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Simultaneous Error Performance of Antenna Pattern Diversity and Vertical Space Diversity

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1 *Introduction*

Compared to vertical space diversity (VSD), antenna pattern diversity (APD) does not require any vertical separation between antennas; in some cases, difficult problems of tower height can thus be overcome and tower loading and costs can be reduced, specially if APD is realized with one single antenna as in this experiment. Therefore the Swiss PTT decided to conduct an experiment to compare the performances of a 64QAM digital radio hop receiving simultaneously with APD, VSD and also without diversity protection. The initial results were presented at the last European Conference on Radio-Relay Systems [1] and this paper reports on the results measured till May 1990.

2 *Implementation*

21 *Antenna with Pattern Diversity*

The APD antenna applied in the experiment is a prototype developed by *ANT* (F.R.G.). It is based on an existing four meter shell antenna with a prime focus fed offset reflector in which the feed system has been modified. Two APD lobes are generated in the vertical plane by the utilization of higher order modes in a manner similar to the one used in the well-known monopulse antenna [1]. These kidney-shaped lobes can receive off-boresight signals from upper and lower directions weighting both signals with a phase-difference of 180 degrees. This discrimination-like characteristic should give a good de-correlation between the signals received from the well pointed main lobe and the diversity lobes during multipath propagation. This antenna has two ports for the vertical polarisation: the main port, corresponding to the main lobe, is used to transmit and receive without loss of gain when in boresight, and the APD port, corresponding to the two APD lobes, is only used for reception.

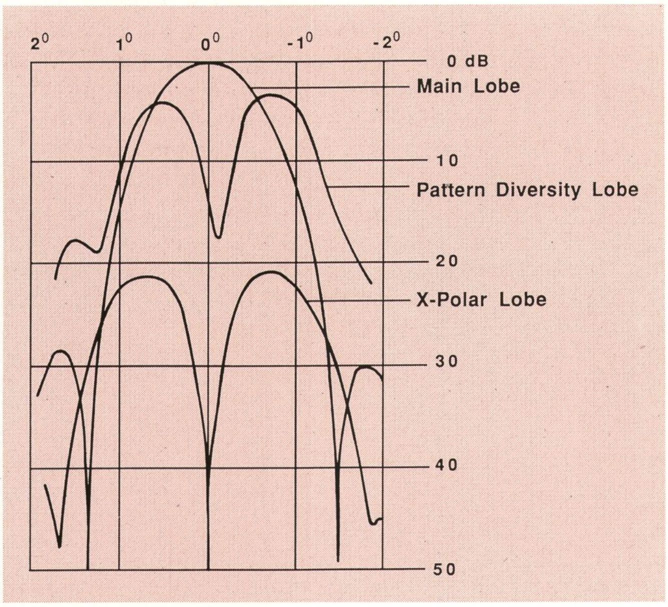

Fig. 1 Antenna diagram

Figure 1 shows the antenna diagram for the two ports with the main lobe, its crosspolarized pattern and the APD lobes. The APD lobes are slightly unsymmetrical due to the offset reflector antenna (prime focus fed). The maximum gain of the APD lobes is $\pm$ 0.6 degrees out of boresight at 2.5 to 3 dB below the gain of the main lobe.

22 *Radio Path*

The long radio path used for this propagation experiment extends between Geneva and Chasseral *(fig. 2)*. A 30 km portion on one end of the hop crosses over the lake of Geneva, where a reflection area can be spotted on the lake with simple geometrical rules. The reflection direction results in angles of 0.43° (receive side) and 0.07° (transmit side) relative to the boresight axis. The magnitude of the reflected signal is only a few dB less than the magnitude of the boresight signal (compare these angles with the antenna diagramme and add the loss due to the reflection on the lake). Its delay relative to the boresight signal is about 1.7 ns (51 cm for the upper antenna, 42 cm for the lower antenna; with k = 1.33 earth radius). One can notice that the lower APD lobe is directed towards the reflection area.

23 *Radio Equipment*

The radio equipment allows to receive a 64QAM modulated digital signal simultaneously with APD, with VSD and without protection [1]. Three four meter shell offset antennas are used: the antenna specially equipped for pattern diversity plus a standard antenna (vertically

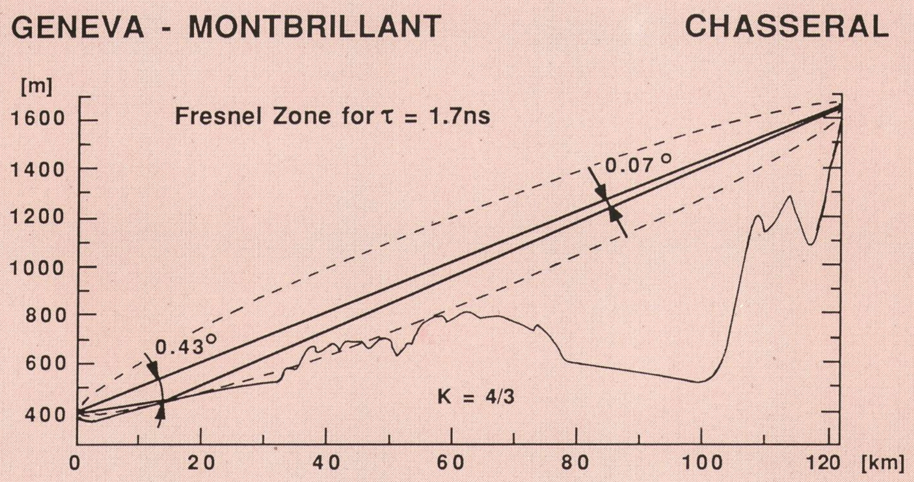

Fig. 2 Terrain elevation profile

spaced by 13 m) at the receiving site and another standard antenna at the transmitting site. The vertical distance between the receive antennas was given by the architecture of the antenna tower used. The pattern of the main lobe is the same for all three antennas. The 64QAM digital radio *(Northern Telecom* RD-6B) system transmits 140 Mbit/s at 6.4048 GHz over a 30 MHz wide channel. The digital transmitter is located at Chasseral; three RF-receivers, using the same local oscillator, and three demodulators are installed at Geneva. The receivers are equipped with an IF in-phase (e.g. maximum output power) combiner whose gain from input to output is unity when both inputs are equal; an IF adaptive slope equalizer, a baseband transversal equalizer and a forward error correction circuit (FEC) are also included.

The normal received power level (during periods without propagation problems) for the main port of the APD antenna is −37 dBm with a thermal fade margin of 36...37 dB.

24 Data Collection Equipment

The digital signal is generated at the transmit side using, as is usual, a pseudo-random pattern generator [1]. The three digital patterns received after demodulation are tested by three error detectors at the receive side. The bit error counts and the alarms of the error detectors are measured every second (gating time: 1 s). In addition to the error performance, the incoming signals are measured with respect to the dispersions of the radio path. The signals coming out of the three antenna ports are measured after transposition to the intermediate frequency of 70 MHz. Three filters with a bandwith of 1.5 MHz are used to sample the spectrum of the modulated IF signal for each antenna port (before the combiner) at 60, 70 and 80 MHz at a rate of 100 samples per second. All data are temporarily stored on a hard disk, then partly or wholly transferred to a magnetic tape which is processed later on in the laboratory. All data are transferred to tape whenever the level in one of the analog inputs exceeds a given threshold or whenever the error count value of one of the error detectors changes; otherwise only the values taken every 10 seconds by each data input are transferred to tape to allow for long-time statistics.

3 Statistical Results

31 Single-Tone Fade Depth and In-Band Linear Amplitude Dispersion

The statistics are given here for the worst month (July 89), but the other months are similar. The single-tone fade depth (STFD) statistics are given relative to the normally received power level from the main port of the APD antenna and are made at channel center (70 MHz) for each antenna port. The in-band linear amplitude dispersion (IBLAD) is defined as the absolute value of the fade depth difference between the two spectrum samples placed at both ends of the spectrum (60 and 80 MHz). To allow a comparison with the measured error performance, the effect of the in-phase combiner of unity gain was simulated by software: the amplitude of the three single-tone signals from each of the three ports were added in phase with the following formula:

$$P_{rx}\,(\text{main}+\text{diversity}) = \left(\frac{\sqrt{P_m}+\sqrt{P_d}}{2}\right)^2$$

with P_m, P_d in Watt

This calculating method is optimistic because of the nonideal combiner which can not add in-phase over the whole spectrum.

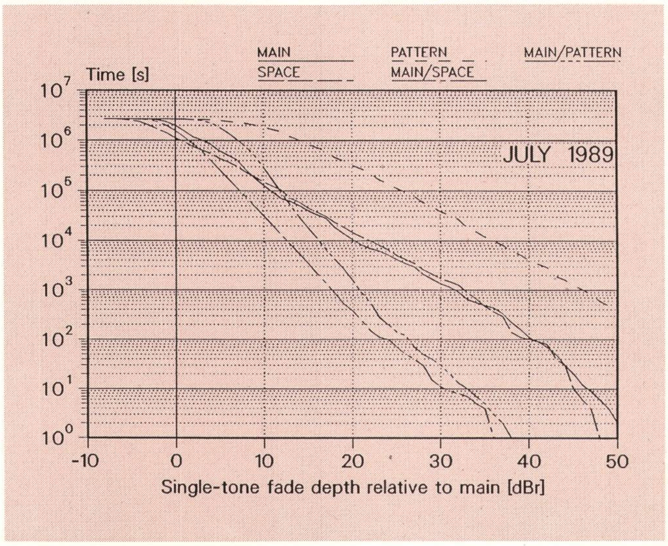

Fig. 3 Time that single-tone fade depth exceeded abscissa

Monthly cumulative distribution statistics of STFD and of IBLAD can be seen in *figures 3* and *4.* In both cases the time shown is the time that the abscissa value is exceeded. The STFD statistics of the three single port signals follow the 10 dB per decade slope. The STFD statistics from the main and space ports are practically identical (with the exception of very deep fadings, where they can diverge depending on the month), and those from the APD port are only shifted. The IBLAD statistics for the three single port signals are practically the same (with the exception of very high IBLAD, depending on the month). APD and VSD combined signals follow the 5 dB per decade slope of non-correlated signals. The combined STFD statistics are more favourable to VSD but the advantage tends to decrease with the fade depth: the gain loss of the APD lobes relative to the main lobe tends to have less effect on deep fadings than on shallow and more correlated fadings. The combined IBLAD statistics show larger improvements than the combined STFD statistics; one can also see that APD performed much better than VSD for large IBLAD (dispersions of the two single port signals more de-correlated).

Figure 5 shows the monthly delay distributions for the two receive antennas, obtained from the measured main and VSD single port signals with the help of the two-path model. The reflected path received by the space diversity antenna, which is the lower antenna, shows a path difference which is 9 cm (0.3 ns) smaller than the one received by the main antenna.

32 Error Performance

The error performance is given in monthly amounts of errored seconds (ES), severely errored seconds (SES), non-available seconds (NAS) and degraded minutes (DM). An ES is defined as a second with at least one error but less than the amount of errors corresponding to a bit error ratio (BER) of 10^{-3}. A SES is defined as a second with a BER of at least 10^{-3} and counts as such only when the link is in a state of availability. The link passes from a state of availability to a state of non-availability from the first of ten consecutive SES and returns to availability only after ten consecutive seconds without SES: during this interval minus the last ten seconds, all seconds are solely counted as NAS. A DM is defined as a minute with at least 170 errors for a 140 Mbit/s channel (BER of 2×10^{-8}); the seconds counting as SES or NAS and occurring during this minute are not taken into account in the DM whose duration is prolonged correspondingly. A second with an alarm insertion signal (AIS) counts as a second with a BER higher than 10^{-3}.

Figure 6 shows the error performance of the three types of reception. For the three demodulators, the number of SES is very often higher than the number of ES: this is due to the relatively large number of seconds during which the output of one of the demodulators supplies an Alarm Indication Signal (AIS). It is caused by the specific characteristics of the 64QAM radio equipment, which sends out an AIS when the signal is degraded by a BER of at least 10^{-3} during more than 500 msec and which features, thanks to its FEC circuit, a very steep BER-curve. Averaged over 17 months (November 1988 to

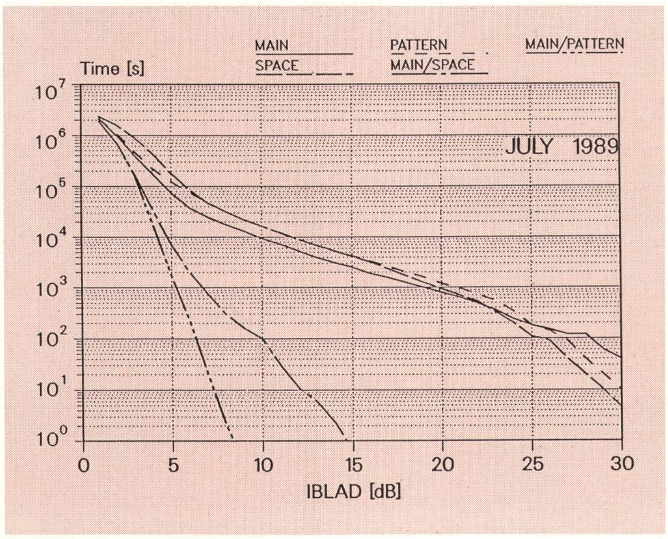

Fig. 4 Time that in-band LAD exceeded abscissa

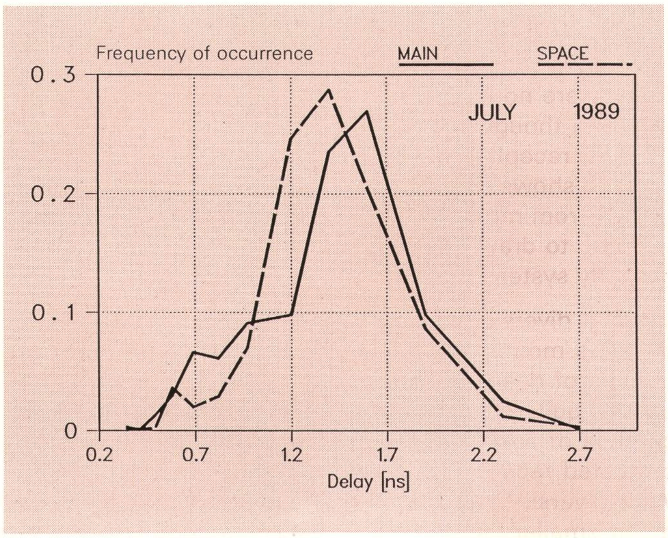

Fig. 5 Delay distributions

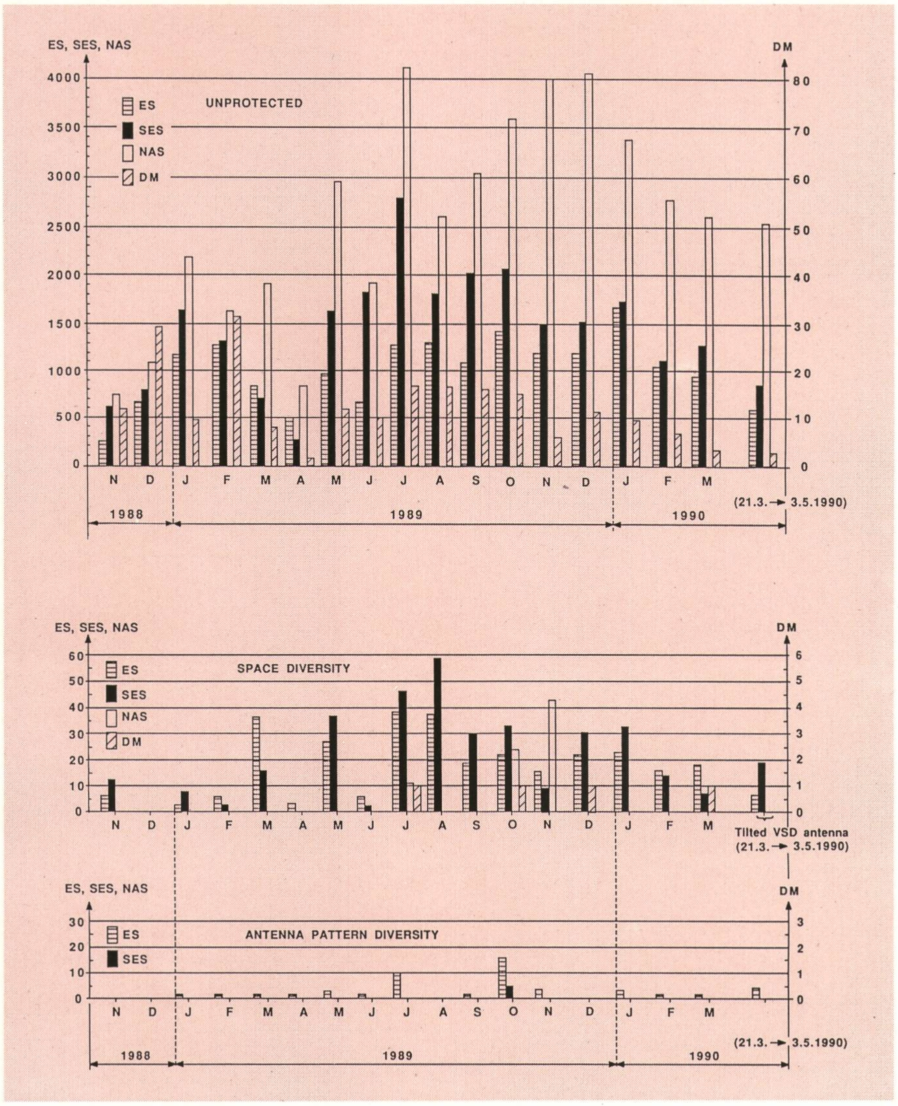

Fig. 6 *Errored Seconds, Severely Errored Seconds, Non-Available Seconds and Degraded Minutes. Measured Data from 1st November 1988 to 3rd May 1990*

March 1990), the following diversity improvement factors (DIF) were measured:

DIF/VSD	DIF/APD
ES : 59	ES : 432
SES : 75	SES : 6151
NAS : 560	NAS : –
DM : 54	DM : –

There were no NAS and no DM on the APD demodulator. Even though the VSD reception produced high DIF, the APD reception for each individual month was better. Figure 6 shows also that the various monthly DIFs varied greatly from month to month: this illustrates the danger in trying to draw conclusions about the performance of diversity systems based upon limited data sets.

Without diversity the monthly amount of NAS is higher than the monthly amount of SES; that means that the number of deep fading events lasting more than 10 seconds is quite high. *Figure 7* shows the frequency of occurence of NAS events of a given duration for the unprotected reception during the month of January 1990. With diversity, the duration of fading events becomes much smaller; the amount of NAS is sharply reduced and becomes lower than the amount of SES (fig. 6). The CCITT is discussing whether to lower the limit of 10 seconds to 4 seconds in the definition of NAS. *Figure 8* shows that this would sharply decrease the number of SES and increase the number of NAS.

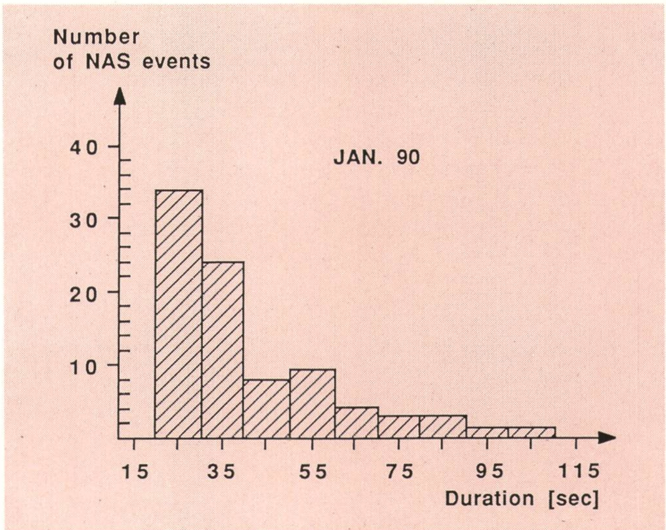

Fig. 7 *Frequency of occurrence of NAS events of a given duration*

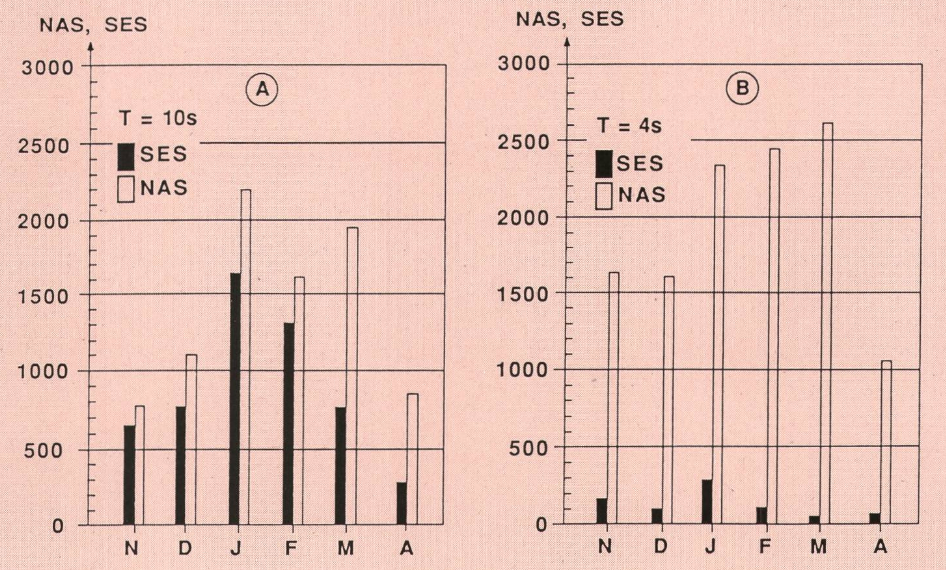

Fig. 8 Influence of the NAS definition on Severely Errored Seconds and on Non-Available Seconds performance. Unprotected reception, from Nov. 1988 to April 1989
A) 10 consecutive seconds
B) 4 consecutive seconds

4 Tilted VSD Antenna

From the 21st of March to the 3rd of May 1990 the VSD Antenna was tilted by 0.4° in direction of the lake reflections. The STFD and IBLAD statistics from the VSD antenna port show no significant difference from the statistics of the previous period. By the combined VSD statistics, only the probability that a given IBLAD value is exceeded shows a improvement of a factor of about 10. But this was not enough to outperform the APD reception whose error performance remained better (fig. 6).

5 Concluding Remarks

Over a 18 months period, APD has yielded, month after month, better error performance than VSD on this particular hop, even when VSD showed good performance. This was mainly due to the greater improvements brought by APD against dispersive effects (IBLAD). The large lake surface reflections directed towards the lower APD lobe and the big angle they form relative to the boresight axis could explain this extremely good performance of APD.

In a second phase of this experiment, transmit and receive sides will be inverted in order to assess the influence of the angle of the lake reflections relative to the boresight axis. At that occasion, a new dual offset reflector shell antenna, based on the same multimode principle and having similar kidney-shaped APD lobes in each polarisation, will be used.

Bibliography

[1] Vergères D., Jordi P., Loémbé A., Rubli S. and Mörz G. 'Simultaneous error performance of antenna pattern diversity and vertical space diversity on an 64QAM-radio-link: first results', 2nd European Conf. on Radio-Relay Systems, April 1989.

Zusammenfassung

Gleichzeitige Messung des Bitfehlerverhaltens von Antennenkeulen-Diversity und vertikaler Raumdiversity

In diesem Beitrag werden die Ergebnisse einer Untersuchung dargestellt, die die Schweizerischen PTT-Betriebe an einer 124 km langen Richtfunkverbindung durchführten. Es wurde das Verhalten von Antennenkeulen-Diversity und von vertikaler Raumdiversity unter Verwendung einer Mehrmoden-Strahleinheit verglichen. Die Messdaten wurden seit Ende September 1988 laufend festgehalten und ausgewertet. Auf der untersuchten Richtfunkstrecke, die einer starken Streuung und starken Reflexionen von der Wasserfläche eines Sees unterlag, brachte die Antennenkeulen-Diversity sehr gute Resultate, die deutlich besser sind als jene der vertikalen Raumdiversity. Die Methode dürfte deshalb auf ähnlichen Strecken eine wertvolle Alternative bieten.

Résumé

Mesure simultanée du comportement lors d'erreurs sur les bits dans la réception en diversité par lobes d'antennes et la réception en diversité verticale d'espace

On donne les résultats de recherches réalisées par l'Entreprise des PTT suisses sur une liaison par faisceaux hertziens de 124 km de longueur. Les comportements de la réception en diversité par lobes d'antennes et en diversité verticale d'espace ont été comparés en utilisant un rayonneur multimodes. Les données de mesure ont été relevées et interprétées de façon continue depuis septembre 1988. Sur la section hertzienne examinée, sujette à une forte dispersion et à d'importantes réflexions dues à la surface d'un lac, la réception en diversité par lobes d'antennes a donné de très bons résultats, c'est-à-dire nettement meilleurs que ceux de la réception en diversité verticale d'espace. Sur des sections analogues, cette méthode pourrait représenter une variante intéressante.

Riassunto

Misura simultanea del tasso d'errore dei bit di antenne a lobi diversificati e di antenne a diversificazione verticale di spazio

L'autore presenta i risultati di un'indagine eseguita dall'azienda svizzera delle PTT su un collegamento in ponte radio lungo 124 km. Con l'impiego di un illuminatore multimodale viene confrontato il comportamento delle antenne a lobi diversificati e quello di antenne a diversificazione verticale di spazio. I dati delle misure sono stati rilevati e analizzati ininterrottamente dalla fine di settembre 1988. Sulla tratta in ponte radio esaminata, sottoposta a una forte dispersione e a intense riflessioni prodotte dalla superficie di un lago, la diversificazione dei lobi d'antenna ha dato risultati molto buoni, notevolmente migliori di quelli del sistema a diversificazione verticale di spazio. Su tratte analoghe, il metodo dovrebbe perciò rappresentare un'alternativa molto valida.

Summary

Simultaneous Error Performance of Antenna Pattern Diversity and Vertical Space Diversity

This paper reports on the results of an experiment performed in Switzerland by the Swiss PTT Research and Development Centre to compare the simultaneous performances of antenna pattern diversity and vertical space diversity on an microwave radio link 124 km in length. The experiment is conducted using a multimode feed system. Data are being recorded continuously since the end of September 1988. On the involved radio hop, which is very dispersive and subject to intense reflections from a lake surface, antenna pattern diversity performed extremely well and better than vertical space diversity; it should therefore offer a valuable alternative on similar hops.