siae microelettronica

# ADAPTIVE CODE AND MODULATION

## AL Plus 2 Equipment

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## Introduction

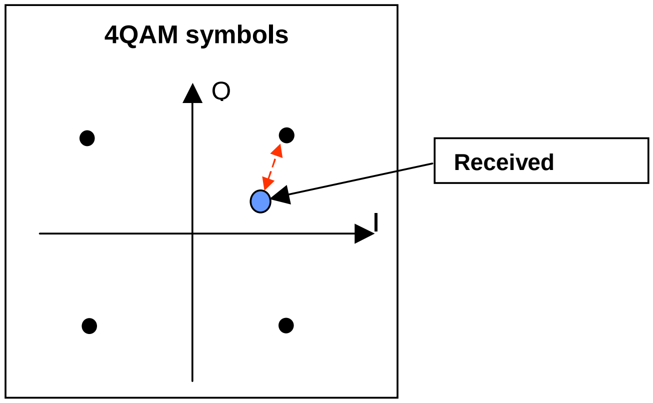
SIAE MICROELETTRONICA equipment can use different code and modulation levels on the basis of the ACM (Adaptive Code and Modulation) profiles set on the equipment. Each ACM profile is defined by a modulation level and an error correction code. SIAE MICROELETTRONICA ACM implementation uses seven different modulation levels, from 4QAM to 256QAM. The 4QAM modulation is implemented with two different codes, in order to provide a further level of extra system gain which can be used to improve the radio link availability (known as 4QAM and 4QAM 'Strong').
Eight ACM profiles are available with the ALplus2 radio series. In the following table, the net throughput for each ACM profile is shown, with respect to different RF Channel Bandwidths and Modulation Schemes.

| Radio Net Throughput [Mbps] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Physical Mode** | **4QAMs** | **4QAM** | **8QAM** | **16QAM** | **32QAM** | **64QAM** | **128QAM** | **256QAM** |
| **Channel Spacing 7 MHz** | **8.866** | **10.953** | **15.05** | **21.362** | **25.777** | **31.847** | **35.781** | **42.083** |
| **Channel Spacing 14 MHz** | **17.798** | **21.221** | **29.589** | **41.852** | **52.466** | **62.784** | **73.032** | **85.796** |
| **Channel Spacing 28 MHz** | **35.736** | **41.9** | **62.664** | **83.256** | **104.244** | **124.902** | **145.238** | **170.602** |
| **Channel Spacing 56 MHz** | **71.66** | **83.31** | **124.314** | **165.734** | **202.221** | **240.593** | **286.926** | **340.626** |

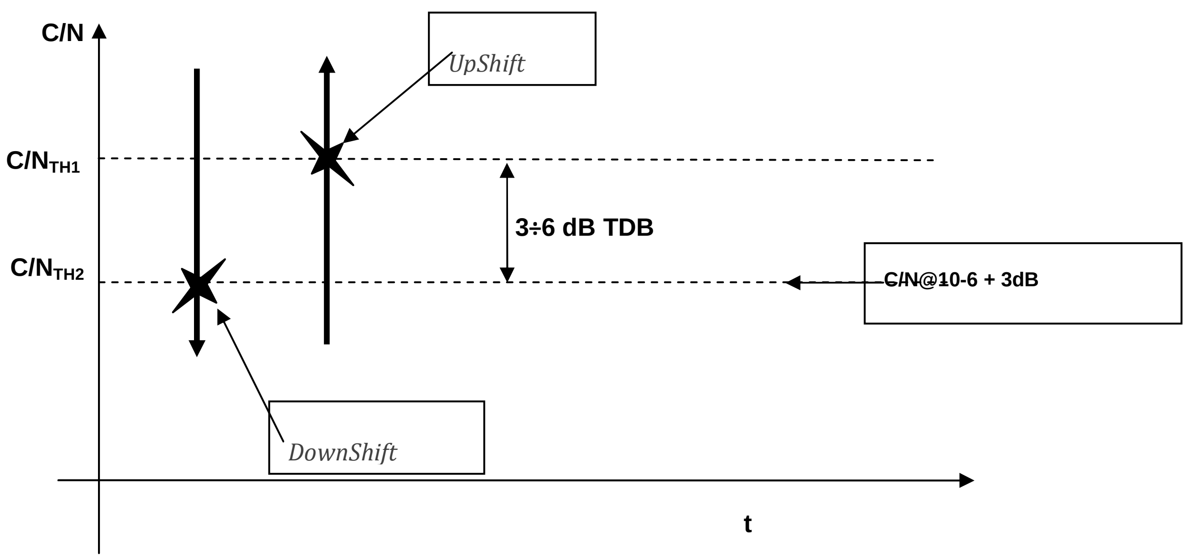
The switchover between these different profiles is dynamically managed by the radio equipment, via the monitoring of the received signal quality (MSE - Mean Square Error). The use of the MSE criteria allows taking into account all of the signal degradation sources :

- Receiver Noise
- Channel Fading
- Interfering Signals

The MSE is a measure of the distance between the effective received signal and the modulation symbol. This distance takes into account the C/(N+I) ratio (Carrier over Noise plus Interferer ratio), i.e. the combined effect of, noise, fading and interferer.




The switchover between two adjacent ACM profiles is triggered by the crossing of an upper or lower MSE threshold for each modulation level.




Default ALplus2 thresholds are set in the following way :

- DownShift threshold - when the estimated C/(N+I) goes down below this level the ACM switches to the profile under the current one. This switching level is set 3dB above the C/N @BER=$10^{-6}$ threshold.

- UpShift threshold: when the estimated C/(N+I) goes over this level the ACM switches to the profile above the current one. This switching level is set from 3 to 6dB above the DownShift threshold.

## ACM Implementations with ALplus2 Equipment

In general,  working with Adaptive Modulation enabled, the system is able to switch between several ACM profiles. One of these profiles is named the Reference Modulation and it is used for link budget and frequency coordination.

As stated in Annex I of the ETSI standard EN302217-2-2, the use of Adaptive Modulation in Point-to-Point links can, in principle, with predefined link parameters (hop length, channel B/W), offer more efficient operating conditions :-

1. Capacity increase over the same radio frequency channel, during periods with favourable propagation conditions, by the use of higher modulation schemes than the one that was used for defining the link budget and related frequency co-ordination constraints at the conventional availability objective.

2. Availability increase availability of a smaller portion of the capacity (typically the 'Real Time Traffic'), during the periods with less favourable propagation conditions, by the use of lower modulation schemes than that one that was used for defining the link budget and related frequency co-ordination constraints at the conventional availability objective.

In ALplus2 equipment these two implementations are achieved through two different working modes :-

- Constant peak value of the transmitted power (relevant to the above Option 1), or over boost mode.

- Constant mean value of the transmitted power (relevant to the above Option 2)

When working with Adaptive Modulation the transmitted output power at the different modulation levels is a trade-off among  the following constants :

- Keeping the transmitted spectrum inside the Reference Modulation mask.

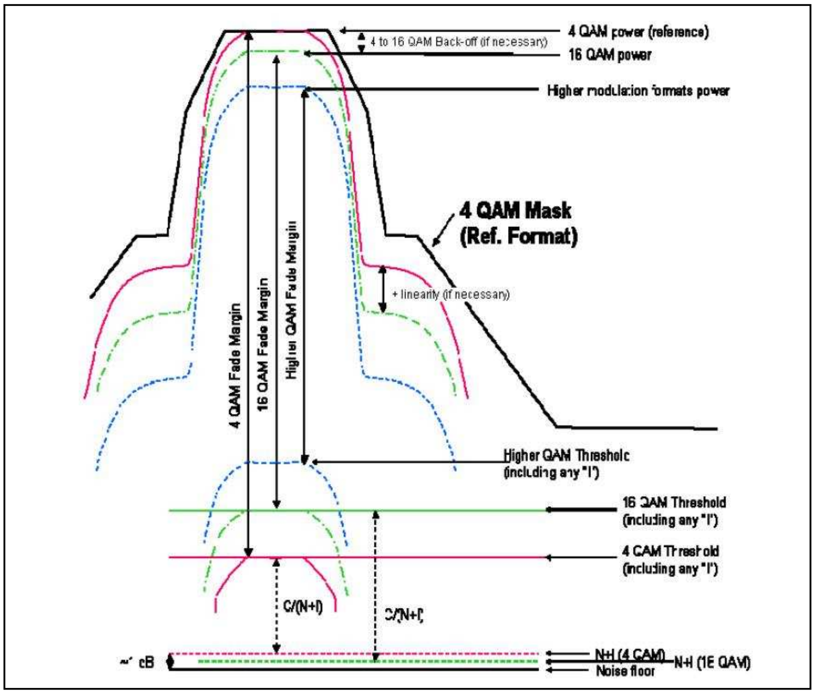
- Avoiding inter-modulation effects that can prevent the correct working of each modulation level.

- Providing a proper Net Filter Discrimination (NFD) factor between adjacent channels that do not limit the system deployment.

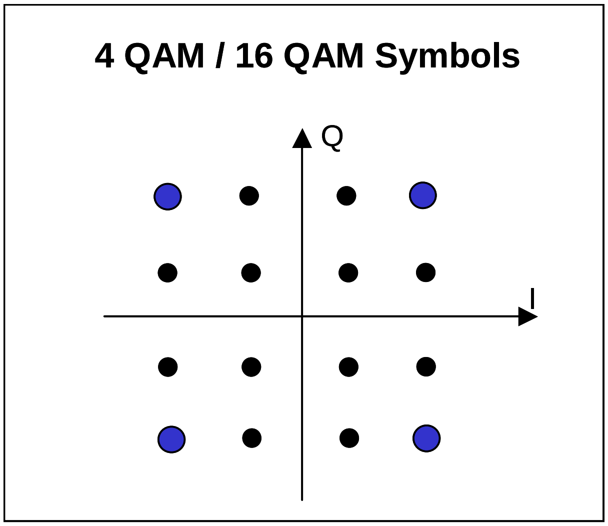
In general lower modulation levels (e.g. 4QAM) are allowed to transmit greater power levels with respect to the higher modulation levels (e.g. 256QAM). However, the effective transmitted power level for each modulation depends on the ACM implementation, as will be explained in the following paragraphs.

## Constant Peak Value of the Transmitted Power

Option 1 for Adaptive Modulation implementation (i.e. increase the available capacity during period with favourable propagation conditions) is implemented in SIAE MICROELETTRONICA ALplus2 equipment by keeping **Peak** value of Output power constant.
This is a typical configuration where the Reference Modulation is the minimum that the system is configured to use (e.g. 4QAM). When the propagation conditions are favourable, the system is allowed to increase the modulation level up to the maximum (e.g. 256QAM). When working at the reference level (e.g. 4QAM) the system transmits the Reference Modulation configured Tx power. However, when the system switches to higher modulation levels (e.g. 256QAM), the transmitted power must be reduced in order to avoid unacceptable inter-modulation effects (see the figure below).

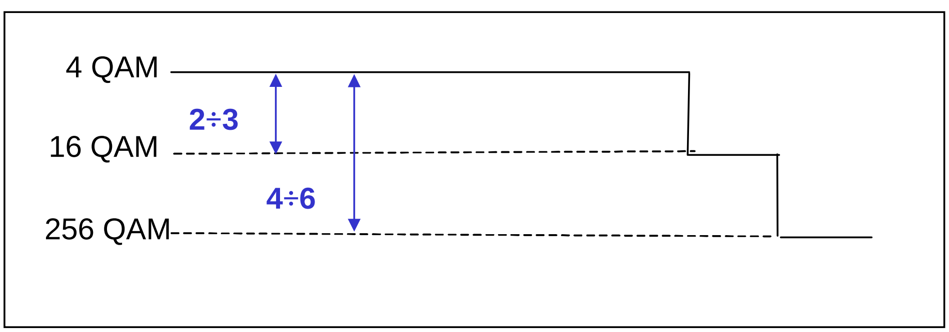



The transmitted power reduction is achieved by keeping the peak value of the Quadrature Modulation constellation constant at the different modulation levels. As an example, consider the figure below where the constellation for 4QAM (blue symbols) and 16QAM (blue and black symbols) are represented. The mean transmitted power can be calculated as the weighted sum of the symbol energy. Keeping the peak Tx power constant, an increase of the modulation level causes a decrease the mean transmitted power. This Tx power decrease is almost equivalent to the minimum variation that must be set on the equipment in order to avoid unacceptable inter-modulation products.



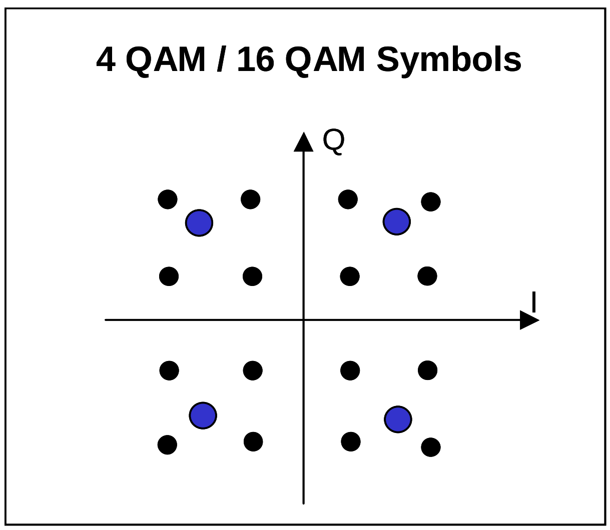

Some non-linear effects can shift practical power gaps from the theoretical ones.
The power gap between the different modulation levels is represented in the following figure. As can be seen, depending, a gap of between 2 & 3dB can occur between 4QAM and 16QAM, while from 4QAM to 256QAM the transmitted power gap is between 4 & 6dB.

**MEAN TRANSMITTED POWER:**



## Constant Mean Value of the Transmitted Power

Option 2 for Adaptive Modulation implementation (i.e. increasing the availability of a smaller portion of the capacity, during periods with less favourable propagation conditions) is achieved in SIAE MICROELETTRONICA ALplus2 equipments by keeping **Mean** value of Output power constant.
This is a typical configuration when the Reference Modulation is not the minimum modulation that the system is configured to use (e.g. 256QAM). When the propagation conditions are unfavourable, the system decreases the modulation level down to the minimum (e.g. 4QAM). When the system switches to lower modulation levels than the reference one (e.g. 4QAM), the transmitted power cannot be increased, in order to preserve a Reference Modulation spectrum limitation.
So, in this configuration and differently to what happened in the Constant Peak case, the peak value of the Quadrature Modulation constellation changes with the modulation level in order to maintain the mean output power constant, as shown in the following figure, where the constellation for a 4QAM (blue symbols) and a 16QAM (black symbols) are represented. Keeping the Mean transmitted power constant requires increasing the peak value of the 16 QAM symbols.




In conclusion, the Constant Mean transmitted power implementation does not allow one to exploit the maximum system gain available for the lowest modulation level (4QAM), but it does permit one to exploit the additional system gain advantage in a frequency band where the regulatory requires to respect a high modulation level reference mask (e.g. 256QAM).

## Frequency Planning with ACM

The frequency plan when ACM is used must be evaluated in the following conditions :-

- Evaluate the Total Interfering Signal received from the neighbouring radio links when these are transmitting at the minimum modulation level (worst case)

- Calculate the C/(N+I)[1] ratio considering the wanted signal working at its nominal value. This C/(N+I) value must be greater than C/N @BER=$10^{-6}$ + 3dB of the maximum modulation level.

- Calculate the total outage and unavailability at the reference modulation level, this must comply with the design constraints.

- Calculate the total outage with all the other configured modulations.

## System Performance with ACM

In the following are shown some reference results achieved when SIAE MICROELETTRONICA ALplus2 equipment, with ACM, are used in different frequency bands and with different hop lengths.
The link budget calculations have been done at BER=$10^{-6}$, using the ITU-T 530-8 recommendation, with the following assumptions :-

- PL factor = 30, zone Europe, Unknown terrain type, inland propagation, 2mrad of path inclination

- Rain intensity = 42 mm/h

- Channel bandwidth = 28MHz, 1+0 system configuration, constant peak ACM with 4QAM as reference modulation and 256QAM as maximum modulation.

The results have been achieved by calculating the maximum link length that allows the 4QAM modulation to comply with the quality and availability objectives. When the system is working at 4QAM it usually carries high priority real time traffic, while Best Effort traffic that exceeds the available capacity is discarded. So, best effort traffic availability is usually less and is related to the quality and availability of the maximum modulation level (256QAM) available on the radio link. The following table shows the Best Effort traffic quality and availability that is achieved for different frequency bands (from 7 to 38 GHz), different antenna diameters (up to 1.2 meters) and different quality and availability objectives for the 4QAM modulation (99.995% and 99.999%).

[1] A Gaussian statistic is supposed for the interferer.

| Frequency [GHz] | Real Time Traffic Quality/Availability (4QAM) [%] | Antenna diameters [mt] | Hop Lenght [km] | Best Effort Traffic Quality/Availability (256QAM) [%] |
|---|---|---|---|---|
| 7 | 99.999 | 2 x 0.6 | 19.9 | 99.72 |
| | | 2 x 0.8 | 25 | 99.73 |
| | | 2 x 1.2 | 32.1 | 99.776 |
| | 99.995 | 2 x 0.6 | 26.4 | 98.604 |
| | | 2 x 0.8 | 33.1 | 98.666 |
| | | 2 x 1.2 | 42.7 | 98.853 |
| 13 | 99.999 | 2 x 0.3 | 13.6 | 99.712 |
| | | 2 x 0.6 | 21.1 | 99.728 |
| | | 2 x 1.2 | 32.5 | 99.805 |
| | 99.995 | 2 x 0.3 | 17.9 | 98.607 |
| | | 2 x 0.6 | 27.9 | 98.62 |
| | | 2 x 1.2 | 43.1 | 98.96 |
| 18 | 99.999 | 2 x 0.3 | 7.6 | 99.971 |
| | | 2 x 0.6 | 9.9 | 99.986 |
| | | 2 x 1.2 | 13.2 | 99.992 |
| | 99.995 | 2 x 0.3 | 12.7 | 99.526 |
| | | 2 x 0.6 | 17.9 | 99.632 |
| | | 2 x 1.2 | 25.8 | 99.735 |
| 23 | 99.999 | 2 x 0.3 | 5.6 | 99.981 |
| | | 2 x 0.6 | 7.3 | 99.99 |
| | | 2 x 0.8 | 8.1 | 99.992 |
| | 99.995 | 2 x 0.3 | 9.1 | 99.824 |
| | | 2 x 0.6 | 17.9 | 99.92 |
| | | 2 x 0.8 | 25.8 | 99.939 |
| 38 | 99.999 | 2 x 0.3 | 2.8 | 99.989 |
| | | 2 x 0.6 | 3.2 | 99.993 |
| | | 2 x 0.8 | 3.5 | 99.994 |
| | 99.995 | 2 x 0.3 | 4.4 | 99.951 |
| | | 2 x 0.6 | 5.3 | 99.967 |
| | | 2 x 0.8 | 5.9 | 99.973 |