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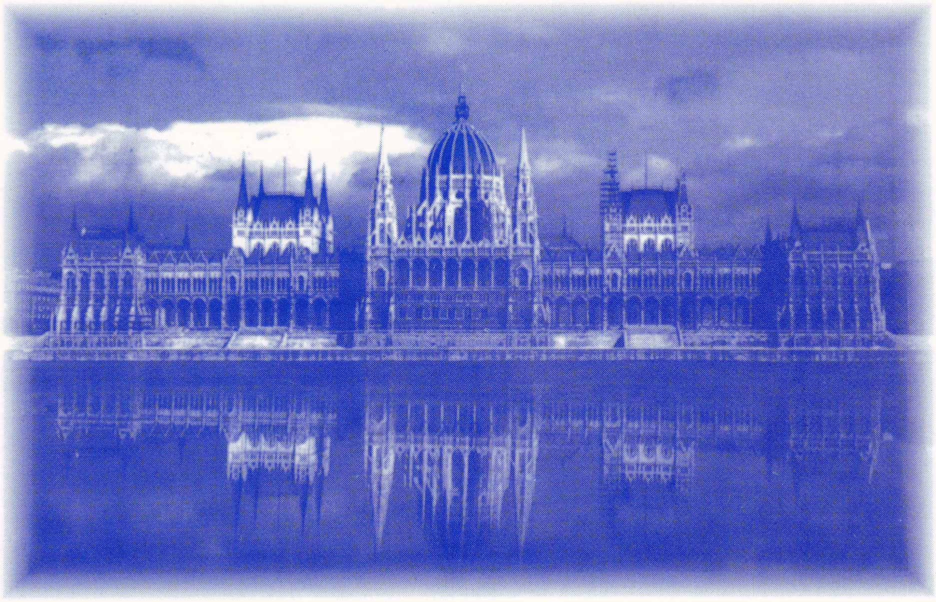

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RADIO-FREQUENCY INTERFERENCE IN RADIO-OVER-FIBER DISTRIBUTION NETWORKS

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INTRODUCTION

Radio-over-fiber distribution networks have been investigated by several authors recently [1-4]. The different proposed solutions combat the difficulties arising in the optical part of the network such as chromatic dispersion or phase noise of the optically transmitted microwave or millimeter-wave (MW/MMW) carriers [5]. This paper addresses the problem of radio-frequency interference (RFI) in the wireless part of the network. The necessity of channel separation as well as the importance of good receiver RFI immunity is shown. An efficient method is presented for the characterization of interference properties of the MMW digital radio receivers employed in the network.

RADIO-OVER-FIBER SYSTEMS

The growing demand for broadband services and the increasing number of new subscribers require the transmission and distribution of very high-speed digital data. The lack of available free radio spectrum in the lower MW range has pushed carrier frequencies towards the MMW range. The high free space loss at the proposed 26 GHz, 42 GHz and 60-70 GHz bands shows the evident necessity of a fiber-optical backbone.

Consequently, future radio-over-fiber networks combine the emerging fields of MMW photonics and digital radio to offer wideband access of the subscribers. In the picocellular system the radio base stations are connected to a remote central station via optical-fibers. But in the last few hundred meters wireless connections are established (Fig.1). Advantages of these radio-over-fiber systems are in the easier installation and reduced maintenance costs. Furthermore, due to the wireless connection in the last few hundred meters some limited mobility of the users is also tolerated [7].

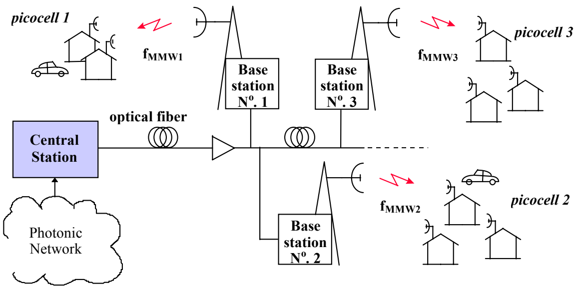

Figure 1. Radio-over-fiber distribution network

RADIO FREQUENCY INTERFERENCE

Much effort has been carried out to reduce the complexity of the base stations. Various solutions are proposed for the optical generation and distribution of MW/MMW carriers in the network [1-6]. Laser diode or photodetector nonlinearities, special optical modulator structures and self heterodyning techniques are investigated. These solutions are often compared in term of phase noise of the MMW carrier, since phase noise results in a bit error rate (BER) degradation in the digital channel. Experimental system trials are usually performed on individual fiber-radio links [2] and less investigation has been carried out on the wireless extension of the network. Since a real system incorporates multiple picocells, a further source of BER degradation is introduced. In the radio channels RFI due to neighboring transmitters should be considered as a main reason of BER degradation. Only a few papers deal with the case of several channels [7] and less mention RFI problems [8].

The three main possibilities to avoid RFI are in the spatial, frequency or time domain multiplexing. Spatial separation is a rather complex but perspective possibility applying intelligent adaptive antennas. Phased arrays can follow even a moving subscriber with a very narrow antenna beam [7]. By this method, the same radio frequency can be simultaneously allocated within the picocell, but the complexity of the base station is significantly increased. Time domain separation is successfully employed in low capacity time domain multiple access (TDMA) networks. In the MMW range however, frequency domain separation is the most obvious solution. High capacity systems can benefit the inherent advantage of the wide available radio spectrum meanwhile proper radio channel allocation reduces undesired RFI effects.

RFI Sensitivity of Digital Receivers

First the BER degradation due to RFI in digital radio receivers operating at MW or MMW frequencies is studied. The importance of good selectivity and immunity of the digital receivers employed in the radio-over-fiber system, as well as the necessity of frequency separation is emphasized.

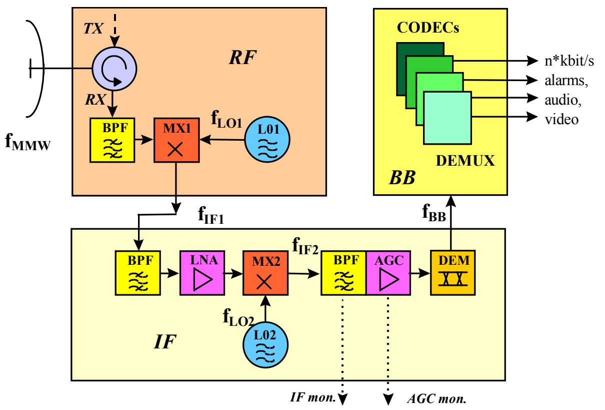

Figure 2. Block diagram of a dual-down-conversion MW/MMW digital receiver

A generalized block diagram of dual-down-conversion MW or MMW digital radio receivers is shown in Fig.2. In the absence of interferer signals entering the receiver, the BER is mainly determined by the signal-to-noise (*S/N*) ratio. The *BER*(*S/N*) function has the well known *erfc(x)* shape [9]. It is shown by the lowest curve of Fig.3, indicating the case of the measurement of a 38 GHz receiver. If an interferer signal is present at the frequency of the wanted signal then the value of the BER is deteriorated. At a given received signal level (*RSL*) the BER degrades as the level of the interferer signal increases. Measured BER degradation curves due to co-channel interference are shown as a function of *RSL* in Fig.3. The parameter of the curves is the signal-to-interferer (*S/I*) power ratio.

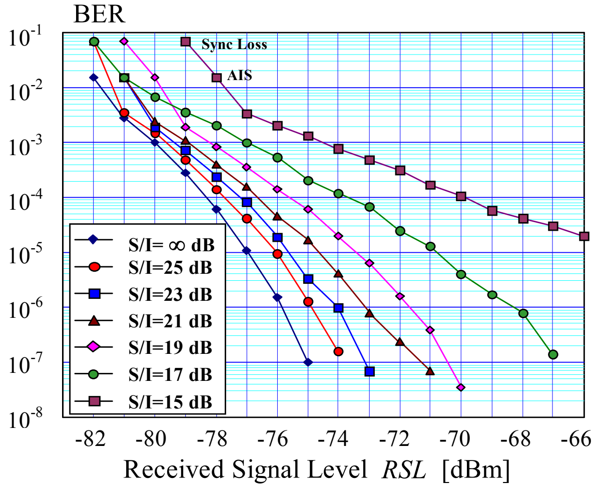

Figure 3. Measured co-channel interference of a 38 GHz 8 Mbit/s digital receiver

Fig.3 is the conventional representation of BER degradation caused by co-channel RFI. Similar curves are obtained either for CW sinusoidal or for like-modulated interferer signals. Without RFI or for very low interferer levels ($S/I \approx \infty$) the usual thermal noise limited *BER(RSL)* curve is recovered.

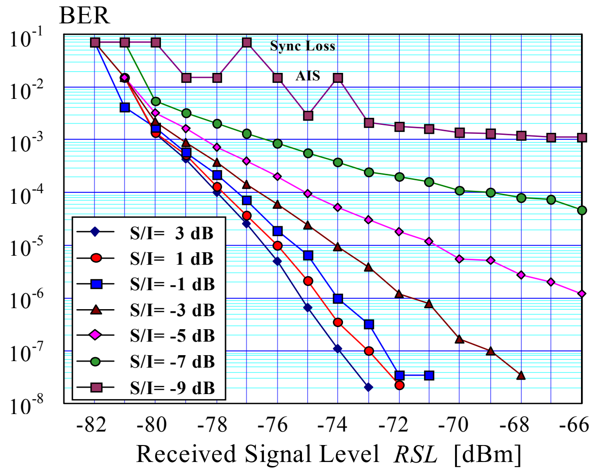

Figure 4. Measured adjacent-channel interference of a 38 GHz 8 Mbit/s digital receiver

For each different interference frequency a new set of curves should be plotted. For comparison, the effect of adjacent-channel RFI is depicted in Fig.4. Due to the selectivity of the digital receiver, higher level of interferer signals are tolerated in this case compared to that of Fig.3.

Receiver and Demodulator Thresholds

The curves of Fig.3 and Fig.4 can be represented in another way as well. Fixing the *BER* at a given level, the *S/I* values are plotted as a function of the *RSL* in Fig.5. These curves have two asymptotes. As the *RSL* of the digital receiver is increased the *S/I* ratio can be decreased maintaining the same BER level. But independently of the predefined error rate, a minimally required *S/I* level remains always, which is essential for the demodulation. It is referred the demodulator threshold and its value depends mainly on the actual modulation mode used and on the quality of the receiver. Typically, it is between 10 and 15 dB for commonly used digital modulation modes [9].

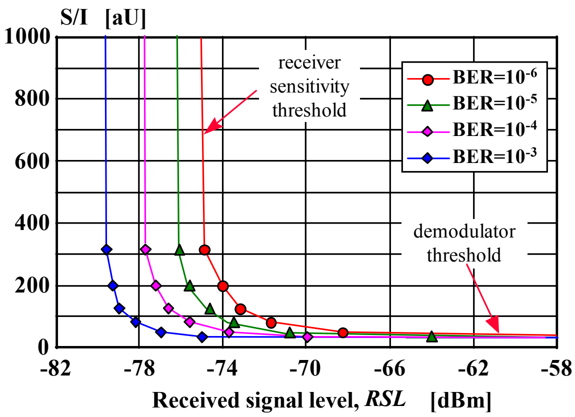

Figure 5. Required *S/I* resulting in a $BER=10^{-x}$ as a function of *RSL* in a MMW digital radio receiver

On the other hand, if we decrease the *RSL*, at the receiver sensitivity threshold the correct demodulation will always be distorted by errors, even for extremely good *S/I* ratios. At the absence of RFI or at negligible interferer levels, the reception is limited by the thermal noise being always present in the channel.

MEASUREMENT OF RFI

A test method is shown for the RFI immunity characterization of MMW digital receivers. The typical measurement setup is shown in Fig.6 [10]. The interferer signal is introduced either by a radio transmitter (TX) similar to that of transmitting the wanted signal or by a synthesized signal source. The interferer signal frequency f_I is tuned over the frequency band of interest around the nominal reception (RX) frequency of the receiver under test. At each f_I interference frequency, the amplitude of the interferer signal is increased until the predefined constant BER value (typically between $BER=10^{-6}$ and 10^{-3}) is not achieved.

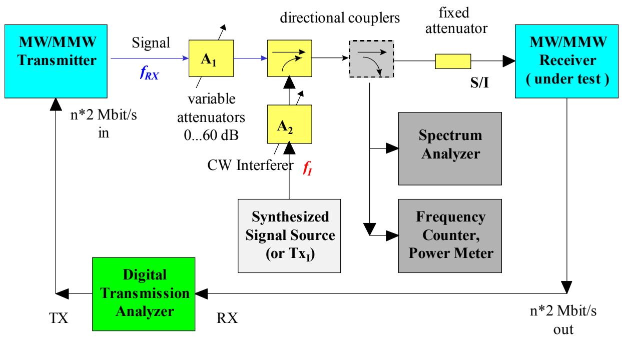

Figure 6. Measurement setup for RFI sensitivity tests of MW/MMW digital radio receivers

Measured *S/I* contours of digital receivers operating at 23 and 38 GHz are plotted in Fig.7. The channel capacities under tests have been 16, 8 and 2 Mbit/s, respectively. The curves are drawn for the *S/I* ratios degrading the error free connection to a *BER* level of 10^{-6} due to the presence of a sinusoidal CW interferer. The measured points have been normalized to the midband *S/I* ratio denoted as $S/I(f_{RX})$. The normalizing factor and the shape of the curves of Fig.7 depend on the capacity of the digital channel as well as on the quality of the receiver. In the demonstrated cases 4FSK modulation was used without any error correction algorithm.

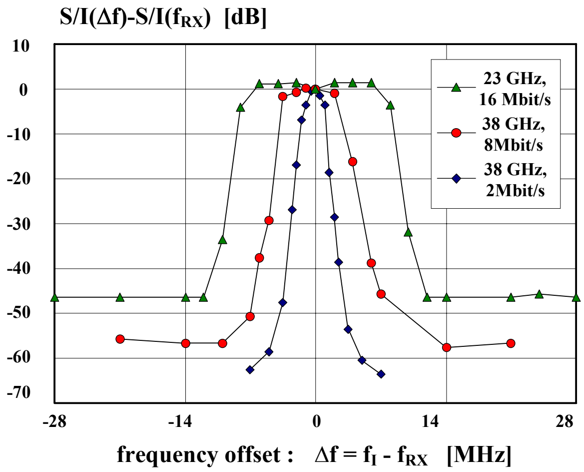

Figure 7. Normalized signal-to-interferer ratio resulting in $BER = 10^{-6}$ in the digital radio receivers

Applying higher interferer levels inside the RX channel, the reception becomes faulty. However, outside the reception band the radio receivers tolerate interferer levels of about 50 dB higher than the wanted signal. Applying the presented method, we performed sensitivity measurements of MW and MMW FSK and PSK receivers operating in the frequency bands of 1.5, 15, 18, 23, 26 and 38 GHz. The method has the advantage of simplicity, meanwhile the radio receiver can be treated as a “black-box”. Besides co-channel and adjacent channel RFI tests, image rejection and spurious reception properties of the receiver under test can be traced as well. It is worth to compare Fig.3-4 to Fig.7. The curves in Fig.7 recall the frequency response shape of bandpass filters. In fact, all the frequency selective elements within the radio chain (Fig.2) have their influence on the shape of the measured curve. The width is determined mainly by the IF filter characteristics and the spectral efficiency of the modulation mode. But the shape of the curves depend also on the bit rate of the digital data, on the bandwidth of the RF and IF amplifiers of the receiver, on the scrambling and error correction algorithm used (e.g. Viterbi or FEC) as well as on the modulation format of the transmitter.

CONCLUSION

Future radio-over-fiber systems will find available free radio spectrum in the 26, 42 or 60 GHz communication bands [1-8]. In the paper the BER has been investigated in presence of RFI in the wireless channel. Interfering signals exist due to the transmitters of neighboring picocell base stations. In digital radio theory the effect of RFI has been widely studied [9-10]. RFI tolerance is already a standardized parameter of MW/MMW receivers [11-12]. However, until now less attention has been forwarded to this fact in fiber-radio distribution systems. An efficient method was shown for testing the selectivity of MW/MMW digital radio receivers. Compared to other interpretations of RFI, the measured values are presented by curves recalling the shape of a bandpass filter response. It gives a better understanding of digital receiver immunity and selectivity. Measured results have been shown for 23 and 38 GHz digital receivers appropriately indicating the necessity of frequency domain separation in radio-over-fiber systems.

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