 Features

C&C-NET STAR2800 system adopts time division multiplexing for communication among many terminals without requiring additional software. Therefore, data contention and business do not occur in return for decreasing transfer efficiency.

Two transmission modes are available. One is 1 to 1 interconnection between several pairs of terminals in the same room. Another is also 1 to 1 interconnection but between optical repeater and up to four data terminals.

In the latter mode, communication outside the room can be made via a controller which has four connectors with modem interface for connecting the controller connects the particular interface unit with one of these four connectors in addition to generation of frame pulse for synchronizing all interface units and retransmission of signals from transceivers.

Table IV Specifications.

Connectable terminal number	Max. 37 (at 1200 bps)
Signal interface	Asynchronous 1.2 kbps, 2.4 kbps, 4.8 kbps, 9.6 kbps based on CCITT V.24/V.28
Connection	1 to 1 fixed connection
Service range	Max. 10 m from repeater to transceiver
Light source	Light emitting diode
Light detector	Photodiode
Wavelength	0.8 ~ 0.9 μm

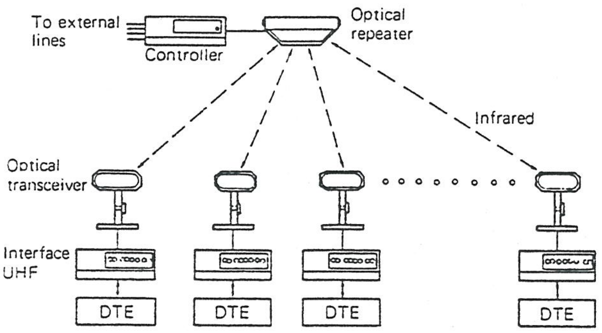

Fig. 8 System configuration.

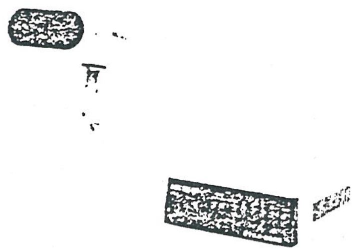

Photo 4 Optical transceiver and interface unit.

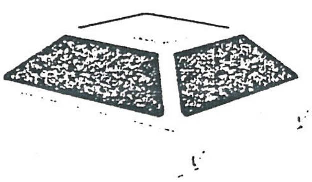

Photo 5 Optical repeater.

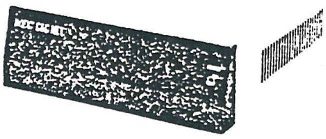

Photo 6 Controller.

3.4 Application

C&C-NET STAR2800 transmits data by using free space propagation of infrared light to exclude the above-mentioned defects in cable communication systems. Therefore, the system is expected to have many advantages in the following application fields.

- Many terminals exist in one room and floor re-arrangement is anticipated as the task advances.
- Installation of the communication cable on the floor is impossible because of building structure.
- Severe EMI exists in factories or other facilities.

4. CONCLUSION

A number of NEC C&C-NET STAR2600 Packet Switching System and C&C-NET STAR2800 Optical Star Link System based on computers of the conventional type are installed and operated successfully at present both in Japan and in several foreign countries. The NP series introduced in this report are new systems that have been developed quite recently by our state-of-the-art technology based on our long operation experience in the field of packet switching systems to meet wider market needs. Our next target is to expand and consummate its functions to offer another system that accommodates a greater number of multifarious terminals including telephone sets and facsimiles and that provides the convenience of improved value-added communication means.

Received October 12, 1984

9.6 K FRAMES/SEC

TDM 768 KBPS

* * * * * * * * * * * * * * *

UDC 621.396.73:681.327.8

Radio Terminal System

By Tsutomu MIYAMOTO* and Takakuni KUKI*

ABSTRACT Recently, a portable wireless I/O data computer terminal has been developed. This report describes the Radio Terminal System construction and discusses radio data communication techniques.

1. INTRODUCTION

In many cases, I/O terminal equipment for on-line data processing is desired to be portable and wireless. For this purpose, the Radio Terminal System supplies a new easily portable terminal, "Data Transceiver," shown in Photo 1. The data transceiver has a keyboard, a display unit, a transmitter and a receiver in a compact case. Operators can feed various data in to the computer from any place in the service area, and can receive processed data in response, using the equipment.

The applications of the equipment are mainly for factory source data collection, warehouse inventory control, stock broker sales data inquiry, etc.

2. SYSTEM CONFIGURATION AND OPERATIONAL FUNCTIONS

Figure 1 shows a diagram of the system layout. The Terminal Control Unit (TCU) is designed to permit controlling various types of terminal equipment such as keyboard-printers, character display terminals, data transceivers (mentioned in this report), etc. Input data from various terminals are stored in the TCU buffer memory, edited and transmitted to the host computer through public or private telecommunications circuits. Output data from the host computer are stored, edited and sent to the terminals in the same way.

Radio Base Units (RBUs) are set up in warehouses, shops, factories, etc. An RBU has a transmitter and a VHF and/or UHF receiver. The transmitter modulator input and the receiver discriminator output are connected to the TCU over metallic lines.

RBU receives a radio signal from the data transceiver and relays data to the TCU. RBU transmits the channel busy or idle signal and the output data signal from the TCU.

The service area, wherein the data transceiver can be used, is about fifty meters in radius from the RBU antenna. Many RBUs can be set up to enlarge the service area. The data transceiver has a keyboard for data input, memories for data storing, an alphanumeric display unit for displaying the stored data, function indicators, a transmitter for data transmission and a receiver for reception of a response signal and channel idle or busy signal. The response signal consists of acknowledge or non-acknowledge code and processed data.

The operational function of this system is as follows. When an operator inputs data by means of the key switches of the data transceiver, the input data are stored in the memory and indicated in the data transceiver display unit. The capacity of the memory and display is 16 characters. The operator can transmit stored data by pushing the "Send" buttom, while the

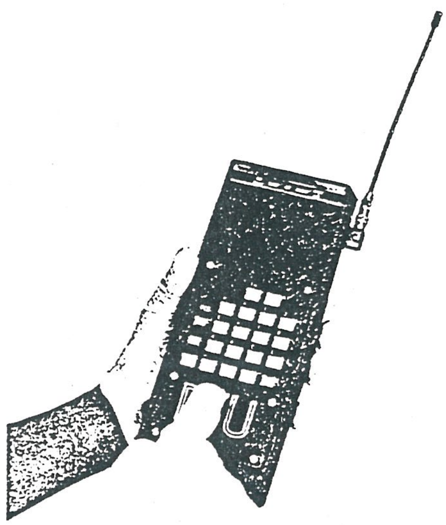

Photo 1 Data transceiver.

*VHF and UHF Communications Division

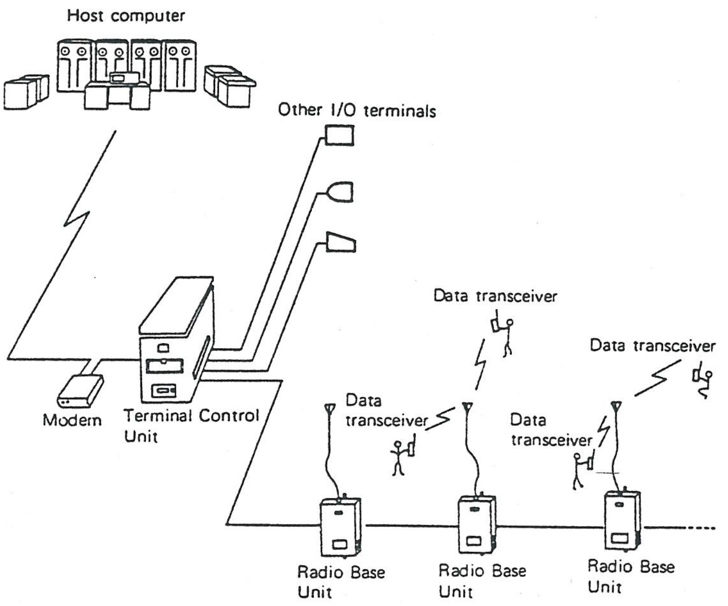

Fig. 1 Radio Terminal System layout.

channel idle signal is received. When the data have been transmitted, a "Send" lamp turns on.

The transmitted data are received by the RBU and relayed to TCU. TCU checks the data and sends clean data only to the host computer. The host computer processes the data and sends back an acknowledge signal and a response message. The acknowledge signal and the response message are received by TCU, and relayed to the data transceiver through the RBU. The data transceiver, which receives the acknowledge signal and the response message, turns on the "OK" indicator and displays the response message.

If the TCU detects non-correctable errors in the data from the data transceiver, TCU does not send them to the host computer, but sends back a non-acknowledge signal to the data transceiver. The data transceiver, which receives the non-acknowledge signal, turns on the "Error" indicator. Thus, the operator can confirm the completion of transmission.

3. RADIO CHANNEL DATA TRANSMISSION

Reducing data transceiver volume and weight is important. To simplify the data transceiver hardware, this system is designed as follows.

3.1 Portable Unit to Base Data Transfer

In this section, techniques used for portable unit to base data transfer are explained.

3.1.1 Modulation and Data Speed

To simplify the data transceiver transmitter, frequency shift keying by a PM modulator is used. In this modulation method, large frequency deviation brings about a high signal-to-noise ratio at the receiver output of RBU, but it cannot be easily realized when the baseband signal has low frequency components.

Then, the split phase code is used. This code has no DC component and few low frequency components. (See Fig. 2). Data speed is fixed at 2400 bit/sec. A single section modulator can realize 4 kHz deviation. Moreover, split phase code makes the bit synchronization easier, because each data bit has a polarity turning point.

3.1.2 Multireceiver Reception

It is impossible to determine beforehand which one of RBUs will receive signals from the data transceiver, because the operator moves around in the service area. So, the method shown in Fig. 3 is used.

The demodulated output of each receiver is connected to an amplifier whose gain is controlled by the receiver field strength output. The amplifier output is led to an adding circuit and mixed with the signal from the neighboring RBU, whose amplitude is controlled in the same manner. Adding circuit output signals are led to the next RBU, one after another.

The mixed signal is finally led to the TCU. Merits of this receiving method are:

i) TCU can easily detect data transceiver transmission start by monitoring amplitude only. TCU stops

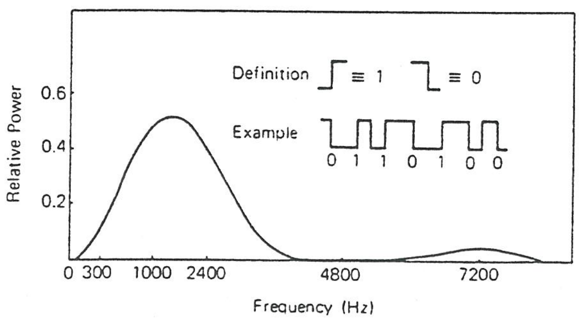

Fig. 2 Split phase code definition and its spectrum.

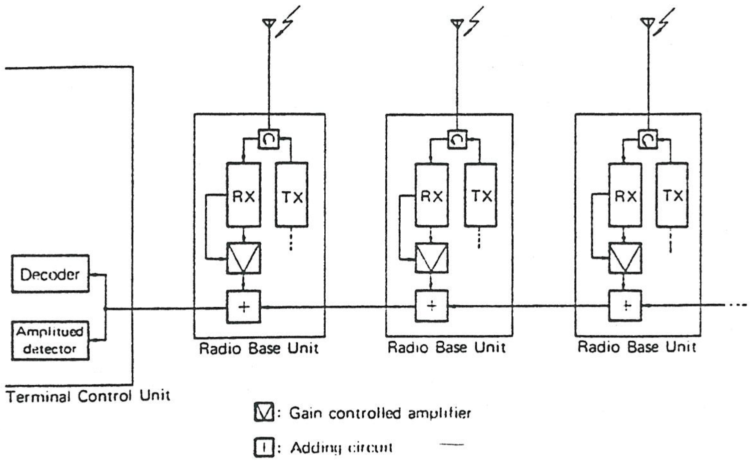

Fig. 3 Portable unit to base signal reception block diagram.

sending channel idle signal and starts to send a channel busy signal.

ii) Start-pattern detection reliability is improved. This will be explained later.

iii) Bit error rate is improved by space diversity reception.

3.1.3 Word Synchronization

Single start bit is often used in wired systems, but a longer start pattern is necessary for radio systems, because of the high bit error rate.

A 16-bit pattern was chosen as the start pattern. Bit length is not long enough to avoid regard noise as the start pattern. However, this mistake seldom occurs, because the pattern match circuit starts pattern search when the previously mentioned amplitude detector detects the existence of an input signal. The chosen pattern has the sharpest peak on the correlation coefficient. Figure 4 shows the correlation coefficient curve when the pattern follows the preamble signal.

Since the pattern match circuit in a TCU is designed to detect the start pattern correctly if it includes a single error bit, the probability of successful start pattern reception amounts to nearly 99.99%, when bit error rate is 10^{-3}.

3.1.4 Error Correction

Transmitted data always consists of 16 words because of the data transceiver memory capacity. (If the operator inputs less than 16 words and pushes the send buttom, the remainder words are space codes.) Each word is 8-bit ASCII code. So, 128 bits are transmitted. Since the data transceiver transmission power is reduced, the received data often include erroneous bits. The probability of reception without error is less than 78% when bit error rate is 10^{-3}, but the probability exceeds 97% when there is one error or less. This fact means that an error correction technique is very useful. Well-known 1-error correcting code with 128 information bits is BCH (136, 128) code, which is a shortened form of BCH (255, 247) code. This code has 8 check bits. That means a necessity for an 8-stage feedback register for the check bit calculation [3]. Its encoder is too big for a portable set.

A partial coding repetition was used instead of complete coding. Figure 5 shows the signal format. The data are encoded as follows.

Each 8-bit ASCII code is separated into the first half and second to shorten the block length and make the decoder circuit simple. Four check bits are calculated from the first half in the rule of Hamming (8, 4) code and added to the first half. Other 4 check bits are calculated and added to the second half in the same manner.

Block shortness simplifies the encoder circuit. This encoder can be built by 6 exclusive-or gates only. The decoder which checks every 8 bits is capable of 1-error correction and 2-error detection.

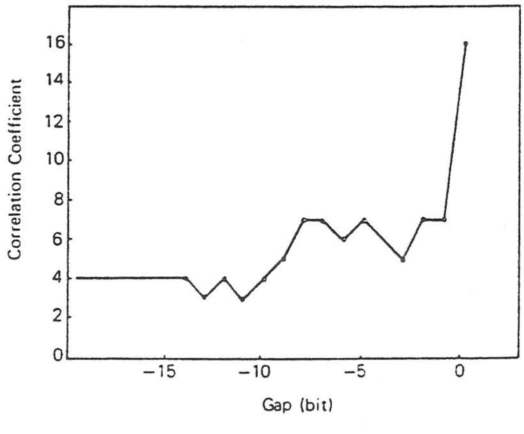

Fig. 4 Start pattern correlation.

This method has sufficiently good correction ability, but not detection. In order to avoid misdecoding caused by high bit error rate, the decoder is designed to regard received data as inreliable and throw it away when 3 or more correctable errors occur in sequence. Four kinds of calculated probability are shown in Fig. 6.

"Received correctly" curve expresses the probability of reception with 2 or less correctable errors. "Received but thrown away" curve expresses the probability of reception with non-correctable errors, or 3 or more correctable errors. "Not received" curve expresses the probability of reception with 2 or more errors in the start pattern. "Received erroneously" curve expresses the probability of reception with errors, which the decoder fails to detect or correct.

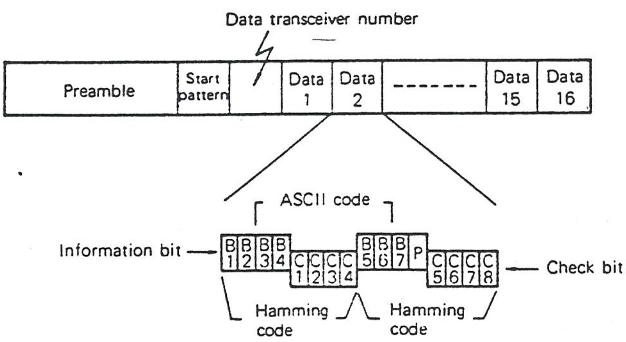

Fig. 5 Portable unit to base signal format.

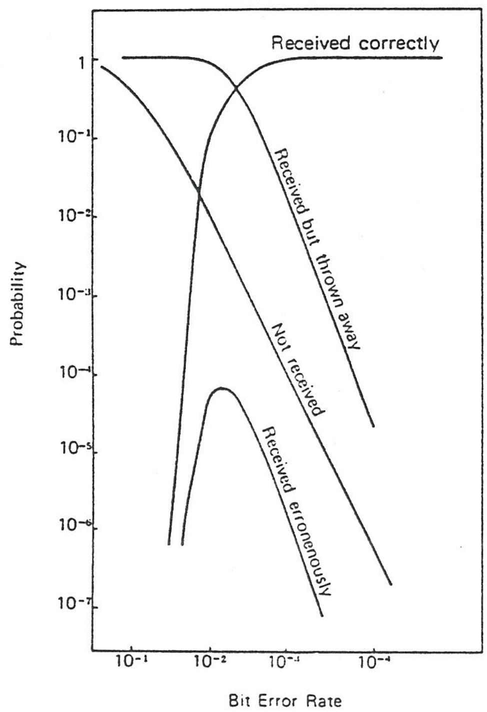

Fig. 6 Error correction and detection probability.

3.2 Base to Portable Unit Data Transfer

The techniques used in the base to portable unit data transfer are as follows.

3.2.1 Multitransmitter Frequency Control

Many transmitters are set up so that electric field strength will be high enough to reduce bit error rate. There are two frequency control methods. One uses offset frequencies. The other uses exactly the same frequencies. The former is more useful in an alternating field, but the latter is chosen, because the electric field strength received by the data transceiver is almost static, and because it is easier to control all the oscillators at the same frequency than to keep the difference between frequencies constant.

Figure 7 shows a block diagram of the base to portable unit transmission. The first in the RBU sequence has a master oscillator. Others have slave oscillators. The output of the master oscillator is connected to a 1/100 frequency dividing circuit. Its output signal is transferred to a neighboring slave oscillator as a reference signal and relayed from one to another. Each slave oscillator forms a Phase Lock Loop. Its oscillating frequency is locked to the frequency of the master oscillator by phase comparison between reference signal and the output of its own divider.

3.2.2 Modulation

Data from TCU are also relayed in baseband and modulated into an FSK signal. The data are screened into a 2400-bit per second split phase code. A data transceiver often receives signals from 2 or more RBUs, but demodulated signal distortion is small, because the frequency shift lag time is negligible.

3.2.3 Error Correction

It is necessary, when transmitting from the base to portable unit, to transfer not only output data but also channel idle or busy signal in order to avoid the simultaneous transmissions of plural data transceivers. It is desirable that these signals can be decoded in the

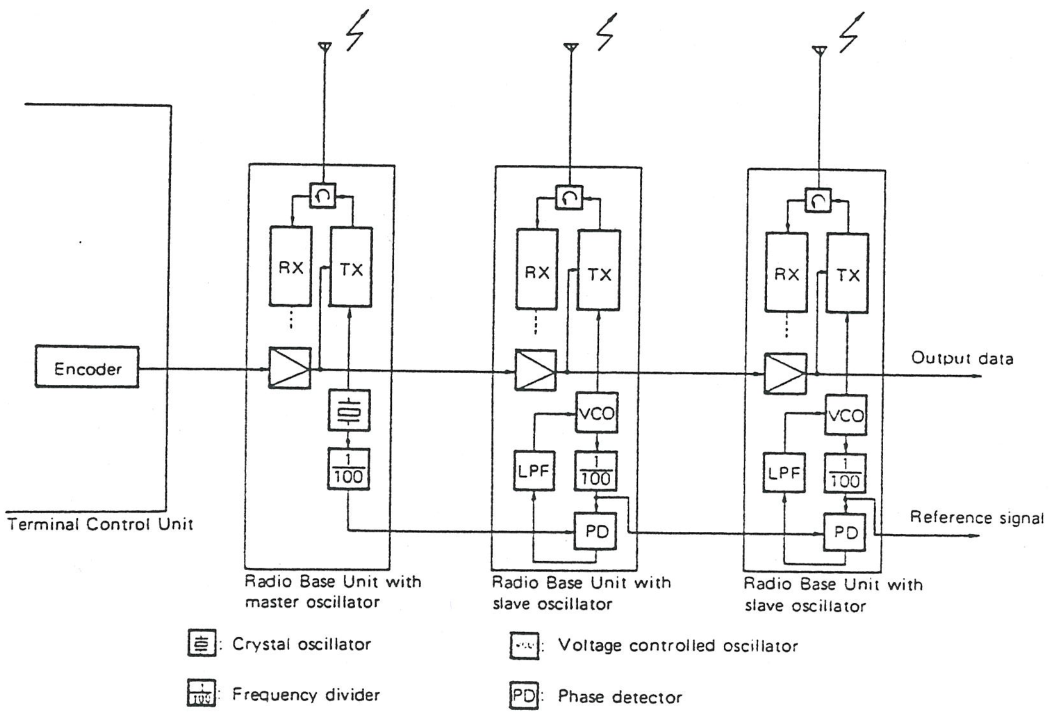

Fig. 7 Base to portable unit signal transmission block diagram.

same decoder circuit.

A convolutional code fits this purpose. Various convolution codes are known, but one with long constraint length is not suitable, because the idle signal detection lag time sometimes causes simultaneous transmission from plural data transceivers.

Wyner-Ash (2, 1) code was chosen, whose constraint length is 4 bits [4]. This code is capable of performing single error correction within the constraint length. Encoder and decoder circuits are shown in Fig. 8. The decoder is very simple.

As the encoder transmits information bits and check bits alternately, the decoder must separate them. The successfulness of this separation is checked by watching a parity check sequence, called "syndrome." As the idle signal was fixed to a continuous "1" pattern, and since all information bits are "1" and all check bits are "0," the opposite separation causes an appearance of too many "1"s in the syndrome. So the decoder notices the failure and replaces the information and check bits.

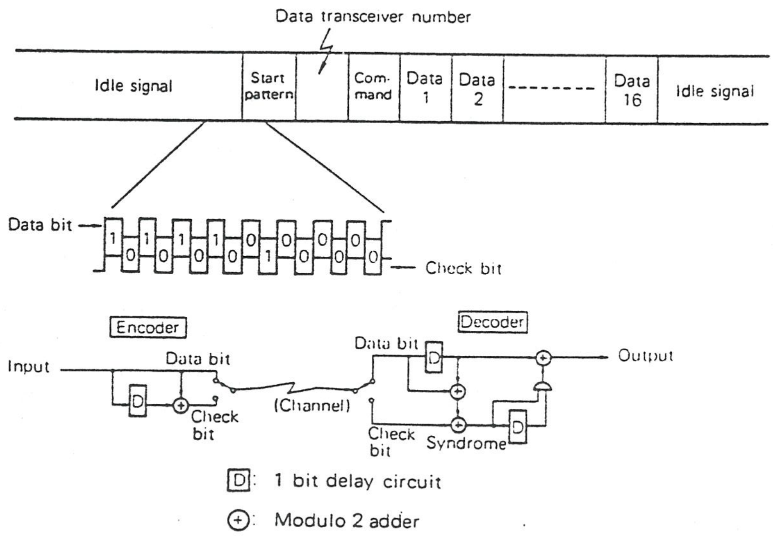

Fig. 8 Base to portable unit signal format and Wyner-Ash encoder and decoder block diagram.

The idle signal can be easily detected by monitoring the decoder output.

3.2.4 Word Synchronization

The start pattern can also be detected by monitoring the decoder output. When transmitting from a portable unit to the base, the pattern matching circuit needs to correct one error. However, it is not necessary in this case, since the monitoring pattern has already been corrected in the convolutional decoder.

3.2.5 Error Detection

Wyner-Ash code is capable of performing error correction as mentioned, but not error detection. When too many errors occur, the decoder outputs incorrect data without activating any alarm.

The horizontal parity byte was added as well as the vertical parity bits. Horizontal parity check can detect almost every error which the convolution decoder can not correct. This improves output data reliability. Signal format decided in this manner is shown in Fig. 8.

4. DATA TRANSCEIVER DESIGN

Data transceiver consists of a keyboard, a 16 word display, a control circuit, a transmitter, a receiver and a battery unit. Photo 2 shows the construction of data

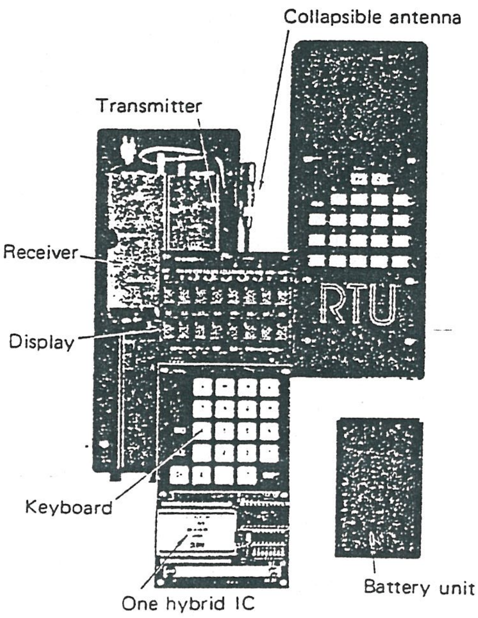

Photo 2 Data transceiver structure.

transceiver. It is 236 x 90 x 56 mm in size and weighs about 0.95 kg.

4.1 Keyboard

The keyboard is specially designed for this equipment. A small keyboard is desirable to reduce equipment size, but large key tops and wide pitches are desirable for easy handling. This problem was settled by using the 3-state shifting method.

This keyboard has 21 keys, 14 of which are for data input, while the others are for functions. Two function keys are shift keys that change the data key range. So, 14 data keys can be used to input 42 different kinds of data. The 42 kinds of data include 10 numerals, 26 alphabet letters and 6 symbols.

4.2 Display

Light emitting diode arrays indicate 16 characters in 5 x 7 dot-matrix forms. They are driven dynamically in order to reduce power consumption. Power consumption amounts about to 35 mA when all of 16 digits are displayed. Decimal point of every array behaves as a cursor. The display starts to indicate when any one of the keys is touched, and keeps on for 10 seconds after the last key input is completed.

4.3 Radio Section

Transmitter and receiver are designed to be compact and light. They are individually shielded and operate reliably with low voltage power supply. The RF part of the transmitter has power supplied only during the transmitting time. Radio section consumes 10 mA during the waiting time and 30 mA during the transmitting time.

4.4 Control Section

Data transceiver operations are controlled by a microprocessor. It is easy to change the specifications by replacing the program stored in programmable ROMs. All devices, except ROMs, are selected from C-MOS ICs, and consume a small amount of power.

The power is supplied to ROMs only when ROMs are used. Control circuits are housed in 6 flat packages by thin film hybrid integration. Power consumption of this section is about 25 mA, on an average.

4.5 Battery Unit

The battery unit houses 4 Ni-Cd alkaline battery cells in its package. A fully charged battery unit can supply power for more than 8 hours continuously. When the supply voltage drops below the value which will cause malfunction of the data transceiver, an alarm lamp glitters near the data display.

5. CONCLUSION

This report shows several countermeasures for problems pertinent to data transmission in mobile radio application. The Radio Terminal Systems are now operating in iron-works and warehouses. Expected reliability is achieved in spite of severe atmospheric and noise conditions. The authors intend to go ahead with their study in order to realize various mobile radio data communication applications.

ACKNOWLEDGMENT

The authors wish to express their thanks to the staff members of Sumitomo Metal Industries, Ltd. for their advice in determining data transceiver specifications. They are also grateful to the members of NEC concerned with this system for their help and encouragement during the development.

REFERENCES

[1] E. D. Sunde, "Ideal Binary Pulse Transmission by AM and FM," *Bell Syst. Tech. J.*, 38, 6, pp. 1357-1426, Nov. 1959.

[2] Wm. C. Jakes, Jr., "Microwave Mobile Communications," Wiley, New York, 1974.

[3] W. W. Peterson, "Error Correcting Codes," MIT Pr., Mass., 1961.

[4] Shu Lin, "An Introduction to Error Correcting Codes," Prentice Hall, New Jersey, 1970.

Received April 18, 1978

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He joined Nippon Electric Co., Ltd. in 1961 and is now Engineering Manager of the Mobile Radio Telephone Systems Department, VHF and UHF Communications Division. He has been engaged in the design and development of mobile radio equipment and mobile system control equipment for sixteen years.

Mr. Miyamoto is a member of the Institute of Electronics and Communication Engineers of Japan.

Takakuni KUKI was born on January 1, 1949. He received the B.E. degree in communicative engineering from Osaka University in 1974.

He joined Nippon Electric Co., Ltd. in 1974, and is now a member of the Mobile Radio Telephone System Department, VHF and UHF Communications Division. He has engaged in the development of radio data communications equipment.

Mr. Kuki is a member of the Institute of Electronics and Communication Engineers of Japan.

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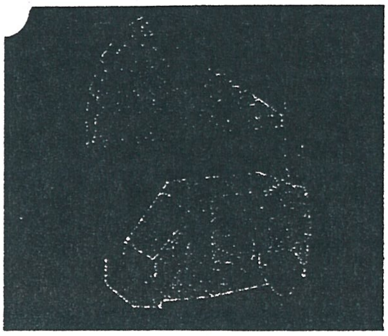
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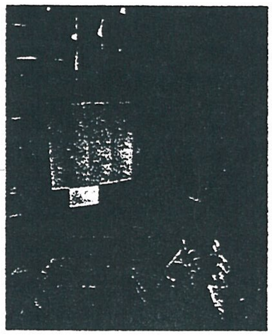

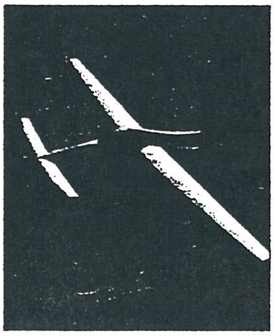
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Cover A guided vehicle transfers computer disks being assembled at Magnetic Peripherals (Minneapolis). Photograph by Steve Niedorf.

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October 25, 1986

COPY

Mr. David Greenstein,
Chairman, IEEE Standards Committee 802.4L
General Motors Technical Center
Manufacturing Building A/MD-39
30300 Mound Road
Warren, MI 48090-9040

RE: Report on **Seminar on Digital Land Mobile Radio Communication**
Stockholm, October 14-16

Dear David:

While this Seminar was mainly concerned with a new pan-European standard for digital telephony, there were many papers on subjects technically relevant to the task of 802.4L. A very large amount of information was presented on propagation and many different approaches to overcoming time dispersion. Data rates discussed wnet from 9.6 to 2000 kilobaud. Radio ranges were 50 meters to 15 kilometers. The representation was so broad that consensus in technical approach was quite apparent on many techniques.

I think the presentations at this conference to represent state-of-the-art in digital transmission at 900 MHz and higher. Accordingly, I have prepared a report and copied about 25 of the 75 papers given as reference material.

Attached, are two sets of material. I am directly mailing an additional set to C. Thurwachter (ITI). I have available three more sets that I would mail to you or addresses you furnish. One copy of the reports sent to you, is unbound for reproduction.

At this moment with the knowledge from this conference, I lean toward a plan with many repeaters place so that the longest normal radio path is under 100 meters and using a rate of 500 to 1000 kilobaud. The intent is to avoid a need for the adaptive equalizer or powers beyond 50 milliwatts.

I be on a trip next week (Dallas) returning the week starting November 3.

Cordially,

Chandos A. Rypinski

Second Nordic Seminar on Digital Land Mobile Radio Communication October 14-16, 1986 -- Stockholm

Report to IEEE Standards Committee 802.4L
By C. A. Rypinski

1. SUMMARY

Many technical matters, relevant to radio medium local area network technology, were discussed at this meeting. Most presentations were by major European, Japanese and US companies and by European Telecom administrations. In addition, participants in CEPT, CCIR and CCITT were present. There were 550 attendees including less than 20 from USA.

Of relevance to the 802.4L committee, were a number of papers analyzing multipath propagation and the equalization of its degrading effects, diversity methods and error correcting coding using in the medium kilobaud rates of 250-350 and 1500-2000 at 900 MHz. In addition, one paper addressed the relationship of the protocols to the 7 layer model and related software. Some of the discussion was directed to very high service densities requiring very small cell dimensions.

A surprise was that most authorities were advocating a mixed TDMA/FDM system with a 250-350 kilobaud rate in the medium which was generically called "narrowband TDMA". (There was no advocate for a pure FDM system.) A number of presentations were concerned with adaptive equalizers for this type of system. "Broadband TDMA" characterized systems operating at 1 megabaud and higher rates.

Many papers attempted comparative evaluations of the proposals eventually ending with a conclusion in capacity per square kilometer per MHz of spectrum.

There was no mention whatever of local area network functions or interfaces, however it was commonly assumed that ISDN compatibility inherently provided any necessary capability.

1.1. Discussion of Papers

The discussion in the text portion of this report is a compilation of reported propagation, modulation methods, signal spectrum, channel coding and error rates, and adaptive equalizers arranged by subject. In addition, there is a section on "broadband TDMA" related to megabit rate propagation and processing.

1.2. Attachments

25 selected papers (out of 75) are copied and attached as printed for the proceedings. Certain figures and quotations are taken from these for use in the discussions above. Also, the agenda for the meeting is copied with titles and authors for use as a Table of Contents showing the Paper No. used in the references in the discussion above. The last page in the attachment shows the USA attendees.

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2. DISCUSSION OF PAPERS

Almost all submissions were concerned with high error rates resulting from multipath propagation using conventional modulation and no special coding; and they proposed many methods to overcome this difficulty improving from 10^-1 to 10^-2 BER to 10^-3 to 10^-4 packet error rate.

> "It is concluded that powerful means of signal processing are necessary to safeguard digital land mobile radio communication systems operating at transmission rates of several hundred kbits/s." -- **Lorenz, Bundespost, FRG [49]**

> "As the transmission is increased beyond the coherence bandwidth of the radio channel, the frequency selective fading becomes apparent with significant impairment in transmission unless it is mitigated by added signal design and receiver processing. It can be viewed as a natural diversity provided by the channel and perhaps harnessed, to improve the radio systems performance." -- **Bajwa, TSCR, UK [46]**

> "It was found that the multipath characteristics and the corresponding coherence bandwidth for digital data transmission is extremely dynamic with large variations." -- **Szabo, SEL, FRG [53]**

The primary methods of offsetting multipath errors were coding, diversity and modulation/detection technique. Methods were proposed for making use of multipath to obtain a form of diversity transmission.

2.1. Cellular System Concept

The cellular concept provides a wide area service from whatever number of sites is required. If frequency space is limited, larger capacity is obtained from more sites and more closely spaced reuse of the same frequencies. In the beginning, radio sites with a service radius of 10 km or more is reasonable; but as saturation is approached, the coverage radius of cells may be decreased to 2 km or less. "Small cells" are associated with higher frequencies, interiors of buildings and low transmitter power. Also the absolute magnitude of multipath delay spread is less in "small cells."

A primary consideration in small cell design is the frequency reuse factor in a regular cell pattern system layout. Conventional analog telephone systems use a pattern of 21 groups in conservative designs and 12 in aggressive designs. The speakers arguing for digital technique, which inherently takes more frequency space for the same information, all depend on a lower requirement for desired/undesired signal level ratio with digital than with analog modulation. Reuse factors of 3 to 9 are typical. Some plans depend on a statistical character for interference that is offset by channel coding or diversity.

No. channels per cell = No. channels available / Reuse factor

If the 802.4L group were to settle on small cells (radio context) dimensioned to cover cells (manufacturing context), stock areas, aisles, lines and arteries inside a building, as might be necessary for microwave or very low power operation, a frequency reuse type of plan would be essential.

"The minimum cell radius is limited to 2 km because of nonpredictable propagation characteristics (which) may occur inside buildings etc. To this end it is essential to use a modulation format which is robust against cochannel interference which will determine the no. of adjacent cells in which a particular frequency can only be used once (frequency reuse factor)." -- **T. Maseng, ELAB, Norway [19]**

"If we have to utilize higher frequency bands, for example in a microwave region, radio zone radius may be limited to 100 meters with transmitting power of 1 watt. In such a case, a new concept referred to as 'Tree Radio Zone' may be considered, in which each radio zone looks like a tree instead of a hexagonal cell, as shown in Fig. 4." -- **Ikegami, Kyoto University, Japan [6]**

"On the other hand, the lower powers and lower antenna masts of a dense personal system create an environment with lower delay spread; and in so doing, systems using Time Division Multiplexing become more attractive." -- "For providing universal portable communications, the separate circuits at the ends of the the telephone loops can be provided using low-power digital radio links for the last 300-500 meters." -- **D. C. Cox, H. Arnold, P. Porter; Bell Communications Research, USA [43]**

2.2. Bit Error Rate Comparisons

Bit error rate comparisons must be made on a channel with fast **Rayleigh** fading resulting from changes in position of the order of a radio wavelength (25 cm). For analytical purposes, a two-ray model with worst-case phase relationship and various relative amplitudes is often used. (See **Svensson [19]**) More complex models have been used, and experiments conducted as propagation studies. For laboratory experiments, complex fading simulators have been built.

Because the reflectors causing multipath are not stationary, nor is the dielectric medium through which the signals pass stable, Rayleigh fading occurs when vehicles are stationary. One inducement to use frequency-hopping schemes is to avoid the possibility that a stationary vehicle is at a singular low-signal location.

Most reports on methods of improving BER show a reference level before the improvement. This reference could be the Shannon relation, but it is more often a conventional modulation without benefit of the particular aids described. Reference modulations are commonly a smoothed phase transition form of MSK referred to as GMSK or TFM.

Reference Definitions

MSK is Minimum Shift Frequency Keying invented by M. L. Doelz and described in U.S. Patent 2,977,417. He teaches that the minimum separation of the two frequencies for frequency shift keying is one-half the baud rate. Expressed in another way, the accumulated phase shift during one bit interval must be at least 90 degrees different for the two possible frequencies.

TFM is "tamed FM" disclosed by F. de Jager and C. B. Dekker ("Tamed Frequency Modulation--A Novel Method to Achieve Spectrum Economy in Digital Transmission," IEEE Trans. Commun. vol. CM-20, May 1978) The technique is frequency shift with non-instantaneous, gradual changes in phase under keying and changed always in the direction with the least discontinuity from previous keying transitions.

GMSK is Gaussian-filtered MSK. It is described by K. Murota et al ("GMSK Modulation for Digital Mobile Radio Telephony," IEEE Trans. Commun. CM-29, July 1981). The logical keying signal is passed under a Gaussian shaped lowpass filter before application to a voltage controlled oscillator.

R. J. C. Bultitude, Communications Research Centre, Canada [45]

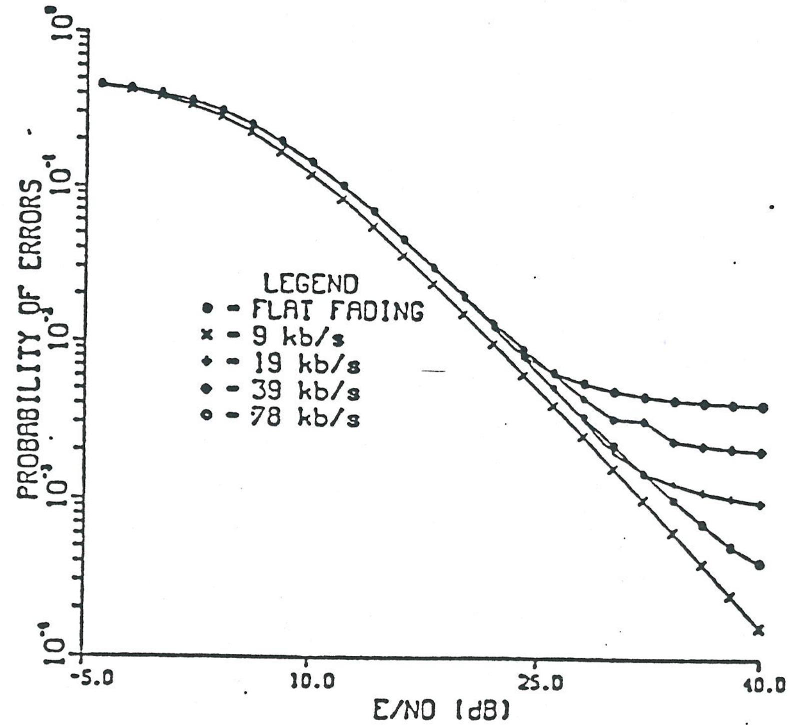

Fig. 7. Probability of error predictions for the experimental DPSK system operating along the first street section.

For each street section the probability of error as a function of average bit energy to noise ratio was calculated using equations derived in this paper for data rates ranging in one octave steps from 9.765 kb/s to 78.125 kb/s. Accepted flat fading equations for DPSK [10] were modified [11] to make use of envelope fading data derived from the impulse response estimates, and flat fading performance characteristics were also computed for comparison purposes. Figure 7 shows results for the first street section. Only small differences from these results were shown in performance curves for the other street sections in the measurement area. The figure shows that the channel can be classified as a flat fading channel for data rates below about 10 kb/s. In addition, there is excellent correspondence between the flat fading curve calculated using well known equations, and the 9.765 kb/s curve. This is considered confirmation of the new techniques for error prediction presented in this paper. Above 10 kb/s the performance characteristics show that the channel is frequency-selective, and intersymbol interference effects rather than noise set the lower boundary for error performance. This lower boundary is seen to be independent of E/N_0, and increases monotonically with increasing data rate, for data rates greater than that for which the channel is frequency-selective. Comparison of computed performance characteristics with the shape of measured spaced frequency correlation functions showed that the flat fading/frequency selective boundary is, on average, at a transmission bandwidth (twice the data rate for the system discussed here) which is about eight percent of the frequency separation from the reference at which the real part of the spaced frequency correlation function decreases to a value of 0.5

T. Naerhi, Telecommunications Laboratory, Finland [21]

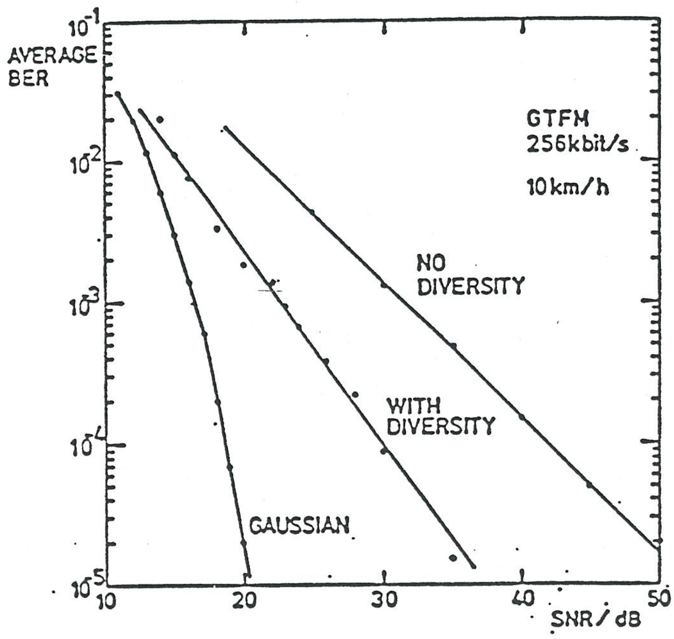

Fig. 13

4 BER MEASUREMENTS AT 256 kbit/s

In the recently started experimental program switched diversity is being implemented in a narrowband TDMA experimental system. Figure 13 shows the first results from these measurements, where GTFM-modulated data at 256 kbit/s (without TDMA structure) is transmitted through the simulated Rayleigh fading channel. In the receiver non-coherent discriminator detection is used together with a bit-by-bit decision method. The figure shows BER vs. signal to noise ratio (SNR) in the Gaussian channel and in the fading channel with and without switched diversity at the vehicle speed 10 km/h. With the switching threshold adjusted to the optimum value, the improvement in the average BER is 5...6 dB at BER = 10^{-2} and 8...9 dB at BER = 10^{-3}.

2.3. Radio Propagation

Enough has been said about bit error rate to establish that a problem exists. Suitable remedies depend upon understanding the nature and dimensions of the distortions in the channel. The studies presented explored short and medium distance and a range of time resolution that would include megabit baud rates.

Correlation in time and frequency is an important matter. There is an indication that if an adaptive equalizer is set at the beginning of a packet, the settings will remain valid for 0.1 to 1 millisecond. It is also known that the transmission is level only over a narrow frequency band. Megabaud bandwidths may be strongly non-uniform across the bandwidth. Depending on the detection method and modulation, this can be advantage or disadvantage.

The main subject of **Bultitude [45]** is dimensioning the correlation of changes in frequency and location as a propagation calculation and experiment. The parameters obtained can be used to calculate BER as a function of symbol rate.

R. W. Lorenz, Bundespost, FRG [49] reports average power delay profiles, frequency correlation function, transfer function/impulse response calculated from the average power delay profiles for New York (Cox) and Berne. His work is related to 100 kbs BPSK and 200 kbs QPSK.

Comparisons of signal level variation in bandwidths of 25 kHz and 8 MHz are given by **L. Szabo, Standard Electric Lorenz, FRG [53]**. His conclusions are show below:

> "The measured maximum width data show that delays beyond 8 microsec are very seldom and there are no substantial differences in the various degrees of urbanization. The observed maximum delays are up to 32 microsec. It seems that values in excess of 8 microsec are comparatively rare. The maximum width has a relatively higher probability between 1 and 5 microsec.
>
> Based on the measurements (more than 6000 impulse response recorded in different German cities and environments) the following statistical weighted results are detected: (The amplitude resolution for the paths is limited to 20 dB.)
>
> * Maximum width caused by multipath is less than 7 microsec for 99% of the records.
> * The strongest path is positioned in the first 2 microsec of the received structure in 90% of the cases.
> * The strongest path is definitely not the first path in about 30% of the records.
> * The main signal energy is concentrated in the first 3 resolvable paths and in the first 5 microsec for 99% of the records.
> * The paths in the first 2 microsec are mainly Rayleigh-fading loaded.
> * The paths more than 4 microsec behind the time of arrival are more stable."

2.4. Diversity

Well known diversity techniques depend upon a second antenna or transmitter to enable selection of the best of more than one propagation path. With a single transmitter and two receiving antennas (with sufficient spacing to have a low level of level correlation) switch selection or linear combining are both possible and used.

As shown on page 5, **Naerhi [21]** observes considerable advantage for a two-antenna, selection diversity receiver in a handheld unit at 256 kbs. He concludes:

> "With the switching threshold adjusted to the optimum value, the improvement in BER is 5-6 dB at BER 10^-2 and 8-9 dB at BER 10^-3."

The subject of diversity selection is presented in considerable detail by **L-F. Chang, H. Arnold, R. Bernhardt and P. Porter of Bell Communications Research** [24]. The system they offer uses two-antenna selection at both fixed and mobile terminals, and the selection is based on error detection in the channel coding. They conclude:

> **"As has been shown many times before, diversity is a very effective way to mitigate the wide variability in the instantaneous signal in the radio environment; a system with 3-branch macroscopic diversity can be 20 dB or more superior to one with no diversity, and diversity against Rayleigh fading adds even more advantage. Conversely, at the same quality level, a system with diversity can use much larger coverage areas and smaller capital investment. As a result, diversity can be considered a system necessity."**

Their Figures are shown below and on the following page.

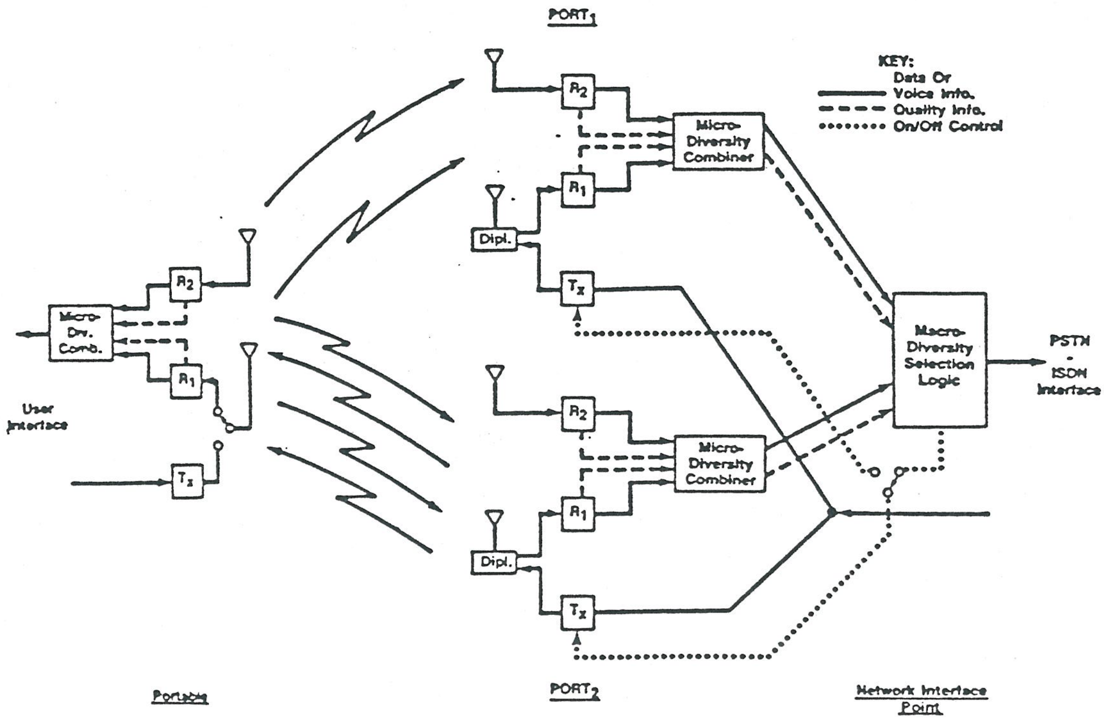

Fig. 1 Functional Block Diagram of the Diversity Selection Process

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L-F. Chang, H. Arnold, R. Bernhardt and P. Porter, Bell Communications Research, USA [24]

Figures showing probability of word error vs. average SNR per branch (5 dB/div)

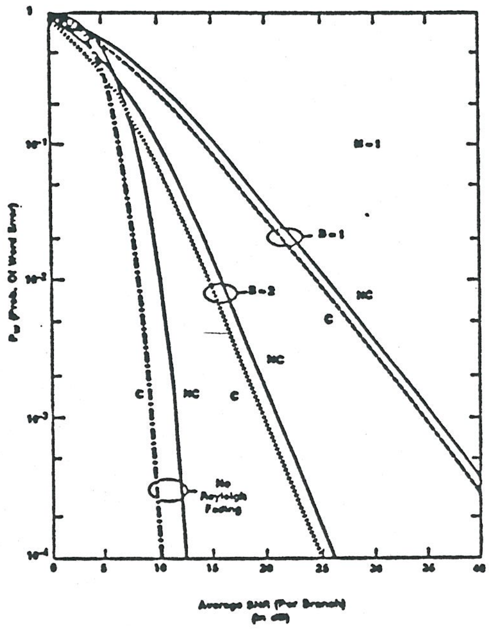

Fig. 2 Performance of a BCH(31, 21, 5) Code -- Selection based on Power

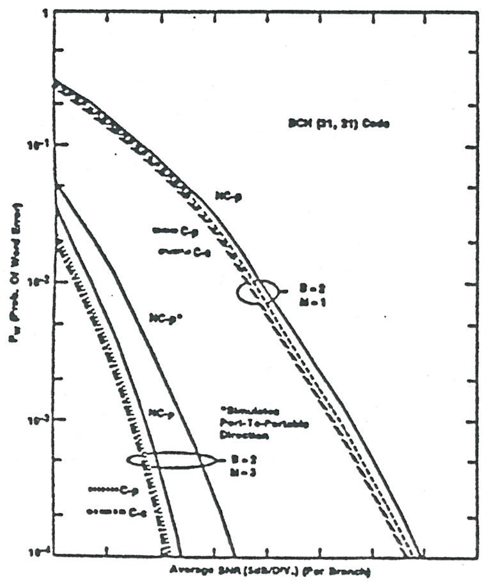

Fig. 3A Performance over a Multipath, Shadowed, AWGN Channel, using a BCH(31, 21, 5) Code

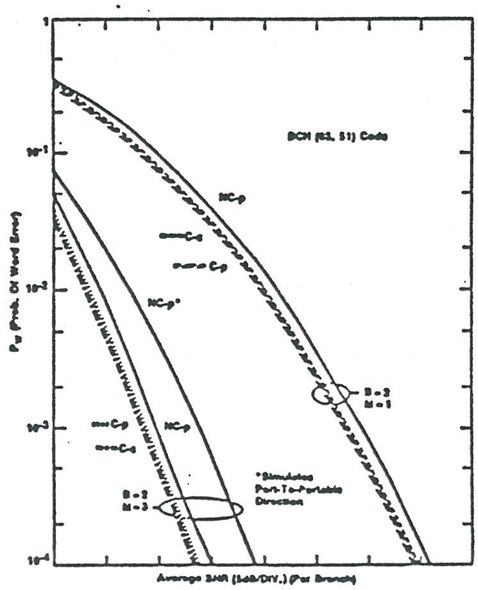

Fig. 3B Performance over a Multipath, Shadowed, AWGN Channel, using a BCH(63, 51, 5) Code

Note: to compare this curve to Fig. 3A, a factor of 21/51 must be applied to P_w.

2.5. Channel Coding

All papers were agreed on the imperative need for channel coding for 1/4 to 1/2 the available baud capacity. **T. Maseng, ELAB, Norway [19]** said from the platform: "The more coding, the less bandwidth." His paper presents details of a combined modulation, coding and adaptive equalizer plan with block diagrams of the implementation.

Most frequently used in system plans, were the Reed-Solomon codes, though BCH and others were suggested. Coding is limited by exhaustion of speed and capacity in the processing stage, a subjective level differently evaluated by various presenters. In most cases, the selection of the channel code is intimately related to other features of the system that control the distribution of error bursts and lost messages from interference.

H. Jokinen, Nokia-Mobira, Finland [22] shows an example using a Reed-Solomon code word of 448 bits in which 400 bits are payload. He shows an implementation using an 8051 microprocessor with additional hardware functions in CMOS that is capable of decoding with 9 errors in 5 milliseconds, 2 errors or less in 1.6 milliseconds.

The Nokia-Mobira proposal presented by **E. Kuisma, Finland [29A]** uses Reed-Solomon (57,39,19), symbol 7 bits for channel coding. Figure 6 (3 graphs) shows BER with and without channel coding and diversity.

"Reed-Solomon codes of length 8 to 25 are used" in the plan described by **J. L. Dornstetter, LCT, France [30]**.

The Ericsson DMS 90 proposal, described by **J. Uddenfeldt [26]** includes a Reed-Solomon (12,8) 4 bits/symbol code with a data transmission rate of 340 kbs. Test results are presented in a companion paper by **Uddenfeldt, Raith and Hedberg, Ericsson Radio Systems, Sweden [27]**. Below is Figure 1 from this paper showing the effect on BER of the channel coding.

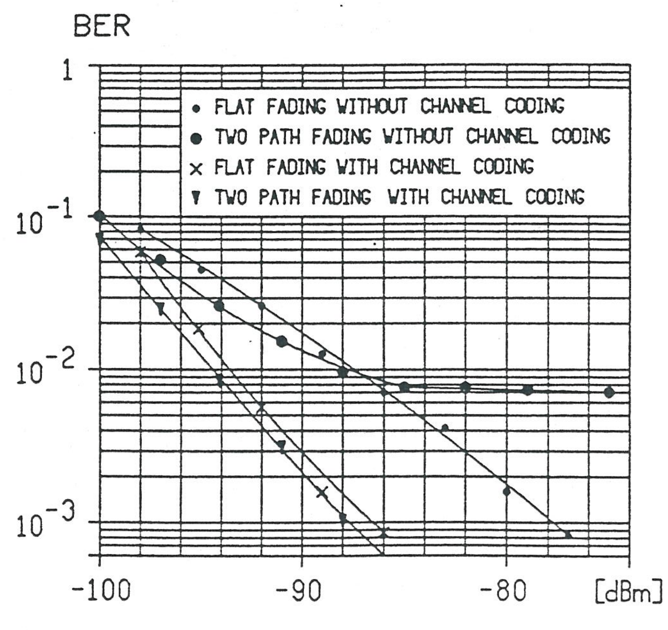

Figure 1. Laboratory measurements.

2.6. Frequency Hopping

Some of the proposals contain frequency hopping as part of the system plan. The main value is that signal level is more consistent among all users and with time for one user. The bad path is not used for more than one packet by any particular mobile. With some interleaving and time displacement of parts of packets, it is possible to distribute error bursts so that the forward error correction is effective. This is well described by **J. Uddenfeldt, Ericsson Radio systems, Sweden [26]**, paragraph 2.3.

In a plan described by **J. L. Dornstetter, LCT, France [30]**, frequency hopping is used in a more complex way where there is no simultaneous use of the same frequency within the same cell, but there is a possibility of collision between cells and the lost packets are overcome with coding. The description of the advantages is:

> "It is often claimed that the only interest of Frequency Hopping (FH) with respect to conventional FDMA lies in a potential benefit for the stationary user experiencing a deep fade on its assigned frequency. While true, this statement nevertheless represents an overwhelming simplification of the situation.
>
> ....
>
> Beside such an advantage for the stationary user, FH provides another advantage: the spectrum efficiency can be increased by introducing simultaneously FH and an adequate channel coding scheme.
>
> ....
>
> The net gain in spectrum efficiency due to FH lies about 50%.
>
> ....
>
> Roughly speaking, the old situation was '20% of the users have a channel that performs poorly 100% of the time' while now we are faced to the new situation '100% of the users have a channel that performs poorly 20% of the time.'"

The intimate relationships between coding, frequency hopping, diversity and C/I limits on frequency reuse are fully used in this plan.

2.7. Modulation and Modems

There is much art in the selection of a modulation and the technique of the receiver demodulator. For delays of less than 1 bit interval, **Ikegami [6]** shows a considerable advantage for anti-multipath modulation/demodulation in Figure 3 though he gives no usable explanation of the modulations compared.

There is considerable detail and math given by **S. Mahmoud and M. El-Tanay, Carleton University, Canada [17]**, analyzing TFM, Gaussian MSK, 3RC and duobinary MSK all of which are continuous phase modulation with index 0.5 . Figure 1 compares all of these for BER vs. Eb/No. The emphasis is on carrier recovery from a squaring process which is not necessarily an absolute requirement.

The modulation and modem are a part of the description of adaptive equalization given by **T. Maseng [19]**.

A two-ray model is used as a tool in evaluating details of coherent detection of continuous phase modulated signals by **A. Svensson, University of Lund, Sweden [20]**. He concludes:

> "We have shown that CPM schemes with h=0.5 can be used effectively to combat multipath fading on a two-ray channel, when the impulse response can be measured relatively accurately. The question is how to adaptively adjust the filters in the detector. This seems to be a difficult task for the linear detector but might be possible to overcome for an ML (maximum likelihood) detector."

The modulation chosen by **Kuisma, Nokia-Mobira, Finland [29B]**, is filtered MSK (GTFM or GMSK). He gives considerable detail on size, complexity, power drain of the circuits required to implement the modem, channel coding and radio.

R. Failli and M. Sentinelli, SIP D. G., Italy [37] refer to a block diagram of a flexible modem for

> "transmission rates up to 300 kbit.s, using any phase modulation of the 12PM3 class, which includes MSK, GMSK, TFM, GTFM, CCPSK, etc.; these modulations differ from one another only by the shape of the phase trajectories by which the signal vector shifts from one state to another."

Cox, et al, Bell Communications Research [43] picks QPSK in a plan with short range and no special treatment for multipath adaptive equalization.

H-P. Ketterling and D. E. Pfitzmann, Bosch, FRG [32][33A], as part of the system, S 900 D, describe CP-4FSK (continuous phase 4 frequency shift) modulation and demodulator circuit for a rate of 128 kbs without using an adaptive equalizer.

2.8. Adaptive Equalizers

Adaptive equalization adjusting to the measured impulse response of the channel is used by almost all plans at rates above 100 kbs. The problem is well stated by **T. Maseng, ELAB, Norway [19]**:

> "The input bit stream is not continuously transmitted, but concentrated in bursts which are transmitted at a higher data rate. Each burst has a duration of 0.1 to 1 millisecond, so the channel is assumed to be constant during a burst. At the start of each burst, a known signal is transmitted which is utilized in the receiver to determine the channel characteristics valid for the same burst. The receiver is then "tuned" to receive a signal in such a channel, and the information part of the burst is decoded by the adaptive Viterbi algorithm. During the period of no transmission, other mobiles may use the same frequency band, thus performing Time Division Multiple Access (TDMA)."

The same subject is treated by **J. Uddenfeldt, Ericsson Radio systems, Sweden [26]** in the description of the Ericsson DMS 90 system:

> "With TDMA transmission, severe time dispersion occurs. A typical value for the spread of time delay in an urban area is 0.5-2 microseconds. This will make a TDMA system virtually useless at a transmission rate of 340 kb/s.
>
> The experimental system for DMS 90 uses an adaptive decision feedback equalizer (DFE) to eliminate time dispersion. The DFE is an adaptive filter with both a feedforward and a feedback part. The filter coefficients are updated for each new TDMA-burst, and they can be updated during the burst. The equalizer compensates for the channel time response and eliminates the time dispersion.
>
> Furthermore, the adaptive equalizer can make positive use of the multipath propagation in the form of a diversity function. This stems from the fact that, with time dispersion, the same signal travels multiple ways before it reaches the receiver. With independent fading of the rays, it is possible to provide a diversity function.
>
> The adaptive equalizer can perform these functions without any bandwidth expansion."

This equalizer is described in greater detail by **J-E Stjernvall, et al, Ericsson Radio Systems, Sweden [27]** in paragraph 3.5 and attached figures.

Another design for the adaptive equalizer is described by **E. Kuisma, Nokia-Mobira Oy, Finland [29A]**:

> "The equalizer includes a T/2 spaced, 6 tap forward section and a T spaced 3 tap decision feedback section. The sampling rate is four times the bit rate (4/T). The adaptation is based on stochastic gradient update algorithm.
>
> There are two modes of operation. A training mode in the beginning of the subframe (32 bits) is used to make the initial tap setting; and a decision feedback mode during the sub-frame will make the adjustment of tap coefficients according to the varying conditions. Different step sizes are used in different modes. Adaptation is performed once during a symbol (every fourth sample) but equalization is performed for all samples.
>
> In addition to removing intersymbol interference, the equalizer also reduces effects of noise, random FM and non-idealities of the receiver by maximizing the eye opening before decision."

Kurisma [29B] continues to describe this equalizer (for a rate of 28 kbs) in the form of the engineering model intended to eventually result in a design for a hand-held portable:

> "The implementation is based on TMS 32020 signal processors. 6 processors and additional hardware, 4 double Eurocards together, are used to get a flexible system."

2.9. Plans Using Megabaud Rates

The "**MATS-D Radio Transmission Plan**" proposes wideband transmission from base to mobile at a 1.248 Mbs rate. The plan is described by **R. Beck, U. Wellens, et al, Philips Kommunikations, FRG [36]**. None of the other related papers listed in the references were available at the meeting. Description of the adaptive equalizer is given. The plan is described as suitable for high speed trains at 230 km/hr.

The title "**A Digital TDMA Micro Cell System for Business Cordless Telephones**" describes the context for **D. Aokerberg and B. Persson, Ericsson Radio Systems, Sweden [44]**. The data rate is 1250 kbs in a 1.5 MHz bandwidth with 32 millisecond frames. There is no adaptive equalization, however the system assumes a time dispersion of only 50 nanoseconds with 800 nanosecond bit intervals for a transmission range of 50 meters.

The plan of **F. Ikegami, Kyoto University, Japan [6]** uses 1 Mbs outward rate for 1 kilobit packets with anti-multipath modulation. He estimates a zone radius of about 100 meters with transmitting power of 1 watt at microwave frequencies. Ikegami's Figure 3 (shown below) suggests that suitable modulations may well tolerate average delay spread of up to 0.7 bit period. At 1 Mbs, this point is the difference between 50 and 500 meters range limitation without adaptive equalization.

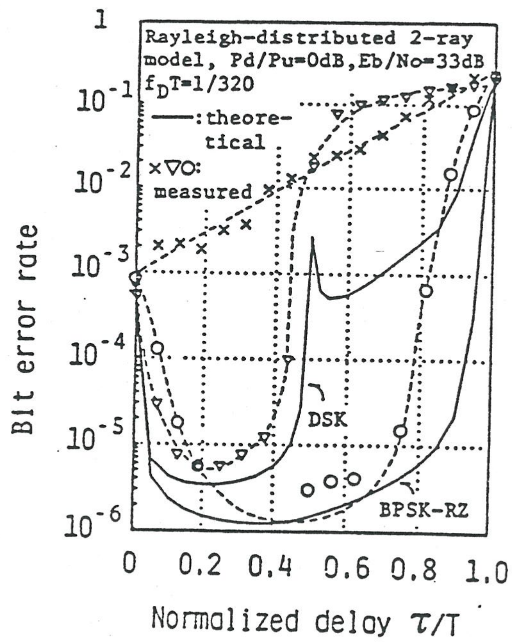

Fig.3 Bit error rate performance of anti-multipath modulation/demodulation systems DSK and BPSK-RZ, compared with conventional BPSK.

2.10. ISO Model and the Access Protocols

Only Madame M. B. Pautet, CNET, France [72] was the only speaker concerned with the ISO model. She gave the following specifics on where a mobile radio system is not accomodated in the 7-layer structrure:

". . . .the radio interface of a digital multiservice PLMN differs from an ISDN user interface, because of three main reasons:

1) The absence of a fixed physical support (the physical channels are taken from a shared pool) implies soe kind of switching at the radio interface; moreover, demand for spectrum efficiency leads to a tight allocation of channels both in time and bit-rate.
2) The mobility of users results in constant changes in their access-point to the network, and this even during communication periods (handover).
3) The non-stationarity of the transmission medium is due to attenuation, masks and Rayleigh fading and results in frequent losses of bit bursts.

For all these reasons, the ISDN user-accesslayer protocol, dscribed in CCITT recommendation Q.931 cannot be used as a basis for part of the signaling protocols as will be explained in section 1.3."

Madame Pautet leaves the data link layer behind and goes on to propose management blocks and structure which resolve these difficulties in a stucture with minimum departure from CCITT recommendations and ISO standards.

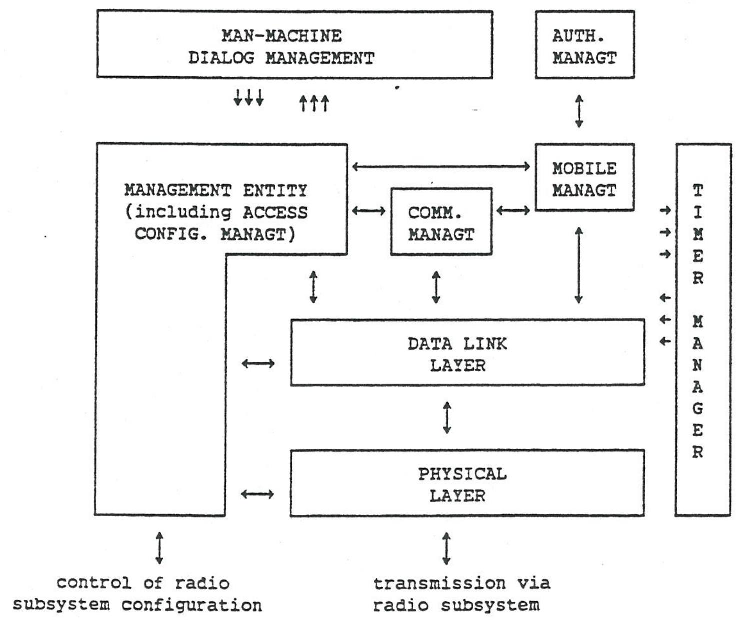

Figure 3 - Mobile Station Modules

3. PAPERS INCLUDED IN ATTACHMENT

Number	Author(s), Title, Affiliation
6	F. Ikegami, **Discussions on the "Ultimate Communication"** Kyoto University, Japan
17	S. Mahmoud & M. El-Tanany, **Design and Performance of Continuous Phase Modems for Mobile and Portable Radios**, Carleton University, Ottawa, Canada
19	T. Maseng & O. Trandem, **Adaptive Digital Phase Modulation**, ELAB, 7034 Trondheim-NTH, Norway
20	A. Svensson, **On Coherent Detection of Continuous Phase Modulation On A Two-Ray Multipath Fading Channel**, University of Lund, Box 118, S-221-00 Lund, Sweden
21	T. Naerhi, **Experimental Results on Diversity in Digital Mobile Radio**, Technical Research Centre of Finland, 02150 Espoo, Finland
22	H. Jokinen, **Channel Coding and Bit Error Measurements in a 900 MHz Digital Mobile Telephone Test System**, Nokia-Mobira Oy, 24101 Salo, Finland
24	L-F Chang, H. Arnold, R. Bernhardt, P. Porter; **Coding as a Means to Implement Diversity Selection in a Frequency Re-Using Portable Radio System**, Bell Communications Research, Red Bank, NJ 07701 USA
26	J. Uddenfeldt & B. Persson, **A Digitial FD/TDMA System for a New Generation Cellular Radio**, Ericsson Radio Systems AB, S-163 80 Stockholm, Sweden
27	J-E Stjernvall, K. Raith, B. Hedberg; **Performance of an Experimental FD/TDMA Digital Radio System**, Ericsson Radio Systems AB, S-163 80 Stockholm
29A	E. Kuisma, **Performance Analysis of a Digital Mobile Radio System Based on Narrowband TDMA**, Nokia-Mobira Oy, 24101 Salo, Finland
29B	E. Kuisma, **Feasibility Study of the Radio Equipment Including Hand Portables in a Narrowband TDMA System**, see 29A
30	J. Dornstetter, **The Digital Cellular SHF 900 System**, Laboratoire Central de Telecommunications (LCT), Villacoublay Cedex, France
32	H-P. Ketterling, **The Digital Mobile Radio Telephone System Proposal S 900 D**, Robert Bosch GmbH, Berlin, FRG
33	D. Pfitzmann, H-P. Ketterling, K-H. Tietgen; **A New CP-4FSK Sampling Demodulator for the FD/TDMA System S 900 D and Numerical Modulation Methods**, Robert Bosch GmbH, Berlin, FRG
36	R. Beck, C. Grauel, K. Stry, U. Wellens; **MATS-D Radio Transmission**, Philips Kommunikations Industrie AG, Nuremberg, FRG
37	R. Faili et al, **Provisional Results of Italian Experiments on Digital Land Mobile Radio**, SIP D. G. & CSELT, Rome & Torino, Italy
43	D. Cox, H. Arnold, P. Porter; **Universal Digital Portable Communications: A System Perspective**, Bell Communications Research, Red Bank, NJ
44	D. Aokerberg, B. Persson; **A Digital TDMA Micro Cell System for Business Cordless Telephones**, Ericsson Radio Systems AB, S-163 80 Stockholm

Number	Author(s), Title, Affiliation
45	R. J. C. Bultitude, **Error Rate Calculations for the Transmission of DPSK on 800/900 MHz Mobile Radio Channels with Measured Characteristics,** Communications Research Centre, Ottawa, Canada K2H 8S2
46	A. Bajwa & O. Kafaru, **900 MHz Wideband Multipath Propagation Measurements and Modelling,** Telecom Securicor Cellular Radio Ltd. & University of Liverpool, London EC1 and Liverpool L69, UK
49	R. Lorenz, **Variation of Multipath Spread in Mobile Radio and its Impact on Digital Transmission,** Forschungsinstitut der Deutschen Bundespost, D-6100 Darmstadt, FRG
53	L. Szabo, **Experimental Investigations on the Time Variations of the Mobile Communication Channel,** Standard Electrik Lorenz AG, Stuttgart, FRG
69	R. Cheeseman, P. Munday, B. West; **An Experimental Test Bed for Digital Cellular Radio;** British Telecom Research Laboratories, Racal Research Ltd., GEC Research Ltd.; UK
71	P. Matthews & B. Rashidzadeh, **A Comparative Study of Wideband TDMA and TD/FDMA Systems for Digital Cellular Mobile Radio,** Univ. of Leeds, UK
72	M. B. Pautet & F. Courau, **Modular Implementation of Signalling Protocols in a Digital Mobile Communications System,** CNET, France

COPY

CHANDOS A. RYPINSKI

130 Stewart Drive
Tiburon, California 94920
Telephone: 415 435 0642

September 25, 1986

Mr. David Greenstein,
Chairman, IEEE 802.4L
General Motors Technical Center
Manufacturing Building A/MD-39
30300 Mound Road
Warren, MI 48090-9040

RE: **References on Digital Technology Relevant to Radio Token Bus**

Dear David:

Since my preparation to submit relevant technology references was incomplete on the occasion of out meeting of 24 September, I would like, now, to redo the submission in more usable form now attached.

The references are in three groups which are as follows:

1. Highly relevant and current references dealing in particular with multipath delay equalization, diversity and coding for mobile UHF or microwave applications.

2. Background and tutorial references on digital radio modulation and related band filtering problems. Material has been developed mainly for point-to-point microwave.

3. Title pages of relevant books and paper collections of background material.

To the group of papers that I gave you at Irvine, I have added papers prepared by the Ericsson Radio Research Group presented at the 1985 Conference on **Digital Land Mobile Communication** at Helsinki, and at other places. These are quite important in evaluating the tradeoffs between parallel frequency and higher speed time division methods.

Cordially,

Chandos A. Rypinski

Copy: C. Thurwachter, ITI

REFERENCE TECHNICAL PAPERS ON DIGITAL RADIO TECHNOLOGY

GROUP I -- CURRENT AND HIGHLY RELEVANT

1. **DIGITAL CELLULAR GOALS AND CHOICES**, J. Swerup, J. Uddenfeldt, Ericsson Radio Systems, Personal Communications Technology, May 1986. *Non-mathematical discussion of trade-offs for 27 kilobaud channels by frequency or by time division of higher rate using ADAPTIVE EQUALIZATION, REED-SOLOMON CHANNEL CODING AND FREQUENCY HOPPING between data bursts. Defines ERA 340 kilobaud system.*

2. **DMS 90 - AN EXPERIMENTAL TDMA DIGITAL MOBILE TELEPHONE SYSTEM**, Jan Uddenfeldt, Ericsson Radio Systems AB. *Detailed, non-mathematical description of 340 kilobaud GMSK system with described adaptive equalization, channel coding to overcome 25% lost symbols with forward error correction, and frequency hopping. Channel spacing is 300 kHz.*

3. MULTI-PATH EQUALIZATION FOR DIGITAL CELLULAR RADIO OPERATING AT 300 KBIT/S, K. Raith, J-E. Stjervall, J. Uddenfeldt, Ericsson Radio systems AB, 36th IEEE Vehicular Technology Conference, 20 May 86, 86CH2308-5. *Detail description of adaptive equalizer.*

4. **MODULATION AND CHANNEL CODING IN DIGITAL MOBILE TELEPHONY**, S. Ekemark, K. Raith and J-E, Stjernvall, Ericsson Radio Systems AB, Conference on "Digital Land Mobile Radio Communication" at Helsinki, 5 Feb 85. *Shows curves for BER in Rayleigh fading with different configuration and interference details at 27 kilobaud at 16 kilobaud with 15 kHz channel spacing.*

5. **DIGITAL PORTABLE TRANSCEIVER USING GMSK MODEM AND ADM CODEC**, H. Suzuki, K. Momma and Y. Yamao, Yokosuka Electrical Communication Laboratory (NTT), IEEE Journal on Selected Areas in Communications, Vol. SAC-2 No. 4, July 84. *Shows small portable radio with implementation of GMSK.*

6. **GENERALIZED TAMED FREQUENCY MODULATION AND ITS APPLICATION FOR MOBILE RADIO COMMUNICATIONS**, K-S Chung, Philips Research Laboratories, IEEE Journal on Selected Areas in Communications, Vol. SAC-2 No. 4, July 84. *Shows methods and simulation results for various implementations of GTFM modulators and demodulators.*

7. **MODELING AND ANALYSIS OF A DIGITAL PORTABLE COMMUNICATIONS CHANNEL WITH TIME DELAY SPREAD**, J. Chuang, Bell Communications Research, 36th IEEE Vehicular Technology Conference, 20 May 86, 86CH2308-5. *Conclusion for non-equalized system is "For BPSK with idealized NRZ signaling, the bit rate cannot exceed about 0,2 if the normalized rms delay spread for an average 10^-3 BER if a coherent detector is used;..."*

8. **ON COHERENT DETECTION OF MSK ON A TWO-RAY MULTIPATH FADING CHANNEL**, Arne Svensson, University of Lund (Sweden), 36th IEEE Vehicular Technology Conference, 20 May 86, 86CH2308-5. *Shows quantitative degradation of MSK by second path.*

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9. **LABORATORY EVALUATION OF A MOBILE RADIO DATA SYSTEM**, M. Bruneau, et al, Communications Research Centre, Department of Communications (Canada), 36th IEEE Vehicular Technology Conference, 20 May 86, 86CH2308-5. *Shows results of experimental comparison of various digital modulation techniqwues in mobile radio environment. Prefers 9.6 kbs system with GTFM, BCH code rate 75%, switch-and-stay diversity.*

PART II -- BACKGROUND AND TUTORIAL PAPERS

10. **A COMPARISON OF MODULATION TECHNIQUES FOR DIGITAL RADIO**, John D. Oetting, Booz-Allen & Hamilton, IEEE Transactions on Communications, Vol. COM-27 No. 12, Dec 79. *Compares most types of digital modulation for power, bandwidth and resistance to delay distortion and Rayleigh fading. <u>Definitive work</u> with extensive reference list. Attached with Table of Contents for "Special Issue on Digital Radio."*

11. **TELECOMMUNICATIONS BY MICROWAVE DIGITAL RADIO**, D. P. Taylor and P. R. Hartmann, McMaster University (Canada) and Collins Transmission System Division of Rockwell International, IEEE Communications Magazine, Vol. 24 No. 8, Aug 86. *Current evaluation of problems and efforts at solution in point-to-point microwave. Diversity, adaptive equalizers discussed. Bibliography.*

PART III -- BOOKS AND SPECIAL ISSUES (Cover and Contents Only)

12. **MICROWAVE MOBILE COMMUNICATIONS**, William C. Jakes, Bell Telephone Laboratories, John Wiley & Sons, 1974. *Authoritative work on propagation, diversity and system design factors. Mostly related to analog FM and 900 MHz, but includes other assumptions.*

13. **LAND-MOBILE COMMUNICATIONS ENGINEERING**, D. Bodson, G. McClure, S. McConnoughey, IEEE Press, 1984. *Collection of most significant papers in the development of land-mobile radio. Includes classic papers on propagation, diversity and analog modulation.*

14. **SPECIAL SECTION ON COMBINED MODULATION AND ENCODING**, Edited by J. Anderson and J. Lesh, IEEE Transactions on Communications, Vol. COM-29 No. 3, March 81. *Definitive papers on phase modulation by T. Aulin and C-E Sundberg and others. Important references.*

15. **SPECIAL ISSUE ON MOBILE RADIO COMMUNICATIONS**, Edited by J. Davis, J. Mikulski and P. Porter, IEEE Journal on Selected Areas in Communications, Vol. SAC-2 No. 4, July 84. *Contains many good papers on channel coding, modulation and diversity.*

16. **SPECIAL ISSUE ON DIGITAL RADIO**, Edited by K. Feher, et al, IEEE Transactions on Communications, Vol. COM-27 No. 12, Dec 79. *<u>Classic issue on microwave digital modulation</u> of all types for microwave. Extensively treats filtering of square wave inputs for spectrum shaping.*

17. **MICROWAVE HOMODYNE SYSTEMS**, Ray J. King, University of Wisconsin, Peter Peregrinus Ltd. (Herts., U.K.) for IEE, 1978. *Important reference on direct conversion from microwave to baseband particularly suitable for minimum cost radio on a chip. Mostly directed at instrumentation, but contains much useful design information.*

18. **MICROWAVE INTEGRATED CIRCUITS**, J. Frey and K. Bhasin, Cornell and NASA, Artech House, Dedham MA 02026, 1985. *Useful survey of microwave integrated ciruit design techniques relevant to feasible microwave radio equipment design.*

NOTE: The **Second Nordic Seminar on Digital Land Mobile Radio Communication** will take place at Stockholm, October 14-16, 1986. This event is certain to produce additional relevant technical papers. C. Rypinski will attend.

MOTOROLA INC.

July 14, 1986

MEMO TO: Robert A. Bruce
Robert M. Cullen
David Greenstein
Chandos A. Rypinski
Charles N. Thurwachter, Jr.

FROM: Max Allen

SUBJECT: FCC Mailing Address

As agreed in the 804.2L Committee meeting on July 9, the Committee urges a letter to the FCC in support of Docket 86-174, which is Codex's request for spectrum allocation for a radio local area network (RLAN). The letter is to reference support of the need of proposed spectrum allocation for this use and support of the solution as proposed. The mailing address is:

Federal Communications Commission
Public Records Office
1919 M Street NW
Washington, DC 20006

Responses are to arrive by July 23, 1986.

Next meeting of the Committee is scheduled in Brighton, England, for the week of July 27 through August 1 at the Metropole Hotel. The complete notes of the Committee meeting will follow shortly.

Regards,

MOTOROLA, INC.

Max Allen

Max Allen
Software Acquisition & Third-Party
Interface Manager

jmc
BY020

Communications Sector
1301 E. Algonquin Rd., Schaumburg, Illinois 60196 (312) 397-1000

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HUGHES
AIRCRAFT COMPANY
MICROELECTRONIC SYSTEMS DIVISION
Industrial Electronics Group

21 July 1986

Mr. David Greenstein
General Motors Technical Center
Manufacturing Building A/MD-39
30300 Mound Road
Warren, Michigan 48090-9040

Dear David:

The next scheduled meeting for the IEEE 802.4L working committee will be held at Hughes Aircraft Company, Microelectronic Systems Division, Building 713, in Irvine, California. The meeting is scheduled for Wednesday, September 24, 1986, starting at 9:00AM.

Enclosed for your distribution are maps of the Irvine, California area showing the Hughes location and local hotels. All telephone numbers within area code 714. Also enclosed is a travel guide indicating airlines, restaurants, etc. in the local area.

If there are further questions, please call me at 714-752-3633.

Sincerely,

Robert A. Bruce

Robert A. Bruce

RAB:bah

enclosures

802.4L = "THROUGH-THE-AIR" (RADIO OR OPTICS)
TOKEN BUS | MDS

2601 CAMPUS DRIVE • P.O. BOX 19618 • IRVINE, CALIFORNIA 92715
714-752-3800 • TWX: 910-595-2435

CHANDOS A. RYPINSKI
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Tiburon, CA 94920
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COPY

April 25, 1986

Mr. David J. Greenstein,
Senior Project Engineer,
Planning and Operating Systems
Manufacturing Engineering and Development
General Motors Corporation
General Motors Technical Center
Warren, Michigan 48090-9040

RE: 802.4L Radio Medium Token Bus

Dear David:

Your idea that Token Bus protocol might be advantageous for a radio system, which is inherently broadcast, appeared to me worth an effort to understand the possibilities and limitations. I have written a MEMO to you, attached, in which I have listed constraints and attempted a trial system plan. I ask that you read it, and consider it for a submission to the committee (802.4L).

Also enclosed, is a confidential disclosure agreement. I would be grateful if you signed it and returned one copy. I do not wish to lose, if I can avoid it, patent rights on one critical idea in it. If it is impossible for you to sign it for General Motors, I would make out another one with only your name. If it comes down to it, I would rather have you read the paper even if you can't complete the agreement—it is a favor.

I plan to attend the meeting, and by then, have some sort of feeling about how important a possible patent may be. I don't see how a committee could adopt anything that it can't talk about.

Over the years, I have worked with many types of digitally modulated radio systems. It is a field where I can contribute if there is need.

Cordially,

Chandos A. Rypinski