A Comparison of Indoor Radio Propagation Characteristics at 910 MHz and 1.75 GHz

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Abstract—There has recently been much deliberation regarding whether indoor radio communications systems should operate in the 900 MHz band, or in the 1.7 GHz band. However, there are no propagation results available in the literature which compare indoor channel characteristics in the two bands. This paper presents the results of temporally and spatially distributed wideband (impulse response) propagation measurements on fixed indoor radio channels in these bands. Impulse response parameters, as well as envelope fading and frequency correlation statistics are presented and compared for the two bands, and for two different buildings.

Results from the temporal experiments show that for a specific location in either of the two buildings, the dynamics of indoor channels are slightly less random at 910 MHz than at 1.7 GHz. It is believed, with due regard for the quasi-static nature of the fading, that this would result in marginally better performance on a given transmit/receive link in the 900 MHz band. The spatially distributed measurements showed that the structures of average impulse response envelopes differed for channels in the two buildings. In one building, rms delay spreads were slightly greater in the 1.7 GHz band for over 90 percent of transmit/receive link configurations. In the other building, rms delay spreads were marginally greater in the 900 MHz band for 70 percent of the configurations. It was also found that the standard deviation of rms delay spreads for different link configurations was greater for both frequency bands in this building. In both buildings, the standard deviation was greater for the 1.7 GHz band results. These differences in rms delay spread standard deviations are considered to be important in the evaluation of coverage capabilities in different buildings and for different frequencies of operation.

I. INTRODUCTION

CURRENTLY, based upon spectral allocation considerations, debates are being conducted regarding whether indoor radio communication systems should operate in the 900 MHz band, or in the 1.7 GHz band. To date, however, there are no propagation results available in the literature which compare indoor radio channel characteristics in the two bands. This paper details the results of temporally and spatially distributed wideband (impulse response) propagation measurements made on fixed indoor radio channels at center frequencies of 910 MHz and 1.75 GHz. Impulse response parameters, as well as envelope fading and frequency correlation statistics are presented and compared for the two bands and for two different buildings.

II. DESCRIPTION OF THE MEASUREMENT ENVIRONMENTS AND EQUIPMENT

Experiments were conducted at the Communications Research Center (CRC), and at Carleton University (CU), both in Ottawa. The measurements at CRC were made in two wings of a 30-year-old four story brick building with reinforced concrete and plaster, as well as some ceramic block interior partitions. The ceilings in the building vary in height from 2.5 to 2.9 m and finishes are of perforated sheet metal, or nonmetallic ceiling tile. Some of the frames around windows and doorways are metallic. Asphalt tiles cover the floors, and are laid on concrete subfloors with metallic and nonmetallic cable conduits beneath. Each wing of the building is partitioned into many small offices and laboratories bordering a central hallway. One wing measured 60 m in length and the other was 45 m in length.

At Carleton University, the measurements were made in a modern three story building constucted of concrete blocks with steel support members at periodic spacings. Most internal partitions are of the same construction as the outside walls, but some consist of plasterboard fastened to galvanized steel studs. Small offices surround a hallway and central core, where there is a classroom and several laboratories. The dimensions of the wing in which the measurements were conducted are about 35 m square. Fire doors with windows which have embedded wire mesh separate this wing from the rest of the building.

The block diagram for the 910 MHz measurement system transmitter is shown in Fig. 1(a). The parameters of the transmit signal were the same as those employed by Devasirvatham [2]. A 40 Mbit/s pseudorandom binary sequence (PRBS) was used to phase (BPSK) modulate a 910 MHz carrier. The resulting spread spectrum signal was band limited to 80 MHz, amplified and transmitted via a laboratory-constructed quarter-wavelength monopole antenna with four quarter-wavelength radials. The transmit power used during the measurements was +26 dBm. Fig. 2(a) shows that the same configuration was employed at 1.75 GHz, except a frequency doubler was inserted at the RF carrier input to the upconverter mixer. Transmit power in this band was +25 dBm.

The 910 MHz receiver block diagram is shown in Fig. 1(b). Reception of the off-air signal was via a monopole identical to that used at the transmitter, connected to an
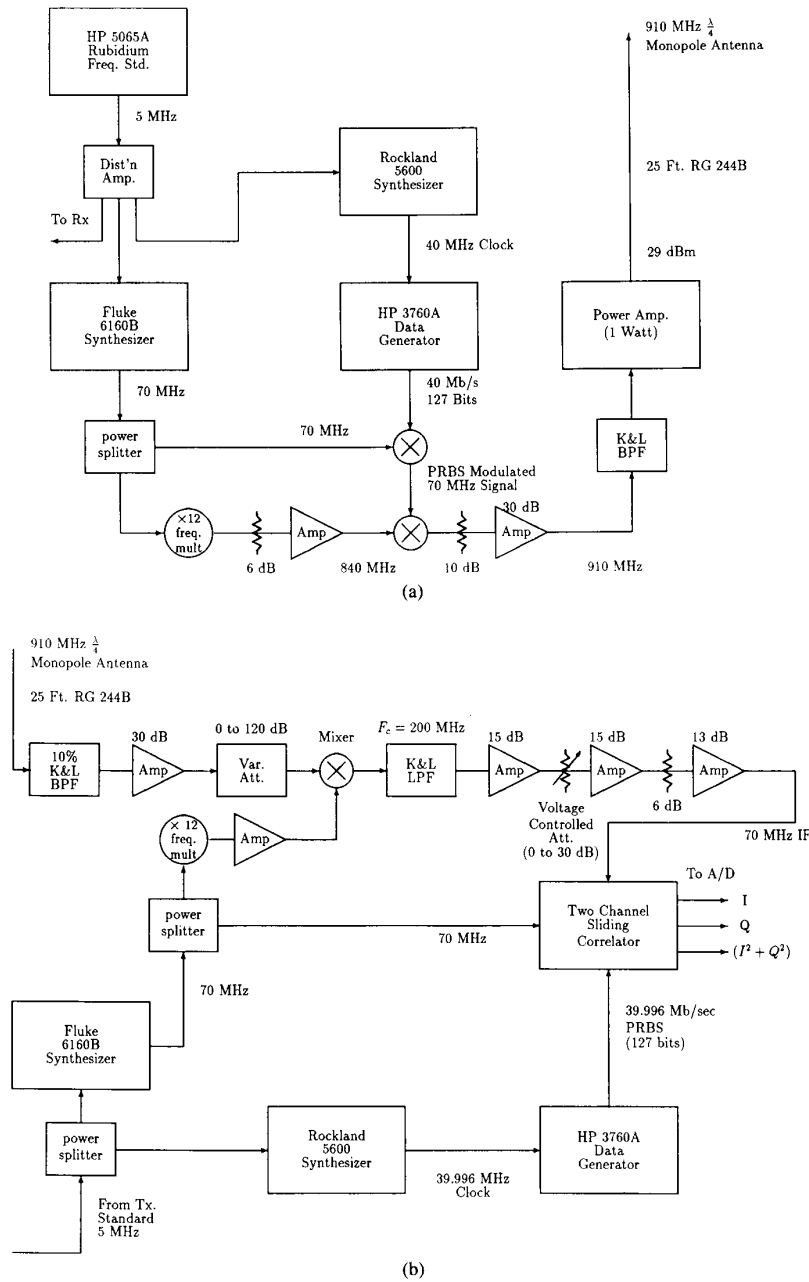
Fig. 1. Block diagram of the 900 MHz band measurement system: (a) the transmitter; and (b) the receiver.

80 MHz bandpass filter. The output from the filter was amplified, down-converted to 70 MHz, then amplified a second time in an amplifier-voltage-controlled-attenuator-amplifier chain, and applied to a sliding correlator. The second amplifier-attenuator combination was used to ensure that the peak of the power envelope output from the correlation, and therefore the operating range of the signals at the correlator output was approximately the same for all transmit locations. The input to the correlator was split into two channels, and each was applied to a double-

balanced mixer for multiplication with a 70 MHz BPSK-modulated signal identical to the one generated at the transmitter, but with a modulation rate 4 kbits/s lower [1]. The correlator mixers were followed by integrators implemented with single-pole *RC* filters having 3 dB cutoff frequencies of 4 kHz. Since the 70 MHz input to one of the local BPSK modulators was phase shifted by 90 degrees, the correlator outputs were in phase quadrature. These signals represent good estimates [2] of the impulse response of the propagation channel between the trans-
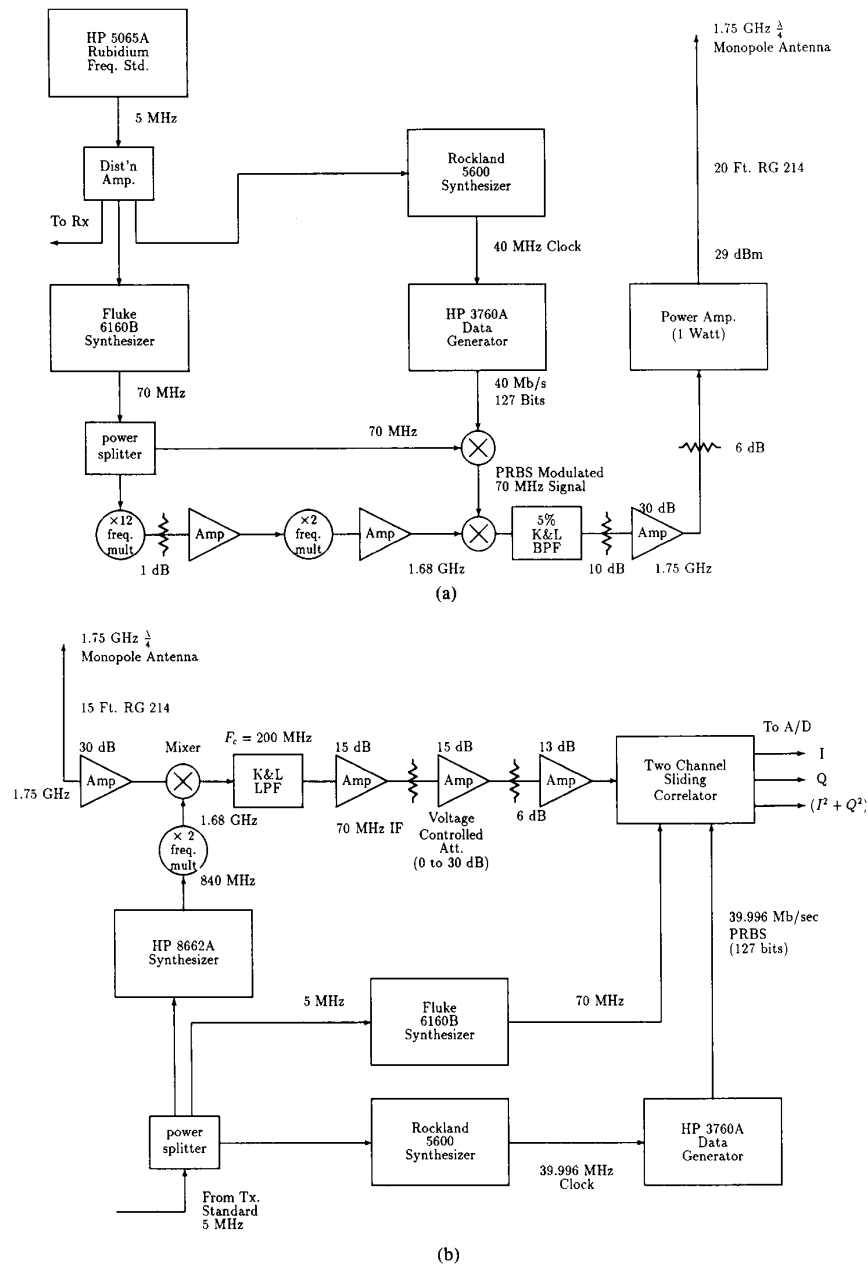
Fig. 2. Block diagram of the 1.7 GHz band measurement system; (a) the
transmitter; and (b) the receiver.

mitter and the receiver. All transmit and receive system
clocks and oscillators were synchronized to one rubidium
frequency standard by means of a coaxial cable which was
run along the floor between the transmitter and receiver.
This was done in order to obtain a stability such that mul-
tipath component time delays could be measured. In pre-
vious experiments it has been found that the presence of
such a cable has little influence on propagation character-
istics. It is believed that this is a result of the fact that the
environment is already extremely cluttered with conduc-
tors so that one more, directly grounded to the equip-

ment, is of little significance. The configuration employed
for the 1.75 GHz receiver was slightly different, as shown
in Fig. 2(b). Since a second times-twelve frequency mul-
tiplier was not available at the time of the 1.75 GHz ex-
periments, two synthesizers, rather than one, as in the
transmitter, were employed to generate the receiver local
oscillator signals. One supplied an 840 MHz CW signal
to a frequency doubler for the initial downconversion. The
second provided the 70 MHz local CW input to the cor-
relator circuitry. A block diagram of the correlator is
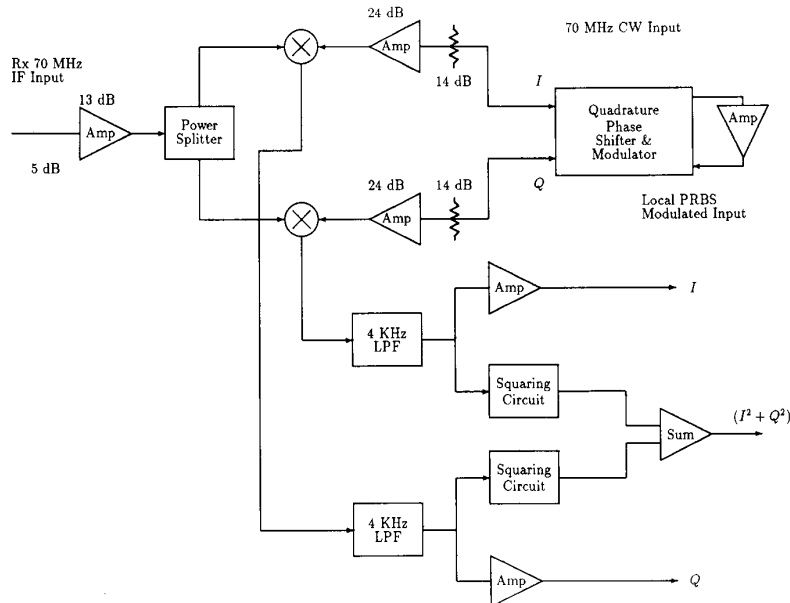shown in Fig. 3. This circuit functions in an identical

Fig. 3. Receiver correlator block diagram.

manner to that described by Cox [2]. Because of the 40 Mbit/s modulation rate used at the transmitter, the base widths of the correlator output pulses were 50 ns. The peaks of two such pulses can readily be distinguished even when half of their widths overlap at their bases. The time resolution of the measurement systems was therefore nominally 25 ns in both frequency bands.

The in-phase (I) and quadrature (Q) signals from the receiver correlator were passed to a Compaq AT 286 microcomputer-based data collection system, where they were each sampled at a rate of 16 k samples/s and converted to digital form in a 12-bit A/D converter. This sampling rate resulted in an effective interval of 6.25 ns between each of the 508 samples in each impulse response estimate due to the time-scaling effect of the sliding correlator [1]. The data were initially stored on a 40 Mbyte hard disk, then transferred to 9-track tape for later processing on a mainframe computer.

Fig. 4 shows logarithmic plots of averages for 50 measurement system impulse response estimates recorded for each band of operation when the transmitter and receiver were connected via coaxial cable through a 60 dB attenuator. For these tests, the received power level was adjusted by means of receive system attenuators to be within the power range which was typical during experiments. The figures show that there were imperfections in the systems which gave rise to multipath-like peaks with nonzero excess delays. These were probably a result of RF system mismatches or a combination of minor frequency-selective RF component characteristics across the 80 MHz system bandwidth. All impulse response aberrations, however, were at power levels below −25 dB with respect to the system impulse response envelope peaks. These could be distinguished from multipath components during off-
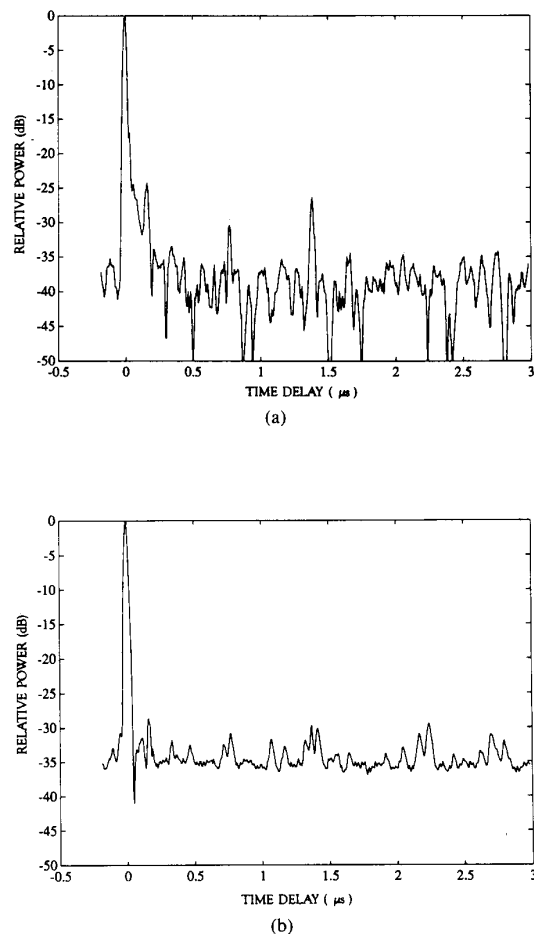

(a)

(b)

Fig. 4. Measurement system impulse response envelopes for operation in: (a) the 900 MHz band; and (b) the 1.7 GHz band.

air measurements by methods outlined in Section III of this paper. The areas bounded by the envelopes of frequency correlation functions (FCF's) computed from the back-to-back test results between ±20 MHz from midband were 40 and 38 correlation-MHz (C-MHz) at 910 MHz and 1.75 GHz, respectively. On a perfectly functioning system, these areas would each be 40 C-MHz. The perfect result at 910 MHz and the small degradation at 1.75 GHz attest to the integrity of the measurement systems and the correlation computation procedures. In particular, it is clear that the small unwanted peaks in the impulse response envelopes had little influence on the correlation results. On fading communication channels, the FCF area decreases as the correlation properties of the channel become poorer. It is therefore believed [3] that FCF areas are useful parameters for the assessment of the quality of radio channels for digital communications.

III. DESCRIPTION OF THE EXPERIMENTS AND RESULTS

A. Temporal Characteristics

Experiments were conducted to determine the temporal statistics of the signal received at a fixed location from a fixed transmitter. Results of these experiments are intended for use in the design of fixed indoor radio systems. The measurement system receiver was thus stationed in one location while the transmitter was moved to consecutive, fixed desk-top positions, and recordings were made during 2 min intervals. These experiments were conducted during the daytime on week days, with personnel moving throughout the building as usual. During each 2 min period 3779 impulse response estimates were measured for analysis by methods reported in other publications [3]–[5].

At CU, 2 min recordings were made at 910 MHz with the transmit antenna in 19 different locations, while the receiver remained fixed at point A, shown in Fig. 5. At a later date, measurements at 1.75 GHz were made with the receiver at point A for nine different transmit locations, eight of which were the same as those for which 910 MHz data were recorded. In addition, 1.7 GHz band measurements were made at 11 transmit locations with the receiver fixed in location B. Data recorded for locations 1 and 17 are not discussed in this paper, as the propagation paths to these locations were distinctly different from paths to the other locations because of line of sight between the transmitter and the receiver at point A.

Equivalent CW envelope fading statistics were computed [5] from the wideband data. Since the primary purpose of the measurements was to compare 900 MHz and 1.7 GHz band propagation conditions, rather than to gather data for use in system performance calculations, recording periods were shorter than those that would be required to obtain high confidence levels for statistical results. In addition, data from quiescent periods were not removed from envelope time series before fading distribution computations, as would be required [4] for application in performance calculations. For the 30 910 MHz transmit locations, the average fading range was 25 dB,
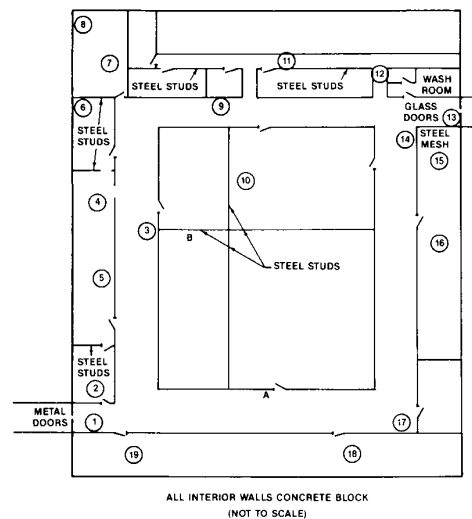

ALL INTERIOR WALLS CONCRETE BLOCK
(NOT TO SCALE)

Fig. 5. Floor plan of the measurement area at Carleton University.

the maximum was 35 dB, and the minimum was 14 dB. Fading distributions were Rician in all cases, even though there was no line of sight between the transmitter and receiver. For mobile channels, Rayleigh fading would be expected under such conditions. This, however, is not always true for fixed propagation channels. The details of propagation environments leading to the Rician distributions for fixed indoor links are explained in [4]. Theoretical distributions which best fit the experimental distributions corresponded to K (random/specular power) ratios between −1 (one case only) and −16 dB. Good fits were obtained between theoretical and experimental distributions in all but one case. Confidence levels for the experimental distributions were not computed, but are considered to have been roughly the same for each of the measurements. Frequency correlation function areas between ±20 MHz from midband were between 14 and 35 C-MHz.

For the nine transmit locations used during the 1.75 GHz experiments, the maximum range of envelope fading was 42 dB, the average was 35 dB, and the minimum was 22 dB. Three of the computed envelope fading distributions were Rayleigh, and K ratios for the remainder, which were Rician, were between −6 and −8 dB. Experimental data gave a poor fit to theoretical distributions in 3 cases. The minimum, average, and maximum FCF areas were 17, 29, and 36 C-MHz, respectively.

In summary, statistics from the measurements indicated that the average fading range was about 10 dB greater, fading distributions had slightly higher K values, and with only a few exceptions, FCF areas were approximately the same as 1.75 GHz, as compared to corresponding channel characteristics in the 900 MHz band. The dynamic ranges for fading and the K ratios were similar to those reported [4], based on data recorded during CW measurements at CRC.

To permit more comprehensive comparisons of channel characteristics in the two bands, results for only the eight

TABLE I
FADING STATISTICS FOR EXPERIMENTS AT CARLETON UNIVERSITY

Frequency Band (MHz)	Location	Fading Range ± (dB)		K Ratio (dB)	FCF Area (C·MHz)
900	2	10	25	-1	24
1700		2	20	-8*	27
900	5	3	20	-10	28
1700		4	22	-8	23
900	6	8	25	-7	17
1700		9	25	-6	16
900	7	6	19	-8	32
1700		10	30	-8	18
900	15	4	13	-16	38
1700		12	30	∞**	23
900	16	5	19	-16	23
1700		7	28	-6	24
900	18	1	22	-10*	28
1700		10	30	-6	27
900	19	2	13	-14	33
1700		15	25	∞*	34

* poor fit.

** The Rayleigh distribution is represented by an infinite K ratio.

transmit/receive link configurations that were identical in the two bands are given in Table I. It can be seen that results in the table support the conclusions from the larger pool of data. Data recorded in location 5, a moderately busy secretarial office, are typical and have been chosen for detailed reporting. Receiver gains were identical in the two frequency bands at this location. Examination of the envelope plots for short sequences of individual impulse response estimates recorded at 30 ms intervals showed that the powers of resolvable multipath components varied extremely rapidly. This indicates that there were multipath components within the resolution of the measurement equipment in both frequency bands. It was also evident that variations in the phase of these components as a result of movements within the building could result in precursors to the primary impulse response peaks. The average impulse response power envelopes (delay power density spectra [3], [6]) for each band in this location are shown in Fig. 6. The multipath-like peaks with low powers and excess delays (delays with respect to that of the first peak) greater than 500 ns are considered to have been the result of measurement system imperfections, as discussed earlier. This is because the propagation distances corresponding to these delays, coupled with building penetration loss, would have reduced their powers with respect to the earliest received signal to powers below those indicated in the plots. Except for these equipment effects, it can be seen that the multipath characteristics were similar in the two frequency bands. There are four clearly resolvable multipath components with monotonically decreasing relative powers. As well, the plots indicate there may have been two or three other multipath signals that had delays relative to those of the four identifiable components which were less than the 25 ns resolution capability of the equipment. The difference in the shapes of the two plots for excess delays less than 500 ns is a result of a difference in relative phases of the multipath com-
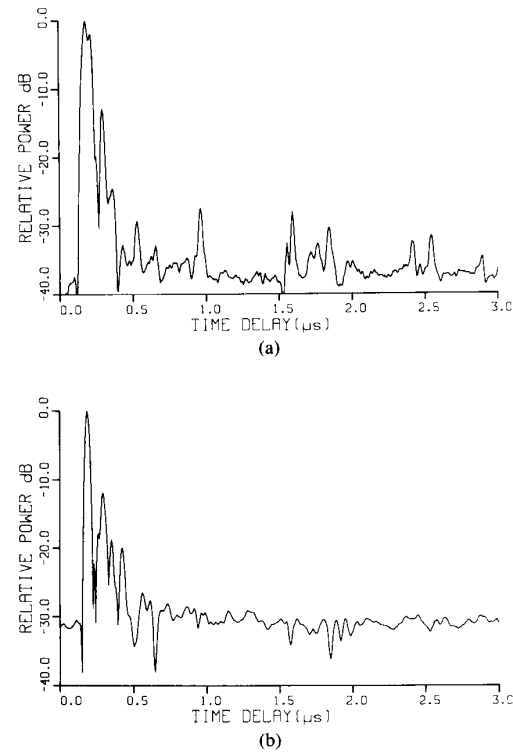

(a)

(b)

Fig. 6. Envelope of the average for impulse response estimates recorded in a 2 min interval with CU transmit location 5 in: (a) the 900 MHz band; and (b) the 1.7 GHz band.

ponents in the two bands. One minute long excerpts from equivalent CW envelope and phase time series are shown in Fig. 7. There was plenty of activity around this transmit location, and it can be seen that fading had very similar characteristics in the two frequency bands. For transmit locations remote from activity it was invariably found that at 1.75 GHz, the fading range was greater, and fading occurred at more frequent intervals than fading at 910 MHz. Cumulative distribution functions (CDF's) for data measured in both frequency bands are shown in Fig. 8. As indicated by the higher K value for the 1.75 GHz data, the relative power of the random (scattered) content in the received signal was slightly higher in this band. The envelopes of the FCF's are plotted in Fig. 9. It can be seen that in this location correlation properties were slightly better in the 900 MHz band, as reflected by comparison of the corresponding FCF areas listed in Table I. Note also that the functions are asymmetrical with respect to the midband frequency. This is a result of the lack of statistical stationarity in the frequency domain, and indicates that these channels were not uncorrelated scattering channels [7], [8]. The wide bandwidths over which there is significant correlation appear to indicate that fairly high data rates can be transmitted on these channels without degradation due to intersymbol interference, even when no equalization or diversity is employed. There are difficulties [3], however, with the prediction of error performance based on frequency correlation characteristics for
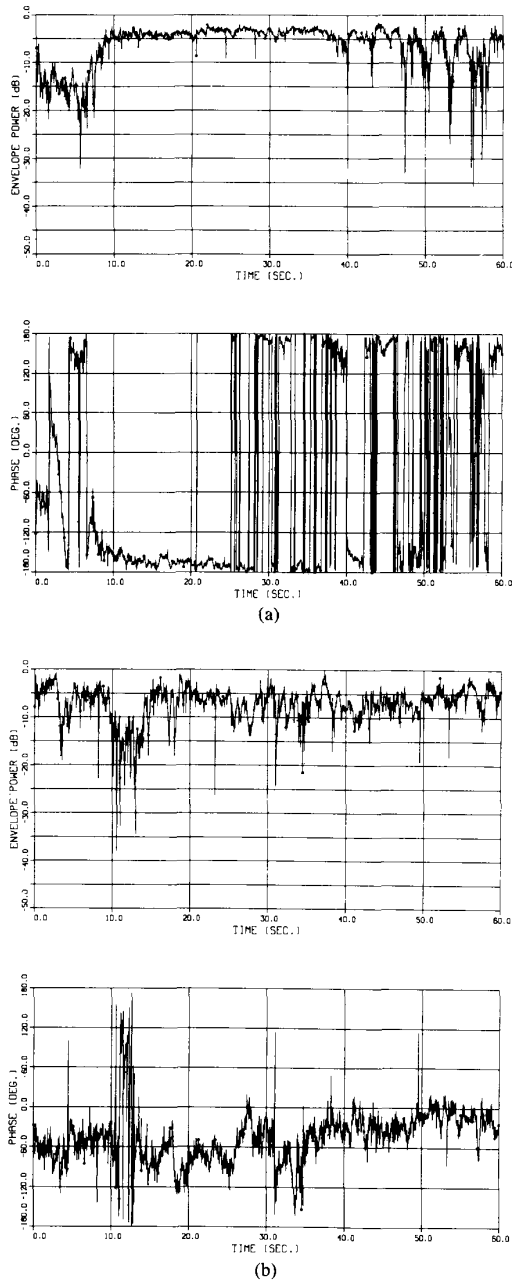
Fig. 7. Envelope fading time series recorded for CU transmit location 5 in: (a) the 900 MHz band; and (b) the 1.7 GHz band.
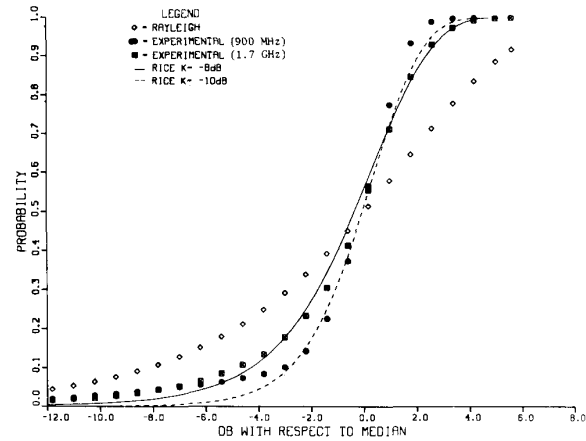

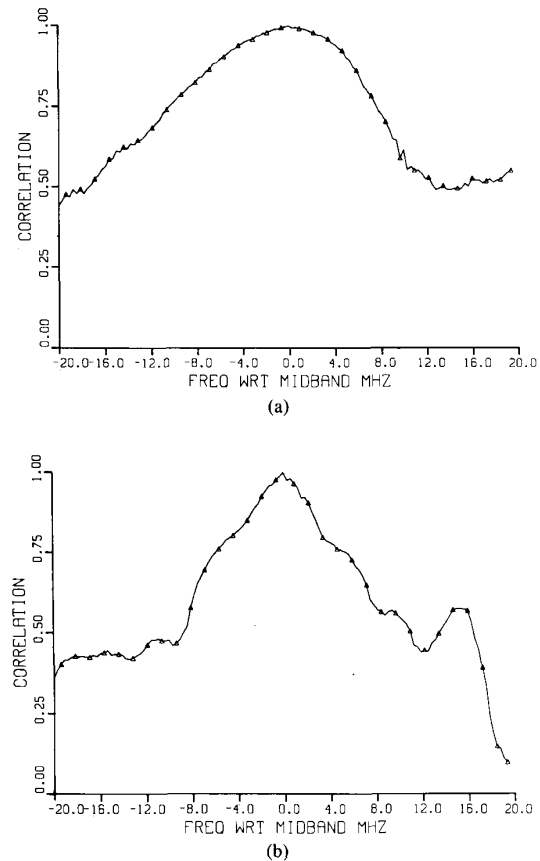Fig. 8. CW envelope fading distributions for each band of operation, computed from data recorded for CU transmit location 5.

Fig. 9. Frequency correlation function envelopes for CU transmit location 5 in: (a) the 900 MHz band; and (b) the 1.7 GHz band.

Rician channels. Such predictions are therefore not given in this paper.

Temporal data were recorded at CRC for 13 different transmit/receive link configurations, five of which (Fig. 10) were identical for measurements in the two frequency bands. The receiver and data recording equipment remained fixed, at either location 1 or 2 (shown in the figure) and the transmitter was moved to different locations for 2 min recording intervals. A summary of results is shown in Table II. As for the CU measurements, the aver-

age fading range was greater, K values were slightly higher, and frequency correlation statistics were similar at 1.75 GHz, compared to those at 910 MHz. Generally, however, channel characteristics were more random at CRC than at CU. Fading distributions corresponded to higher K values, and FCF areas were lower. The FCF for a particularly poor channel with the transmitter in room
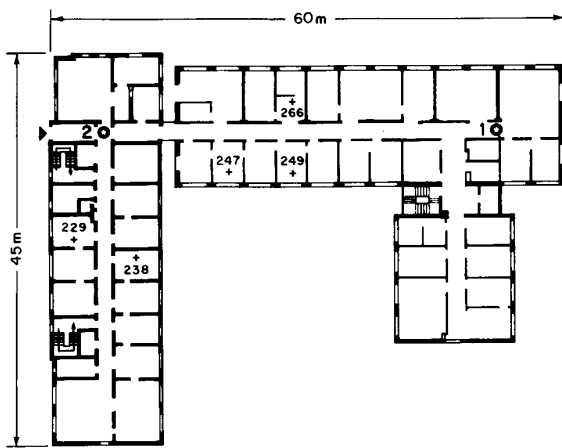
Fig. 10. Floor plan for the measurement area at CRC

TABLE II
FADING STATISTICS FOR EXPERIMENTS AT CRC

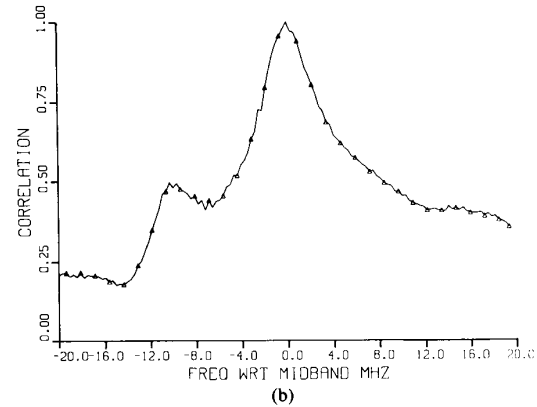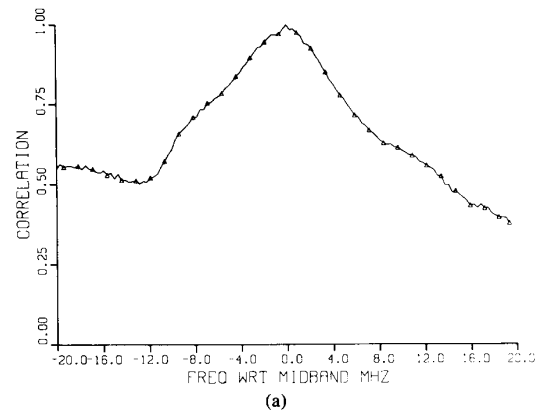| Frequency Band (MHz)	Location Rx	Location Tx	Fading Range + (dB) -		K Ratio (dB)	FCF Area (C-MHz)
900	2	229	7	22	-10	20
1700			7	25	-7	24
900	2	238	10	25	∞	26
1700			15	25	∞	19
900	1	247	7	25	-2	22
1700			15	25	-1	23
900	1	249	7	30	-3	15
1700			10	35	∞	26
900	1	266	7	25	-1*	17
1700			12	35	-1	24

* poor fit.

(a)

(b)

Fig. 11. Examples of frequency correlation function envelopes for poor channels recorded with the transmitter in Room 238 at CRC in: (a) the 900 MHz band; and (b) the 1.7 GHz band.

238 and the receiver in location 2 is shown in Fig. 11. The equivalent CW received signal envelope CDF for this location corresponded well with a Rayleigh distribution.

B. Spatial Characteristics

For use in the prediction of the percentage of building area that can be served from a fixed base station, experiments were conducted in which channel impulse response structures in the two bands of interest were compared for a large number of different transmit locations, while the receiver remained fixed. Short duration (5 s) impulse response recordings were made at CU in both frequency bands with the receiver at location *B* of Fig. 5, and the transmitter in each of 85 different locations scattered randomly, starting from the office across the hall from location *A*, in offices along the left side of the floor plan in Fig. 5, and ending at location 11, along the hall at the top of the floor plan. None of the locations had line of sight to the receiver. At CRC, measurements were made for a total of 100 different transmit locations, throughout the dimensioned wings shown on the building floor plan in Fig. 10. The receiver was fixed in location 2. Some of the CRC locations were in the hallway and had line of sight to the receiver. At both CU and CRC, the attenuation of

the voltage controlled attenuator in the receiver varied between 0 dB and 22 dB for different link configurations. The signal-to-noise ratio at the receiver input therefore varied by 22 dB. This variation, however, was too small to have significant effects on the measurements, owing to the 40 dB processing gain afforded by the sliding correlator frequency offset ratio of 10^4. This made the effective signal-to-noise ratio at the correlator output in even the most shadowed locations greater than 50 dB.

Root mean square delay spreads were calculated from the first 50 estimates recorded in each location. These statistical parameters [3] represent the square root of the ratio of the power in the second term to that in the first term of a Taylor series expansion for the transfer function of a fading channel [6]. They give an indication of the degree of frequency selectivity that can be expected on the channel and were originally reported in connection with mobile radio propagation measurements by Cox [1]. Under specific conditions, [3], [6], if measurements are made over time durations which are long enough to characterize the fading, it is possible that they could be applied in error rate predictions. The rms delay spreads reported in this paper, however, were computed from data recorded over time periods that were too short to characterize the chan-

nel fading, and hence, they should not be applied for error rate predictions. They were measured to allow the comparison of static channel multipath structures, and the variation in such structures in the measurement areas.

Cox reported [1] that caution must be exercised in the calculation of rms delay spreads from impulse response estimate measurements to ensure that results are not unduly biased by noise and low powered equipment-related impulse response aberrations having long effective excess delays. Because of the imperfections discussed earlier which gave rise to long delayed components in the back-to-back results for equipment used for measurements reported in this paper, extreme caution was exercised during the delay spread analyses. First, the averages of 50 impulse response estimates for each transmit location were plotted and examined. Equipment-related effects were then distinguished from genuine multipath signal components, as outlined below.

At CU, the median distance between the transmitter and the receiver was about 10 m. If a loss calculation is made for the 10 m distance at 1.75 GHz, given a transmit power of +25 dBm, and estimated antenna gains of 2.8 dBi the received power in a free space environment would be −8 dBm. Allowing a 12 dB diffraction, or penetration loss, which is typical [4] for non-line-of-sight conditions inside buildings, the received power would be −20 dBm. The measurement system impulse response averages plotted in Fig. 4 show that the noise excursions extended to −30 dB, and on rare occasions to −25 dB below the impulse response envelope peak. Therefore, in order to be detected above the system noise, multipath components, or their vector sums, would have had to be received with powers of at least (−20 dBm − 30 dB), or −50 dBm. Link budget calculations show that in the absence of propagation loss, the received power would be +49 dBm. Thus, for a received signal power of −50 dBm, the propagation loss would have had to be 99 dB. At 1.75 GHz, if 12 dB penetration or reflection loss is undergone on both transmit and receive paths, this corresponds to a propagation distance of 79 m, resulting in an excess delay of 263 ns. Based on these values, the authenticity of average impulse response features with relative powers greater than −30 dB and excess delays greater than 263 ns would be considered questionable. If reasonable error is allowed in the estimated penetration loss values, longer propagation distances would have been possible. Also, given the possibility of the vector addition of several multipath components within the same receive system resolution interval, multipath component peaks could have had greater powers. Thus, in the analysis of recorded data, average impulse response envelope components were rejected if their powers were greater than −25 dB with respect to the envelope peak, and their excess delays were greater than 500 ns. The conservative assignment of these thresholds permitted application of the same rule in the analysis of the 900 MHz results, and of the CRC results, which were recorded in a larger building.

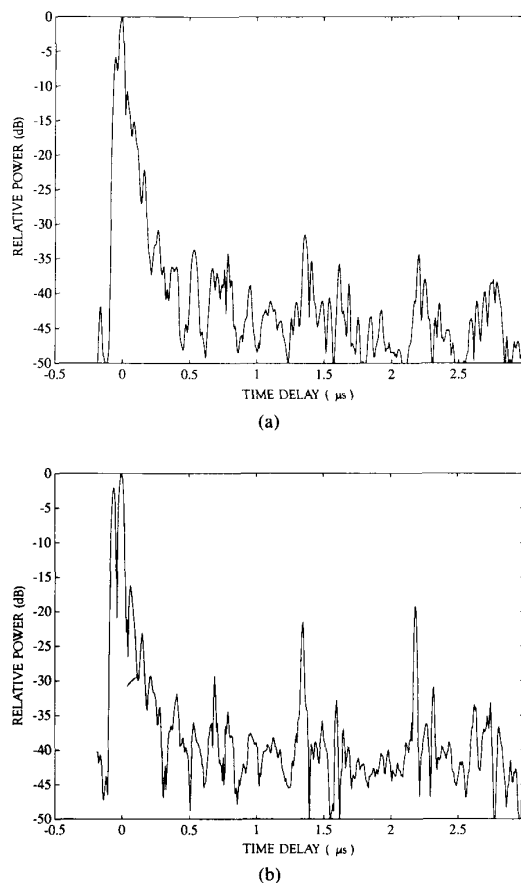The impulse response averages computed from the

Fig. 12. Examples of (a) type 1, and (b) type 2 average impulse response envelopes recorded during the experiments.

measured data were then classified into two basic types. Those classified as type 1 [Fig. 12(a)] had no questionable structures with relative powers greater than −25 dB with respect to the envelope peak. In such cases, only components with powers less than the nominal 30 dB noise floor of the measurement system were omitted from the rms delay spread calculations [3]. About 60 percent of computed averages were of this type. Type 2 impulse response averages [Fig. 12(b)] had significant components with relative powers greater than −25 dB and delays greater than 500 ns. Such components most often occurred at delays for which there were unwanted peaks in the back-to-back averages of Fig. 4. In such cases the impulse response averages were windowed at 500 ns, and rms delay spreads were computed using a −30 dB threshold.

By screening and processing the measured data as outlined above, the effective threshold employed in the rms delay spread calculations was −30 dB with respect to the envelope peak of each impulse response average. Unless there was continuous multipath over long excess delay intervals, which is atypical, multipath components at lower powers would have little influence on link performance. Based on considerations similar to those discussed by Winters [9], it is believed that for wideband systems, bet-
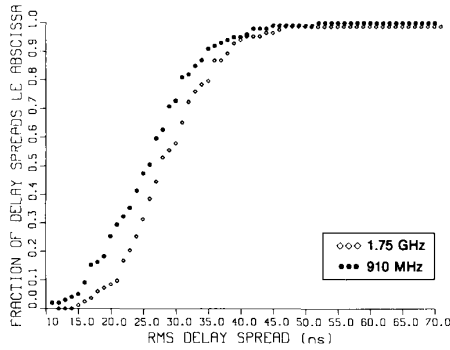
Fig. 13. CDF showing the fraction of transmit locations for which rms delay spreads were less than specified values in the 900 MHz and 1.7 GHz bands at CU.
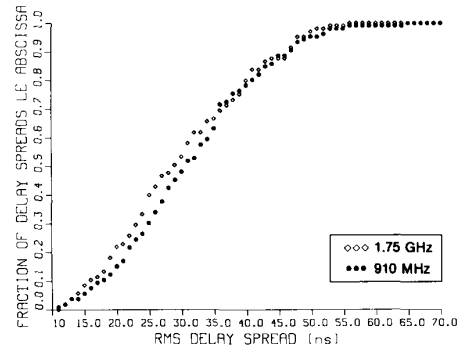

Fig. 14. CDF showing the fraction of transmit locations for which rms delay spreads were less than specified values in the 900 MHz and 1.7 GHz bands at CRC.

ter coverage can be achieved at a specified performance level when conditions (frequency or environment) are such that the difference between rms delay spreads at different locations is small. Therefore, the results of measurements reported in this section are intended for use in indicating relative coverage capabilities in the two bands, or in the two different buildings. The effective -30 dB noise threshold used for rms delay spread calculations is considered to be more than adequate for this purpose.

Cumulative probability distribution functions computed from rms delay spread results for both frequency bands at CU are shown in Fig. 13. Using Komolgorov–Smirnov analyses procedures [10], it was determined that there is 90 percent probability that these experimental distributions are within ±13 percent of the true distribution. It can be seen from the figure that for over 90 percent of transmit locations, the rms delay spread was slightly greater in the 1.7 GHz band. The median rms delay spread in that band was 28 ns, as compared to a median of 26 ns for the 900 MHz band. Similar rms delay spread medians were computed by Saleh and Valenzuela [11], as a result of pulse experiments at 1.5 GHz. The standard deviation of 910 MHz rms delay spread values was 8 ns, and that of the 1.75 GHz data was 17 ns. The larger standard deviation indicates that coverage would be less uniform in the 1.7 GHz band. Fig. 14 shows the cumulative distribution function for rms delay spreads at CRC. The 90 percent confidence interval for these curves was calculated to be ±12 percent. The situation at CRC can be seen to be different. For about 70 percent of locations, rms delay spreads were greater in the 900 MHz band. The difference for the two bands, however, is smaller than that at CU. The median for the 1.7 GHz band was 29 ns, and that for the 900 MHz band was 30 ns. The standard deviation of rms delay spreads was again greater for the 1.7 GHz band, being 22 ns, as compared to 11 ns for the 900 MHz band.

A comparison of Figs. 13 and 14 shows that in both frequency bands, rms delay spreads as well as the standard deviation of their values for different link configurations were greater at CRC. These differences in the results are considered to be due to the differences in size

and construction of the two buildings. They would probably lead to less uniform coverage in an operational system at CRC. The influence of building size, composition, and architectural layout on propagation channel parameters such as these may lead to the possibility that buildings can be classified, based on their structural properties, into a set of categories with predictable coverage characteristics for systems operating in different frequency bands.

IV. SUMMARY AND CONCLUSIONS

The results of propagation experiments in the 900 MHz and 1.7 GHz radio frequency bands in two different buildings on fixed indoor radio links have been reported in this paper. For different transmit/receive link configurations, impulse response recordings were made for 2 min intervals to permit the study of temporal variations in received signal characteristics. The number of different link configurations used during these experiments was not large. However, the characteristics of temporal variations on fixed indoor channels are primarily influenced by the movements of personnel, which are similar in buildings used for similar purposes. In addition, the reported fading statistics correspond well with those measured during CW experiments in other buildings [4]. It is therefore believed that temporal results presented in this paper are representative. In addition to the temporal experiments, short duration impulse response measurements were made for a large number of transmit locations with the receiver fixed in one spot so that impulse response structures, and their variation as a function of radio link geometry within the buildings could be studied.

From the results of the temporal experiments, it was found that fading is less severe for channels in the 900 MHz band than for channels in the 1.7 GHz band. With due regard for the quasi-static [4] nature of the channels, this is believed to indicate that, under fading conditions, the quality of communications channels in the 900 MHz band would be marginally better than that of channels operating in the 1.7 GHz band. On average, the dynamic range of CW envelope fading is 10 dB greater in the 1.7 GHz band. This is because the power of the scattered component of received signals is greater in that band, as

evidenced by slightly higher K values for computed fading distributions. There is little difference in wideband frequency correlation statistics for channels in the two frequency bands. Comparison of temporal characteristics also showed differences for the two buildings. The measured channels exhibited more random behavior in both frequency bands in one of the buildings. Thus, the severity of random behavior, although always greater in the higher frequency band, can be greater for both bands in one building than in another.

The investigation of differences in channel impulse response structures for different transmit locations showed that the basic propagation environment was different in the two buildings. This is believed to be a result of differences in the building structures and sizes. In one building, rms delay spreads were slightly greater at 1.75 GHz for over 90 percent of transmit locations. In the other building, delay spreads in the 900 MHz band were marginally greater for 70 percent of transmit locations. The standard deviation of rms delay spreads was also greater for both frequency bands in this building. However, the standard deviation was greater in both buildings for the results of measurements in the 1.7 GHz band. It is believed that on wideband systems where there is a threat of intersymbol interference, better coverage can be achieved at a specified performance level when rms delay spread differences for different locations are small. Therefore, these results indicate that coverage would be less uniform in both buildings for systems operating in the 1.7 GHz band. They also indicate that coverage would be less uniform in one of the buildings than in the other, regardless of the frequency band of operation.

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