

## THE JUMP FROM 450 TO 900 MHz: EXPERIENCE AND FUTURE INVESTIGATIONS IN LAND MOBILE PROPAGATION

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## 1. INTRODUCTION

Among the numerous parameters which affect the implementation of mobile systems, the knowledge of propagation characteristics for both useful and interference signals, plays a crucial role. Estimation of the received mobile radio signals is required in order to predict the service area, given transmitter location and power, or to define the number and locations of fixed base stations which provide an acceptable quality of coverage, avoiding harmful interferences. Moreover, the impact on modulation, speech encoding, baseband processes, frequency re-use schemes, and specific fading countermeasures (such as macroscopic or microscopic diversity techniques) does not need to be emphasized. Accordingly, CSELT (\*) carried out a large amount of experimental investigations in several regions of Italy [1, 2] in order to determine, on a statistical basis, suitable propagation curves and correction factors, related to different urban and terrain situations. This paper briefly summarizes the most significant propagation results and outlines experiments and theoretical studies planned for the near future.

## 2. PROPAGATION EXPERIMENTS

In the recent past, many experimental investigations were performed in both VHF (160 MHz) and UHF (450 MHz) band, using both unmodulated and modulated (FM) signals, in different situations of terrain irregularities and environmental clutter. Fig. 1 shows an example of propagation curves (median field strengths) for urban areas in large (Milano, Roma) and medium sized (Novara) cities. A fourth-power range dependence law (dashed line) is a good approximation, even if a rigorous least squares best fit gives an exponent of about 4.5; the RMS prediction error appears to be less than 5.4 dB, in the distance range up to about 20 km from the transmitter. As far as field strength standard deviations are concerned, an average value of 4.7 dB comes out. However, for urban areas, a more detailed knowledge of additional attenuations vs percentage  $\alpha$  of the area covered by buildings ("land usage factor") is of great interest, in particular for the planning of cellular systems, which are primarily devised to provide a functional service in large cities. Fig. 2 shows the measured 450 MHz deviations from median field strengths predicted from Fig. 1, due to buildings surrounding the mobile station (reference squares of  $0.25 \times 0.25$  km have been considered for computations) and the corresponding regression line:

$$\Delta \cong 21.37 - 15.28 \log \alpha \quad (1)$$

Using Eq. (1) the RMS prediction error reduces to  $\sim 4.6$  dB. A comparison with similar results reported by Kozono and Watanabe [3] (dashed line) shows a not negligible difference both in slope ( $\sim 15$  dB/decade vs  $\sim 25$  dB/decade) and average urban density ( $\sim 25\%$  vs  $\sim 15\%$ ).

If a linear regression is established (instead of a logarithmic one), Eq. (1) becomes:

$$\Delta \cong 7.06 - 0.26 \alpha \quad (2)$$

No practical impairments may be pointed out: the standard error is now about 4.5 dB; then, a log-regression seems to provide no advantages vs a simple linear one. Incidentally, the slope coefficient in Eq. (2) is very close to the corresponding coefficient (0.265) found by Ibrahim and Parsons from measurements at 455 MHz carried out in London [4]: this corroborates the hypothesis of a different structure of European cities in comparison with Japanese urban areas [2], which reflects into a different field strength-land usage factor relationship.

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A slightly better improvement in the estimation can be achieved if a 2<sup>nd</sup> order correction factor (the ratio  $\beta$  of the average height of buildings to the average width of streets) is introduced. In this case, a multiple linear regression provides an overall RMS error of about 4.2 dB.

The  $\beta$  ratio, however, seems to be more effective if only the highly urbanised parts of the cities (historical town centres) are considered, where  $\beta$  varies from about 0.5 to 3.5, and is sensitive enough for regression purposes. In this case, the following equation can be produced:

$$\Delta \cong 5.95 - 0.06 \alpha - 3.92 \beta \quad (4)$$

with a RMS error of about 3.7 dB. This favourably compares with multiple linear regressions established by Ibrahim and Parsons [4], in which the "degree of urbanisation factor" (defined as the percentage of building area occupied by buildings with four or more floors) is used. Instead of the  $\beta$  ratio, for the centre of London: in their case the RMS error does not exceed 3.2 dB. From [4] such correction factors seem to be not strongly dependent on frequency and distance: therefore, it is expected that they could be applicable, without severe changes, also to the 900 MHz band, which appears to be only partially explored, at least in Europe. Of course, this requires further experimental evidence: a number of field trials is planned for the near future in several Italian cities at 900 MHz. This work, which will be in particular concerned with the study of propagation effects on digitally modulated signals, will be performed within the framework of the Action COST 207 ("Digital land mobile radio communications"). COST 207, in coordination with the Mobile Special Group of CEPT (PT European Conference), will produce guidelines for a harmonized European public mobile communication system for the 1990's [5].

### 3. INTERFERENCE ASPECTS

Evaluation of co-channel interference contributions is of paramount importance in designing cellular systems, in order to test the performances of various modulation methods and define the optimum frequency re-use scheme (i.e., cell size, number of cells per cluster). In a study in course in CSELT, it has been found that, using a Rayleigh fading model for both useful and interference signals, the probability density function of the Carrier-to-Noise plus Interference Ratio (CINR), in the case of a single interference signal, may be expressed as:

$$w(z/\Gamma, \Lambda) = \frac{\Lambda}{(z+\Lambda)^3} \cdot e^{-z/\Gamma} \cdot \left\{ (z+\Lambda + \frac{\Lambda}{\Gamma})^2 + \frac{z}{z+\Lambda} \cdot (2z+2\Lambda - z\frac{\Lambda}{\Gamma}) \cdot e^{z^2/\Gamma(z+\Lambda)} \cdot E_1\left(\frac{z^2}{\Gamma(z+\Lambda)}\right) \right\} \quad (5)$$

where:

$\Gamma$  is the average signal-to-noise ratio (SNR)

$\Lambda$  is the average carrier-to-interference ratio (CIR)

$E_1(x)$  is the exponential integral function, defined as:  $E_1(x) = \int_x^\infty e^{-t}/t dt$

Several Phase Modulation methods are currently under test at CSELT, on account of a possible application to narrowband digital mobile radio systems. They can be grouped into a common class (called 12 PM3 (\*) in [6]), including numerous techniques, such as GTFM, GMSK, CORPSK, etc.

As an example, Fig. 3 shows the average error probability in presence of a single co-channel interference signal (characterized by various average values of CIR) and slow Rayleigh fading, computed using Eq. (5). The modulation under test is of GTFM type, according to the definition reported in the same Figure; the receive filter is a 6-poles Bessel filter with a 8 kHz equivalent noise bandwidth; the bit rate is 16 kHz; an ideal coherent demodulation is assumed. In the same Figure the theoretical reference curve (no interference, no fading) is also reported [12]; degradations due to interference are computed in the conservative hypothesis that pdf of the interfering signal is gaussian. On the basis of these computations, various cellular system configurations are examined, and improvements obtainable using specific countermeasures, such as space diversity techniques (both at the mobile and fixed station) are evaluated.

### 4. SIMULATION

In the last few years, a rapid growth occurred in the demand for simulation of mobile fading, in relation to the design of systems using digital modulation techniques. The simulator (hardware or software) should allow tests and quick comparisons among different mobile radio systems.

(\*) 12 PM3: 12 for the 12 phase states, PM for Phase Modulation, 3 for the correlation over three consecutive bits used to chose the phase shift in each signalling period

A narrow band (not frequency selective) software simulator was implemented at CSELT [8], and has been extensively used to evaluate the performance of different encoding schemes for radiopaging under Rayleigh fading conditions [9]. Typical plots of simulated Rayleigh envelope, phase and frequency (for an unmodulated signal) are reported in Fig. 4: they appear to be in very good agreement with available experimental data and other theoretical simulation results [10].

However, since other concepts for digital mobile radio are based on TDMA or CDMA techniques, delay spreads caused by multipath propagation must be adequately included in the model.

As a conclusion, a "wide band" simulator is needed, in order to take into account frequency selective effects which are usually neglected in analogue systems, due to the narrow band channeling arrangements. (In several cases, however, even the transmission of lower bit rates in FDMA proved to be impaired by severe in-band distortions [7]).

Current studies at CSELT are devoted to turn the model to a wide band one, in order to obtain a complete description (time and frequency) of the channel transfer function stochastic process. In COST 207 opinion [11] these outputs should be used to model the channel parameters of a hardware simulator which will be actually charged to test different digital mobile transmission systems. The additional inputs required by a soft wide band simulator, in comparison with a narrow band one, could be tentatively listed as follows:

- The probability density functions of delays
- The number of the narrow band processes (approximately Rayleigh) which describe, for any given delay, the sum of the multiple scattered signals, and their statistical properties.
- The time and space correlation characteristics of such processes and their spectral contents, with relation to Doppler bandwidth.

## 5. CONCLUSIONS

A condensed outline has been presented of current CSELT activities in land mobile propagation and their impacts on mobile radio systems design, with particular reference to field strength measurements and prediction, theoretical computations of interference contributions and their effects on modulation techniques, and narrow and wide band fading simulations. A particular attention has been given to the 900 MHz band, where a harmonized European mobile communication system (which should be operative in the 1990's) is actually under consideration, in the framework of the Action COST 207. In this respect, digital transmission techniques (speech and/or signalling) will play a crucial role: a large variety of them is examined in CSELT, together with the impairments they may experience due to propagation (fading and interference), and possible countermeasures such as diversity techniques are investigated. Moreover, soft simulation of wide band channel transfer functions are under development, in order to evaluate the performances of radio systems using spread-spectrum encoding with TDMA or CDMA techniques.

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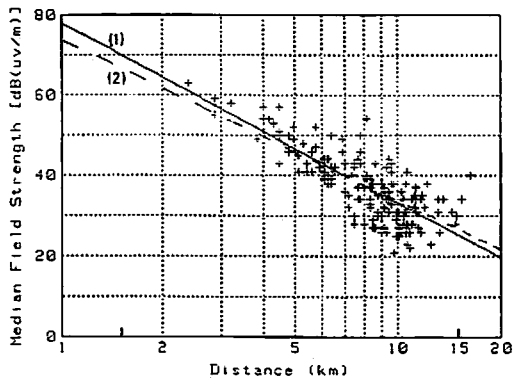


Fig. 1 - Median Field Strength in urban area  
 (Frequency: 450 MHz, Fixed Station antenna height: 120 m, Mobile Station antenna height: 1.5 m, EIRP: 25 W)  
 (1) Best fit curve  
 (2) Fourth power distance law

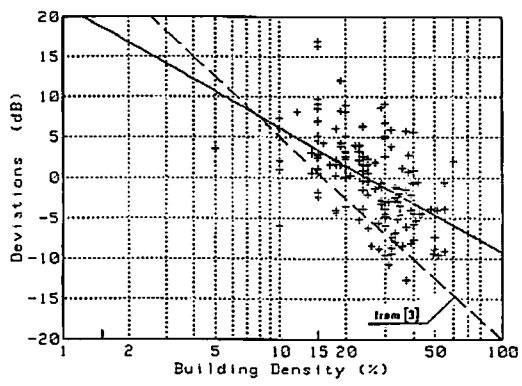


Fig. 2 - Deviations from Median Field Strength vs Building Density (conditions: as in Fig. 1)

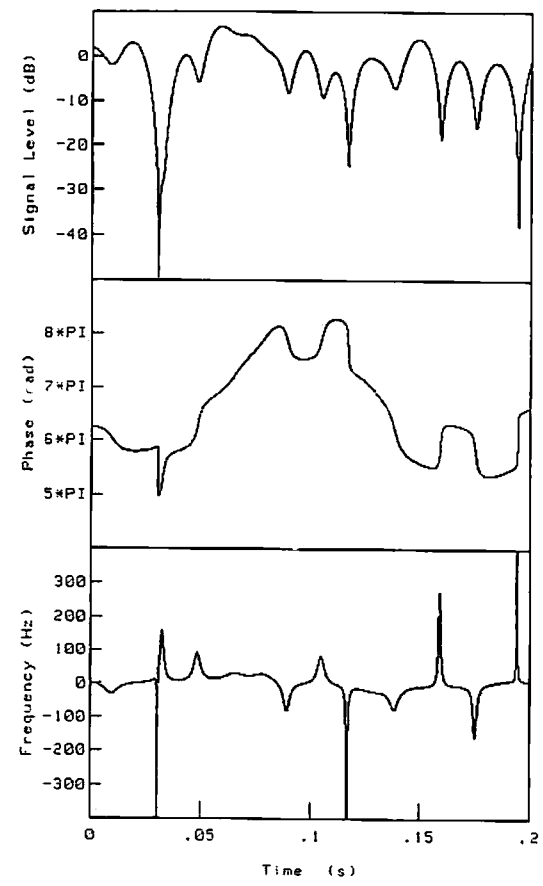
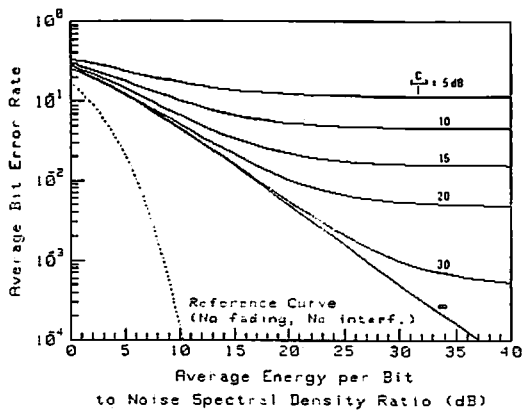


Fig. 4 - Example of simulated Rayleigh envelope, phase and frequency for an unmodulated signal  
 - carrier frequency: 900 MHz  
 - vehicle speed : 50 km/h

Fig. 3 - Average BIT error rate vs  $E_b/N_0$  in presence of a co-channel interference signal and slow Rayleigh fading  
 - Modulation: GTFM, defined with reference to a frequency modulation scheme with roll-off factor of the pre-filter  $\rho = 0$  and phase parameter  $\phi = 47.3^\circ$  [12]