MICROWAVE PROPAGATION AND HIGH CAPACITY DIGITAL SYSTEMS : THE FRENCH APPROACH

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I. INTRODUCTION - As a many other countries, the French long haul terrestrial radio network exhibits a very wide variety of situations, due to either the natural conditions (climate, terrain, ...) or the microwave installations (hop length, tower height, antennas).

To cope with this complex problem, a two-fold strategy was chosen. The microwave channel analysis and the design of adaptive receivers able to suppress most of the channel impairments has been simultaneously carried on. This strategy generates a synergistic effect between the following topics : propagation and communication theory. On the one hand Research in propagation can influence the design of countermeasure devices. For instance the fact that minimum phase fades and non-minimum-phase fades tend to be equally distributed for deep fades led the system design to compensate for both type of fades. On the other hand the design of advanced adaptive equalizers required a better knowledge of the dynamical properties of the radio channel.

Progress in this knowledge allow to obtain flexible 140 Mbit/s systems meeting the CCIR quality objectives and to determine the strategy of Operating Services about the choice of the equipments which have to be installed on a specific hop (space diversity, countermeasure devices).

In section II various already obtained results are presented. Section III is devoted to the existing countermeasure techniques. In section IV the implementation of a dynamic real channel simulator is dealt with. As a conclusion section V presents some future trends in adaptive equalization.

II. PROPAGATION MEASUREMENTS - Different experiments were set up in order to characterize the microwave propagation. Fading statistics at a single frequency have been recorded at twelve radio stations representative of the various conditions expected in the French network. Details on this first measurements are given in a companion paper [1].

The second type of experiment involves broadband measurements to characterize the channel transfer, in order to obtain a better knowledge of distortion statistics and dynamic effects. Broadband measurements were performed in the frequency domain with 400 MHz bandwidth Microwave Link Analyzer (MLA) at 11 GHz. The results from an experiment on a 50 km path near LANNION lead to a simplified three-ray modelling [2] :

$$S(f) = a\,[1 - b\,e^{-j\,2\Pi\,(f-f_c)\,\tau}]$$

a - flat fade attenuation
b - reflection coefficient of the secondary ray
τ - delay of the secondary ray
f_c- noth frequency

The sign of τ determines the minimum or non-miminimum type of fading. The relative notch depth A_{max} is related to b :

$$A_{max} = -20 \operatorname{Log}_{10} (1 - b) \qquad (b \leq 1)$$

Records performed during a worst month period show τ exceeds 5.5 ns only for 1 percent of fading time. The joint cumulative distribution of delay and notch depth shows that τ distribution is independent of notch depth.

A full characterization of multipath fading needs the determination of the medium rate of change in order to specify the required response speed of countermeasure devices. An important measure is the rate of change of notch frequency.

In the experimentation of Lannion the frequency rate of change reached 150 MHz/s during the month of July and 350 MHz/s in December for 5 percent of the fading time (fading time : observation time corresponding to a notch depth above 15 dB) [3].

Observations of the notch velocity were performed in other countries: A.T. BUNDROCK and J.V. MURPHY measured the complex channel response across a 1 GHz bandwidth at 11 GHz on a 36 km path in AUSTRALIA [4]. They obtained a frequency rate of change of 130 MHz/s in two-path events, in which a ground reflection is assumed. A rate of change of 25 MHz/s is observed for assumed three-path events. These considered rates of change correspond to 5 percent of 200 pairs of such records spaced 1 second. M.F. GARDINA and A. VIGANTS observed a frequency rate of change 15 MHz/s on a 37 km path in FLORIDA for the same percentage of the fading time (fading time : in-band power difference above 5 dB) [5].

To compare these different results it would be needed to harmonize the different definitions of the observed time. But it appears that these definitions for the experimentations of FLORIDA and LANNION are relatively close and the results are quite different. Two partial explanations may be given for this difference :

- the carrier frequency of the French experimentation is about twice higher (11 GHz instead of 6 GHz).

- the measurement is more accurate (400 MHz Bandwidth instead of 30 MHz - records every 0,055 seconds instead of 0,4 seconds).

Lastly group-delay sign inversions were observed during different periods [6]. Small change of the notch depth were generally measured during such sign inversions. In 75 percent of sign inversions, the depth variation does not exceed 5 dB.

More accurate measurements with a sweeping time of 3 ms were recently carried on in order to confirm these dynamic results about multipath fading.

III. COUNTERMEASURE TECHNIQUES FOR 140 Mbit/s SYSTEMS

The first 140 Mbit/s system operates in the 11 GHz frequency band with a 8 PSK modulation scheme. More then 25 links are now in operation in the French network. The associated countermeasure devices were tested on the 50 km experimental hop near LANNION [7]. These countermeasure techniques are space diversity using a maximum power combining criterion, IF slope equalization and Feedback Control of the transmitted power. The main conclusions of the field test were (i) the achievement of the quality requirements (ii) the evaluation of the improvement factor of the space diversity and IF equalization. An average figure of 2 was measured for the combiner and about 10 for space diversity. This improvement factor strongly depends on multipath propagation conditions.

To increase the number of digital branch routes from a nodal tower, the concept of automatic transmission power control has been used. The nominal transmission power is decreased by about 15 dB in order to lessen the interference level created by adjacent links. The feedback control signal is transmitted on one auxiliary channel of the digital frame.

The second 140 Mb/s system uses the 16 QAM modulation scheme in the 6.5 GHz band, i.e. the same modulation used in JAPAN for 200 Mbit/s transmission [8].

This system takes advantage of the last refinements in various fields. Space diversity is used with a mimimum distortion combiner. A linear transversal equalizer is implemented at IF stage. Real-time performance comparison of various combinations of the these countermeasure devices were performed on a 43 km experimental hop. The linear transversal equalizer brought a 4 to 6 factor improvement of the outage time. The combination of the space diversity and the linear equalizer lowered 50 to 100 times the outage time depending on the propagation conditions [2].

IV. DYNAMIC RADIO SIMULATOR - With the increasing complexity of the receiver, major differences have been observed between estimated and measured system outage time. It implies that the conventional signature concept is not well representative of the radio equipments characteristic This conventional signature is based upon a two-ray propagation model which particularly does not reproduce the variety of transitions between minimum and non-minimum fading.

The design of a dynamic simulator, fed with transfer function data actually measured in a broad bandwidth represents a key stone in the study of new robust receivers, including newly designed synchronization loops. It should lead to the definition of relevant parameters for the evaluation of system outage.

The basic principle of this simulator is to reproduce channel transfer functions measured in the field, by driving a complex linear transversal filter with precomputed data [10]. The criterion used for calculating the values of the filter taps for each transfer function is the minimum mean-square error criterion.

The impairments of this simulation may be sorted in three parts:

- Tracking impairment. Depth shift at the notch frequency without change of the in-band distortions.

- Edge effets out of the usable bandwidth.

- undesired ripple of the transfer function inside the usable frequency band (50 MHz).

This transversal filter is implemented at the baseband stage in order to improve delay accuracy of the taps. The modelling of the simulator performances lead to choose a thirteen-taps filter with a period of 70 MHz in the frequency domain. Then the residual ripples are estimated to 0.1 dB and 1.5 ns for fadings exhibiting a relative notch depth of 20 dB and a delay τ of 5.5 ns.

V. FUTURE TRENDS IN ADAPTIVE EQUALIZERS - The space diversity on the one hand is an expansive technique and on the other hand exhibits some difficulties of hardware implementation, especially in the case of old-installed microwave towers. Thus for a microwave network as the French network, the main trend is the development of new systems with an improved flexibility, based on electronic countermeasures, rather than space diversity. The improvement factors of these devices are still weaker than that of the space diversity reception. Progress have then to be made to drastically improve them. Most of the commercial systems are using linear equalizers. Their performance appears limited for deep selective fades. Non linear equalization appears to be the most attractive solution for compensating for minimum phase fades. It even shown that such a technique, using properly chosen algorithms and adequate additional device, was able to cope with most of the propagation conditions, including dynamical effects. The problem of defocusing will still remain, but the use of space diversity itself is not very useful in such cases.

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