Adaptive Modem from 4-QAM to 1024-QAM

bc005, “Manero”

The Binary Core coded modulation scheme bc005 (“Manero”) is extremely compact, highly modular, and it supports all square and cross modulation formats from 4- up to 1024-QAM. The modem is well suited for implementation on microwave point-to-point digital radio links and it is compliant with the ETSI EN 302 217-2-2 standard requirements. Typical channel spacings are 3.5-7-14-28-56 MHz (if implemented on low cost FPGAs) and up to 112 MHz (if implemented on high performance FPGAs).

The basic system can be enhanced with asynchronous Cross-Polar Interference Canceler (XPIC) and/or diversity Combiner.

Features

- Eight modulation formats (4-, 16-, 32-, 64-, 128-, 256-, 512-, and 1024-QAM).
- Adaptive modulation switching based on channel measurement and internal service channel signalling.
- Byte interface compatible with both asynchronous and synchronous data flow.
- Finely tuneable symbol frequency.
- Polynomial predistortion.
- TX and RX I/Q impairments recovery (amplitude and phase unbalance).
- Timing recovery with digital re-sampling.
- Carrier recovery with pilot symbols for improved robustness to phase noise.
- Automatic frequency recovery for fast carrier acquisition.
- 20-tap adaptive fractionally spaced equalizer.
• Efficient coding scheme based on punctured convolutional code on the two least significant bits and concatenated Reed-Solomon code.
• Optional asynchronous XPIC and Combiner.
• User definable service channel for closed-loop communication between transceivers.

**FEC Reconfigurability and Throughput**

The Binary Core bc005 Modem “Manero” provides various synthesis options and dynamically reconfigurable parameters in order to optimize the core to your application. For example

• Optional pilot symbol rate – independently selectable for each modulation format, even in the case of adaptive modulation. The number of pilot symbols in a 960-symbol radio frame, \( N_{\text{pilot}} \), can be selected by the user, provided that \( N_{\text{pilot}} + 1 \) is a divisor of 960. A pilot symbol is sent every \( 960/N_{\text{pilot}} + 1 \) information symbols.

• Various control loop gains and bandwidths.
• Convolutional code rate – independently selectable for each modulation format, even in the case of adaptive modulation. Allowed rates

\[
R_{\text{conv}} = \frac{1}{2}, \frac{2}{3}, \frac{3}{4}, \frac{4}{5}, \frac{5}{6}, \frac{6}{7}, \frac{7}{8}, \frac{8}{9}, \frac{9}{10}, 1.
\]

• Reed-Solomon code rate. Allowed rates

\[
R_{\text{RS}} = \frac{k - 1}{n},
\]

with \( n - k \leq 16 \), \( n \) and \( k - 1 \) defined by the user.

• The interleaver depth \( D \) can be set by the user in the range

\[
1 \leq D = \frac{n}{M} \leq 32,
\]

with \( D \) and \( M \) integers.

The transmission bit rate depends on channel spacing, modulation format, pilot symbol rate, convolutional code rate, Reed-Solomon code rate and user service channel rate. Example throughputs are as follows.

• \( N = 7 \) (128-QAM), \( R_{\text{conv}} = 4/5 \), no pilot symbols, \( R_{\text{RS}} = 242/252 \), we obtain

\[
\eta = 6.325 \text{ b}/2D,
\]

which is adequate for SDH STM-1 transmission in 28 MHz channel spacing.
An example adaptive modulation scheme that switches between 8 modulation formats, $R_{RS} = 235/252$, and the other parameters defined in the following table.

<table>
<thead>
<tr>
<th>$N$</th>
<th>$R_{conv}$</th>
<th>$N_{pilot}$</th>
<th>$\eta$ (bit/2D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-QAM</td>
<td>1/2</td>
<td>0</td>
<td>0.923</td>
</tr>
<tr>
<td>4-QAM</td>
<td>4/5</td>
<td>0</td>
<td>1.481</td>
</tr>
<tr>
<td>16-QAM</td>
<td>1/2</td>
<td>0</td>
<td>2.784</td>
</tr>
<tr>
<td>32-QAM</td>
<td>3/4</td>
<td>0</td>
<td>4.179</td>
</tr>
<tr>
<td>128-QAM</td>
<td>1/2</td>
<td>0</td>
<td>5.576</td>
</tr>
<tr>
<td>512-QAM</td>
<td>1/2</td>
<td>29</td>
<td>7.219</td>
</tr>
<tr>
<td>1024-QAM</td>
<td>1/2</td>
<td>47</td>
<td>7.978</td>
</tr>
<tr>
<td>1024-QAM</td>
<td>1</td>
<td>47</td>
<td>8.865</td>
</tr>
</tbody>
</table>

**XPIC and Combiner (Optional)**

The adaptive modulation “Manero” can be enhanced with an embedded XPIC/Combiner block, for systems using space diversity and frequency reuse.

- Asynchronous with respect to RF local oscillators.
- 20-tap fractionally-spaced equalization for main, cross-polar, and diversity branches.
- Embedded differential carrier recovery with frequency error compensation for asynchronous operation.
- Fixed delay compensation (e.g., different cable lengths) between main and diversity (cross-polar).
- I/Q delay compensation.
- Maximum tolerable dynamic delay between main and interferer: $4 \times$ symbol time (about 160 ns in 28 MHz channel spacing).
- Combiner performance: 3 dB gain on $10^{-6}$ BER threshold for balanced input signals.
- XPIC performance is measured using XPIC Improvement Factor (XPIF)

$$XPIF = \left| \frac{C}{I} \right|_{\text{w/o XPIC}} - \left| \frac{C}{I} \right|_{\text{with XPIC}},$$

where $\left| \frac{C}{I} \right|_{\text{w/o XPIC}}$ is the Carrier-to-Interferer ratio without XPIC and $\left| \frac{C}{I} \right|_{\text{with XPIC}}$ is the Carrier-to-Interferer ratio with XPIC, required to have 1 dB degradation of the $10^{-6}$ BER threshold (reference: single equalizer, no interferer). Using 128-QAM, 28 MHz channel-spacing, convolutional code rate 4/5 and Reed-Solomon code rate 242/252, gives $\left| \frac{C}{I} \right|_{\text{w/o XPIC}} = 30$ dB, $\left| \frac{C}{I} \right|_{\text{with XPIC}} = 12$ dB, resulting in a XPIF of 18 dB.