6. PHYSICAL LAYER SPECIFICATION

This section describes the physical layer of the Out-Of-Band downstream and upstream channels.

6.1. PHYSICAL LAYER FOR OOB TRANSMISSION

The aggregate information rate of the Out-Of-Band (OOB) channel is 2.048 Mbps. Up to 1.544 Mbps may be utilized for access control and other control information as well as application data, application program downloads, program guides, etc. The OOB data channel provides continuous communication from a headend to the Digital Terminals. The Digital Terminal typically remains powered-up even when it is in the "off" state. The OOB channel remains active independent of the tuned video channel, whether the received TV channel is analog or digital, and whether the Digital Terminal box is turned "on" or "off". Thus, whenever the Digital Terminal connected to the coaxial cable and AC power, the OOB channel is active for downstream communication.

6.1.1. OOB TRANSMISSION FORMAT

The following table summarizes the physical attributes of the OOB channel.

Parameter Name	**Specifications**
Modulation:	QPSK, differential coding for 90°phase invariance
Symbol Rate:	1.024 Msps
Symbol Size:	2-bits per symbol
Channel Spacing (BW):	1.8 MHz
Transmission Frequency Band:	70 to 130 MHz
Carrier Center Frequency (default):	75.25[1]MHz± 0.01%
Data Rate:	2.048 Mbps ± 0.01%
Forward Error Correction:	96,94 Reed-Solomon block code, T=1, 8bit symbols
FEC Framing	Locked to MPEG-TS, two FEC blocks per MPEG packet
Interleaving	Convolutional, (96,8)
Nominal Information Rate:	2.005 Mbps (132.8 b/s margin)
Frequency Response:	Raised Cosine filter, α = 0.5 (receiver only)

1. Other possible OOB carrier center frequencies are 72.75 MHz and 104.2 MHz.

Table 1: Out-Of-Band Transmission Specifications

The OOB channel spacing is 1.8 MHz with frequency step size of 50 kHz. The center frequency for the downstream cable frequency plan can be between 70 to 130 MHz, with 75.25 MHz as the default value.

6.1.2. OOB CODING SCHEME

The forward-error-correction scheme for the OOB channel is composed of the randomization, Reed-Solomon (R-S) coding, and interleaving layers as shown in Figure 1.

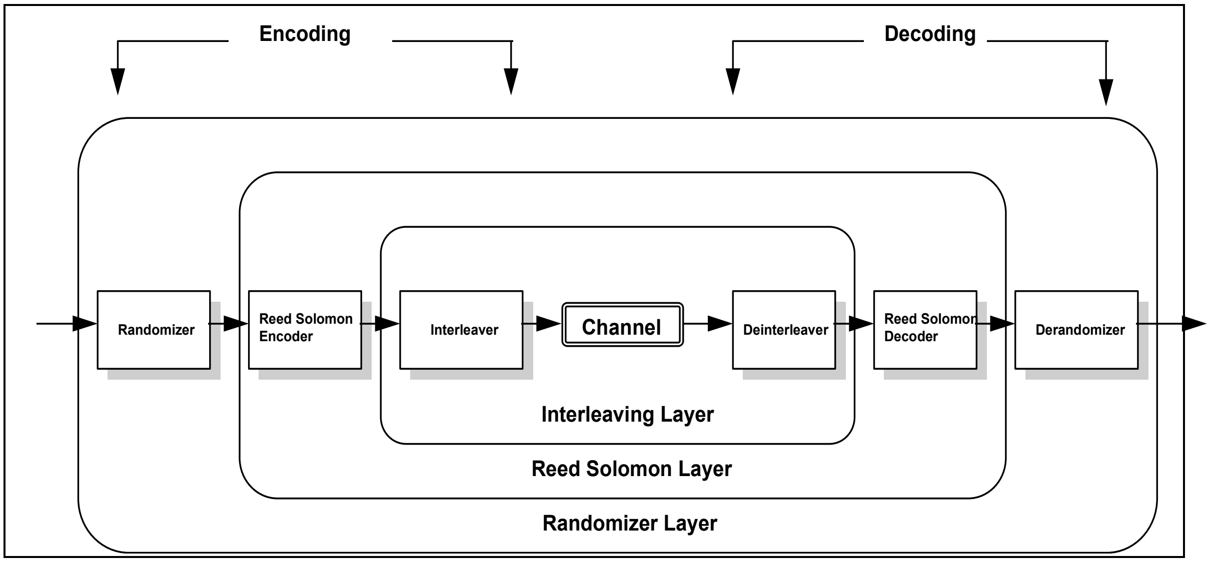

Figure 1: A Block Diagram for Layers of Coding in the OOB Channel

6.1.2.1. OOB RANDOMIZER

The MPEG-TS is randomized to ensure balanced modulation by removing unequal excitation of the QPSK modulation states. The randomizer circuit performs the exclusive OR function on the input MPEG transport sequence with the randomizer's Pseudo-random Number (PN) generator output sequence. The randomization frame consists of two MPEG packets with the randomizer PN generator pre-set at the start of every second MPEG-TS packet. Alternate MPEG-TS Sync bytes are converted from 0x47 to 0x64 by the randomizer. This improves receiver synchronization performance.

The randomizer PN generator is a 13-bit Linear Feedback Shift Register (LFSR) as shown in Figure 2**.** Binary arithmetic XOR gates and taps are placed at the output of stages 13, 11, 10, and 1. The shift register is preset with a seed value. The stages 10 and 1 are loaded with a seed value of "1" and all other stages, 2 through 9 and 11 through 13 are loaded with a seed value of "0". The seed corresponds to 0x0201. The corresponding generating polynomial is defined as:

$$f(X) = X^{13} + X^{12} + X^{10} + X^9 + 1$$

The randomizer PN generator is preset to the seed value on the 385th byte after clocking for a total of 384 bytes. The MPEG Sync byte 0x47 is converted to 0x64 on the 193rd byte by being exclusive OR'd with the 193rd PN generator output byte output which is 0x23. The randomizing action is gated out during bytes 95-96, 191-192, 287-288 and 383-384. The reason for these gaps in the randomization process is to permit the insertion of Reed Solomon parity bytes. The PN generator continues to run during these gaps but the output is not used. The RS bytes are inserted without being randomized.

The same circuit is used for de-randomizing the received MPEG-TS packets. The sync symbol of the first MPEG-TS packet in a frame remains 0x47 after randomization because the first randomizer output byte after reset is "0x00". The second MPEG-2 Sync byte is changed by the randomizer but will be returned to the MPEG-TS standard value 0x47 by the de-randomizer at the receive site.

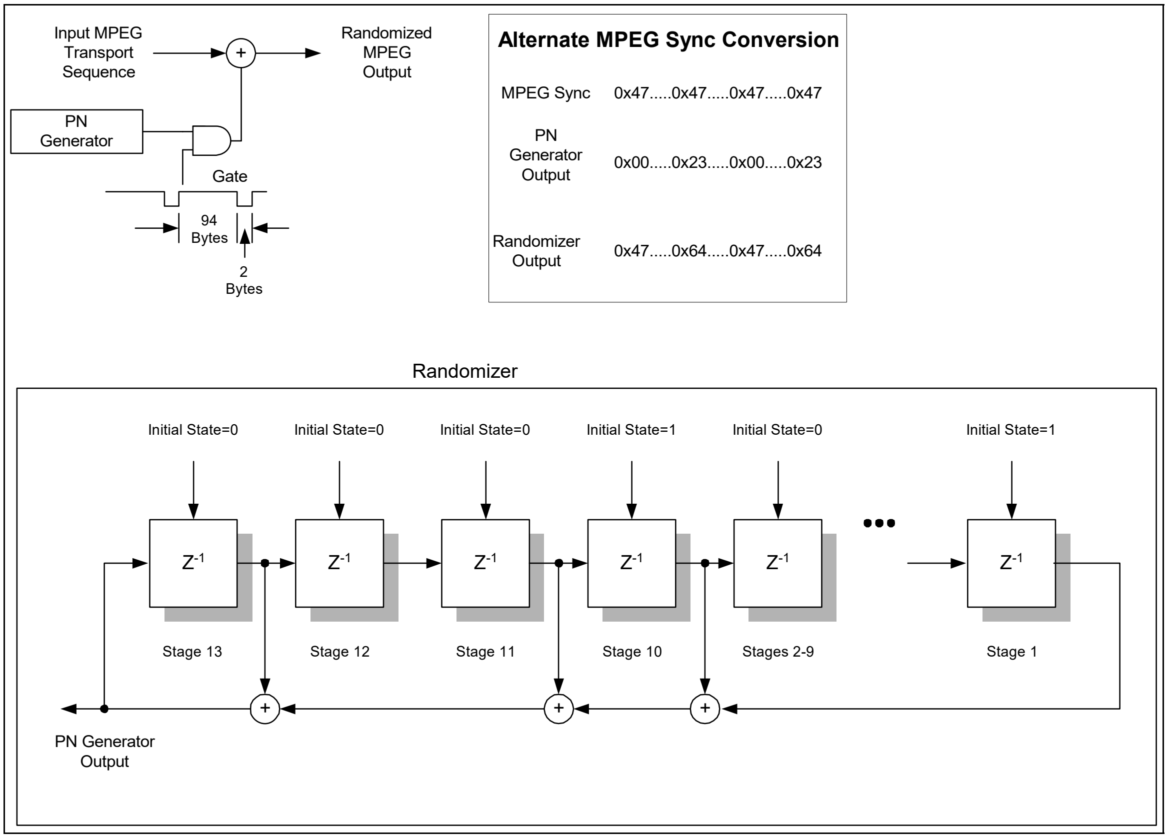

Figure 2: The Out-Of-Band Randomizer

6.1.2.2. FORWARD ERROR CORRECTION CODE

The forward-error-correction (FEC) code in the OOB transmission system is a Reed-Solomon (R-S) block code [5] No codeword shortening and padding is used with the R-S coding. No convolutional coding is required for the relatively robust QPSK transmission on cable-TV transmission networks. The FEC scheme uses (94,96) Reed-Solomon code defined over Galois Field GF(2^8). The R-S code is T=1 (96, 94) over Galois Field GF(256), which is capable of performing 1 symbol error-correction every R-S block of 96 symbols. The (94,96) code is equivalent to a (253, 255) R-S code with 159 leading zero symbols followed by 96 non-zero symbols.

The GF(256) is constructed based on the following primitive polynomial over GF(2), namely,

$$p(X) = X^8 + X^4 + X^3 + X^2 + 1$$

The generating polynomial for the R-S code is defined as:

$$g(X) = (X-\alpha)(X-\alpha^2)$$

where α is a primitive element in GF(256). The OOB FEC frame consists of two Reed-Solomon blocks. This OOB FEC frame equals one MPEG transport packet as illustrated in Figure 3.

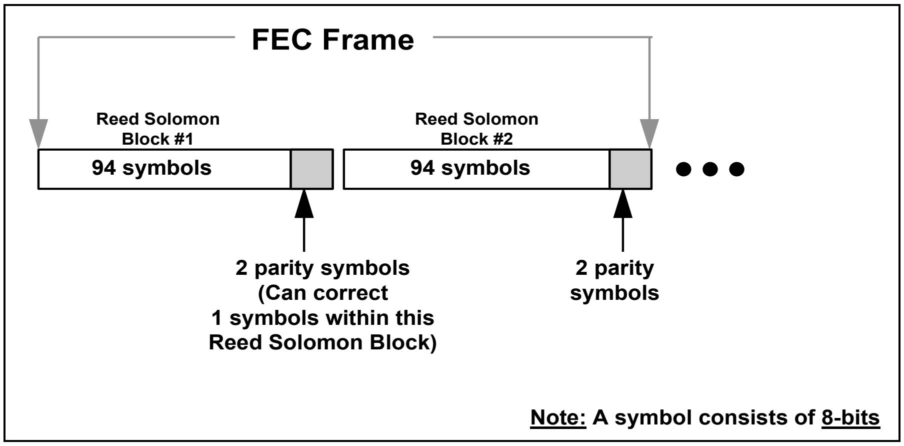

Figure 3: The OOB FEC Frame Packet Format

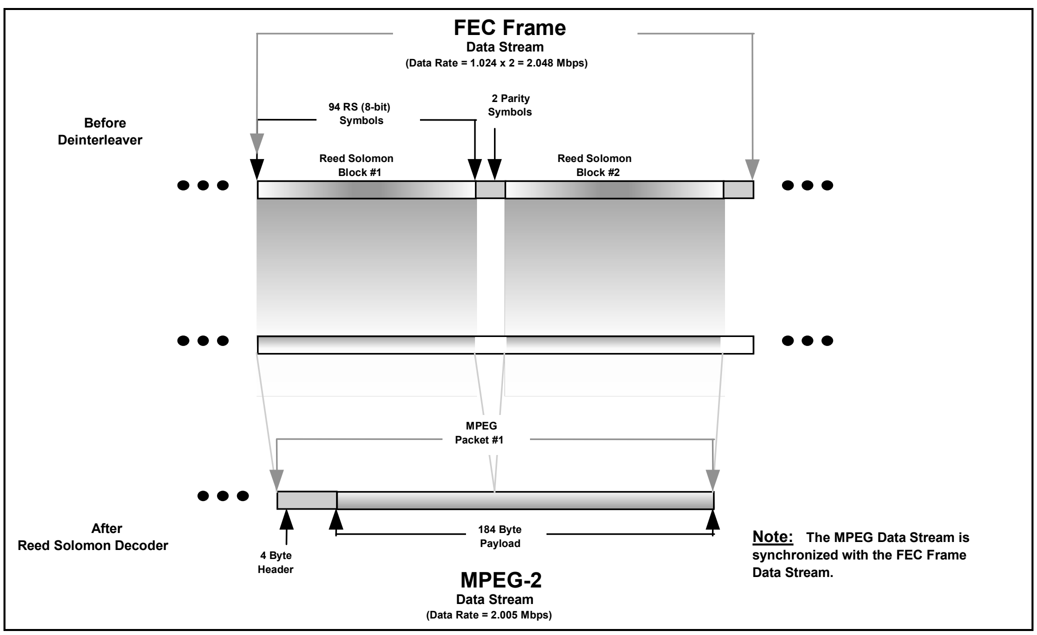

Figure 4: The Out-Of-Band FEC Frame to MPEG-TS Framing

Mapping from an FEC Frame to an MPEG-TS packet is illustrated in Figure 4. The first 94 bytes are un-altered and used directly as received. The next 2 bytes are the parity bytes obtained from the Reed-Solomon polynomial calculation. Two blocks of 96 bytes are sent for every 188 byte MPEG packet received. The FEC frame is reset at the start of each MPEG-TS packet.

6.1.2.3. **OOB INTERLEAVER**

Interleaving the coded R-S symbols before transmission and de-interleaving after the reception may cause multiple burst errors during transmission to be spread out in time. Thus, the receiver has to handle them as if they were random errors. Separating the R-S symbols in time enables the random-error-correcting R-S code to be useful in a bursty-noisy environment. Using a convolutional interleaver with a depth of I = 8 symbols, the R-S T=1 (96,94) decoder can correct an error burst of 8 symbols, which corresponds to a burst noise protection of 32 µsec.

Interleaving is synchronized to the R-S blocks and hence to MPEG-TS packets. MPEG-TS Sync bytes always pass through commutator branch 1 of the interleaver and hence are not delayed through the interleaver. The convolutional interleave algorithm delays various blocks of bytes in a systematic way, as illustrated in Figure 5.

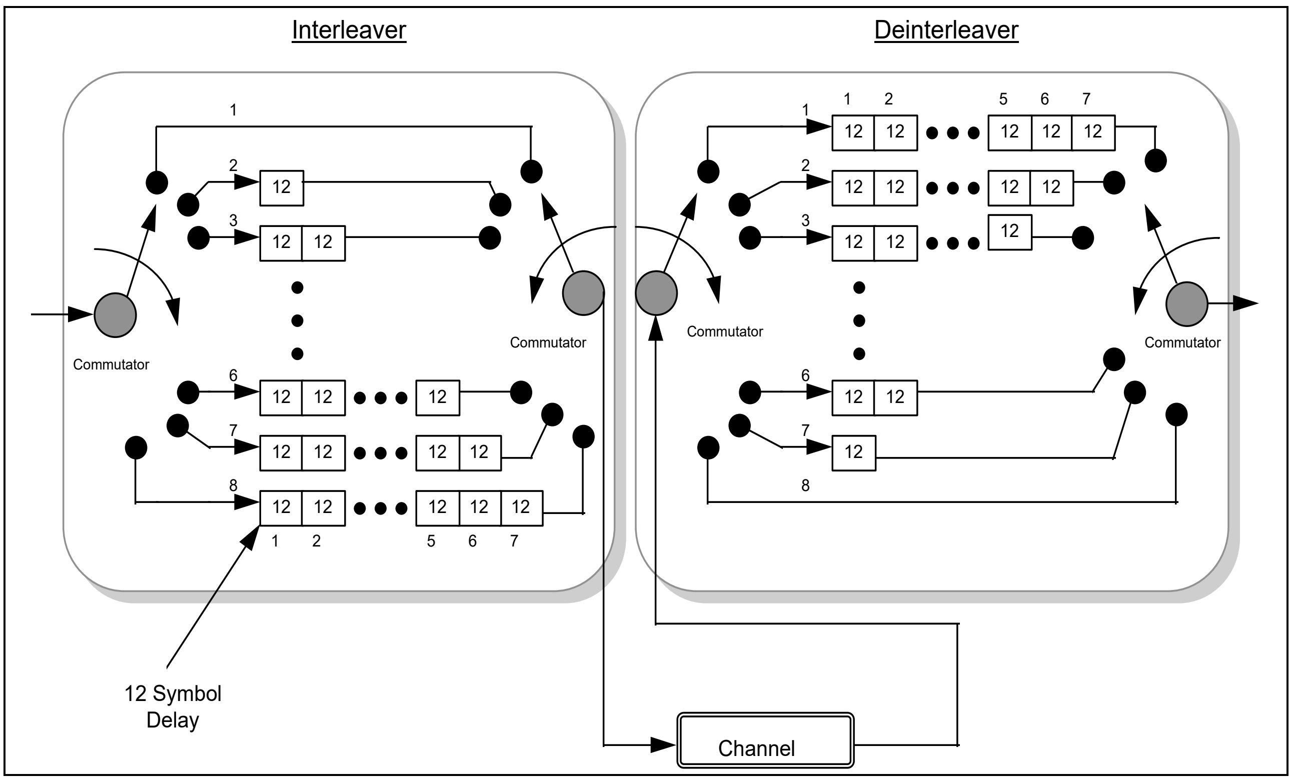

Figure 5: Out-of-Band Interleaving Functional Block Diagram

6.1.3. OOB QPSK MAPPING

The OOB modulator uses differential encoding scheme to resolve the 90° ambiguity in the detection of the QPSK signal at the demodulator. The OOB QPSK demodulator should be capable of handling both forms of differential coding as listed in Table 2**.** Also, a means of selecting the appropriate form of decoding for the user's system must be present in the QPSK demodulator.

I Data	Q Data	Default Carrier Phase Changes	Alternate Carrier Phase Changes
0	0	No Change	No Change
0	1	-90 degrees CW	+90 degrees CW
1	0	+90 degrees CW	-90 degrees CW
1	1	180 degrees	180 degrees

Table 2: The Differential Coding Scheme for OOB QPSK Signal

6.1.4. OOB MODULATOR RF OUTPUT

The OOB QPSK modulator RF output specifications are shown in Table 3.

Parameter Name	Specification
Center Frequency RF Output	75.25[1] MHz carrier frequency
Step Size for RF Output	50 kHz
RF Output Power range	+30 to +50 dBmV
Output level stability vs. time & temperature	±2 dB
Output level stability vs. frequency changes	±2 dB
RF Center frequency accuracy	±0.01%
I/Q Amplitude Imbalance	0.5 dB typical
I/Q Phase Imbalance	1.0 degree typical

1. Other OOB carrier frequencies in the 70 to 130 MHz are possible.

Table 3. The OOB Modulator RF Output

6.1.5. OOB CARRIER INPUT POWER AT RECEIVER

The received power level of the OOB carrier at the subscriber's decoder is from +5 dBmV to -10 dBmV at 75 Ω cable impedance.

6.2. PHYSICAL LAYER FOR RETURN-PATH TRANSMISSION

6.2.1. RETURN-PATH MODEM DESCRIPTION

For most applications, the return-path data sent from the subscriber site to the cable-TV headend is generated and must be transmitted in short bursts. The small ATM protocol cell structure is well suited to this need. A block code FEC is used to allow both correction of some transmission errors and detection of packets that cannot be corrected. For many applications upstream packets that cannot be corrected can be re-transmitted. Block or convolutional interleaving is not appropriate since their function is to spread-out error bursts over many FEC blocks. These upstream transmissions are often a single FEC block.

6.2.2. RF RETURN PATH PACKET FORMAT

The upstream data sent from subscriber Digital Terminals to the headend is in ATM packet format. Each ATM packet is concatenated with a 28 bit Unique Word, a one byte Packet Sequence counter, and 8 Reed Solomon parity bytes as shown in Table 4. The 28 bit Unique Word, which can be written as (I,Q), is used to identify the start of the data packet for robust Sync detection by the return-path receiver. The packet sequence byte consists of a message number (3 bits), and a sequence number (5 bits). The message number is used to associate upstream cells with a particular Protocol Data Unit (PDU). It is incremented every time the first cell of a new PDU is sent. The sequence number, which has a field length of 5 bits, is used to identify the order of the cells within a PDU. It starts at 0 for each new message number, and used by the headend return-path demodulator to detect missing cells for the RF modem report-backs.

Parameter	Specification
Unique Word	28 bits (1100 1100 1100 1100 1100 1100 0000)
Packet Sequence	1 byte
ATM data	53 bytes
R-S parity	8 bytes

Table 4: Upstream Packet Format

6.2.3. RF RETURN-PATH FORWARD ERROR CORRECTION

The FEC code in the return-path transmission link is a R-S T=4 (62,54) code over the GF(256) field. Each R-S symbol consists of 8 bits. This FEC code is cable of correcting four symbol errors for a R-S block of 62 symbols. The following primitive polynomial over GF(256) is used:

$$p(X) = X^8 + X^7 + X^2 + X + 1$$

The generator polynomial for this FEC code is:

$$g(x) = (X-\alpha^{120})(X-\alpha^{121})(X-\alpha^{122})(X-\alpha^{123})(X-\alpha^{124})(X-\alpha^{125})(X-\alpha^{126})(X-\alpha^{127})$$

where α is a primitive element in GF(256).

The encoding circuit is efficiently implemented via shift registers using arithmetic over GF(256).

6.2.4. RF RETURN-PATH RANDOMIZER

The randomizer circuit uses a PN generator, which employs a 13 bit shift register. The input bit stream is XOR'ed with this PN sequence. Taps are located at the output of stages 1, 3, 4, and 13 of the shift register. Stages 1 to 5 of the shift register are always initialized to zero for each packet. Stages 6-13 are initialized to a programmable value. The 8 bit default value for this initialization is all ones (0xFF). The randomizer is shown in Table 5. The generating polynomial is identical to the one used in the OOB randomization circuit.

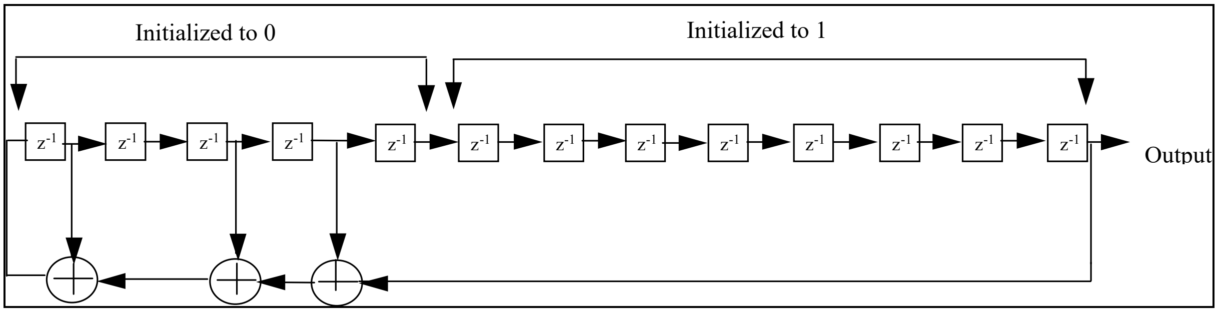

Table 5: RF Return Path Randomizer

6.2.5. RF RETURN PATH MODULATOR

The return path modulator uses differential encoding to enable phase invariant reception at the headend. Two modes of differential decoding are defined to accommodate different system local oscillators. The default mode is used unless the alternate is explicitly selected. The two differential coding schemes are defined in Table 6 as follows:

I Data	Q Data	Output	
		Default Mode	Alternate Mode
0	0	No Change	No Change
0	1	+ 90 degrees CW	– 90 degrees CW
1	0	– 90 degrees CW	+ 90 degrees CW
1	1	180 degrees	180 degrees

Table 6: Phase Change of QPSK Carrier

The output data from the differential encoder feeds the Nyquist pulse shaping filters which are implemented using Square Root Raised Cosine filters with a 50% roll-off ($\alpha = 0.5$). The output of the filters feeds the QPSK modulator which assigns two input bits per symbol. The data transmission rate of the signal is 256 kbps. The return-path modulator operates over the entire specified frequency range from 8 to 40 MHz.

The return path modulator output specifications are summarized in Table 7.

Parameter Name	Specification
Modulation Type	Differentially-Encoded QPSK
Access Scheme	Polling and ALOHA (programmable)
Data Transmission Rate	256 kbps ± 50 ppm

Symbol Rate	128 kbps ± 50 ppm
Channel Spacing	192 kHz
Transmit Filter Shape	Square-Root Raised Cosine, $\alpha = 0.5$
FEC Code	R-S T = 4 (62,54) over GF(256)
RF Output Power Range	+24 dBmV to +60 dBmV
Spurious Output Level (idle state)	< -30 dBmV (in-band), <-65 dBmV (out-of-band)
Spurious Output Level (active state)	< -50 dBc (in-band), <-65 dBmV (out-of-band)
Frequency Range	8.096 MHz to 40.160 MHz in 192 kHz steps
System Clock Frequency	4.096 MHz

Table 7: RF Return-Path Modulator Output Specifications

6.2.6. RF RETURN-PATH DEMODULATOR SPECIFICATION

The return-path differentially-encoded QPSK demodulator uses the same FEC code as the modulator. The required C/(N+I) of the input signal, which includes interference effect (I) due to ingress and impulse noise in the return-path channels, is equal or greater than 20 dB at packet error rate (PER) less than $1 \cdot 10^{-7}$ (corresponds to one packet loss every 5 hours). The required C/(N+I) assumes the simultaneous presence of multiple impairments in the upstream channel. PER is the ratio of the number of error packets to the total number of transmitted packets. The return-path demodulator specifications are summarized in Table 8.

Parameter Name	Specification
RF Input Level	3 ± 10 dBmV
C/(N+I) of Input Signal	≥ 20 dB @ PER[1] < $1 \cdot 10^{-7}$ (post FEC)
Block Synchronization	Unique Word
Channel Tuning Resolution	8 kHz
Signal Level Measurement Accuracy	± 2 dB at the input
Spurious and Harmonics Level	< -40 dBc @ 128 kHz (In-band)

1 PER = Packet Error Rate

Table 8: RF Return-Path Demodulator Specifications

6.3.EXTENDED PRACTICE FOR RETURN-PATH TRANSMISSION

This section provides the specifications of the extended practice for return-path transmission systems. The higher upstream transmission rates are optional for new decoder boxes and cable modems applications.

The return-path modulator output specifications are summarized in Table 9. It references to DOCSIS RFI specifications: Radio Frequency Interface Specification SP-RFIv1.1-I01-990311 [3]. As DOCSIS is still evolving with extended practices for more enhanced data features, the current implementation may be upgraded as future needs arise.

The maximum channel bandwidth (measured at -30 dB) is 25% larger than the symbol rate (in kHz), except for the lowest symbol rate case, which has a bandwidth of 192 kHz.

Parameter Name	Specification
Modulation Type	Differentially-Encoded QPSK and 16-QAM
Symbol Rate	128, 160, 320, 640, 1280, 2560 kSym/s ± 50 ppm
RF output Power Range	8 to 58 dBmV (QPSK), 8 to 55 dBmV (16-QAM)
Transmit Output Power Accuracy	± 2 dB
Output Power Step Size Accuracy	± 0.4 dB
Transmit Filter Shape	Square-Root Raised Cosine, $\alpha = 0.25$
FEC Code	Programmable R-S T = 1 to T=10 over GF(256)
Integrated Phase Noise (in-band)	≤ -43 dBc (including discrete spurious noise)
Spurious Output Level	-53 dBc (during bursts), -72 dBc or -59 dBmV (between bursts)
Frequency Range	5 to 42 MHz

Table 9: RF Return-Path Modulator Output Specifications

The extended transmission specifications, which are based on DOCSIS/MCNS specifications [3] for the RF return-path demodulator, are summarized in Table 10.

Parameter Name	Specification
Nominal Received Power Range (for each carrier)	-16 to +14 dBmV (160 kSym/s) -13 to +17 dBmV (320 kSym/s) -10 to +20 dBmV (640 kSym/s) -7 to +23 dBmV (1280 kSym/s) -4 to +26 dBmV (2560 kSym/s)
RF Input Signal Level Range	± 6 dB of nominal received power
Maximum Received Power	< 35 dBmV
Block Synchronization	Variable-length preamble up to: 512 symbols (QPSK), 256 symbols (16-QAM)
Group-Delay Variation (in-band)	≤ 100 ns

1 SER = Symbol Error Rate

Table 10: Return-path Demodulator Specifications