Zeitschrift: Technische Mitteilungen / Schweizerische Post-, Telefon- und Telegrafenbetriebe = Bulletin technique / Entreprise des postes, téléphones et télégraphes suisses = Bollettino tecnico / Azienda delle poste, dei telefoni e dei telegrafi svizzeri

Herausgeber: Schweizerische Post-, Telefon- und Telegrafenbetriebe

Band: 65 (1987)

Heft: 3

Artikel: Network planning aspects for terrestrial digital radio : implications of using higher order modulation schemes

Autor: Leuenberger, Kurt

DOI: https://doi.org/10.5169/seals-874801

Network planning aspects for terrestrial digital radio: Implications of using higher order modulation schemes

Kurt LEUENBERGER, Berne

1 Introduction

In a dense network, where frequency re-use is required in possibly many directions from different nodes, a new dimension may be added to the definition of spectral efficiency, since contributions of channel interference from other directions have to be considered as well.

The spectral efficiency that is obtained by applying some well known modulation schemes on *one single link* is represented in *figure 1*. For reference, the theoretical Shannon limit is indicated as well. The dark points are valid for spectra with rectangular shape ($\alpha = 0$). The circled points indicate the efficiency obtainable under a scheme such as shown in *figure 2a*, using $\alpha \cong 0.7$. The points represented with "x" finally indicate the efficiency obtained with systems using a channel scheme with alternate polarization, such as indicated in *figure 2b*.

In the following, a simplified derivation of an expression for the deterioration of the detection threshold by channel interference in a digital receiver is given. Subsequently, the necessary filter- and/or cross-polarization discrimination for commonly transmitted channels in one particular direction is evaluated. Finally, a formula for the minimum required angular discrimination of antennas in a node (radio tower) for channel re-use is derived. Applying the known angular and cross-polar characteristics of commercially available antennas, corresponding minimum angular spacings can be specified. A comparison of the results for the different modulation schemes finally leads to some conclusions in respect to the performance of higher order modulation schemes applied to dense networks.

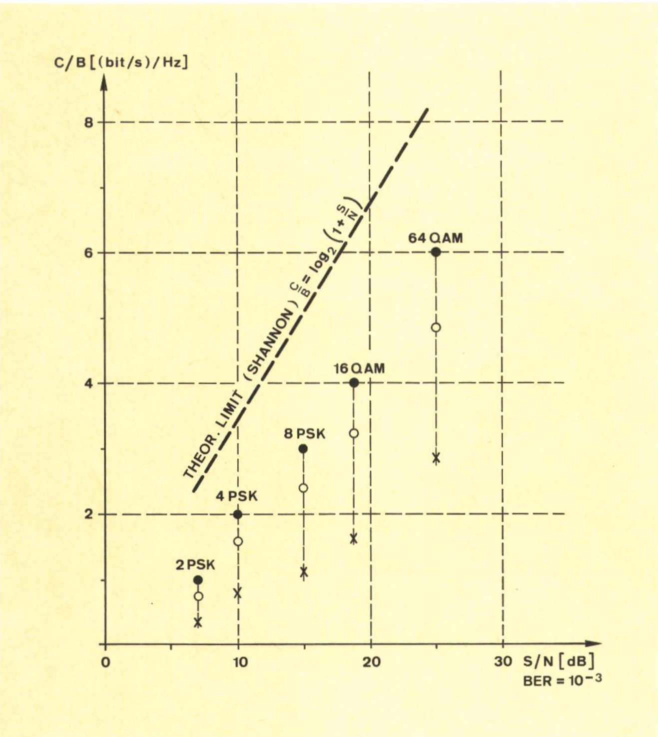

Fig. 1
Spectral efficiency for digital modulation schemes
Ideal, Nyquist-factor:
• $\alpha = 0$
o $\alpha \cong 0{,}7$
x $\alpha \cong 0{,}7$
interleaved channels, per polarisation

2 Deterioration of threshold by interference

To achieve a given BER at the digital receiver, a given signal-to-noise ratio S is required which, assuming similar receiver characteristics, depends on the modulation scheme applied. Despite the fact that the signal-to-noise ratio and the signal-to-interference ratio (desired to undesired channel) for a given BER is not exactly the same due to the differences in their amplitude statistics, this approximation is reasonable for our purposes (conservative by at most a few dB).

We define P_n as the noise power, P_i as the interference power, P_{rxoo} as the receiver input power for the given BER without additional interference and correspondingly P_{rx} as the receiver input power to achieve the given BER with the additional interference power P_i at the input. P_{rxoo} could therefore be defined as the threshold without interference and P_{rx} as the deteriorated threshold due to interference.

The following relationships thus can be stated:

$$S = \frac{P_{rx}}{P_n + P_i} = \frac{P_{rxoo}}{P_n} \qquad (1)$$

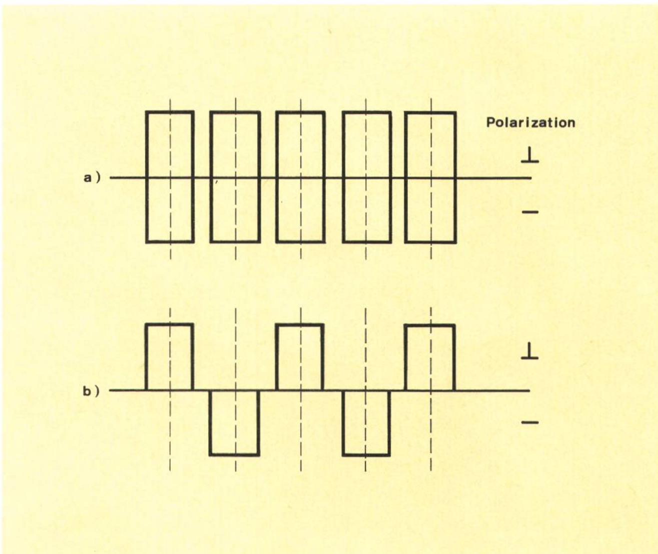

Fig. 2
Channel plans for digital transmission

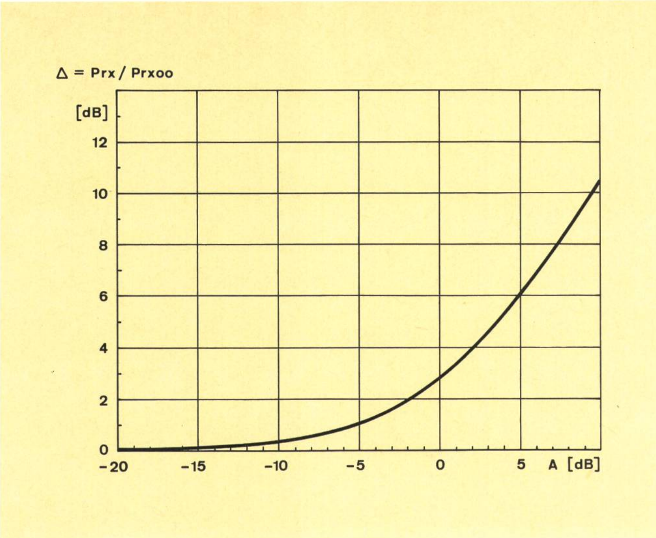

Fig. 3
Deterioration Δ due to channel interference

From this, the deterioration Δ can simply be derived

$$\Delta = \frac{P_{rx}}{P_{rxoo}} = \frac{S \cdot P_i}{P_{rxoo}} + 1 \qquad (2)$$

or using the abreviation $A = S \cdot P_i / P_{rxoo}$

$$\Delta = A + 1 \qquad (2a)$$

The relationship is represented in *figure 3*. The deterioration obviously reaches asymptotically zero for small values of P_i. A proportional deterioration of the threshold is obtained for large values of P_i. A deterioration of 3 dB (equal values of P_n and P_i) is obtained if the level of interference power is $P_i = P_{rxoo}/S$.

With P_{rx} being defined as the nominal level at the receiver (level without fading), the fading margin including interference is defined as

$$M = \frac{P_{rxo}}{P_{rx}} \qquad (3)$$

For given values of S, P_{rxo} and P_{rxoo}, the admissable interference power P_i can thus be derived by inserting (3) in (2), with

$$\frac{P_{rxo}}{M \cdot P_{rxoo}} = \frac{S \cdot P_i}{P_{rxoo}} + 1 \qquad (4)$$

This expression yields the ratio g of the interference power versus the nominal power

$$g = \frac{P_i}{P_{rxo}} = \frac{1}{S \cdot M}\left(1 + \frac{1}{A}\right)^{-1} \qquad (5)$$

In a node, the receiver input levels are typically equal (optimum in respect to interference, as long as antenna gains are equal). The ratio g thus represents the required attenuation for the channel interference, to ensure a given fading margin. In the following, the two main sources of interference, adjacent-channel interference and co-channel interference, are investigated separately.

3 Adjacent – channel interference

Since fadings are strongly correlated for adjacent channels on the same link, the conditions to keep the adjacent-channel interference low can be stated under the assumption of optimal correlation (no differential fading) as

$$P_{ia} << \frac{P_{rxo}}{S} \qquad (6)$$

The pessimistic lower limit (case of zero correlation, such as occurring on adjacent links having one station in common) would be

$$P_{ia} << \frac{P_{rxoo}}{S} \qquad (7)$$

The correlation depends, as mentioned, on the spacing, as well as on the specific application of the equipment (path lengths, etc.). Generally, a deterioration of the threshold of < 1 dB is achieved. Possibilities are also being explored to apply adaptive cancelling systems for adjacent-channel interference [1], or even for crosspolar co-channel operation according to figure 2a.

The theoretically achievable adjacent-channel suppression by filtering is represented in *figure 4*, assuming filters that assure ideal Nyquist conditions at the regenerator (50 %/50 %-filtering) according to [2].

4 Co-channel interference

Co-channel interference occurs in nodes, with channel re-use. As a model case, it will be assumed here that the interference to a desired channel is dominated by *two* main disturbers, transmitting from adjacent directions with angles of $\pm \varphi$ relative to the desired direction. Since the occurrence of fading in different hops has to be considered as uncorrelated, the signal level at the re-

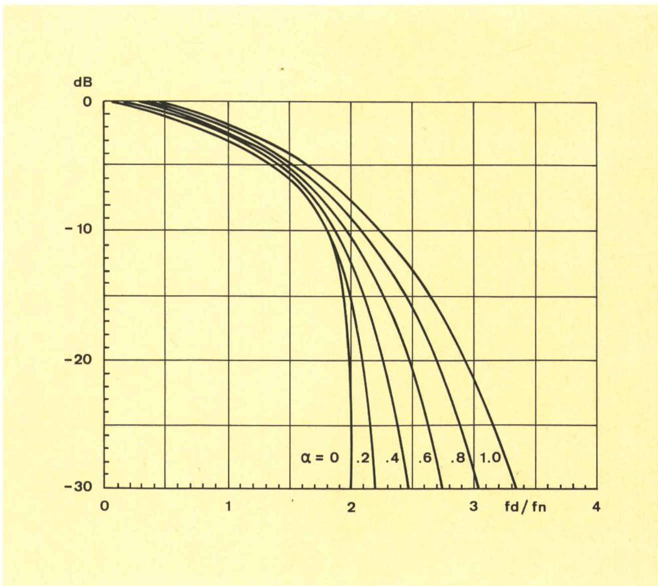

Fig. 4
Adjacent-channel suppression at the regenerator (ideal Nyquist-filtering, 50 %/50 %)
f_d: Difference of adjacent-channel carrier frequency
f_n: Nyquist frequency
α: Nyquist slope factor

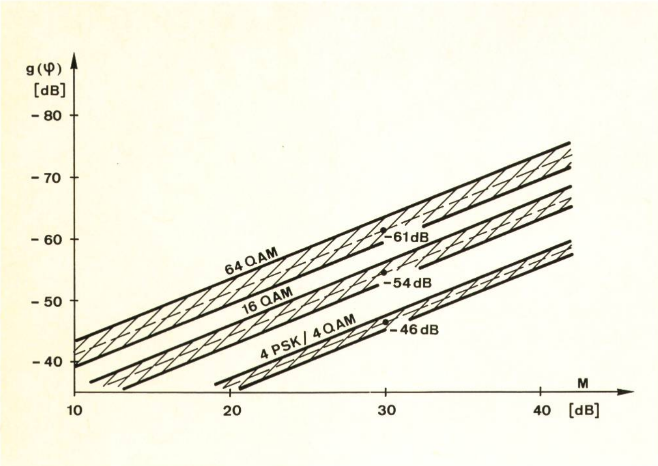

Fig. 5
Minimal relative antenna discrimination g (φ) in function of eff. fading margin M

Conditions: – Interference dominates over noise, for given threshold P_{rx}
– Two major interferers of equal strength
– Equal antennas and equal nominal receiver levels P_{rxo}
– Values for S: 4 PSK: 13 dB, 16 QAM: 21 dB, 64 QAM: 28 dB (typical for BER = 10^{-6})

ceivers from different directions in a node can vary by at least the fading margin (up-fading can occur simultaneously, but the coincidence of fading and up-fading can be regarded as second order).

Thus, the relationship between the resulting fading margin and the relative antenna discrimination (antenna of desired channel) is readily obtained from (5) as

$$g(\varphi) = \frac{P_{ic}}{P_{rxo}} = \frac{1}{2 \cdot S \cdot M}\left(1 + \frac{1}{A}\right)^{-1} \quad (8)$$

Using given equipment and antenna characteristics, the highest nodal density is thus obtained (smallest angular spacing of directions at which channel re-use can be applied) for the case that the co-channel interference is allowed to dominate over the receiver noise. Equation (8) then is written in the simple form

$$g(\varphi)[dB] = -\,(M[dB] + S[dB] + 3) \quad (9)$$

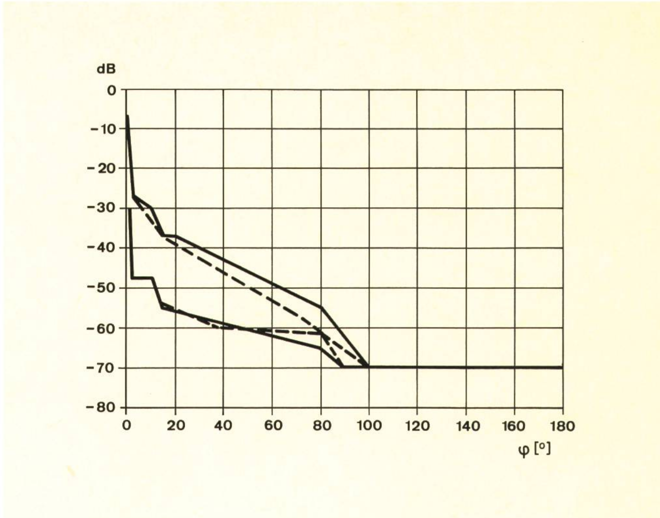

Fig. 6
Radiation pattern, Antenna 7 GHz, 3 m Ø

In practice, a deterioration of the threshold by 5...7 dB may be tolerable in many digital networks, because the equivalent fading margin due to dispersive fading often lies in the order of 30 dB...35 dB, such that a flat fading margin much higher than the dispersive margin is useless anyway.

The results for the minimum angles are indicated as curves in function of the effective fading margin M. They are obtained by applying the different antenna characteristics from *figures 6 to 8*. Depending on the antenna polarization, the minimum angle in *figures 9 to 11*, for *equal* polarization of adjacent directions, is covered by the range indicated by the set of solid curves, per modulation scheme. The corresponding dashed curves show the minimum angle for *crossed* polarization, where the range of variation is mostly small, such that we represent the worst case values by single curves.

The results show the considerable differences in respect to minimum angle that occur for commercial types of antennas depending on the modulation scheme utilized. For 64QAM-modulation, no re-use is possible with some types of antennas at any reasonable fading margin. The

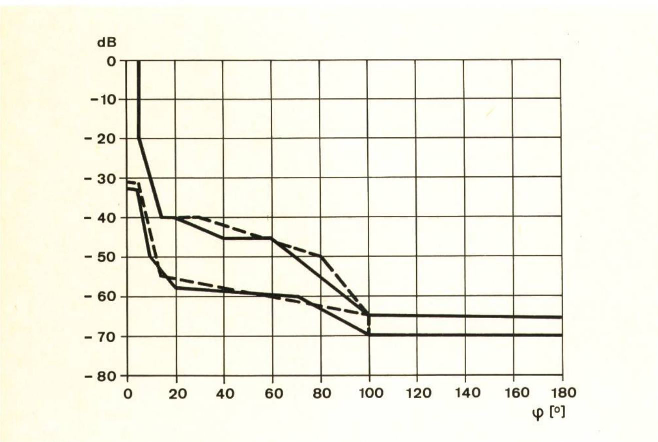

Fig. 7
Radiation pattern, Antenna 4/11 GHz, 4.3 m Ø (multiband)

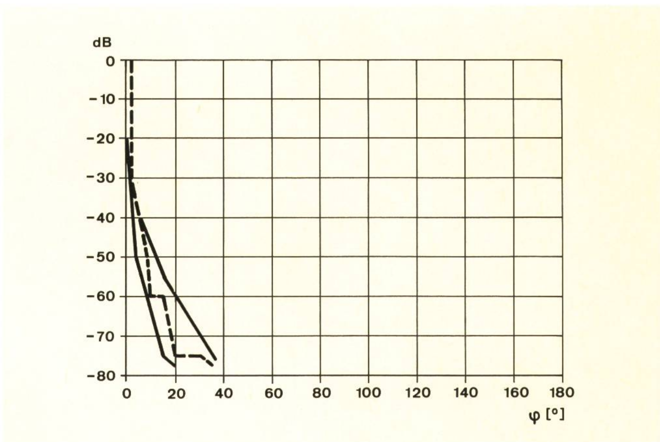

Fig. 8
Radiation pattern, Antenna 11 GHz, 3 m Ø (offset-type)

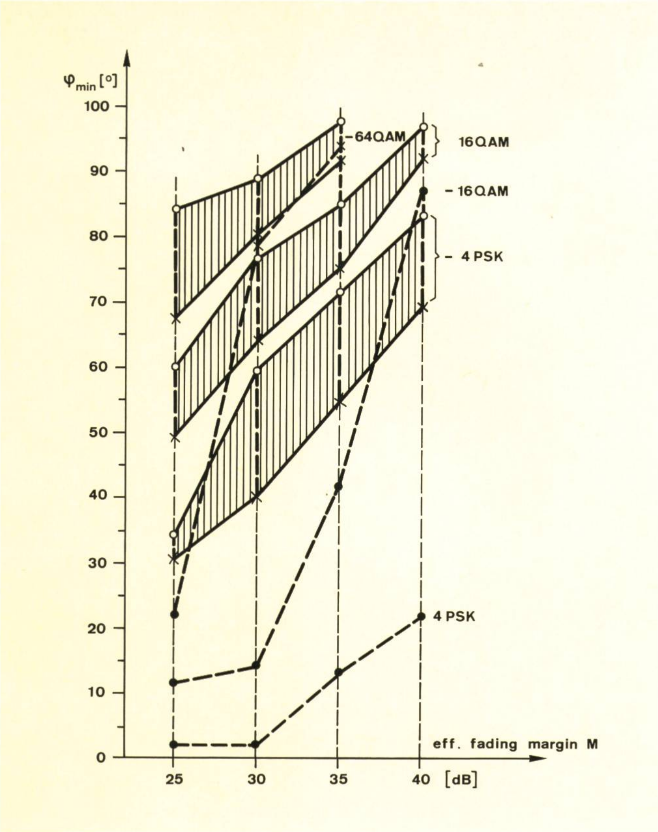

Fig. 9
Antenna: 7 GHz, 3 m Ø, Gain: 45 dB
Minimum angular separation (for two interferers)

x horizontal polarization
o vertical polarization
● maximum of both
—— equal polarizations for adjacent directions, from node
– – alternated polarizations
▨ range of variation, horizontal/vertical polarization

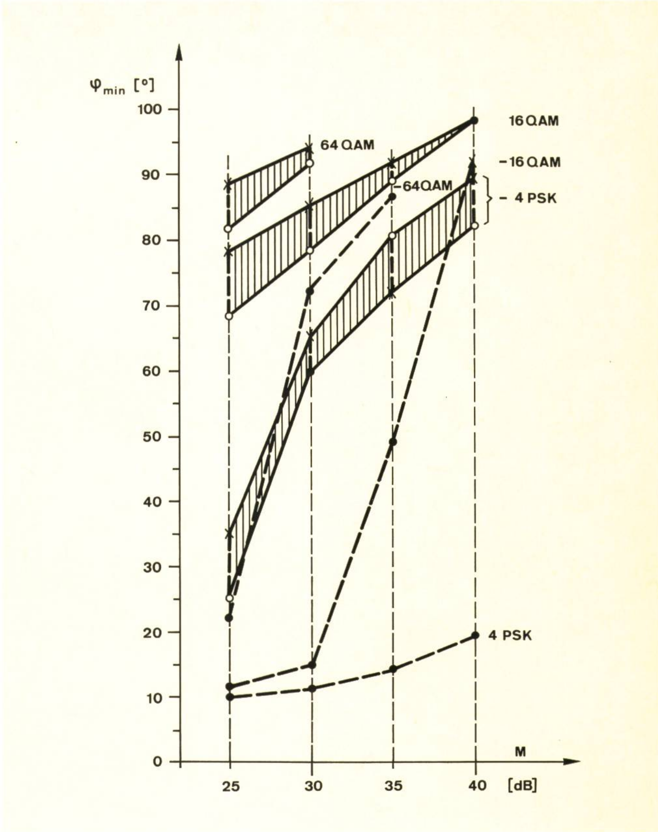

Fig. 10
Antenna: 4/11 GHz, 4.3 m Ø, Gain: 41 dB (multiband)
Minimum angular separation (two interferers)

x horizontal polarization
o vertical polarization
● maximum of both
—— equal polarizations for adjacent directions, from node
– – alternated polarizations
▨ range of variation, horizontal/vertical polarization

superior performance of offset-type antennas is also evident from the results of figure 11, which minimizes the problem. However, the relatively high cost of these antenna types still limits their widespread application.

5 Conclusion

The spectral efficiency achieved with higher order modulation schemes in dense digital radio networks has been investigated. The results show that despite the increase of efficiency that is achieved in networks with nodes of small density, some definite limitations remain in respect to the efficiency in dense networks, as long as standard type antennas are applied. In the design of dense networks with systems using high order modulation schemes, these limitations should therefore be taken into account.

Bibliography

[1] *Tyu T., Takahara M.* and *Noguchi T.* IF-Band Cross-polarization Canceller. ICC 84; IEEE International Conference on Communications, Amsterdam 1984, p. 1442.

[2] *Leuenberger K. J.* Digital Radio Systems Examined – Part I: General State of the Art, Part II: Modulation and Transmission Characteristics. Microwave Systems News & Communications Technology 16 (1986) 1, p. 81, and 16 (1986) 2, p. 131.

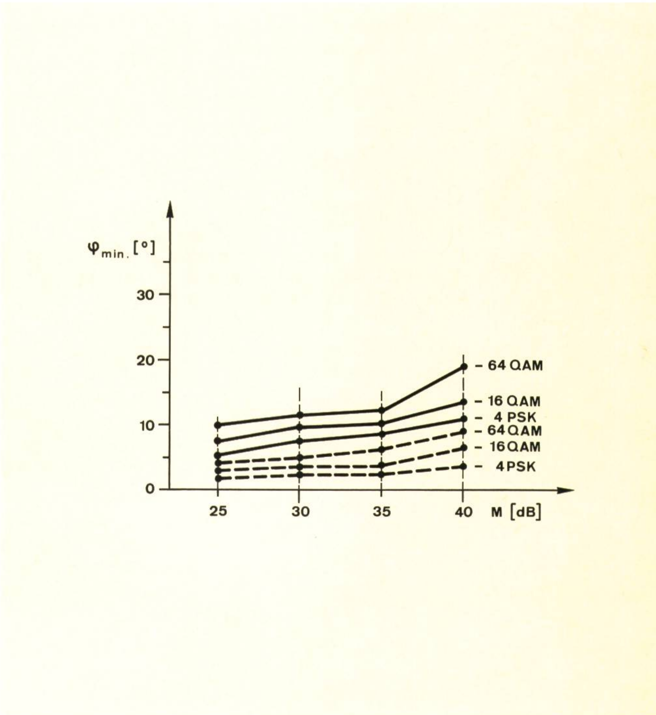

Fig. 11
Antenna: 11 GHz, 3 m Ø, Gain: 48 dB (offset-type)
Minimum angular separation (two interferers)

—— maximum for all combinations of polarizations
– – alternated polarizations