International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R F.1332-1

(05/1999)

Radio-frequency signal transport through optical fibres

F Series

Fixed service

International Telecommunication Union

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Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
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RECOMMENDATION ITU-R F.1332-1*, **

RADIO-FREQUENCY SIGNAL TRANSPORT THROUGH OPTICAL FIBRES

(1997-1999)

Scope

This Recommendation deals with radio-frequency signal transport through optical fibres. The text is largely amplified incorporating concept of hybrid fibre-radio system (HFR). As information on HFR, system configuration, service application, intermediate frequency transmission technology are added. Furthermore, signal level compression technique is introduced in order to improve the dynamic range for the optical link.

The ITU Radiocommunication Assembly,

considering

a) that optical fibres are widely used in subscriber networks or in-building wiring;

b) that radio-frequency signal transport through optical fibres may be applied to access links to radio base stations in many wireless applications;

c) that by using a HFR (see Annex 1, § 2 for acronyms) system the following advantages are expected:

– intensive deployment of modulators and demodulators and other functional equipment in an optical line termination in front of an optical feeder system contributes to simplification of equipment in remote antenna units as well as to maintenance and operation cost reduction;

– efficient use of spectral bandwidth available on the radio link;

d) that the reduction of equipment at the radio base station is realized by the above technique;

e) that the above technique has advantages in maintenance and operation aspects,

recommends

1 that Fig. 1 should be referred to for the basic configuration of a HFR system in which radio-frequency signals are transported directly through optical fibres;

2 that Table 1 should be referred to for possible applications to the fixed service using a HFR system;

3 that when using high-frequency bands above about 10 GHz, the centre frequency of a modulator may be selected to be in intermediate-frequency bands;

4 that Fig. 2 should be referred to for the reference configuration of a HFR system between service nodes and customer premises networks. This is in agreement with the reference configuration for optical access networks in ITU-T Recommendation G.983. To support system interoperability the HFR access link is defined between the reference points V and T or between service node interface and user network interface, and comprises the following functional blocks:

– optical line termination, optical distribution network and remote antenna unit (Part 1) in the optical distribution segment; and

– remote antenna unit (Part 2), drop medium radio and network termination antenna unit in the drop segment.

To enable transverse system compatibility (mid-span meet) additional reference points (interfaces) within the HFR access link are recommended:

– optical reference points: O_1 between optical line termination and optical distribution network, O_r between optical distribution network and remote antenna unit (according to ITU-T Recommendation G.982);

– radio reference points: R_1 between remote antenna unit and drop medium radio, R_2 between drop medium radio and network termination antenna unit;

5 that for the design of HFR systems the technical information contained in the Annex 1 should be referred to for additional guidance in the application of this Recommendation.

* This Recommendation should be brought to the attention of Telecommunication Standardization Study Group 15.

** Radiocommunication Study Group 5 made editorial amendments to this Recommendation in December 2009 in accordance with Resolution ITU-R 1.

FIGURE 1

Basic configuration of HFR system

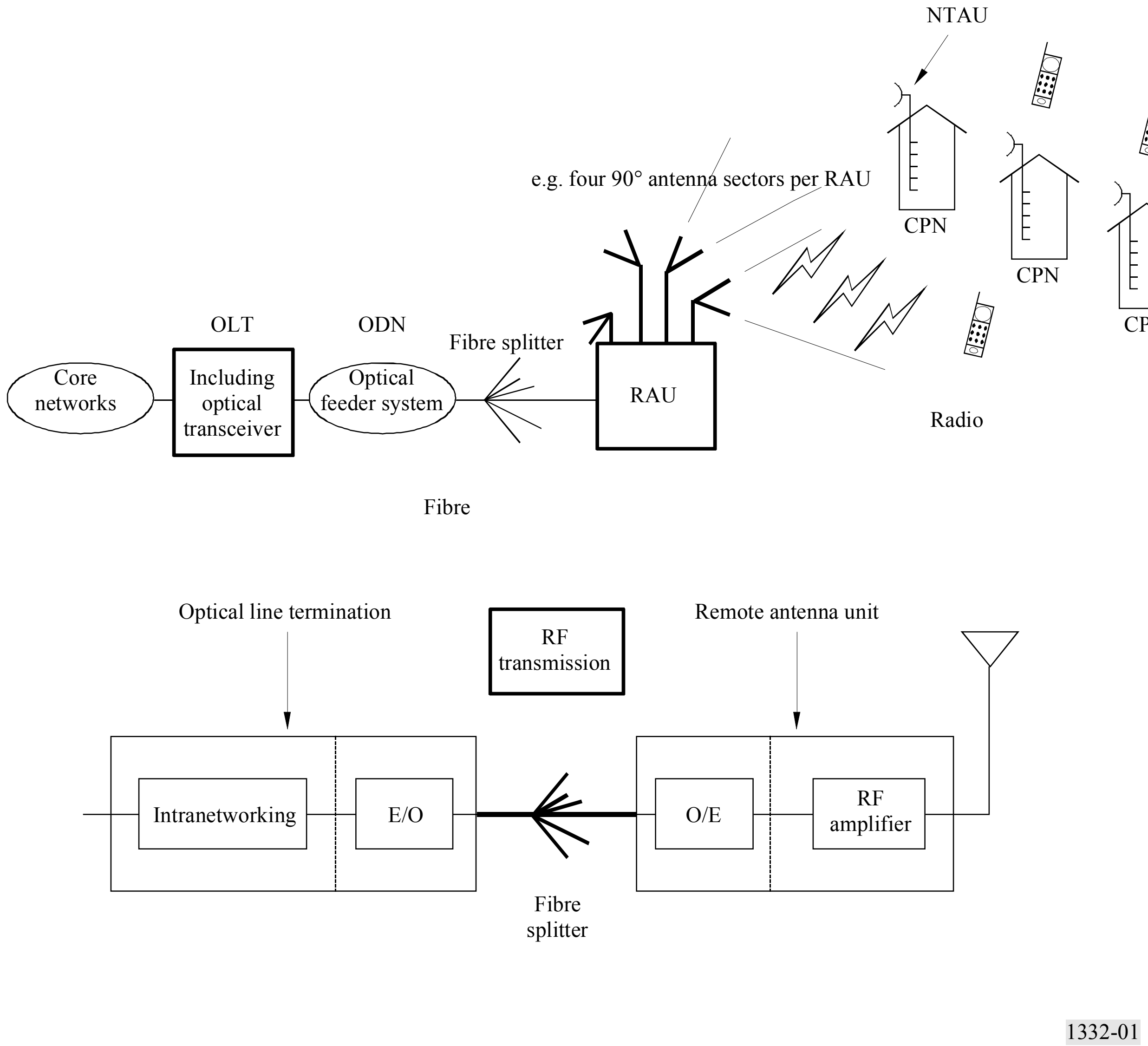


TABLE 1

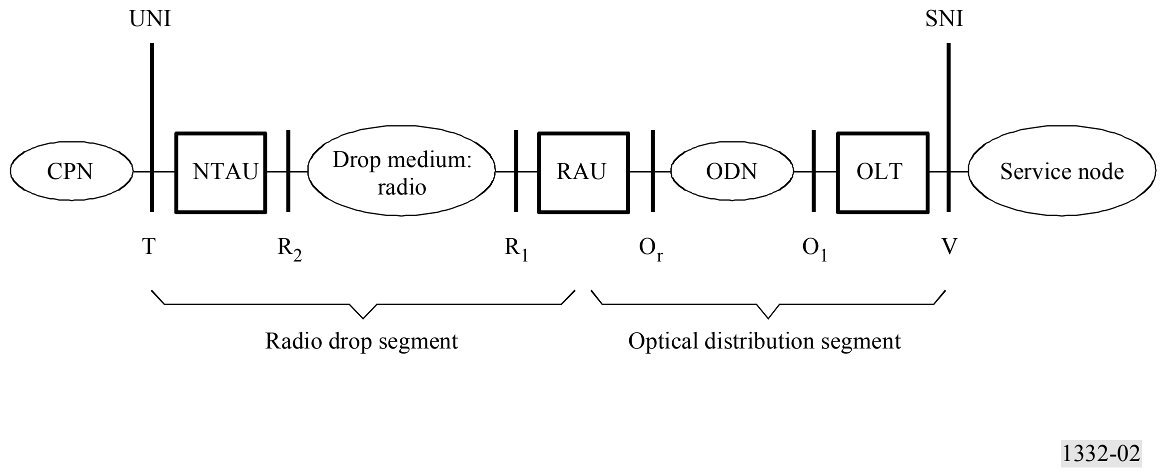
Possible applications for the fixed service using HFR systems

Service area	Indoor	Outdoor	
Application	RLAN	FWA	Transportable service
User's terminal	LAN module	Cellular system terminal for fixed use, point-to-point/ point-to-multipoint fixed terminal	Transportable video/ data/voice terminal
Possible RF(1)	UHF/SHF/EHF	UHF/SHF/EHF	SHF/EHF
Access scheme in the radio link	TDMA/CDMA/FDMA	TDMA/CDMA/FDMA	TDMA/CDMA/FDMA

(1) UHF (decimetric waves): 300-3 000 MHz
SHF (centimetric waves): 3-30 GHz
EHF (millimetric waves): above 30 GHz

FIGURE 2

Reference configuration of HFR access link



ANNEX 1

1 Introduction

For future broadband (interactive) services optical fibres will be extensively introduced in subscriber networks realizing the concept of what is called FTTC, FTTO or FTTH. On the other hand, customers may wish to use various services provided by different core networks also in wireless applications due to increasing demand and competition, lack of available bandwidth or fast and cost effective deployment. These applications include FWA, transportable data/video voice terminals or transportable personal computers used for RLAN modules. In order to satisfy these demands, it will be effective to introduce HFR systems in which radio-frequency signals are transmitted directly through optical fibres.

This Annex discusses the basic concept and technical basis of HFR systems.

2 Acronyms

AGC	Automatic gain control
CDMA	Code division multiple access
C/N	Carrier-to-noise-ratio
CPN	Customer premises network
E/O	Electric-to-optic conversion
FDMA	Frequency division multiple access
FM	Frequency modulation
FTTC	Fibre to the curb
FTTH	Fibre to the home
FTTO	Fibre to the office

FWA	Fixed wireless access
HFR	Hybrid fibre radio
IF	Intermediate-frequency
IM	Inter-modulation
LAN	Local area network
LD	Laser diode
NTAU	Network termination antenna unit
ODN	Optical distribution network
O/E	Optic-to-electric conversion
OLT	Optical line termination
RAU	Remote antenna unit
RF	Radio-frequency
RLAN	Radio local area network
SCM	Subcarrier multiplex
SEFA	Signal extraction and frequency arrangement
SLC	Signal level compression
SNI	Service node interface
TDD	Time division duplex
TDMA	Time division multiple access
UNI	User network interface

3 Basic configuration of HFR systems

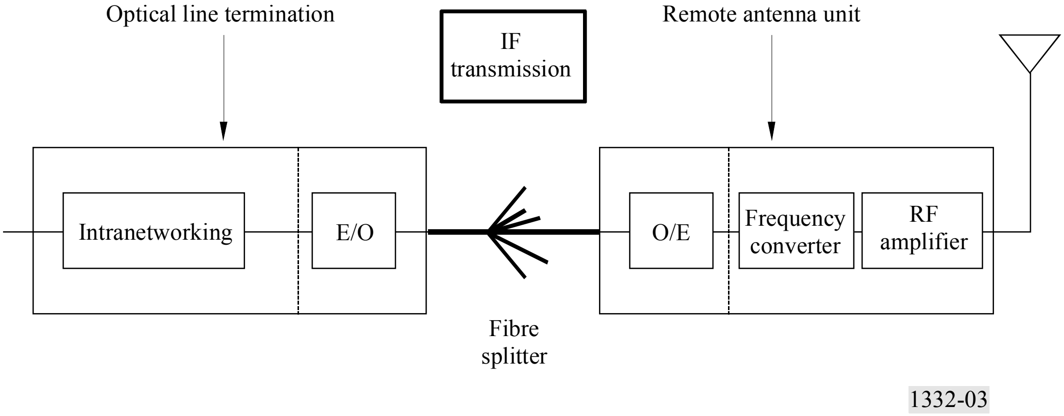
As shown in Figs. 1 and 2 a HFR system is composed of OLT, ODN, RAU, NTAU and fibre/radio links connecting these stations. It can form an infrastructure for access networks providing wireless services to customer premises network which may include many different terminals.

In conventional digital radio equipment, a modulator/demodulator and a power amplifier are generally installed at the same station. However, in HFR systems OLT and RAU comprise many intranetworking functions which are commonly used for more than one RAU (see Fig. 1) depending on the splitting factor of the ODN. Examples for these intranetworking functions are: modulation/demodulation, multiplexing/demultiplexing, control functions and error correction functions the latter of which are mainly necessary because of the worse transmission performance (compared to optical fibre transmission) of the radio link. The system presented in Fig. 1 requires a multiple access technique to cope with upstream traffic demands from many customer terminals. OLT also has a function to control the access technique efficiently utilizing the frequency spectrum. In such cases, the relation between OLT and RAU corresponds to that of point-to-multipoint radio systems for subscriber networks. If radio-frequency signals are already optically transported over the ODN all these functions are located at OLT and the RAUs connected to one OLT are kept small and simple (see lower part of Fig. 1).

However, there is a technical upper limit for the radio frequency to be transmitted through optical fibres due to the operating speed of the E/O (and O/E). When a cost-effective E/O (and O/E) is required to implement HFR systems, an IF transmission could be suitable since the cost effective E/O (and O/E) operates within the IF bands. After being transmitted over the optical fibre link, the IF carriers are converted into radio frequencies at the remote antenna unit (see Fig. 3).

FIGURE 3

IF transmission in HFR system



Another reason to use IF is that filtering of single radio transmission channels (several 10 MHz bandwidth) is much more easier and less expensive in the IF range allowing for channel selection at single RAUs. In this case only relevant data will be sent out of a specific RAU even if the optical feeder includes a passive optical distribution network. Otherwise the limited bandwidth of the shared transmission medium "air" would be wasted. If filtering of IF/RF channels is not possible, single RAUs also could be addressed by optical routing functions in the optical feeder system together with optical filter functions inside the RAU or by a point-to-point fibre feeder to further keep the RAU less complex. Optical routing or point-to-point fibre connection also may be necessary due to high traffic rates as one RAU has to serve more than 10 000 subscribers with an increasing number of BB-services in the far future.

4 Application of HFR systems

Figure 4 illustrates two specific applications of HFR systems. In Fig. 4a) a RAU works as a central module for a RLAN operating at each office room, while the OLT controls the assignment of radio channels used by all the RAUs. As illustrated in this Figure, HFR systems have the following merits:

– Since a modulator/demodulator is separated from a power amplifier in this system, equipment in a RAU becomes smaller. Thus, efforts for site selection of RAUs can be reduced.

– OLT equipments including network interfaces and service units which provide voice service, digital packet service and so on are concentrated in one room. For that reason, maintenance work and replacement of any equipment is efficiently done in a short time.

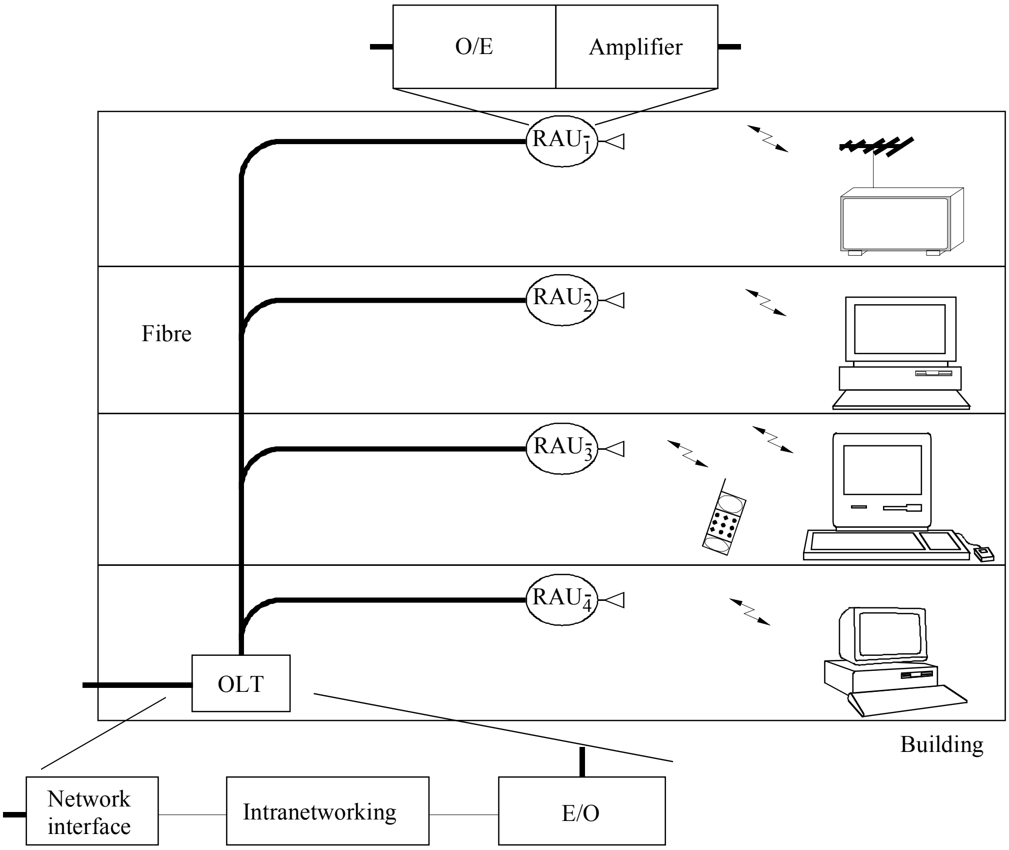
Figure 4b) gives an example of outdoor applications. A RAU provides wireless access link to individual homes within a service coverage. The function of the OLT is almost the same as for indoor systems and the above merits can also be expected in this application. In conventional systems, since radio equipment is usually installed on a high pole, some danger is unavoidable in maintenance works. However, in HFR systems, such works can be much reduced.

This outdoor application is considered to be a last-100 m (or in some cases last-10 m) wireless extension of FTTH. If millimetre-wave bands above 30 GHz can be exploited for this usage, the HFR system will be able to have a capacity as high as 150 to 600 Mbit/s per carrier. Each zone radius of a RAU is assumed to be the order of 300 m to enhance the frequency utilization efficiency as well as to reduce the transmitter power.

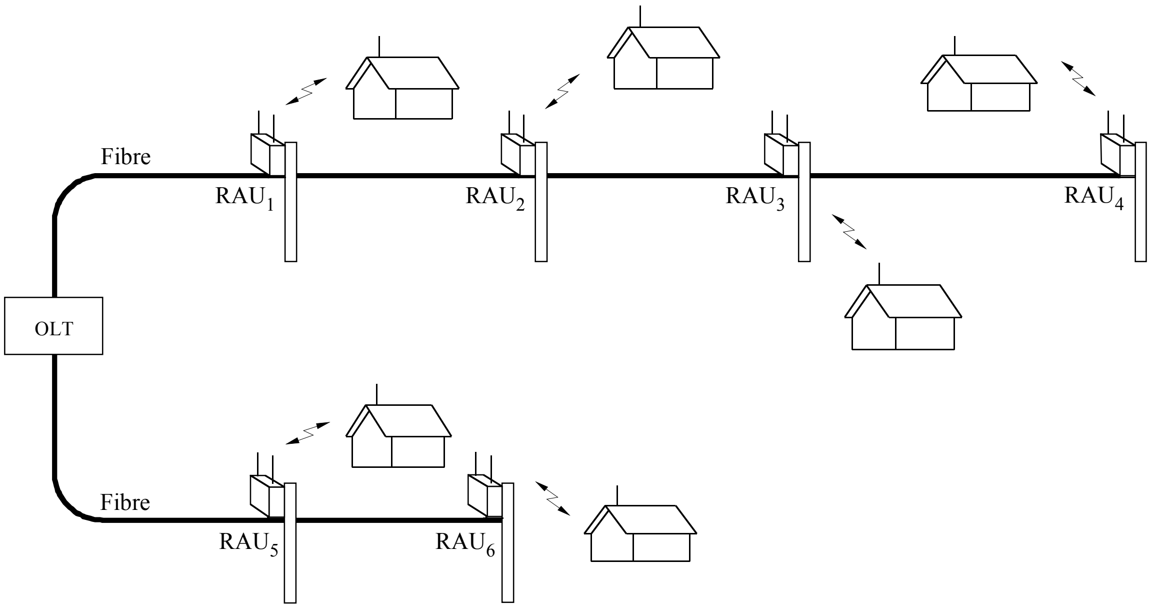
When utilizing millimetre-wave, attenuation due to rainfall has to be taken into account. AGC at the base station (RAU) works as an effective countermeasure in particular for the up-link direction (NTAU to RAU), since noise in the optical fibre section can be well suppressed by the input RF signal with constant level.

FIGURE 4

Examples of applications using HFR systems



a) Indoor application



b) Outdoor application

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5 Implementation examples

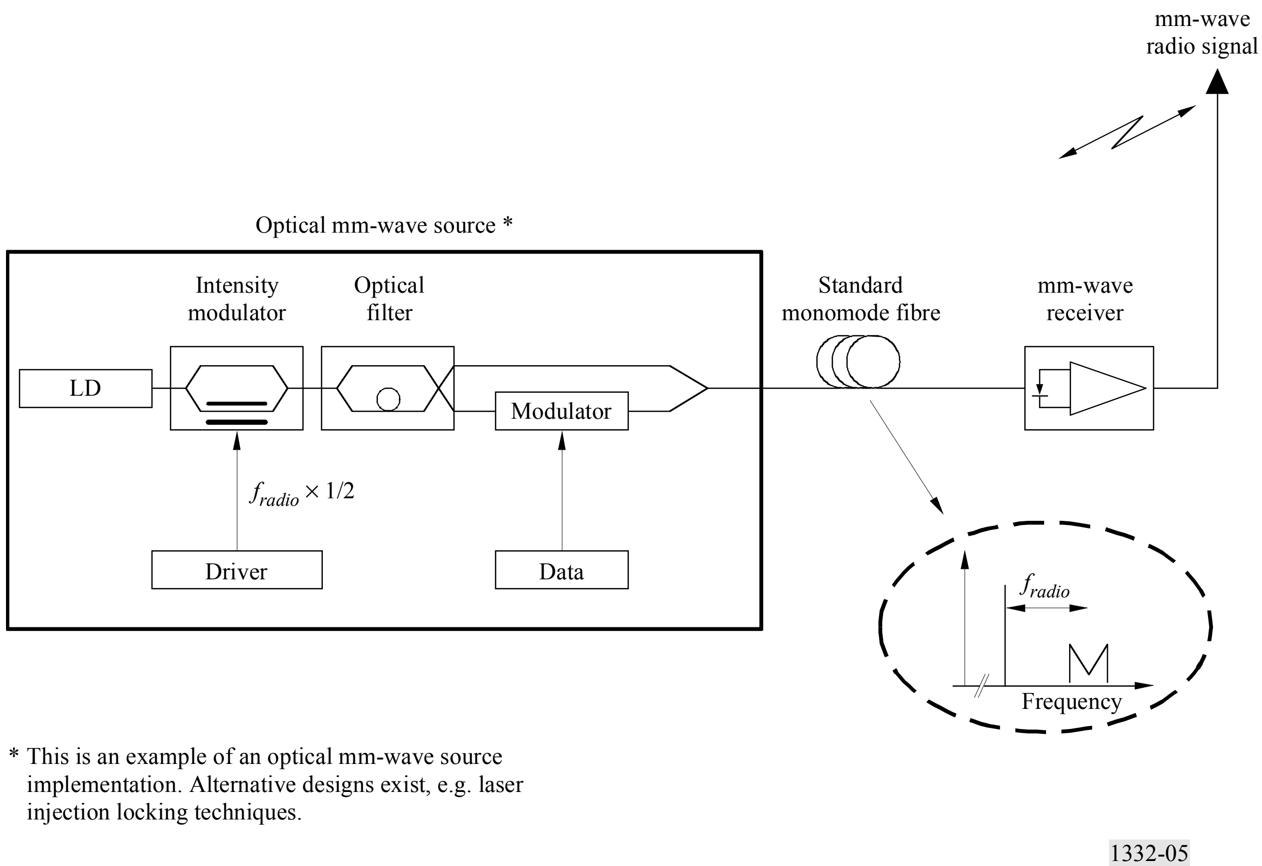
HFR systems generally use an SCM technique. At the E/O side, several outputs from the modulators with different frequencies are multiplexed in the combiner. Then the combined signal composed of the several subcarriers directly modulates the LD. Thus, the subcarriers can simultaneously transmit through the optical fibre. The LD produce a modulated optical signal whose intensity is proportional to the input electrical current. The maximum frequency is limited by the LD characteristics.

In the opposite direction, a photodiode in the O/E converts the received optical power into electrical power with a linear response. Each desired radio channel is separated after the photodetection.

Direct modulation of the laser diode with the combined radio-frequency signal allows only for limited fibre feeder lengths due to optical loss and chromatic dispersion. The former factor can be sufficiently compensated by using an optical amplifier. The problem caused by the latter factor can be eliminated by means of the heterodyne principle where 2 optical carriers separated by the radio frequency are transported via fibre (see Fig. 5). In this case one optical carrier is used as local oscillator for heterodyning in the RAU and the other carrier bears the information stream. By means of this method up to 100 km feeder lengths can be achieved, depending on data rates and transmission performance. Also, the radio-frequency is not limited by the LD modulation bandwidth in this case. However, the usefulness of this heterodyne millimeter-wave source technique depends on the optical filter characteristics.

FIGURE 5

Heterodyne mm-wave source (double frequency source, double sideband modulation)



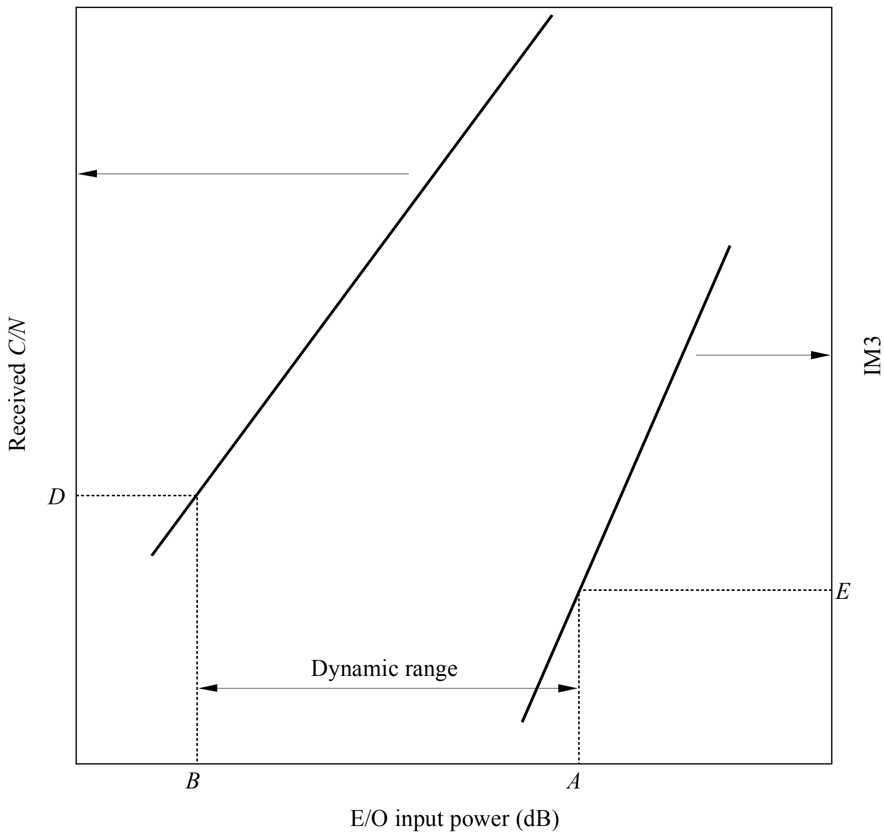
For outdoor microcell applications, the received signal power is subject to a slow or shadow fading and decreases according to the well-known inverse fourth-power law between a RAU and a wireless terminal. When a mobile terminal loses line-of-sight condition, the received signal drops sharply due to the diffraction loss.

Since two or more signals with quite different levels are commonly received at the RAU receiver, it is difficult to select a suitable gain for all the signals. Therefore, for the uplink (from RAU to OLT) a HFR system needs a wide dynamic range. This is called a near/far problem. The dynamic range is limited by the noise and non-linear performance of the whole link. It is important to improve the non-linearity of the optic devices as well as radio equipment.

The non-linearity of the E/O mainly determines the upper limit of E/O input level. In Fig. 6 the input level of *A* produces the maximum permissible IM3 level of *E*. On the other hand, the lowest limit of E/O input level is decided by the required *C/N D* corresponding to the level of *B*. In this case, the dynamic range of the E/O converter is defined by ($A - B$) dB.

FIGURE 6

Dynamic range of fibre optic link



D: required *C/N* (threshold level)
E: maximum permissible IM3 level

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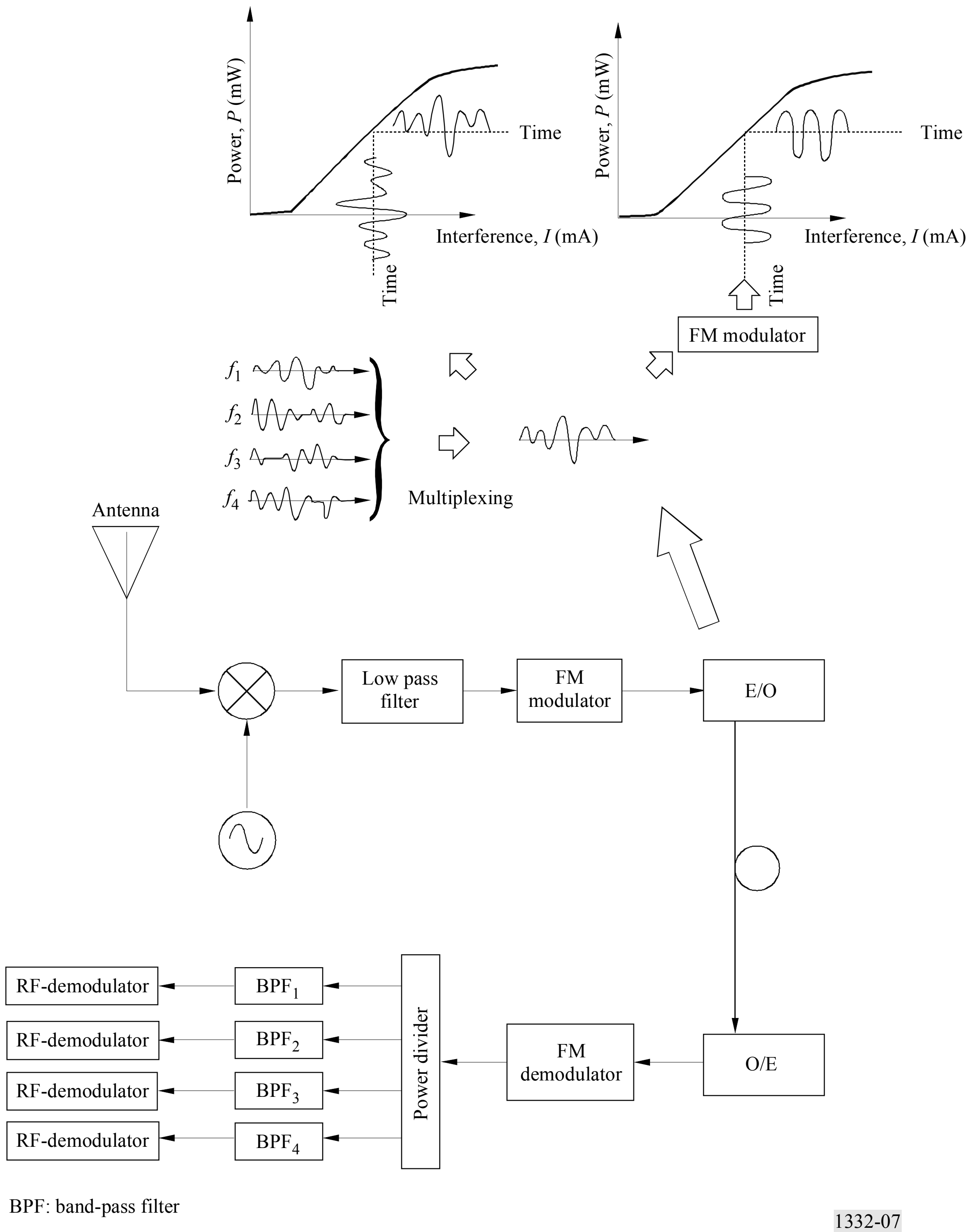
An improvement technique using an FM modulator has been proposed for increasing a dynamic range. Figure 7 illustrates overview of this method. When using the conventional method, the low-level carrier is likely to be affected by IM3 interference due to the non-linearity. On the other hand, the input signal level to the E/O converter is kept constant by using an FM modulator. Although the bandwidth of the FM signal varies depending on the highest frequency and peak voltage of the modulation signal, the peak injection current of the LD is almost fixed.

FIGURE 7

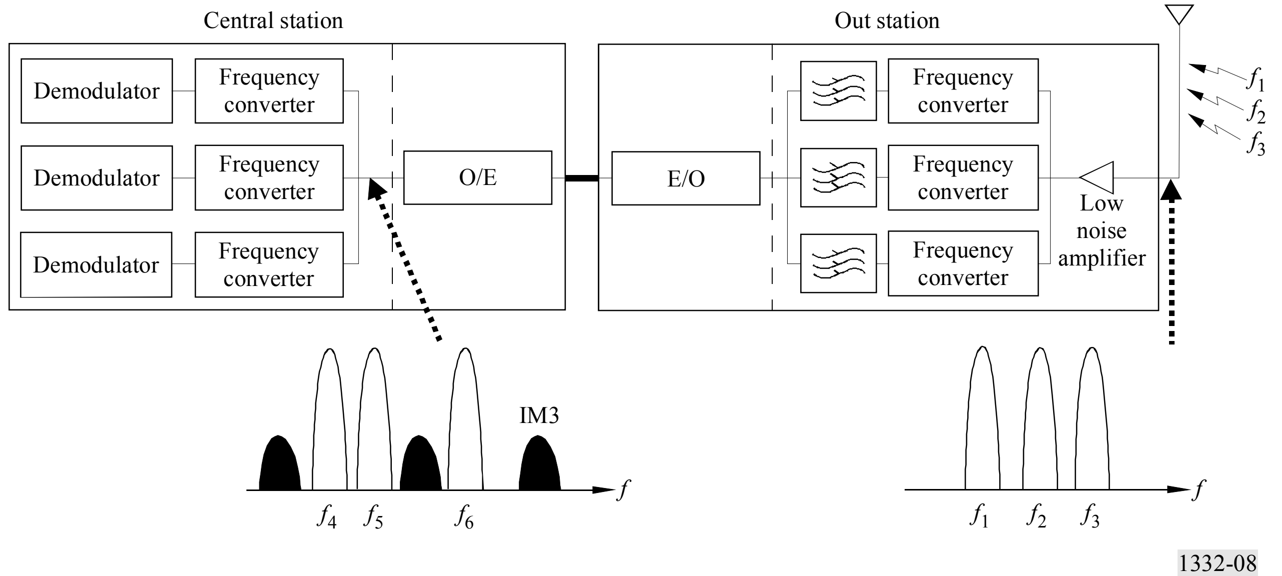
Overview of FM technique for the uplink



SEFA on fibre has also been proposed as a way of increasing the dynamic range as shown in Fig. 8. In this technique, undesired signals from other cells are removed before optical modulation. By extracting the desired signals whose frequencies are f_1, f_2 and f_3 in RAU, and then converting their frequencies to f_4, f_5 and f_6, respectively, the two-tone type signal of IM3, $2f_2 - f_1$, may not interfere with the signal of f_3. The frequency converted signals modulate the LD. Of course, each extracted signal power can be adjusted by an AGC or a limiter. Since LD non-linearity can be ignored, SEFA can increase the optical modulation index leading to the *C/N* improvement.

FIGURE 8

Principle of SEFA technique

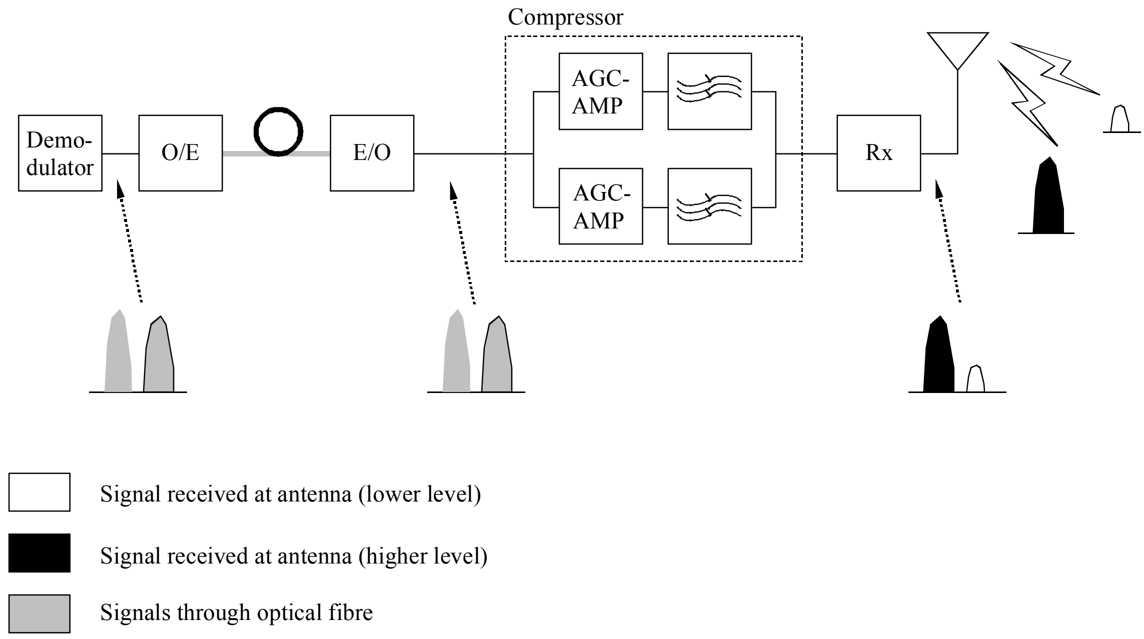


Permissible optical loss should be determined including the loss of the optical connectors so that the total *C/N* performance could meet according to various radio modulation schemes. Fibre delay between a OLT and RAUs is one of the key parameters, in particular for TDMA-TDD systems. A radio signal is delayed by fibre transmission approximately by 5 µs/km for a single-mode fibre compatible with ITU-T Recommendations G.652, G.653 or G.655. This delay over the two-way link may exceed the guard time between the transmitting and receiving timing.

As shown in Fig. 9, the SLC technique has been proposed to improve the dynamic range for the optical link. In this technique, the compressor, which is composed of AGC-amplifiers (AGC-AMPs) or limiters and band-pass filters, is placed in front of the E/O. The higher gain value of the compressor could be adjusted if a signal of lower level is received at the antenna. A received *C/N* at the O/E strongly depends on the E/O input level which is equivalent to the compressor gain. The high compressor gain mitigates the optical link noise factor caused by influence of an optical loss and a noise factor in the optical receiver. Therefore, use of the SLC technique improves the received *C/N* at the O/E for the low level signals received at the antennas. It also decreases the minimum input E/O level for the required *C/N* and improves the dynamic range. In addition, the dynamic range of SLC combined with the SEFA is expected to be improved because the maximum permissible IM3 level caused by intermodulation is neglected, as discussed above.

FIGURE 9

SLC technique for uplink



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