Development Reports

# FOMA Boosters for Indoor Areas

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*Adopting boosters is a cost-effective means of constructing a mobile communication service area since both the equipment itself and the maintenance are low in cost.*
*In general, however, when boosters are used, the uplink capacity of the base station may be degraded due to booster output noise. We developed FOMA booster systems for indoor areas that suppress such capacity degradation.*

## 1. Introduction

As of August 2005, the number of FOMA users had increased to 15,870,000 and the demand is increasing for services provided in indoor environments such as inside buildings and underground shopping malls.

In indoor environments, radio waves are received at a lower power level than that in outdoor environments. Also, the propagation loss increases due to shadowing loss caused by adjacent buildings, underground penetration loss, etc. Moreover, there is severe interference from some Base Stations (BSs) in offices and stores in high buildings. In order to provide service to indoor areas in a cost-effective manner, it is important to consider radio propagation, traffic, the installation and maintenance costs pertaining to the facilities before implementing the appropriate radio equipment for a given location.

In many cases, an effective solution for covering small-scale indoor areas is to use boosters, which receive radio signals from BSs and Mobile Stations (MSs) and reemit them, since they are compact and economical.

This article presents an overview of the FOMA boosters for indoor areas developed against this background.

## 2. Scope of Boosters

**Figure 1** shows an usage overview of boosters. A booster is constructed from an antenna directed at a BS, another antenna directed at MSs, and the booster itself. Downlink radio signals are received at the antenna directed at the BS and uplink radio signals are received at the antenna directed at MSs within the booster area. Both signals are directly amplified and then

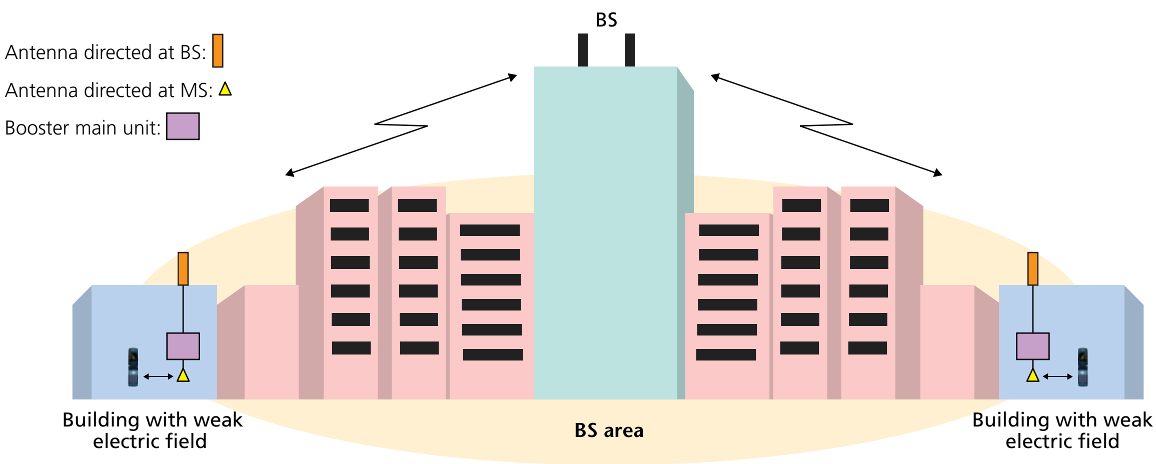


Figure 1  Booster usage concept

reemitted by the booster main unit, thereby increasing the received power at the MSs and the BS.

When constructing an indoor service area, various factors such as the radius of the coverage area, traffic, and cost must be taken into consideration. **Figure 2** shows the general relationship between FOMA indoor areas and the general types of indoor radio equipment that should be chosen for the construction of an indoor service area. Boosters are particularly well suited for the construction of service areas in small-scale stores and narrow spaces where the traffic is light. On the other hand, in large-scale stores and underground shopping malls where the traffic is heavy, it is more efficient to install a local BS connected to RF Multi-drop Optical Feeder (MOF) equipment, which yields a low transmission loss, because a large number of antennas directed at MSs is required, and the distance is long between the radio equipment (BS) and the antennas.

## 3. Booster Design Requirements

The uplink radio specifications of the booster should satisfy the 3rd Generation Partnership Project (3GPP) standard TS25.101 [1], which is a specification for MSs. The downlink radio specifications of the booster should satisfy 3GPP TS25.104 [2], which is a specification of BSs. Other characteristics of the boosters such as the out-of-band gain should satisfy the 3GPP standard TS25.106 [3]. In the development process, it is further necessary to consider the influence of noise emitted by the boosters (hereinafter referred to as booster transmission noise) on the uplink capacity of the BS (hereinafter referred to as the capacity) and the coupling loss between the transmission and reception antennas belonging to the same booster. The requirements for these design considerations are described hereafter.

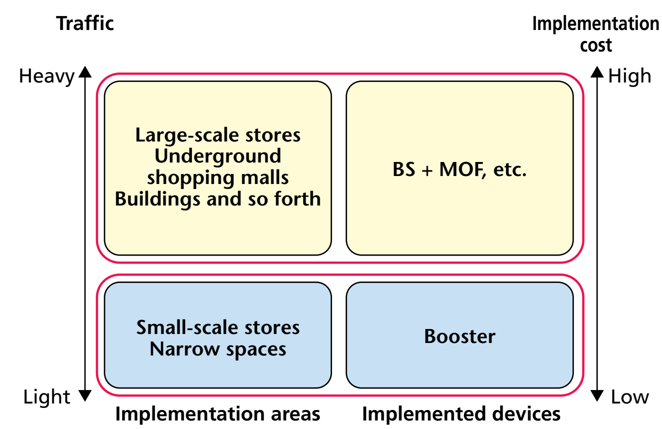


Figure 2  Relationship between FOMA coverage in indoor areas and indoor radio equipment

### 3.1 Booster Transmission Noise and BS Uplink Capacity

While boosters are advantageous in terms of equipment and installation costs, one problem that must be taken into consideration is that booster transmission noise degrades the capacity of the system. In a situation where n boosters are located within a cell covered by a certain BS, the noise from the boosters added to the receiver noise of the BS, $N_{BTS}$, causes an increase in the total noise power [4] [5]. The capacity of the BS can be expressed by equation (1).

$$C'/C=1-\frac{\sum_{k=1}^{n} N_{TBk}}{(\eta-1)\,N_{BTS}} \tag{1}$$

Where C is the capacity of the cell without boosters installed, C' is the capacity with boosters installed, $\eta$ is the interference margin permitted by the BS (hereinafter referred to as the load margin) and $N_{TBk}$ is the noise power generated by the k-th booster received at the BS.

Assuming that the overall capacity is set to one, the booster transmission noise increases and the capacity is degraded as the number of installed boosters increases. **Figure 3** shows the relationship between the propagation loss between the BS and the boosters (hereinafter referred to as the propagation loss), and the capacity degradation, and that between propagation loss and the radius of the booster area. Here, it is assumed that the booster gain is 45 dB or 60 dB, the number of boosters per cell is 10 and the load margin, $\eta$, is 2 dB or 6 dB. The larger the booster gain and the smaller the propagation loss, the larger the radius becomes. However, the capacity degradation also becomes larger because the booster transmission noise received at the BS increases. With boosters with the gain of 45 dB, the capacity degradation is negligible. With boosters with the gain of 60 dB, on the other hand, it is possible to suppress the booster transmission noise received at the BS to a desired level by decreasing the booster gain according to the amount of decrease in the propagation loss within the gain control area.

### 3.2 Coupling Loss Between Antennas

When boosters are used, a phenomenon called a coupling loop occurs in which radio signals sent from a transmission antenna are received by a reception antenna connected to the same booster (**Figure 4**). The coupling loss decreases when the distance between the two antennas of a booster is short and when reflecting objects are located near the antenna. In order for the booster to operate correctly, the conditions expressed by inequality (2) must be satisfied.

$$L_c > -G_{TB} + M \text{ [dB]} \quad (2)$$

Where $L_c$ is the coupling loss between the transmission and reception antennas, $G_{TB}$ is the gain of the booster, and M is the fluctuation margin. If $L_c < G_{TB}$, the booster transmission wave is received by the reception side again and the booster acts as a positive feedback loop. The transmission wave begins to oscillate violently with increasing amplitude and is rendered useless. Since the coupling loss fluctuates depending on the propagation conditions, the fluctuation margin, M, is included in (2) to ensure a certain level of robustness in the operation conditions.

## 4. Overview of Developed Boosters

When conventional boosters are installed, the area design is discussed before installation of the booster to ensure that a sufficient level of downlink power is received, and the gain is adjusted manually to obtain the optimal output power. However, the propagation loss changes constantly. Furthermore, the propagation loss changes due to factors such as the changes in the tilt angle of the BS antennas, the radio propagation changes caused by the construction of new buildings, shadowing caused by construction cranes, the construction of new BSs, and other changes in the surrounding environment.

To accommodate these changes, the conventional boosters require gain readjustment. To avoid this, we developed an auto-

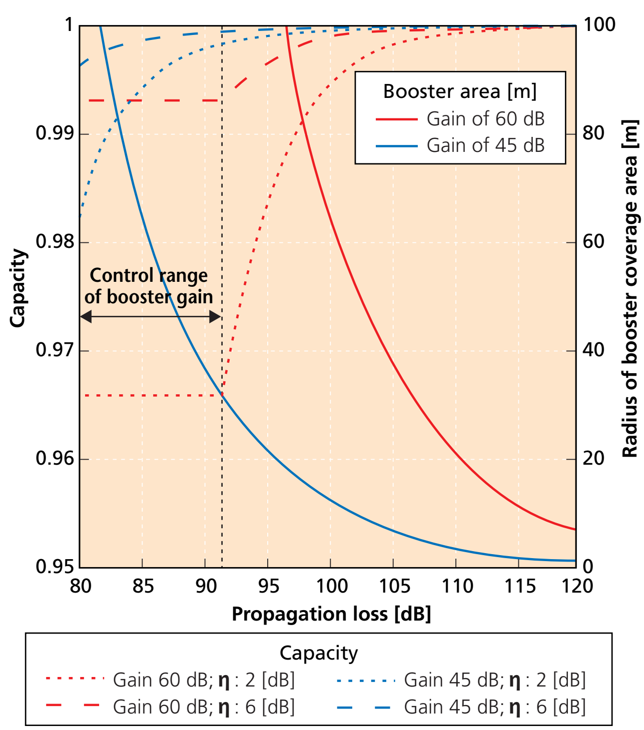


**Figure 3 Relationship between propagation loss between BS and booster and capacity/area**

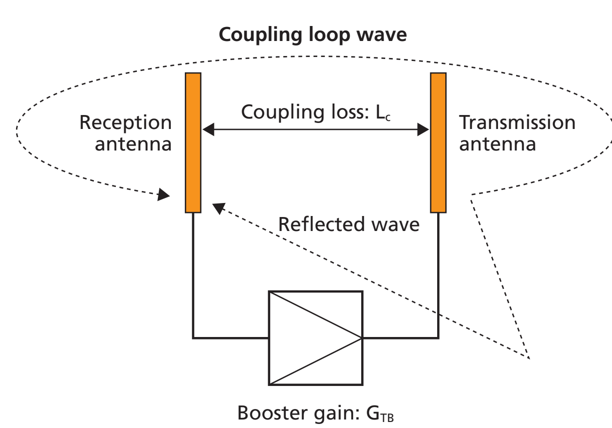


**Figure 4 Coupling loop effect in booster reception antenna**

matic gain controlled booster, which applies a method to adjust the gain continuously according to the changes in the propagation loss and to suppress the capacity degradation [6] [7].

As the usage of FOMA continues to become more and more common, the number of cases is increasing where the communication quality deteriorates due to the influence of spurious waves from illegally installed boosters in small-scale stores and so forth.

We also developed a cost effective fixed gain booster that allows the construction of small-scale areas while reducing the capacity degradation at the same time [8].

An overview of these two boosters is presented below.

### 4.1 Automatic Gain Controlled Booster

1) Booster overview

**Photo 1** shows the external view of the automatic gain controlled booster and **Table 1** gives the basic specifications. The booster gain can vary from 40 to 60 dB, which is handled automatically by the gain control function. The output power is approximately 20 dBm for the uplink and approximately 10 dBm for the downlink. The booster can cover an area with a radius of up to 100 m.

A configuration of the developed booster is shown in **Figure 5**. The booster consists of: a receiver that measures the propagation loss; a controller that controls the gain of the variable gain control amplifiers according to the measured propagation loss; a duplexer that combines the uplink transmitted signal and downlink received signal and connects them to the antenna directed at the BS; another duplexer that combines the uplink received signal and downlink transmitted signal and connects them to the antenna directed at the MS; a power supply; a low noise amplifier; and a built-in antenna directed at the MSs. The antenna directed at the BS and the antenna directed at the MSs are connected to the main unit of the booster using a connector.

2) Automatic gain control method

The automatic gain controlled booster receiver performs a three-step cell search and identifies the scrambling code, in the same way as for MSs. The receiver then measures the power of the Primary-Common PIlot CHannel (P-CPICH) of the BS received at the booster.

The booster finds information related to the BS scrambling code and P-CPICH transmission power around the BS by

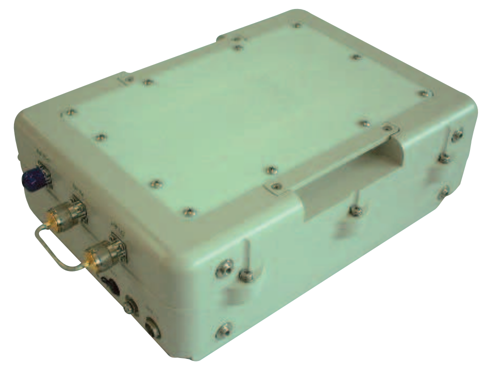

**Photo 1 External view of automatic gain controlled booster**

**Table 1 Basic specifications of automatic gain controlled booster**

| | |
|---|---|
| Output power | Uplink 20 dBm, Downlink 10 dBm |
| Gain | Equipped with automatic gain control function allowing variations from 40 to 60 dB |
| Area | Approximately 20 to 100 m radius |
| Power supply voltage | 100 VAC |
| Power consumption | 100 VA or less |
| Size | 250 × 350 × 120 mm |
| Weight | Approximately 10 kg |

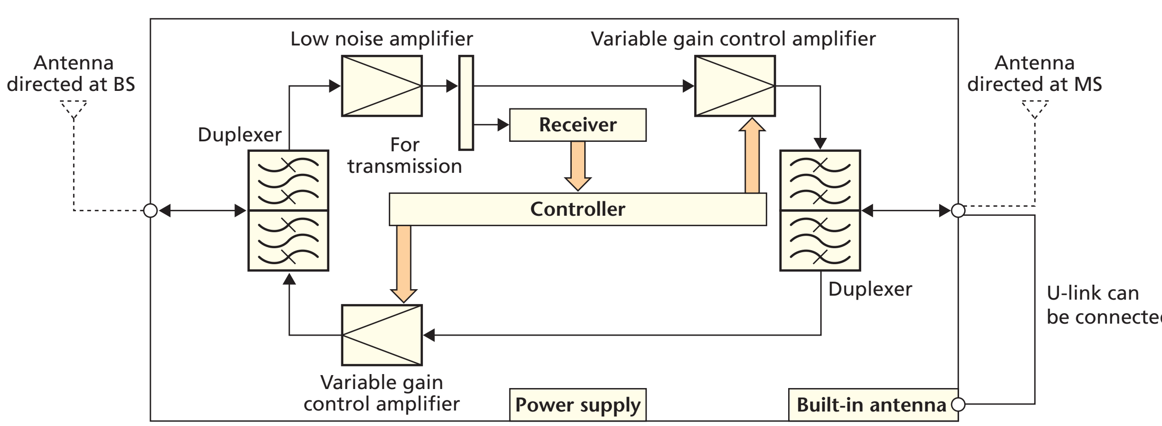


**Figure 5 Configuration of automatic gain controlled booster**

receiving the Primary-Common Control Physical CHannel (P-CCPCH). The propagation loss, L, is estimated using equation (3).

$$L = P_{T\_P\text{-}CPICH} - P_{R\_P\text{-}CPICH}\ [dB] \quad (3)$$

Where $P_{T\_P\text{-}CPICH}$ is the transmission power of the P-CPICH at the BS and $P_{R\_P\text{-}CPICH}$ is the received power of the P-CPICH at the booster.

The booster determines the gain based on the propagation loss to suppress to the allowable noise power received at the BS. The optimal gain of the booster, $G_{TB}$, is expressed by equation (4).

$$G_{TB} = L + NF_{BTS} - NF_{TB} - \alpha\ [dB] \quad (4)$$

Where $NF_{BTS}$ is the noise figure of the BS, $NF_{TB}$ is the noise figure of the booster, and $\alpha$ is the system margin.

**Figure 6** shows the relationship between the propagation loss and booster gain. As long as the propagation loss is within the control range of the booster gain, the gain is automatically adjusted to the optimal value according to the propagation loss. With this control, the booster transmission noise power received at the BS can be constant as described in Section 3.1, and it becomes possible to suppress the capacity degradation to a fixed level. If the propagation loss becomes larger than the upper limit of the gain control range, the gain of the booster is set to the maximum value.

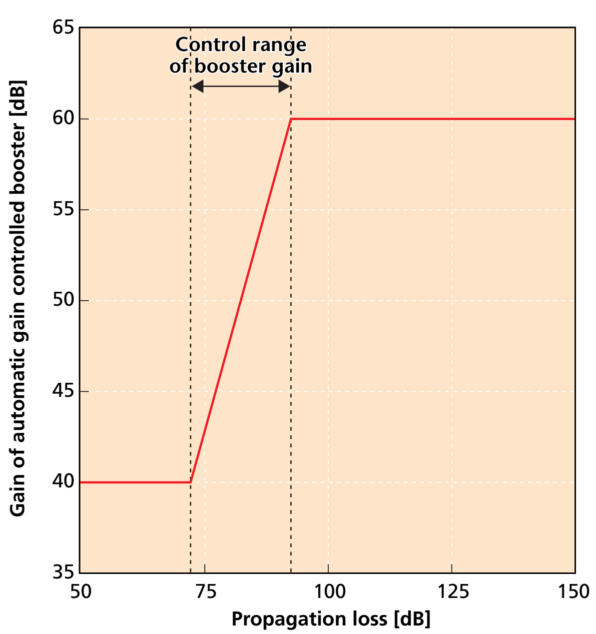


**Figure 6 Relationship between propagation loss between BS and booster and gain**

3) Receiver characteristics

**Figure 7** shows the measured receiver BLock Error Rate (BLER) characteristics of the automatic gain controlled booster. The receiver characteristics of the automatic gain controlled booster are identical to those of MSs. **Table 2** gives the conditions under which the receiver was tested. The required P-CCPCH_Ec/Ior ratio that yields a BLER of the Broadcast CHannel (BCH) of less than 1% is –18.5 dB or less under static conditions and –12.8 dB or less under dynamic conditions. These values satisfy the requirements in the 3GPP standard TS25.101 [1]. Here, the BLER is calculated as the number of erroneous blocks divided by the total number of blocks, and P-CCPCH_Ec/Ior is the ratio between the P-CCPCH energy per chip (Ec) and the total transmission power spectral density of the BS (Ior).

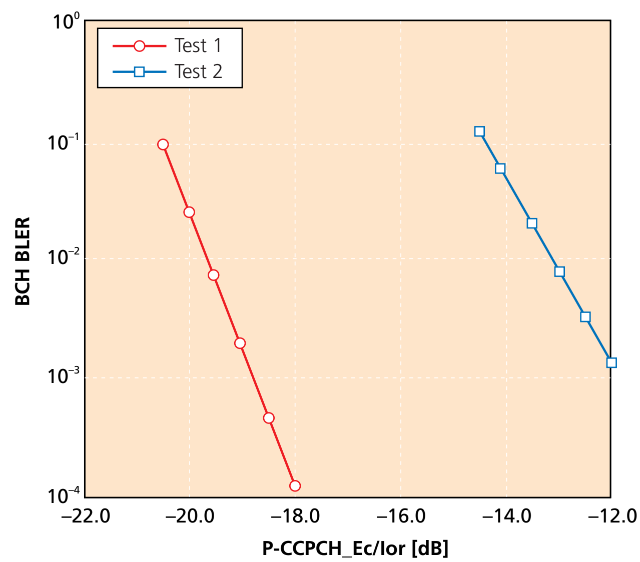


**Figure 7 BLER characteristics of BCH of booster receiver**

**Table 2 Receiver test conditions (3GPP TS25.101 8.11.1)**

| Item | Test 1 | Test 2 |
|---|---|---|
| Ioc | –60dBm/3.84MHz | |
| I^or/Ioc | –1dB | –3dB |
| Fading condition | Static characteristics | Dynamic characteristics, Case 3 |
| Required P-CCPCH_Ec/Ior | –18.5 dB or less | –12.8 dB or less |

Ior: The total transmit power spectral density of the downlink at BS
I^or: The received power spectral density of the downlink measured at booster antenna connector directed at BS
Ioc: The power spectral density of a band-limited white noise source measured at booster antenna connector directed at BS
Ec: Energy per chip

### 4.2 Fixed Gain Booster

**Photo 2** shows the external view of the fixed gain booster developed this time and **Table 3** gives the basic specifications. As described in Section 3.1, this booster operates with a constant gain of only 45 dB, so the capacity degradation can be ignored. For this reason, the area covered by the fixed gain booster is smaller than when using the automatic gain controlled booster. With a coverage radius of no more than 20 m, the fixed gain booster is primarily suited for small-scale stores and similar locations. The output power is approximately 17 dBm for the uplink and 5 dBm for the downlink.

**Figure 8** shows a configuration of this booster. It is only 1/6 the size of the automatic gain controlled booster, since the receiver, variable gain control amplifier and controller were removed. The weight of the unit is decreased to approximately 1/7 of the weight of the automatic gain controlled booster.

**Photo 2 External view of fixed gain booster**

**Table 3 Basic specifications of fixed gain booster**

| | |
|---|---|
| Output power | Uplink 17 dBm, Downlink 5 dBm |
| Gain | 45 dB fixed gain |
| Area | Approximately 20 m radius |
| Power supply voltage | 100 VAC |
| Power consumption | 20 VA or less |
| Size | 180 × 190 × 50 mm |
| Weight | Approximately 1.5 kg |

## 5. Conclusion

This article provided an overview of the characteristics and design policies involved in the development of FOMA boosters for indoor areas. These boosters keep the costs of installation and maintenance low, thus making it possible to increase the areas of mobile communication coverage in a cost-efficient manner, although transmission noise and coupling loss between transmission and reception antennas must be taken into consideration. By providing cost-effective boosters whose characteristics conform to the Radio Law, we expect that illegal boosters will not be used.

In the future, we intend to make these indoor boosters even more economical, compact and power-efficient. Moreover, we plan to develop high-gain boosters that can be used in outdoor environments as well [9] [10].


REFERENCES

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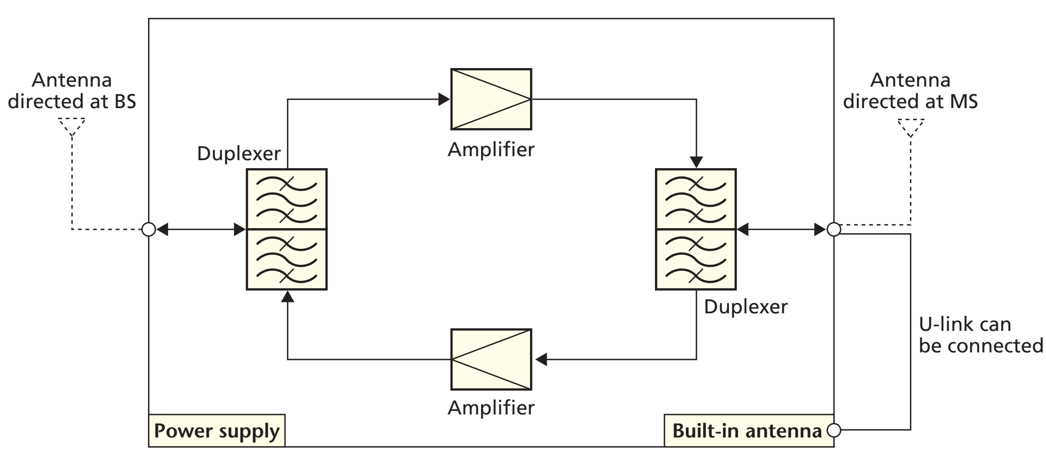


**Figure 8 Configuration of fixed gain booster**

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## Abbreviations

3GPP: 3rd Generation Partnership Project
BS: Base Station
BCH: Broadcast CHannel
BLER: BLock Error Rate
MS: Mobile Station
MOF: Multi-drop Optical Feeder
P-CCPCH: Primary-Common Control Physical CHannel
P-CPICH: Primary-Common PIlot CHannel