

## RECOMMENDATION ITU-R F.1102

**CHARACTERISTICS OF RADIO-RELAY SYSTEMS OPERATING  
IN FREQUENCY BANDS ABOVE ABOUT 17 GHz**

(Question ITU-R 107/9)

(1994)

The ITU Radiocommunication Assembly,

*considering*

- a) that frequency bands above about 17 GHz are allocated to the fixed and other services;
- b) that the propagation characteristics above about 17 GHz are predominantly governed by precipitation fading and absorption and only suited to short range radio system applications;
- c) that differing applications of various administrations may require different radio-frequency channel arrangements;
- d) that several services with various transmission signal characteristics and capacities may be in simultaneous use in the same frequency band;
- e) that the various applications may require differing channel bandwidths,

*recommends*

1. that system design should take into consideration the effects of precipitation outage which critically determines hop length;
2. that the frequency bands above about 17 GHz be used for short range applications which will allow equipment to be compact with smaller antennas;
3. that to allow the use of mixed services, whilst achieving spectral economy, the radio-frequency channel arrangements should be based on homogeneous patterns in accordance with Recommendation ITU-R F.746;
4. that both digital and wideband analogue modulation techniques are applicable;
5. that Annex 1 be referred to for guidance in system design.

## ANNEX 1

**Characteristics of radio-relay systems operating  
in frequency bands above about 17 GHz****1. Introduction**

In the frequency bands above about 17 GHz some allocations are provided for the fixed service on a worldwide basis. At these frequencies, outage is due primarily to precipitation fading lasting in excess of 10 s. Hence parameters of particular importance to the implementation of such systems are availability and transmitter-to-receiver path length (hop length) that may be achieved. These parameters are considered in this Annex for systems which are typically used in the local network.

## 2. Application considerations

### 2.1 Local access/networks

The frequency bands above about 17 GHz are being used mainly for short haul links. Compact and highly reliable radio equipment can support voice, data, video, and broadband data transmission.

The main applications are:

- interconnection of LANs,
- direct interconnection between LANs (IEEE 802.3/Ethernet and IEEE 802.5/Token Ring) with a transmission capacity of the order of 10 Mbit/s,
- subscriber links,
- digital primary group or higher speed data links from end office to user buildings,
- cellular phone applications,
- interconnection between cellular phone exchanges and base stations,
- relief applications,
- transportable radio equipment used for backup links when optical fibre systems or other terrestrial circuits have failed,
- ring closure or point-to-point connection in the SDH access network.

Table 1 categorizes the above applications.

TABLE 1

#### A categorization of applications

|  | Physical link configuration                                       | Transmission capacity  | Content of signal       | Hop length                   |
|--|---|--|-------------------------|------------------------------|
| LAN interconnection  | User to user building   | Order of 10 Mbit/s   | Data                    | Several tens of metres to km |
| Subscriber links   | From end office to user building                                  | Analogue or primary digital group (1.5 Mbit/s or 2 Mbit/s) $\times N$ – or higher PDH capacity | Data or video           | Several km to tens of km     |
| Inter-cell telephone applications                          | Between cellular system telephone exchange and radio base station | 1 to 10 Mbit/s   | Voice or data           | Several km to tens of km     |
| Transportable equipment for relief operations (see Note 1) | Backup for optical fibre links                                    | Analogue or primary digital group – or higher PDH capacity or SDH                              | Voice, data or video    | Several km to tens of km     |
| SDH access network   | ADMs ring closure/interconnection or tributary extension          | SDH hierarchy  | Virtual containers (Vc) | Several km to tens of km     |

ADM: Add/drop multiplexer

PDH: Plesiochronous digital hierarchy

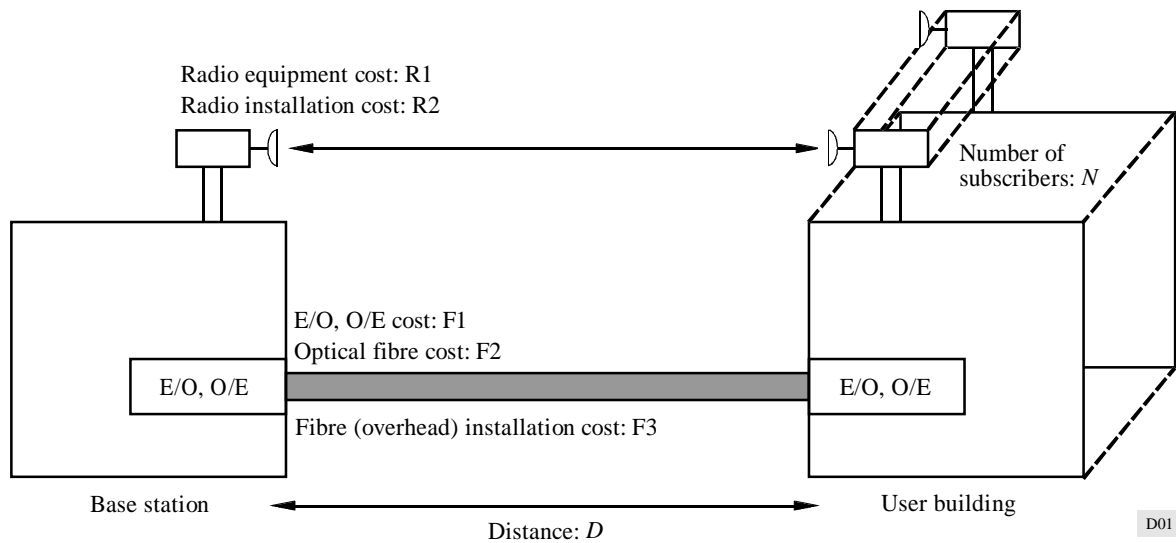
SDH: Synchronous digital hierarchy

Note 1 – See Recommendation ITU-R F.1105.

## 2.2 Cost comparison between fibre and radio links in the local loop

An optical fibre system requires construction work continuously along the cable route. On the other hand, radio systems require such work only at the transmitting and receiving stations. For this reason, the greater the distance between locations, the greater the cost for a fibre system will increase. Costs are compared in the following simple model shown in Fig. 1.

FIGURE 1  
Assumed model



Cost  $R$  for introducing a radio system is given by:

$$R = (R_1 + R_2) N$$

Cost  $F$  for introducing an optical fibre system is given by:

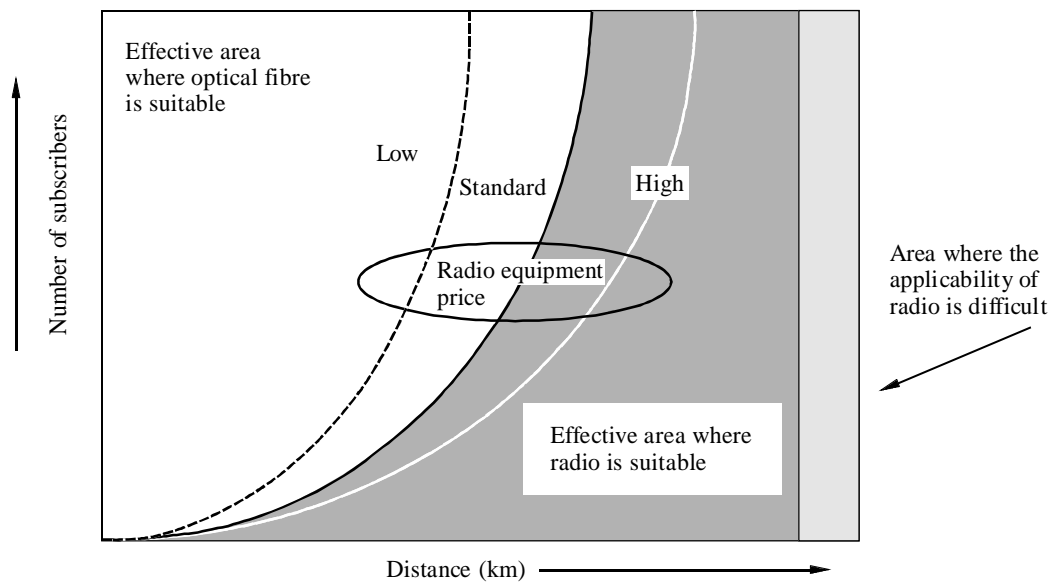
$$F = F_1 N + (F_2 + F_3) N D$$

Figure 2 shows the result of cost comparison. According to Fig. 2, with the same number of subscribers, any increase in distance decreases the cost of radio with respect to that for a fibre system. Further, with the same distance, radio systems are advantageous when the number of subscribers is small. Moreover, the applicable area for radio expands sharply when the distance becomes greater.

If only cost is taken into consideration, the greater the distance, the more the applicable area of radio will expand. However, it is necessary to take into account the fact that the propagation distance of radio systems using frequency bands above about 17 GHz is limited by rain attenuation. The provision of multiple-hop short-range links would therefore tip the balance towards the favour of fibre systems, but generally within the local loop multiple-hop systems are rare. In practice a mixture of fibre and radio would be used depending on which system is the most cost effective and practical for that particular part of the application.

FIGURE 2

## Results of cost comparison between fibre and radio



D02

### 2.3 Rapid deployment

One of the characteristics of radio systems is the speed at which they can be commissioned. Fibre systems require installation of fibres between the locations where communications are to be implemented, resulting in a long construction period until lines can be placed in service. In particular, the construction period increases sharply when optical fibre is laid underground when compared to pole-mounted installation. Further, there may be cases when fibre installation is impossible because of inability to obtain the right of way. The use of radio links to facilitate cable television system installation in such situations is a known implementation of this property. However, the lead-in time for radio systems is very short since it requires installation only at the locations where communications are to be implemented. This makes it possible to open circuits within a few hours. Although link planning, licensing and site clearance procedures increase the lead-in time in practice, the lead-in time is still likely to be significantly shorter than that for a fibre link.

In radio systems, it is necessary to confirm the line-of-sight condition. Studies concerning computer-based line of sight confirmation preparing databases of geographical features and buildings are being made, and a quick antenna alignment procedure may be helpful.

The relative ease of redeploying radio equipment is one of its attractive characteristics. Transportable radio systems are more suitable for rapid communications relief during times of disaster, link and fibre failures and the like.

### 3. Hop length considerations

No universal hop length/frequency characteristic can be constructed, however the following parameters contribute to the availability objectives on hop length:

- *Free space specific attenuation:*  $A_0$  (dB/km)
- Frequency dependent, from Recommendation ITU-R PN.525.
- *$O_2$  and  $H_2O$  specific gaseous absorption attenuation:*  $A_\alpha$  (dB/km)
- Frequency dependent in the relevant frequency ranges from Recommendation ITU-R PN.676.

- *Antenna isotropic gain:*  $G_i$  (dB)
  - Constant depending on geometrical size of antennas, with no theoretical upper bound, but practically limited, to allow feasible boresight alignment, by field operability of the 3 dB main beam angle width (normally not narrower than 1°).

This leads to a practical upper limit of  $G \cong 40$  dBi.
- *Transmit power:*  $P_T$  (dBm)
  - Related to the available technology for RF carrier generation/amplification and to the linearity requirement of the modulation format.
- *Bit error ratio (BER) threshold:*  $P_{Th}$  (dBm)
  - Relative to the relevant BER at which the availability objective is defined. This parameter is related to the receiver noise figure, the transmitted bit rate and the carrier-to-noise performance of the modulation format.
- *Rain attenuation for the objective time percentage:*  $R|_{\%}$  (dB)
  - Estimated on the basis of rain-rate intensity for the relevant unavailability time percentage through the method reported in Recommendations ITU-R PN.530 and ITU-R PN.838, using statistics obtained from Recommendation ITU-R PN.837.

The above parameters may be subdivided into two blocks (see Note 1):

- A fixed, implementation dependent, constant “hop gain” ( $HG$ ):

$$HG = 2G_i + |P_{Th}| + P_T \quad \text{dB} \quad (1)$$

- A rain-rate/frequency dependent “hop attenuation” ( $HA|_{\%}$ ) for a given time percentage over the length  $\ell$  (km) of the hop as foreseen by Recommendation ITU-R PN.530:

$$HA|_{\%} = R|_{\%} + (A_0 + A_{\alpha}) \ell \quad \text{dB} \quad (2)$$

Using the above approach, graphs like those reported in Figs. 3, 4 and 5 (computed as an example for the climatic zones B, G and K with frequency and percentage of unavailability ( $U\%$ ) as parameters) may be derived, from which the maximum hop length for the given implementation/frequency/climatic zone/objective time-percentage may be obtained.

*Note 1* – Since, in general, radio systems above 17 GHz are supplied with integral antennas, in these assumptions feeder losses are neglected; in the case of feeder connection between equipment and antenna, the feeder losses will decrease the hop gain ( $HG$ ).

#### 4. Digital radio implementations

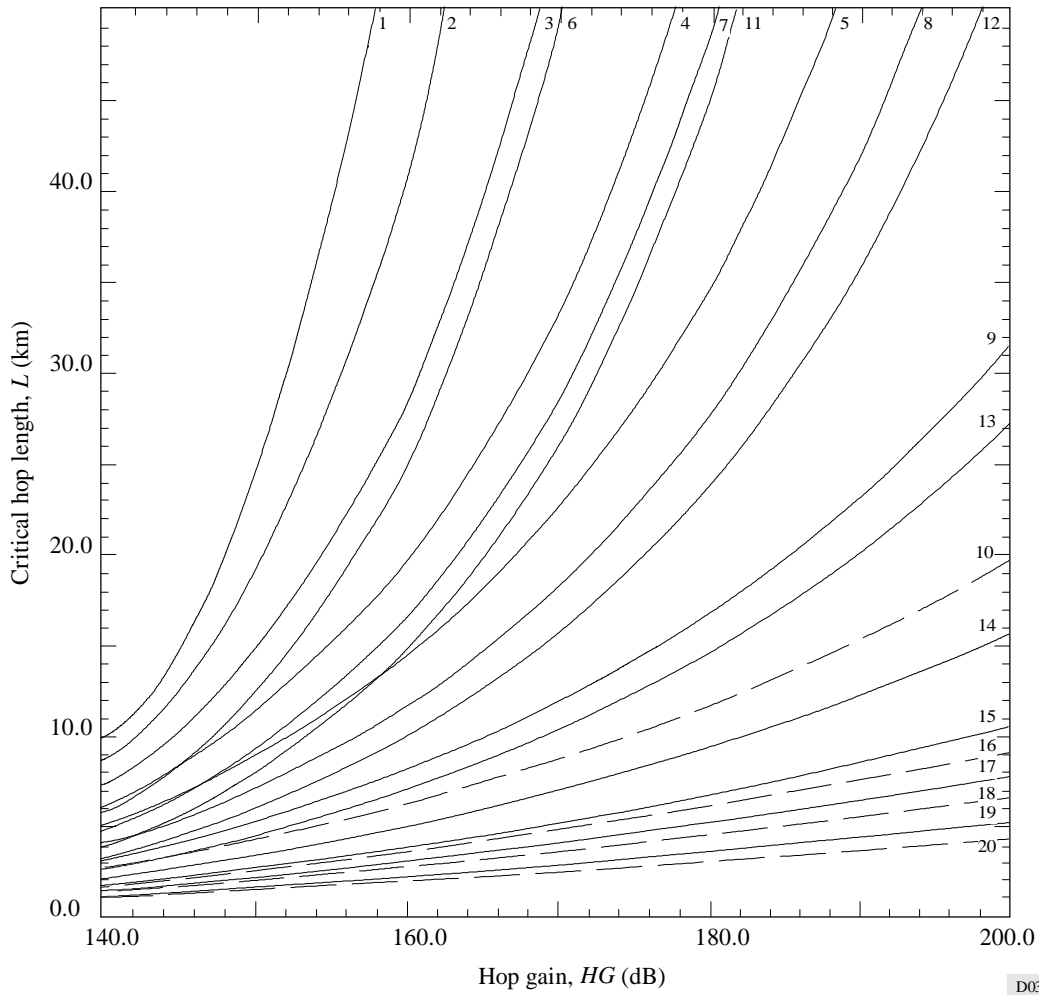
The application requirements, spectrum availability, propagation conditions and available technology above about 17 GHz result in equipment implementations that differ substantially from those that predominate below about 17 GHz. Nevertheless, there is no abrupt transition but a gradual one extending over the 13 GHz, 15 GHz, 18 GHz and 23 GHz frequency bands.

The predominant distinctive characteristics of digital radio applications above about 17 GHz are:

- a wide range of transmission capacities,
- lower spectral efficiencies,
- partitioning of equipment into an outdoor unit consisting of radio front-end attached to antenna, and an indoor unit containing the baseband sub-assemblies and in many cases the IF sub-assemblies as well. This virtually avoids waveguide feeder losses which could be prohibitive and provides great equipment mounting flexibility through low-loss interconnection at baseband and/or IF.

FIGURE 3  
 Critical hop length vs. hop gain for climatic zone B, horizontal polarization

Polarization angle: 0°



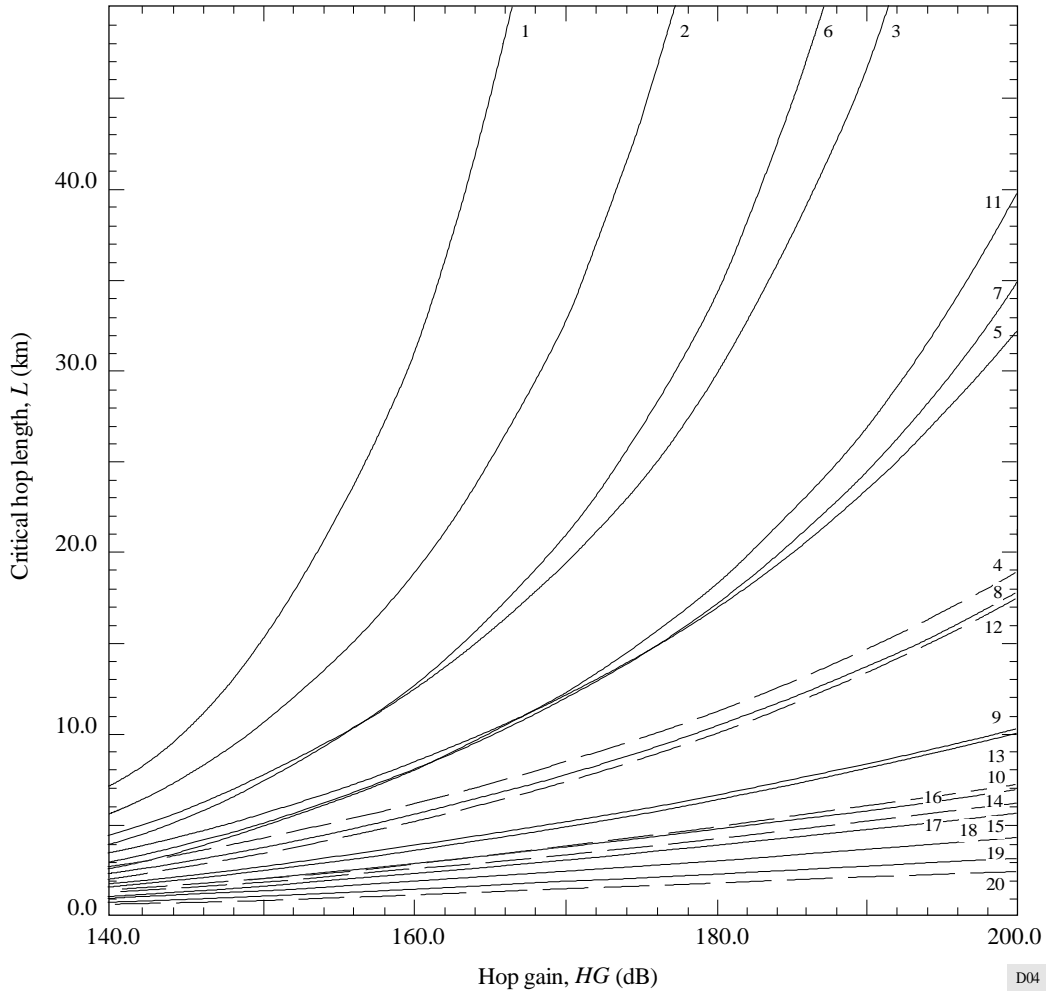
D03

| Curve | $f$ (GHz) | $U$ % |
|-------|-----------|-------|
| 1     | 18        | 0.1   |
| 2     | 18        | 0.03  |
| 3     | 18        | 0.01  |
| 4     | 18        | 0.003 |
| 5     | 18        | 0.001 |
| 6     | 28        | 0.1   |
| 7     | 28        | 0.03  |
| 8     | 28        | 0.01  |
| 9     | 28        | 0.003 |
| 10    | 28        | 0.001 |
| 11    | 38        | 0.1   |
| 12    | 38        | 0.03  |
| 13    | 38        | 0.01  |
| 14    | 38        | 0.003 |
| 15    | 38        | 0.001 |
| 16    | 55        | 0.1   |
| 17    | 55        | 0.03  |
| 18    | 55        | 0.01  |
| 19    | 55        | 0.003 |
| 20    | 55        | 0.001 |

$U$ : unavailability (%)

FIGURE 4  
 Critical hop length vs. hop gain for climatic zone G, horizontal polarization

Polarization angle: 0°



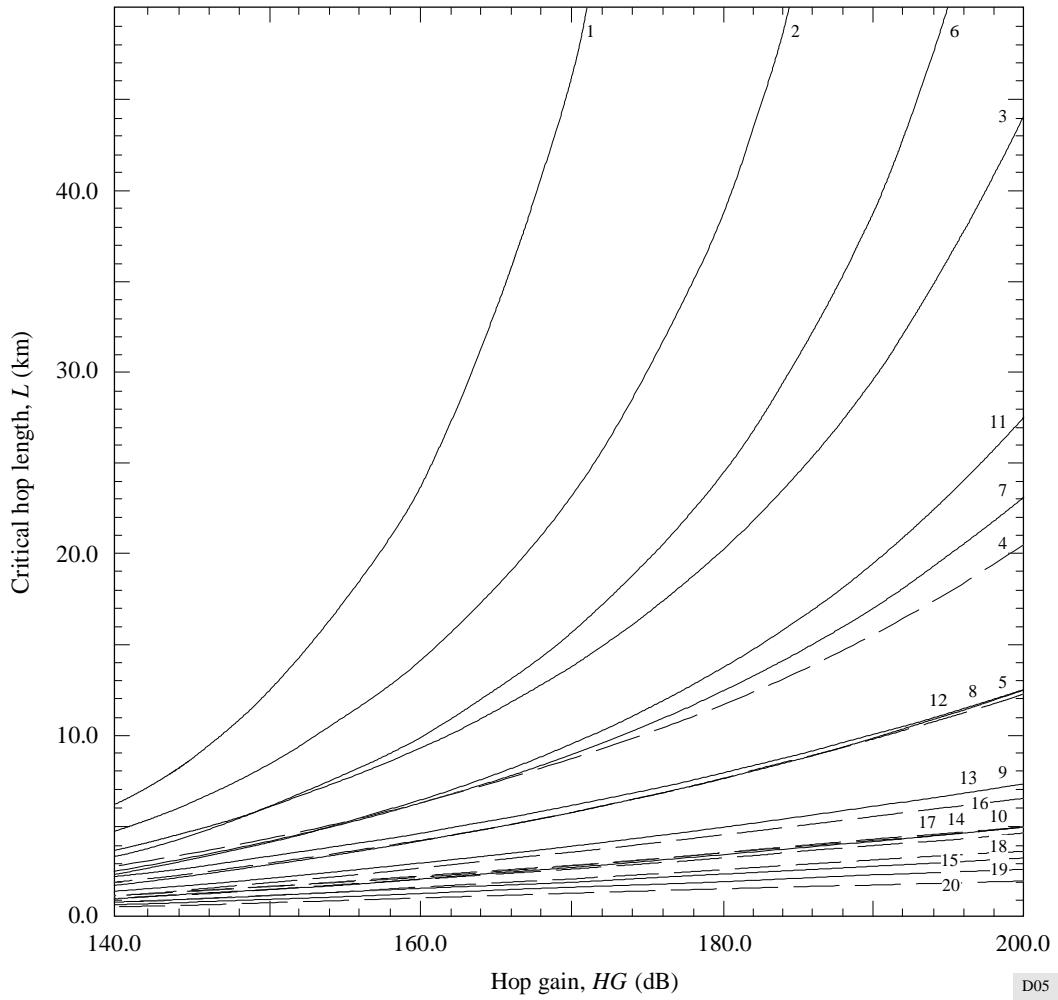
| Curve | $f$ (GHz) | $U$ % |
|-------|-----------|-------|
| 1     | 18        | 0.1   |
| 2     | 18        | 0.03  |
| 3     | 18        | 0.01  |
| 4     | 18        | 0.001 |
| 5     | 18        | 0.003 |
| 6     | 28        | 0.1   |
| 7     | 28        | 0.03  |
| 8     | 28        | 0.01  |
| 9     | 28        | 0.001 |
| 10    | 28        | 0.003 |
| 11    | 38        | 0.1   |
| 12    | 38        | 0.03  |
| 13    | 38        | 0.01  |
| 14    | 38        | 0.001 |
| 15    | 38        | 0.003 |
| 16    | 55        | 0.1   |
| 17    | 55        | 0.03  |
| 18    | 55        | 0.01  |
| 19    | 55        | 0.001 |
| 20    | 55        | 0.003 |

$U$ : unavailability (%)

D04

FIGURE 5  
 Critical hop length vs. hop gain for climatic zone K, horizontal polarization

Polarization angle: 0°



| Curve | $f$ (GHz) | $U\%$ |
|-------|-----------|-------|
| 1     | 18        | 0.1   |
| 2     | 18        | 0.03  |
| 3     | 18        | 0.01  |
| 4     | 18        | 0.001 |
| 5     | 18        | 0.003 |
| 6     | 28        | 0.1   |
| 7     | 28        | 0.03  |
| 8     | 28        | 0.01  |
| 9     | 28        | 0.001 |
| 10    | 28        | 0.003 |
| 11    | 38        | 0.1   |
| 12    | 38        | 0.03  |
| 13    | 38        | 0.01  |
| 14    | 38        | 0.001 |
| 15    | 38        | 0.003 |
| 16    | 55        | 0.1   |
| 17    | 55        | 0.03  |
| 18    | 55        | 0.01  |
| 19    | 55        | 0.001 |
| 20    | 55        | 0.003 |

$U$ : unavailability (%)



#### 4.1 *Design trade-offs*

Design trade-offs are rather complex due to the multiple interdependencies. However, to simplify the task, the trade-off criteria can be subdivided in various ways, depending on specific optimization goals.

For example, it is meaningful to distinguish between service quality and user friendliness criteria, as exemplified in Table 2.

TABLE 2

| Service quality  | User friendliness   |
|--|---|
| Transmission performance<br>System gain<br>Spectral efficiency<br>Power efficiency | Application versatility<br>Maintainability<br>Size and weight<br>Environmental robustness |

These trade-off criteria can be rearranged, as needed. For example, for a selected combination of transmission capacity and performance, the primary service quality trade-off is between system gain and spectral efficiency. If enhancement options are available, such as error correction, the trade-off criteria sub-set expands and increases design flexibility.

Some additional design trade-off criteria may belong to both categories. For example, MTBF affects both service quality and user friendliness.

In many instances the knowledgeable user will be able to recognize the basic design trade-offs from the equipment data sheet, but additional information may be needed in some cases to fully assess the equipment under consideration.

The equipment designer, on the other hand, has the demanding task of translating the transmission performance objectives into the corresponding set of equipment design objectives. This matter is addressed in ITU-T Recommendation M.2100.

#### 4.2 *Baseband signal processing*

Radio implementations for frequency bands above about 17 GHz commonly incorporate the necessary baseband signal processing functions in the indoor unit.

This includes group multiplexing at capacities above the PDH primary group or SDH functionalities. Order wire functions are most commonly included; the specific implementations vary considerably.

Error correction is used to improve the transmission performance and the system gain.

#### 4.3 *Carrier generation and stabilization*

In principle, direct, fundamental frequency generation is preferred for simplicity. However, the availability of active microwave devices for direct generation decreases with increasing frequency, and the cost increases. At some point, which depends on the status of technological development, it becomes preferable to generate a sub-harmonic and to multiply it to the carrier frequency.

The choice of carrier frequency stabilization method depends on the application. Lowest cost radio implementations with the most relaxed frequency tolerances can be satisfied with free-running, resonator stabilized oscillators. Adding temperature control assures tighter yet moderate frequency tolerances for somewhat more demanding applications. The most demanding application category in terms of frequency stability requires crystal controlled oscillators. For both radio manufacturers and users the preferred implementation is with a frequency synthesizer.

#### 4.4 *Carrier modulation formats*

Two factors combine to relax the spectral efficiency requirements above 17 GHz and thereby permit the use of more simple digital modulation formats than below 17 GHz:

- larger frequency band allocations,
- greater emphasis on low-cost radio implementations.

The use of simpler modulation formats, (2- or 4-state) assures higher system gains, which is of great importance in view of the predominance of precipitation fading in the frequency range above 17 GHz. However, the use of any higher state modulation format is practicable, where necessary, for technical and/or regulatory reasons.

An overview of the digital modulation formats is presented in Annex 1 of Recommendation ITU-R F.1101.

#### 4.5 *Basic radio transmit/receive functions*

The implementation of the transmit and receive functions results from the design trade-offs which are based on the considerations presented under § 4.1. The encountered differences in hardware implementations for the same application reflect the manufacturers' different market orientations, product assortments, in-house technological capabilities, component suppliers and, last but not least, subjective design preferences.

The basic radio design differences for the same application are in the choice between direct and indirect transmitter carrier modulation, and in the number of receiver IF conversions. In principle, the simpler the modulation format, the easier it is to implement direct carrier modulation. The number of receiver IF conversions is primarily derived from selectivity requirements, integrated circuit component availability and the required RF channel agility (e.g. with a synthesizer).

Most digital radio applications above 17 GHz are in local distribution systems and require few repeaters, if any. Back-to-back connection of terminals is straightforward, but passive or active RF repeaters are available and represent a cost effective solution where no drop/insert capability is needed. Active RF repeaters may or may not use frequency conversion, as required.

#### 4.6 *Supervisory functions and protection arrangements*

Successive generations of digital radio implementations incorporate ever more sophisticated supervisory functions and network management capability, such as BER monitoring, local and remote loopback, and local display of remote monitoring. Portable, hand-held terminals exist as alternative dedicated implementations. PCs and laptop computers using proprietary software are in use for centralized network management.

Protection arrangements are provided as needed to give the desired reliability and/or availability. Examples of those possible arrangements are:

- route diversity,
- monitored hot standby,
- monitored hot standby with frequency, polarization or space diversity.

#### 4.7 *Conclusion*

The growing demand for digital radio systems above 17 GHz stimulates continuous development of new equipment generations that provide improved service quality and user friendliness at ever lower costs. In addition, cost effective implementations are becoming available for ever higher frequency bands.

This progress is made possible by continuous technological developments in active microwave devices, particularly FETs, MMICs, and integrated circuit implementations of the IF, baseband and auxiliary functions

---