DVB-C2: Ready-PlugFest-Go
System Overview and State of Introduction

Christoph Schaaf, Kabel Deutschland, Munich, Germany, christoph.schaaf@kabeldeutschland.de,
Philipp Hasse, Technische Universität Braunschweig, Germany, hasse@ifn.ing.tu-bs.de

Abstract

DVB-C2 is the 3rd member of the DVB family of second generation transmission systems. Both the DVB-C2 Technical Specification (EN 302 769) [1] and the DVB-C2 Implementation Guidelines (TS 102 991) [2] have been approved by ETSI in 2011 in its current version. The two major building blocks of DVB-C2 are the LDPC (Low Density Parity Check) FEC (Forward Error Correction) Code and the OFDM (Orthogonal Frequency Division Multiplex) modulation scheme. Using DVB-C2, cable operators will be able to increase their downstream capacity of today about 5 Gbit/s to more than 8 Gbit/s. DVB has completed the system design work by system evaluation and verification and has run two PlugFests with prototype equipment in 2012. Both the professional equipment industry and the CE-industry made excellent progress in the implementation of this new standard in future-proof products. Now it is up to Cable operators to start the deployment of DVB-C2. First field tests have been performed and there are plans of a first operator to start DVB-C2 transmission in 4 big cites in Germany. It is obviously a challenge for the relevant market partners to introduce a disruptive new technology, which requires the replacement of all deployed Customer Premises Equipment (CPE).

1. Introduction

DVB-C2 [1], [2] is the third specification in the family of second generation DVB transmission systems [3]. Since 1994, when the first systems for digital video broadcasting had been developed by DVB, almost 1 billion devices with DVB-C [4], DVB-S or DVB-T have been deployed. The take up of DVB-S2 [6] and DVB-T2[7] worldwide is already very impressive.

The commercial requirements for DVB-C2 gave a clear focus on spectrum efficiency and flexibility. Based on that, the technical specification was developed within 9 month after a Call for Technologies (CfT), which was answered by 5 different organisations, delivering very interesting proposals. A mayor milestone of the development process was the decision for OFDM mainly for reasons of flexibility. The available SNR in CATV networks allows for increasing the order of modulation and the commercial requirements requested additional headroom for future enhanced cable networks. Another lesson learnt from DVB-T2 was "keep it simple". Hence DVB found a good compromise between the flexibility OFDM offers and an efficient multiplexing structure meeting the requirements.

2. An overview of DCB-C2

Table 1 shows the features of DVB-C2 [3]in comparison to those of the first generation cable transmission system, DVB-C. The usage of the LDPC/BCH FEC scheme offers a 6 db gain in terms of noise performance. Figure 3 shows that DVB-C2 is quite close to the shannon limit. Furthermore it provides a granularity of 2 dB steps in SNR performance by selecting the appropriate FEC code rates. DVB-C2 therefore covers the whole range of currently deployed cable networks and provides headroom for future extensions.

	DVB-C	DVB-C2
Input Interface	Single Transport Stream (TS)	Multiple Transport Stream and Generic Stream Encapsulation (GSE)
Modes	Constant Coding & Modulation	Variable Coding & Modulation and Adaptive Coding & Modulation
FEC	Reed Solomon (RS)	LDPC + BCH
Interleaving	Bit-Interleaving	Bit- Time- and Frequency-Interleaving
Modulation	Single Carrier QAM	COFDM
Pilots	Not Applicable	Scattered and Continual Pilots
Guard Interval	Not Applicable	1/64 or 1/128
Modulation Schemes	16- to 256-QAM	16- to 4096-QAM

Table 1 Key features of DVB-C and DVB-C2

Figure 1 provides a first overview of the DVB-C2 transmitter block diagram. Similarly to DVB-S2 and DVB-T2, the DVB-C2 system adopts the Physical Layer Pipe (PLP) approach. A PLP is a logical channel that may contain a regular MPEG-2 Transport Streams, but also IP data embedded in the so-called Generic Stream Encapsulation (GSE) protocol [8]. Each PLP passes an input processing block, followed by a Forward Error Correction (FEC) and a QAM Mapping stage. One or multiple PLPs can be combined into so-called Data Slices (similar to channels) that are interleaved over time and frequency to mitigate the influence of burst errors or narrow-band interferers. Finally, the frame builder combines the different Data Slices, puts a preamble in front with the Level 1 signalling information and forwards the resulting frame structure to the OFDM generation stage.

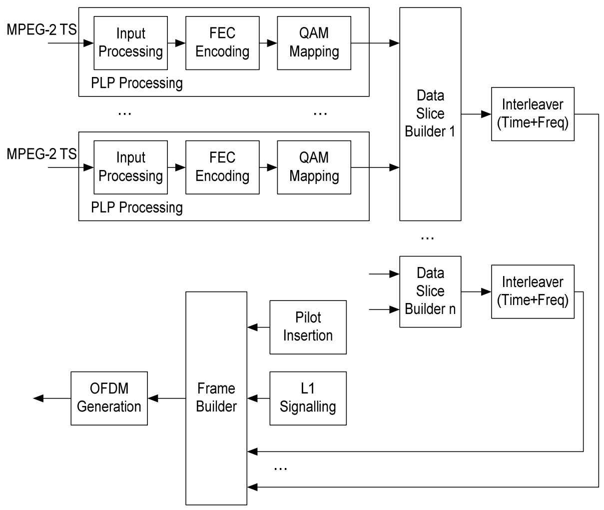

Figure 1. Simplified DVB-C2 transmitter block diagram

2.1. DVB-C2 pre-processing

DVB-C2 supports multiple types of input streams: the well known MPEG Transport Stream, any packetized or continuous input formats by means of the GSE protocol. The pre-processing section multiplexes the input signals into a common baseband framing format and adds service related information in the framing headers.

2.2. DVB-C2: interleaving and framing

The Physical Layer Pipe (PLP) concept allows for the transmission of several independent logical channels. Each PLP is a logical channel that may e.g. contain data based on the MPEG-2 Transport Stream or GSE data. The PLP_ID, that allows identifying a specific PLP on the receiver side, is part of a header preceding each user packet. After decoding this header and evaluating the PLP_ID, the receiver is able to decide whether it has to decode the following data packet. Data packets that do not belong to the requested PLP are ignored and do not have to be processed by the QAM demapper and the forward error correction decoder. Consequently, the effective receiver bit-rate as well as the related processing power decrease significantly. Another advantage of the PLP approach is the possibility to assign different robustness levels to individual streams: Each PLP can adjust its modulation and FEC rate independently from the others. As a result, different 'Quality of Service' levels can be assigned to different services. The robustness settings for broadcast services have to be adjusted in a way that guarantees a high service quality for all reception points in the cable network. For interactive data in point-to-point connections the choice of QoS levels is useful: Depending on cable characteristics like cable length, number of amplifiers or quality of in-house installations, the resulting signal quality can vary significantly. If the cable backend system has knowledge about the channel characteristics to a specific DVB-C2 user terminal, it can adjust the robustness settings accordingly to optimize the data throughput. An example for the application of this technique is VoD (Video on Demand), for which DVB-C2 may be used as a downlink medium. The return channel may be provided via a cable modem, which is able to report the SNR at the relevant wall outlet. Thus, the backend system is able to use the maximum spectral efficiency based on the SNR that is offered by the network.

2.3. QAM mapping and Forward Error Correction

The performance of the forward error correction is key for a powerful transmission system. As part of the DVB-x2 family, DVB-C2 employs exactly the same Low Density Parity Check (LDPC) codes that have been already used for DVB-S2 [6] and DVB-T2 [7]. This code class has already been known since the sixties, but its practical usage became attractive in the recent years due to the progress in semiconductor manufacturing. The impressing benefits of this approach can be shown by the following numbers: The 9/10 code rate of DVB-C2 is able to correct bit error rates of up to $5\ 10^{-2}$ at the input of the FEC decoder. In contrast, the Reed Solomon code applied for DVB-C, which has a similar effective code rate, only tolerates a maximum bit error rate of $2\ 10^{-4}$ to reach the goal of quasi-error-free reception (one erroneous event per day). This high performance of the LDPC codes is especially reached for large LDPC codeword lengths. Hence, DVB-C2 normally uses a codeword length of 64800 bits (instead of 1632 bits or 204 Byte in DVB-C), which consequently is no longer coupled to MPEG-2 Transport Stream packets. Besides the LDPC code, a very high rate (code rate approx. 0.99) BCH code is employed by DVB-C2 after LDPC decoding. This code is used to correct a possible error-floor of the LDPC code. This error-floor, which occurs in most iterative coding schemes such as LDPC or Turbo codes, leads to few remaining bit errors after the decoding process, which cannot be corrected by further iterations of the LDPC decoder.

The significantly increased performance of the forward error correction allows for the application of higher constellation schemes. While DVB-C maximally employed 256-QAM, DVB-C2 now adds 1024-QAM and 4096-QAM. The possible combinations of modulation and coding schemes support the usage of DVB-C2 over a wide range of SNR values from approx. 10 to 35 dB, with granularity of approx. 2 dB.

2.4. Application of OFDM for DVB-C2

In contrast to DVB-C, DVB-C2 uses OFDM instead of single-carrier QAM modulation. OFDM is applied in most state-of-the-art broadcast and bidirectional transmission schemes due to its well-known and proven robustness to different types of channel impairments. DVB-C2 uses a parameter set of DVB-T2 that is well-suited for the cable specific requirements. As a result of OFDM and because of a large amount of other common blocks, combined DVB-T2 and DVB-C2 chips can be realized without much overhead.

DVB-C2 utilizes a 4K FFT mode, with a useful OFDM symbol duration of 448 µs and two Guard Interval fractions of 1/64 and 1/128. Furthermore, DVB-C2 uses the

same scattered pilot patterns as DVB-T2, which allow for a common channel estimation block for both systems.
However, DVB-C2 does no longer require a pre-defined channel raster: As cable networks provide a shielded environment there is no need to coordinate the spectrum with the external terrestrial environment. Thus, cable operators may overcome the fixed traditional channel raster that primarily has been maintained for reasons of compatibility with terrestrial transmissions. With DVB-C2 they now can flexibly adapt the physical channel bandwidth to their actual needs up to a maximum signal bandwidth of 450 MHz. The benefit of such wide channels is the increase of the statistical multiplexing gain due to the integration of a larger number of services. To avoid complex and expensive consumer electronic receivers, segmented OFDM reception is applied: The receiver retains a standard 8 MHz TV tuner architecture which can extract that part of the wider transmission signal that contains the targeted service. This part of the DVB-C2 multiplexing structure is called Data Slice, which never exceeds the bandwidth of an 8 MHz reception tuner. The architecture of the related C2 framing is depicted in figure 2.

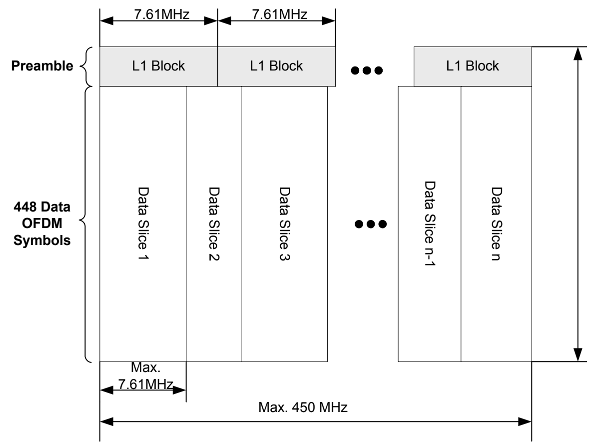

Figure 2. DVB-C2 framing structure in time and frequency direction, no frequency gap is required between adjacent Data Slices, every DVB-C2 frames starts with a Preamble

Each C2 frame starts with a preamble (consisting of one or more OFDM symbols) that has two main functionalities. On the one hand it allows for reliable time and frequency synchronization to the OFDM signal and the framing structure itself. Therefore, a unique preamble pilot sequence is modulated onto every 6th OFDM sub-carrier of the preamble symbols. On the other hand, the preamble carries the Level 1 signalling required for the decoding of the Data Slices and their payload. The preamble consists of a frequency cyclic repetition of the L1 blocks that are repeated every 7.61 MHz. The reason for the fixed allocation of the L1 Blocks and their repetition is the requirement to access the complete L1 signalling in any tuning position of an 8 MHz reception tuner. The receiver is able to restore the complete data by re-ordering the OFDM carriers after transition into the frequency domain. Even the loss of some carriers does not affect the system's performance in a serious way, as the signalling data is transmitted very robustly.

2.5. DVB-C2 performance and key features

In contrast to the L1 Blocks, the Data Slices do not have to follow any raster and can be allocated in a flexible way, which is the reason for the need of accessing the L1 signalling data at any tuning position. The only requirement is that each Data Slice must not exceed the maximum reception bandwidth of 7.61 MHz. As a result, the bandwidth of a Data Slice can be adjusted very precisely to the bit-rate of the source signal. For example, satellite streams with very different bit-rates can be inserted into the C2 signal without the need of exhaustive stuffing or re-multiplexing of the MPEG-2 Transport Streams. Different Data Slices can be accumulated until the overall number of OFDM sub-carriers of the DVB-C2 signal is reached. Both position and bandwidth of the Data Slices may vary between different DVB-C2 frames as this does not require any re-tuning of the receiver. The signalling inside the L1 Blocks does not only indicate the start and the end frequency of the Data Slices, but also the optimal tuning position. Thus, the transmitter may vary the Data Slice parameters inside the transmitter defined receiving window.
The combination of the reduced modulation overhead and the increased robustness of the LDPC codes provides a system performance that closely reaches the theoretical limit, as depicted in figure 3. While DVB-C's distance to this limit is 10 dB, the overall distance (including overhead) for DVB-C2 is only 2-3 dB. Thus, a substantial increase in spectral efficiency has been achieved.

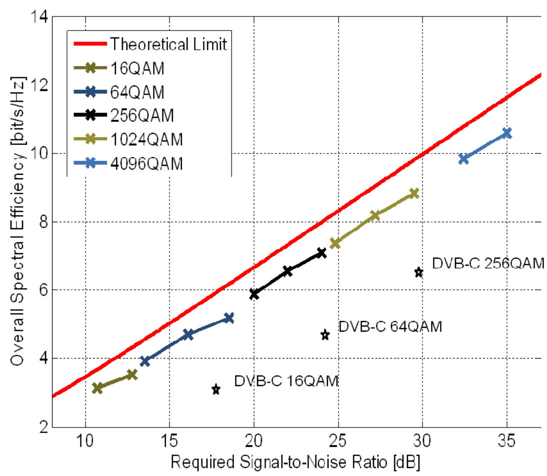

Figure 3. Overall spectral efficiency of DVB-C and DVB-C2 for different code rates and modulation schemes (DVB-C2 parameters: 32 MHz signal bandwidth, Guard Interval 1/128, pilot density 1/96)

For the comparison of both systems, the available spectral efficiency is given. The 4096-QAM with 9/10 code rate of DVB-C2 allows a 65% increased payload bit-rate at 35 dB SNR, which still remains feasible for most state-of-the-art cable networks.
A further big advantage of the OFDM modulation scheme is its capability to cope with cable relevant interference

scenarios. The guard interval eliminates the impact of echoes, especially in in-house networks up to an echo delay of 3.5 □s.

3. Validating DVB-C2

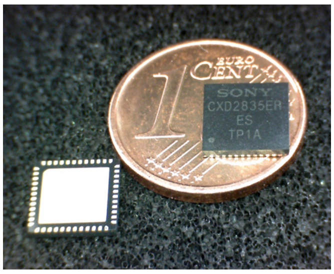

Figure 4. The size of a combined DVB-C2/T2 demodulator IC is 7mm x7mm

An important “lesson learnt” in the development of the DVB-x2 systems was, that it is not sufficient to develop a new specification, but that it is necessary to further support the implementation of such a system by a Validation and Verification (V&V) process and later on, when first prototype implementations are available, to provide a possibility to test the interoperability and performance of the implementations.

3.1. Validation and Verification Task Force

The Validation & Verification (V&V) activity for DVB-C2 was started already during the development process allowing to compare simulation results of building blocks provided by different partners and to test the effect of any proposed enhancement in an open simulation environment. After completion of the specification, interested implementers of the DVB-C2 system used this platform for testing the interoperability of different building blocks of their implementations. The discussions between the different implementers helped to identify and remove any ambiguity in the DVB-C2 specification. This process was also very important.

When the first FPGA implementation was available, the V&V Group had already tested the implementations by comparing the theoretical output streams of the various building blocks amongst the participants to ensure the correct understanding of the standard. More and more test cases for interoperability testing and test streams were made available to all interested DVB members.

In a next phase the V&V Groups defined test cases which allow a silicon vendor or a CPE developer to test the compatibility of their implementation.

3.2. First and second PlugFest

After the successful validation of the first receiver demodulator, the mass production of that chip started quite soon. Receiver manufacturers got samples and implemented those chips into their iDTV chassis. For DVB-C2 the time had come for a first PlugFest. The purpose of such an event is to support manufacturers who are developing DVB-C2 compliant products. It is not a beauty contest, but should help manufacturers to test their prototypes, to discuss technical issues with others and to get an indication of the interoperability and performance of their devices in relation to others. The privacy of company-specific results has to be ensured. The first PlugFest was performed in February 2012 and the second followed in November 2012.

Both PlugFests consisted of 5 different test sessions. As there were significantly more than 1000 test configurations to be evaluated, it was necessary to have a simple test criterion, which allows performing each test within less than a minute. The chosen criterion was an error free video decoding for 10 seconds.

3.2.1. Session 1: Interoperability

During the interoperability test session all prototype modulators were tested against all available prototype tuners (demodulators). About 100 test configurations for the first PlugFest and about 130 test configurations for the second PlugFest allowed covering the most relevant operational modes. Whereas during the first Plug Fest only static modes were tested, during the second PlugFest also dynamic parameter changes were verified.

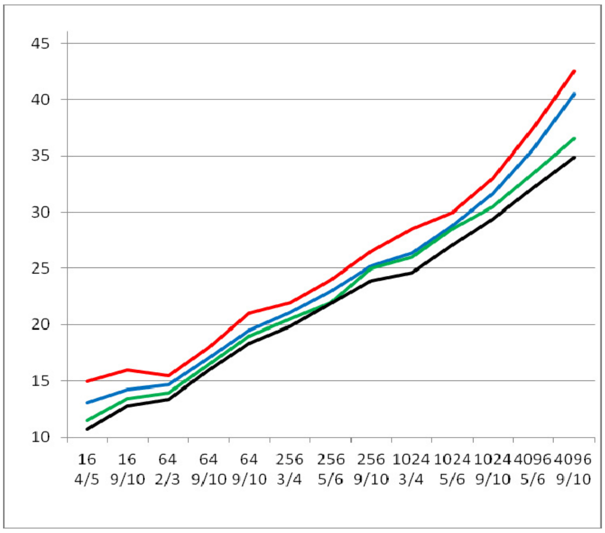

Figure 5. Minimum receiver SNR for error video decoding: Black: theory; green: best, blue: average, red worst

3.2.2. Session 2: Overall performance testing

The second session addressed the system reference chain, measuring the implementation loss of both the transmitter and the receiver and the impairments added by a fully loaded CATV network. As the receiver implementation margins are most significant, the focus was clearly on the receiver implementation loss. Figure 5 shows the results of the measurement of the minimum required CNR value at the receiver input for an error free decoding for every modulation and code rate combination provided by DVB-C2. The average (blue line) of all results shows that the implementation loss is already quite low for all modulation and coding combinations up to 1024-QAM. For 4096-QAM, the results well improved significantly between the PlugFests.

3.2.3. Session 3: Sensitivity testing

The third session focused on the measurement of the minimum and maximum supported input level of the demodulator/decoder devices in a realistic application with a fully loaded (mixed analogue and digital channels) cable network. The measurement was meant to provide an indication of the noise sensitivity and noise performance at low signal levels at the receiver input and of the support for high signal levels, respectively. The results show that the supported minimum input level are far below the nominal signal level at the customers wall outlet typically deployed in cable networks.

3.2.4. Session 4: Frequency linearity testing

The fourth session addressed the tuner linearity with respect to the minimum supported input level as a function of the transmit frequency, again in a fully loaded CATV configuration with a mixed analogue and digital channel allocation.

3.2.5. Session 5: Adjacent channel interference testing

The fifth session was the most time consuming one, addressing the performance of the tuner in case of interference caused by signals in an adjacent channel. Three different configurations in terms of the adjacent channel allocation have been tested: DVB-C2, DVB-C and PAL. The wanted channel was always a DVB-C2 signal. In both PlugFests those tests needed more than 1000 different test configurations, taking into account all modulators and the variation of all possible modulation schemes in the adjacent channel and applying different back-off values.

Figure 6. DVB-C2 PlugFest activities in November 2012

4. Plans for the introduction

The major issue with the introduction of DVB-C2 is: How to resolve the "chicken and egg"-problem? The CE-Industry tends to wait for first commitments for DVB-C2 services and cable operators tend to wait until a reasonable technical reach of DVB-C2 compliant receivers are deployed. A new physical layer is a disruptive technology, since the deployed basis of CPEs needs to be replaced. Cable operators do not have the resources to simulcast their digital services. Currently several cable operators are considering either to start with new services, which are delivered via DVB-C2 exclusively or to start DVB-C2 services with the introduction of a new generation of CPEs. A further realistic opportunity to start with DV-C2 is any customer individual services, such as VoD.

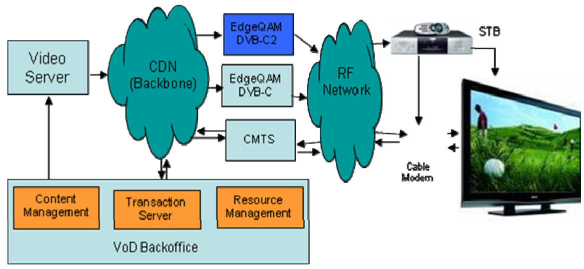

Figure 7. Technical VoD system architecture for mixed DVB-C and DVB-C2 content delivery

Figure 7 shows that DVB-C and DVB-C2 can be operated in parallel in the same network, because the VoD resource manager in the backend system knows which modulation scheme is appropriate for the CPE of a VOD customer.
For the coming years further disruptive technologies are emerging, such as HEVC (H.265) or the DVB Common Scrambling Algorithm Version 3. Any cable operator who wants to use the increased efficiency of HEVC or the higher security level of CSAv3 will bundle the usage of such new technologies in a new generation of CPEs.

4.1. What kind of DVB-C2 equipment is available today

The situation today is that there is one silicon vendor providing chips in mass production. These demodulator chips are capable to demodulate all three DVB-x2 signals. DVB-C2 is deployed in the high end series of iDTVs (integrated DigitalTV Receivers) of one manufacturer since April 2012. There are at least three further silicon vendors working on a consumer-type demodulator chip. Several small companies are offering IP-cores for the FPGA implementation of DVB-C2. At the ANGA Cable exhibition 2012 four different cable head end solutions with DVB-C2 functionalities have been presented. DVB-C2 measurement equipment is available in the form of a first measurement signal generator and a first measurement receiver.

4.2. First DVB-C2 services planned in Germany

DVB-C2 has been successfully field-trialled in different countries, such as Finland, Germany and Spain. Kabel Deutschland will start with DVB-C2 services in several big cities end of Q1/2013. Due to a limited number of customers being offered this new service, the first phase can only be considered as an extended field-trial. The backbone system of Kabel Deutschland is already designed to deliver DVB-C2 to the head-ends, so that the technical coverage can be easily extended as soon as more compliant CPE will be available.

5. Conclusions

In 1994 many experts were seriously concerned that the complexity of DVB-C was too high and modulation schemes such as 16- and 64-QAM had never been used in consumer type applications. Meanwhile, more than 200 Million devices with DVB-C frontends have been deployed already worldwide.

18 years later the change to OFDM and modulation schemes up to 4096-QAM are again a more revolutionary approach and there were doubts whether such high order of modulation will work in CATV networks. Meanwhile DVB-C2 has been successfully field-trialed in German CATV networks in a fully loaded configuration. In DVB considerations are starting to introduce even 16k-QAM as a professional profile for enhanced cable networks (hybrid-fibre-coax networks) and RFoG (RF-over-glass) networks.

Significant progress has been made testing and validating the DVB-C2 standard. The interoperability and the performance of prototype implementation of transmitters and receivers have been tested during two PlugFests successfully. It is now up to the relevant market partners to plan and organize the necessary and indeed challenging migration process.

DVB-C2 provides efficiency combined with flexibility, a powerful PHY-system for a future-proof, fully digital cable, meeting the customer demand for more and more choice of services and higher and higher bandwidth for broadband access.

6. Acknowledgments

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7. Literature

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