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# Performance Evaluation of a High Frequency ATM Wireless Access System Using Directional Antennas

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**Abstract:** This paper presents the results of a series of evaluation trials undertaken in the scope of the ACTS project AWACS in order to investigate the feasibility of the use of directional antennas to support high bit rate transmissions using a single carrier unequalised modem. The relationship between the antenna directivity, propagation statistics and modem performance are reported here. The results illustrate the effectiveness of correctly aligned, high gain antennas in reducing the undesired effects of multipath propagation. Further, the transceiver trials indicate the need for balancing antenna directivity at both ends of the link.

## 1. Introduction

The increasing need for more bandwidth and asynchronous communications to support new time-critical multimedia and videoconferencing applications has resulted in Asynchronous Transfer Mode (ATM) emerging as the primary networking technology for next-generation, multimedia communications mainly due to its flexibility to support a wide range of services [1]. However, ATM is currently mainly a standard for wired information transfer, and therefore future wireless LAN products should be fully ATM compatible. For this purpose spectrum both in the 5GHz and 17 GHz bands have been allocated for a new European High Performance Radio LAN (HIPERLAN) system and it has been proposed that the HIPERLAN family should address four types of HIPERLANs [2] used for local, in-house and on-premises networking. A description of these HIPERLAN types are beyond the scope of this paper and details can be found in [2] [3]. In this paper the results of a programme of field trial evaluations undertaken by the ACTS AWACS project [4] is presented in order to meet the evolving wireless ATM specifications in the 17 GHz frequency band. From the AWACS point of view, it is the HIPERLINK (HIPERLAN type4) that is of particular interest, aiming at operating in the 17 GHz band and to provide point-to-point interconnection at very high data rates (up to 155 Mbps) over distances of up to 150m [2]. Mobility is restricted in the type of connection envisaged for HIPERLINK systems, and therefore AWACS has considered to use directional antennas to advantage in order to achieve both higher bit rates and to improve spectrum re-use. Furthermore, since the transmission power at 17 GHz is limited to 100 mW, use of directional antennas can become very effective for portable applications in terms of extending the coverage range.

The project has access to an existing experimental ATM Wireless Access (AWA) demonstrator which has been developed by the NTT's Wireless Systems Laboratories [5]. This pre-prototype demonstrator offers low mobility terminals operating in the 19 GHz band to support user bit rates of up to 34Mbps with radio transmission range of up to 100m.

A series of measurement trials were performed in order to characterise various indoor radio environments using 4 antenna types (Omni, 30° and 60° patch antennas and a 15° horn). The results of the propagation measurements have been reported in [6]. Here the results of stand alone ATM performance evaluation trials are presented and the relationship between the propagation parameters, antenna directivity and modem performance is considered.

Sections 2 and 3 outline the specifications of the measurement equipment and describe one of the indoor environments used during the trials respectively. Section 4 presents the results and discusses their impact on the design of future wireless LANs.

## 2. AWACS testbed

The AWACS pre-prototype testbed employs a single carrier unequalised modem. To protect data, Forward Error Correction (FEC) coding is used. The equipment uses two types of Reed-Solomon FEC for the ATM cells. RS(14,8,3) is used for the ATM header and can correct up to three bytes. The ATM payload is protected with RS(50,48,1), offering a one byte correction capability. The multiple access scheme is based on a TDMA-TDD frame format. The frame consists of 16 time slots for each forward or reverse link, with each frame having a duration of 2 ms.

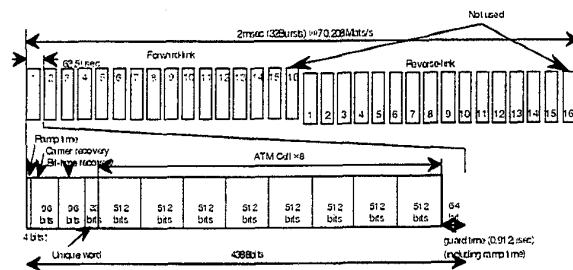


Figure 1 - Frame Format used in the AWACS Air-Interface

Figure 1 shows the frame format used in the AWACS air-interface. The lower section of Figure 1 shows the structure of the frame during each time slot. Each time slot includes 8 ATM cells (each containing 53 bytes) together with the necessary FEC parity bits. The user bit rate is 1.5 Mbit/s per time slot, taking into account the frame duration of 2 ms. The equipment uses two fully digital VLSIs for its modulator and demodulator developed by NTT [5]. The equipment uses Offset QPSK (OQPSK) to modulate the data onto the RF carrier. Each frame also includes carrier recovery (CR) and the bit-timing recovery (BTR) words to enable successful reception. Furthermore, ramp time bits and guard time bits are also added to the frame structure. The total number of bits per time slot is 4388 and the total duration per slot is 62.5 microseconds (i.e 70.2 Mbit/s total for both up and down links).

### 3. Measurement environment

The results presented in this paper are mainly related to an open plan office of 12m x 6m dimensions in a modern building. The floor was made of hard floorboard with metal sheet covered by plastic carpet. The suspended ceiling was 3m high. The office was furnished with a number of desks and metal cupboards as shown in figure 2. The walls of the room were made from reinforced concrete and large double glazed windows in the office overlooked a street. Part of the office area was separated by a ceiling high glass and metal partition in order to form a meeting room of dimensions 5m x 6m. The partition included a metallic blind which could be open or shut. Within the meeting room there was an oval wooden meeting table and 8 chairs as depicted in Figure 2.

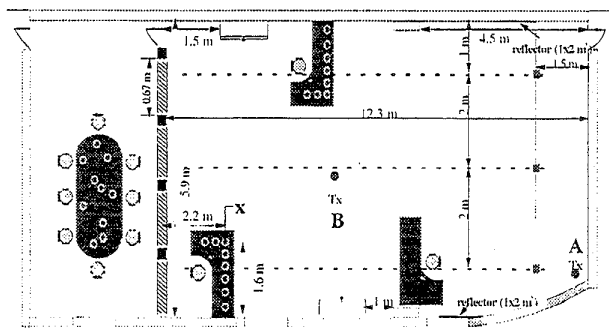


Figure 2 - Plan of the medium size office

### 4. Overview of the Results

The measurement campaign described in [6] considered propagation characteristics and system performance of 8 combinations of BS (Base Station) and MS (Mobile Station) antennas for 3 indoor environments and a total of 9 different scenarios. The results gave a good indication of the propagation characteristics that can be expected in the emerging 17GHz frequency band.

Variations of the channel parameters for various scenarios and antenna combinations have been presented in [6], in particular the relationship between the Rician K-factor and the RMS Delay Spread was considered. It was shown that as the K-factor remained high (>7 dB), values of rms delay spread less than 15 ns were measured corresponding to a better modem performance in terms of BER.

The results presented here consider various combinations of four different types of antennas employed during the trials:

omni-directional, 60° and 30° beamwidth patch, and a 15° beamwidth horn. The corresponding gain of these antennas in the azimuth plane was 0dBi, 10.9dBi, 14.1dBi and 21.0dBi respectively.

Two important areas have been addressed in the measurements presented in this paper: sensitivity of the link to the correct alignment of the directional antennas and the impact of the increased antenna directionality at one end of the link (for mixed antenna combinations where either BS or the MS make use of a narrower beam antenna).

#### 4.1. Sensitivity of the link to the correct alignment of antennas

In order to determine the sensitivity of the correct alignment of the BS and MS when employing directional elements as far as link quality is concerned, the BS employing a 30° antenna was first placed in the middle of the open plan office at the height of 2.6m (position B in figure 4) while an Omni antenna was used at the MS at the point X on a desktop (1.3m high) also shown in figure 2. Figure 3 (a) shows variations of the system performance (in terms of the measured Bit Error Ratio) as the BS antenna was rotated through 360° starting where it was facing the MS. Figure 3(b) shows the variation of the channel parameters (rms delay spread and K-factor) for the same operation condition. Clearly, it can be seen that a good link is observed only when the antennas at the MS and the BS are correctly aligned to face each other.

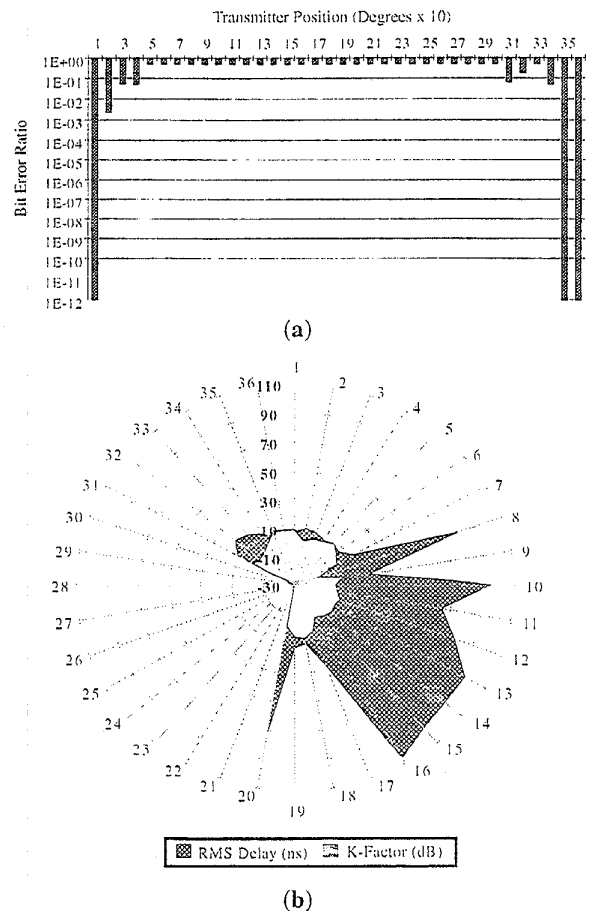
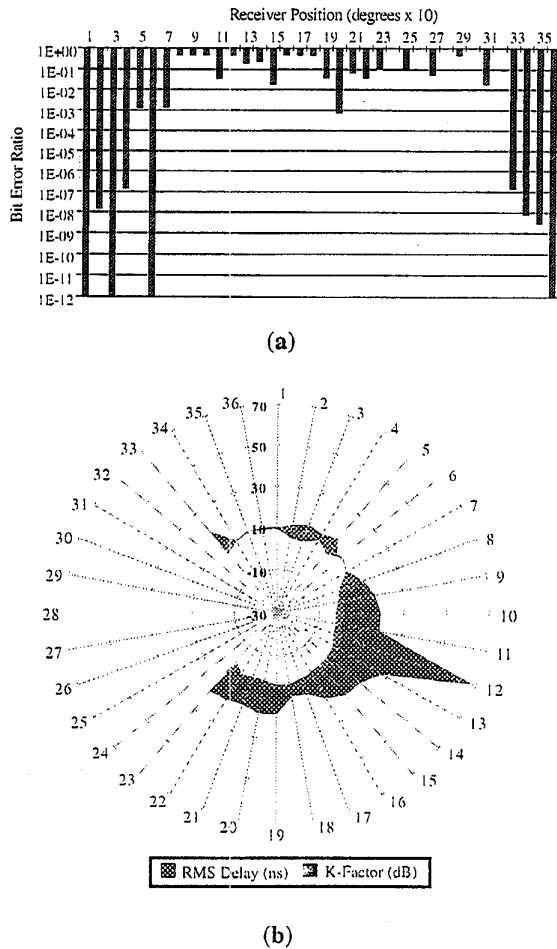


Figure 3 - Angular variation of (a) link quality and (b) propagation parameters (Perimeter scale: BS position x 10 degrees) - BS 30 - MS Omni

Figure 4 shows the same results obtained when the position of the antennas was interchanged, i.e. 30° antenna was placed at the MS rotating in steps of 10°, while the omni was placed at the BS. Here it can be seen that the link sensitivity is clearly reduced, and the link characteristics improved, when the 30° antenna is employed at the MS. It should be noted that no data was recorded for positions 200° to 310° in figure 3(b) and positions 220° to 340° in figure 4(b), since no signal could be received by the ATM measurement equipment. From these results it can be said that generally the sensitivity of the system performance to the correct antenna alignment is directly related to the directionality of the antennas used at both BS and MS ends. However when the less directional antenna of the pair is used at the BS the system seems to become less sensitive to small non-alignment of the antennas.



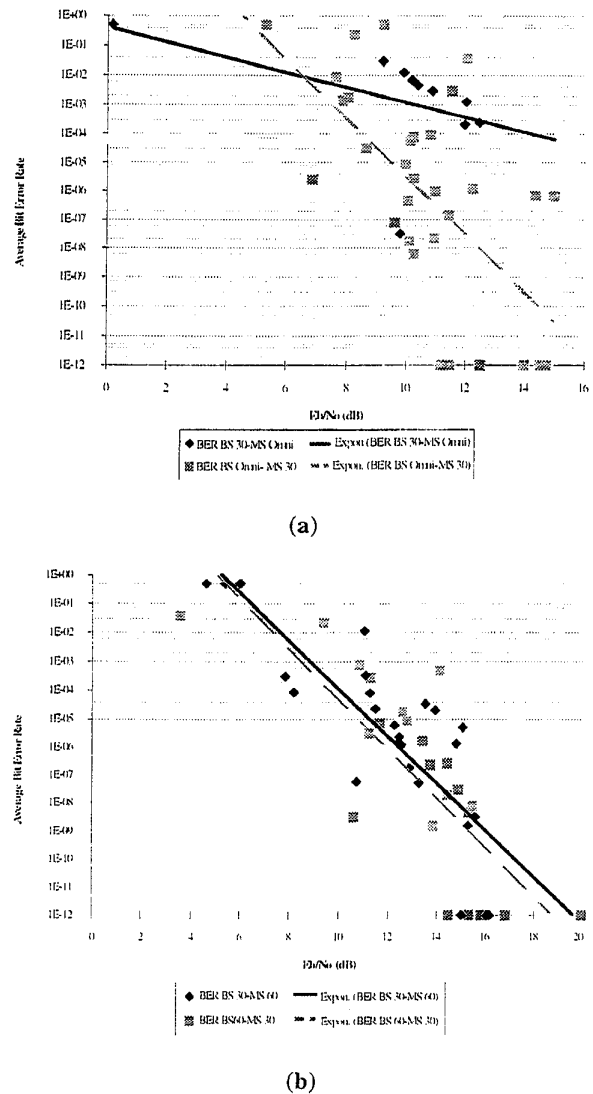
**Figure 4** - Angular variation of (a) link quality and (b) propagation parameters (Perimeter scale: BS position x 10 degrees) - BS Omni - MS 30°

#### 4.2. Distribution of antenna Gain

In order to determine the optimal deployment of the directional antenna elements, a selection of 3 different antenna types (30°, 60° and Omni directional) were used in the following experimental analysis. The test environment was the small office described in Section 3. Figure 5(a) shows the BER performance of the modem when one end of the link was using an Omni antenna while at the other end a

30° was employed. It can be seen that when the more directional antenna is used at the MS there is an improvement in the performance of the transceiver. However, the effect is less clear when both BS and MS are using directional antennas as shown in figure 5(b).

This has to do with the nature of the scatterers around the BS and MS. Generally the BS antenna would be ceiling mounted, as in this case, while the MS is at the desk height, and frequently there are more scatterers around the MS location. This in turn will result in the more effective use of the spatial filtering at the MS end of the system link, thus enabling the receiver to reject more of the multipath components.

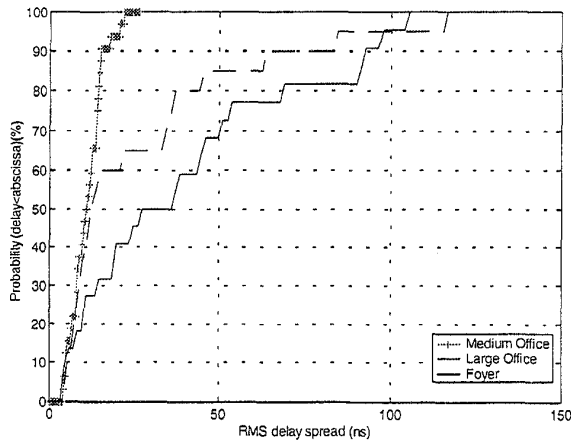


**Figure 5** - Comparison of the effective use of the more directional antenna element at either BS or MS (a) where one end of the link is using an omni antenna and (b) where both BS and MS are using directional antennas

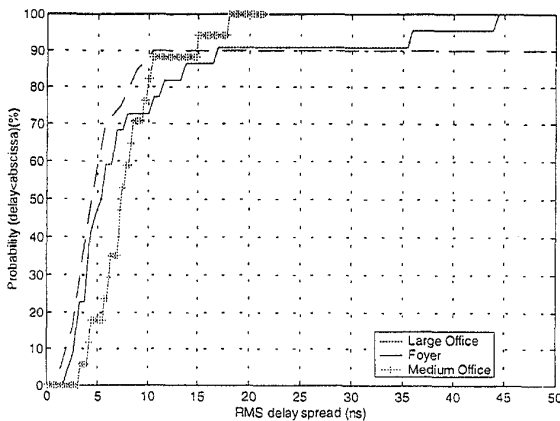
#### 4.3. Comparison of performance of the same antenna combination in various environments

Figure 6(a) shows the cumulative distributions of the rms delay spread measured for the BS Omni - MS 60° configuration for three different environments. The medium

size office scenario refers to the open plan office considered in section 3. The large open plan office is a room of 18.5x12m<sup>2</sup> dimension. The room is divided into work areas separated by partitions of height 1.6m. The foyer refers to a large entrance lobby of a modern building. Details of the plan of the above two indoor environments are given in [6]. As expected it can be seen that as the size of the test environment has increased higher values of rms delay spread is measured. However this distinction becomes much less obvious when both BS and MS employ 60° antenna as shown in figure 6(b). With 60°-60° configuration variation of the rms delay spread with respect to the size of the environment has considerably decreased making this configuration less sensitive to the type of the operational radio environment.



(a)

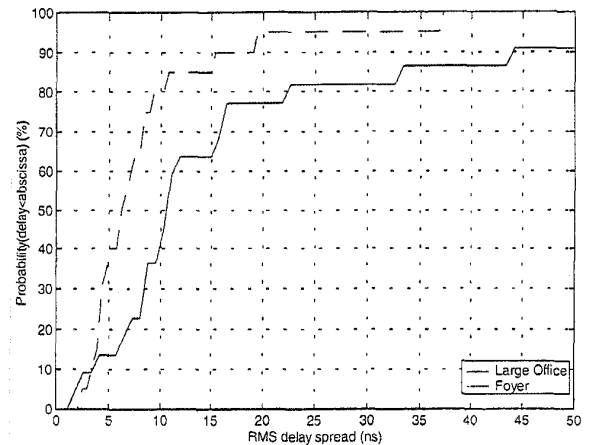


(b)

**Figure 6** - Cumulative Distribution Functions of (a) BS Omni-MS 60° and (b) BS 60°-MS 60° configurations for three indoor environments

When using mixed antenna combinations it is common practice to use the combined gain of the BS and MS antennas as a guide to the total directionality of the link. A comparison of the CDF graphs shown in figures 6 (b) and 7 clearly demonstrate that two different antenna configurations with similar combined gains, namely 60°- 60° and Omni - 15° both having a total gain of about 21dB, differ in their ability to reduce the measured delay spread. For example

while 90% of the delay values measured with the 60°- 60° configuration in the foyer were below 17ns, for the omni-15° arrangement this value has increased to around 43ns. This seems to confirm our assumption that it is the directionality of the link that determines which of the configurations is more effective in reducing the multipath experienced by the system.

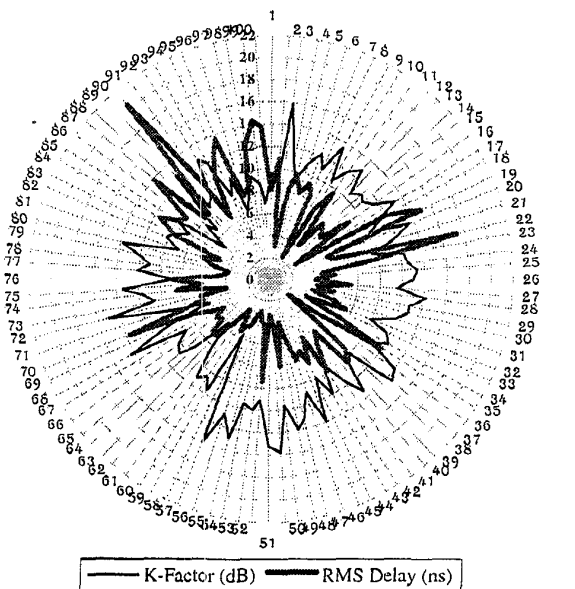


**Figure 7** - Cumulative Distribution Functions of BS omni-MS 15° configuration for two indoor environments

#### 4.4. Link availability

In order to ascertain link availability within a service area, a series of measurements using various BS - MS antenna combinations were performed with the BS placed at the height of 2.6m at one corner of the room (position A in Figure 2) with the MS moving to various points along the three paths identified by the dotted lines shown in the same figure. For each measurement point the radio propagation parameters (k-factor and rms delay spread) and quality of service parameters (BER and CLR) were measured simultaneously. A threshold of  $10^{-4}$  was set on the BER (after decoding and evaluated over the cell payload) as an acceptable QoS [7]. This was considered to be a reasonable threshold since the Forward Error Correction option (capable of correcting 3 bits on the header and 1 bit on the payload) was disabled. Assuming some ARQ strategy that allows up to five repetitions, a cell loss rate (CLR) in line with the requirement adopted in AWACS ( $CLR = 3 \cdot 10^{-7}$ ) can be achieved. The radio propagation parameters of *all* the measurement points were checked to identify the points satisfying the BER of  $10^{-4}$ . The k-factor and rms delay spread of the points meeting this criterion were extracted and are plotted in figure 8. The axis around the circle represents the number of measurement points meeting the set criterion while the vertical axis is the associated value of the k-factor (dB) and rms delay spread (ns). It can be seen that the variation in the k-factor is the lower of the two parameters presented here, thus making it the focus of our attention. The results support the conclusion made in [5] that in the presence of a dominant path (typically the LOS scenarios which are considered here), it is the Rician K-factor which determines the performance of the system more than the rms delay spread. Our analysis of the measured data shows that for 90% of the measurement points with BER less than  $10^{-4}$ , the K-factor was above 8 dB while the rms

delay spread was below 12ns. Similar comparisons were made for two other scenarios. The results are summarised in Table 1.



**Figure 8** - Propagation statistics of the locations meeting the BER & CLR criterion within the open plan office

The scenarios referred to in Table 1 refer to the following measurement conditions:

*Scenario 1:* The measurement points were 1.5m apart in the open plan office described in Section 3 with BS in A.

*Scenario 2:* The measurement points were 10cm apart in the above open plan office with BS in B.

*Scenario 3:* The measurement points were 50cm apart in the foyer area of a modern building [6].

For	Scenario 1	Scenario 2	Scenario 3
<b>BER &lt; 10<sup>-4</sup></b>			
<b>RMS DELAY (&lt;12ns)</b>	90%	79%	95%
<b>K-FACTOR (&gt;8 dB)</b>	91%	84%	100%

**Table 1** - The probability of link availability given values of the Max. RMS Delay and Min. K-factor

## 5. Conclusions

In this paper performance of a 34 Mbps single carrier unequalised modem operating at 19.37 GHz have been presented for a typical wireless LAN operating environments. It has been shown that for a given threshold on the performance requirement of a system it is possible to specify a bound on the channel parameters in order to ensure good performance. As an example for a BER limit of 10<sup>-4</sup>, it is shown that K-factors greater than 8dB and rms delay spreads of less than 12 ns would ensure that the errors would not pass the given threshold for more than 90% of the time.

When mixed antenna configurations are employed in the system, the directionality of the link is more important than

the combined gain of the antennas. This was shown with the experiments where a pair of 60°- 60° antennas were used and compared against an Omni-15° arrangement. Both have a combined gain of around 21 dBi but the performance measured with the 60°- 60° was much better than that of the omni-15°.

An important conclusion made from the measurements is that when employing a mixed antenna combinations, the best use of the more directional antenna is made when it is placed at the MS. This was shown in a series of comparisons made with a variety of antenna arrangements.

The correct alignment of the antennas is another important point which should be emphasised particularly when a more directional arrangement is used. The rotation measurements show that even when an omni directional antenna is used at one end of the link, a good performance is limited only to the points where the LOS was maintained. For other orientations no signal could be detected (by the ATM tester) or the number of errors measured was very high. A possible way of overcoming the negative effects of this sensitivity are the use of diversity techniques such as employing sectored antennas or site diversity. Another option would be to make use of tracking algorithms or intelligent beam steering of the antennas which can detect the strongest signal.

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