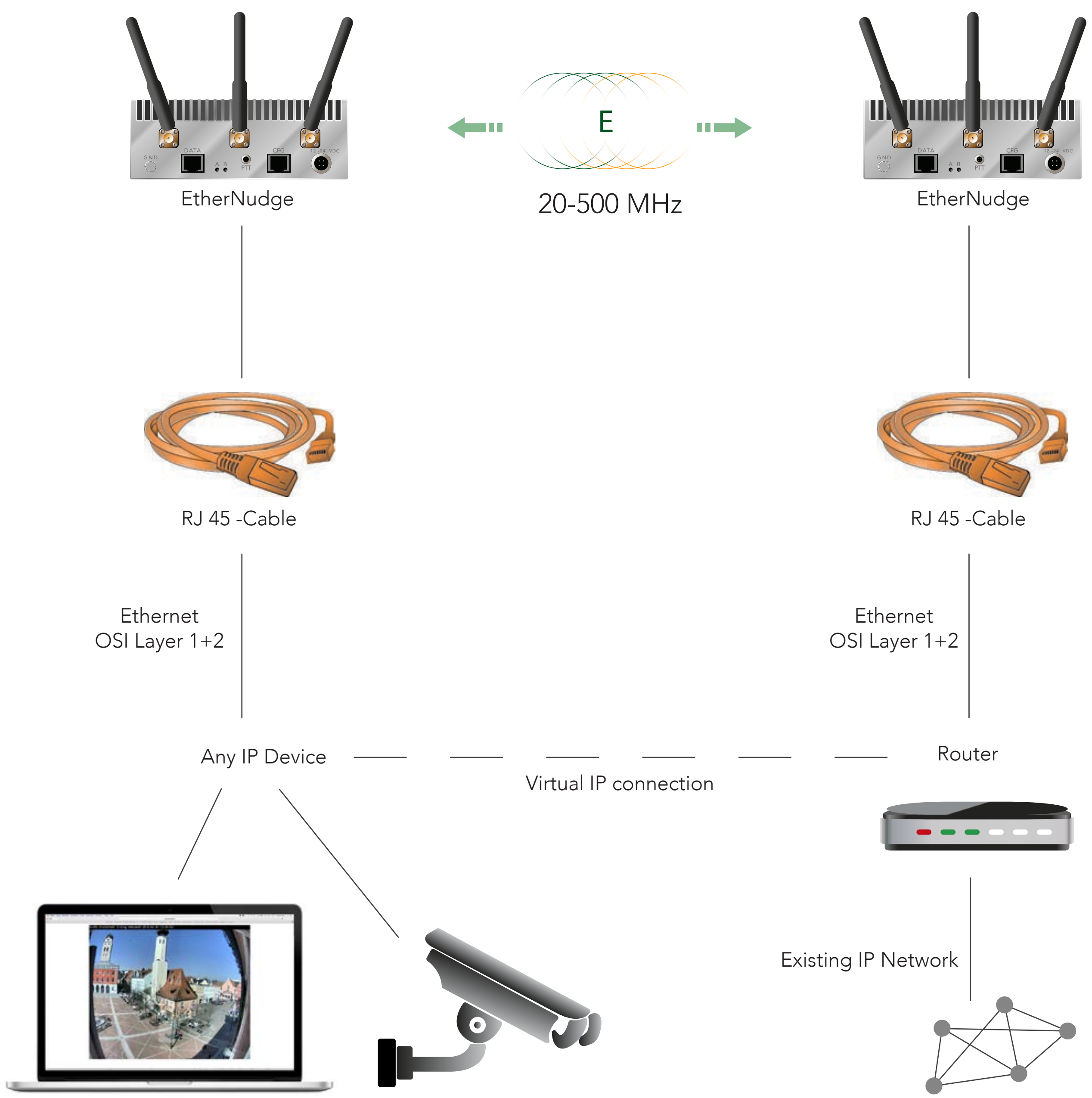
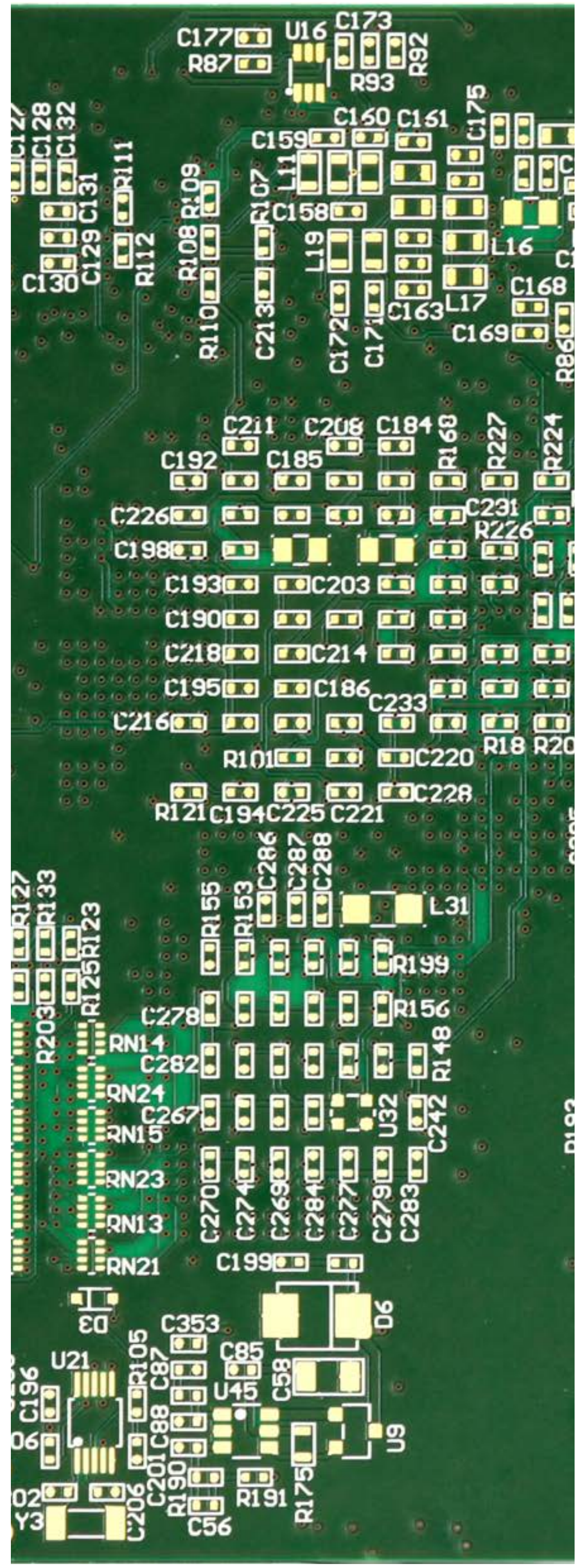
MODULATEAM

Technical Deck

01 OVERVIEW

EtherNudge is a transparent LAN extender used in terrestrial narrow-band mid/long distance communication systems for stationary or mobile applications.
It steps in where conventional solutions reach their limit.



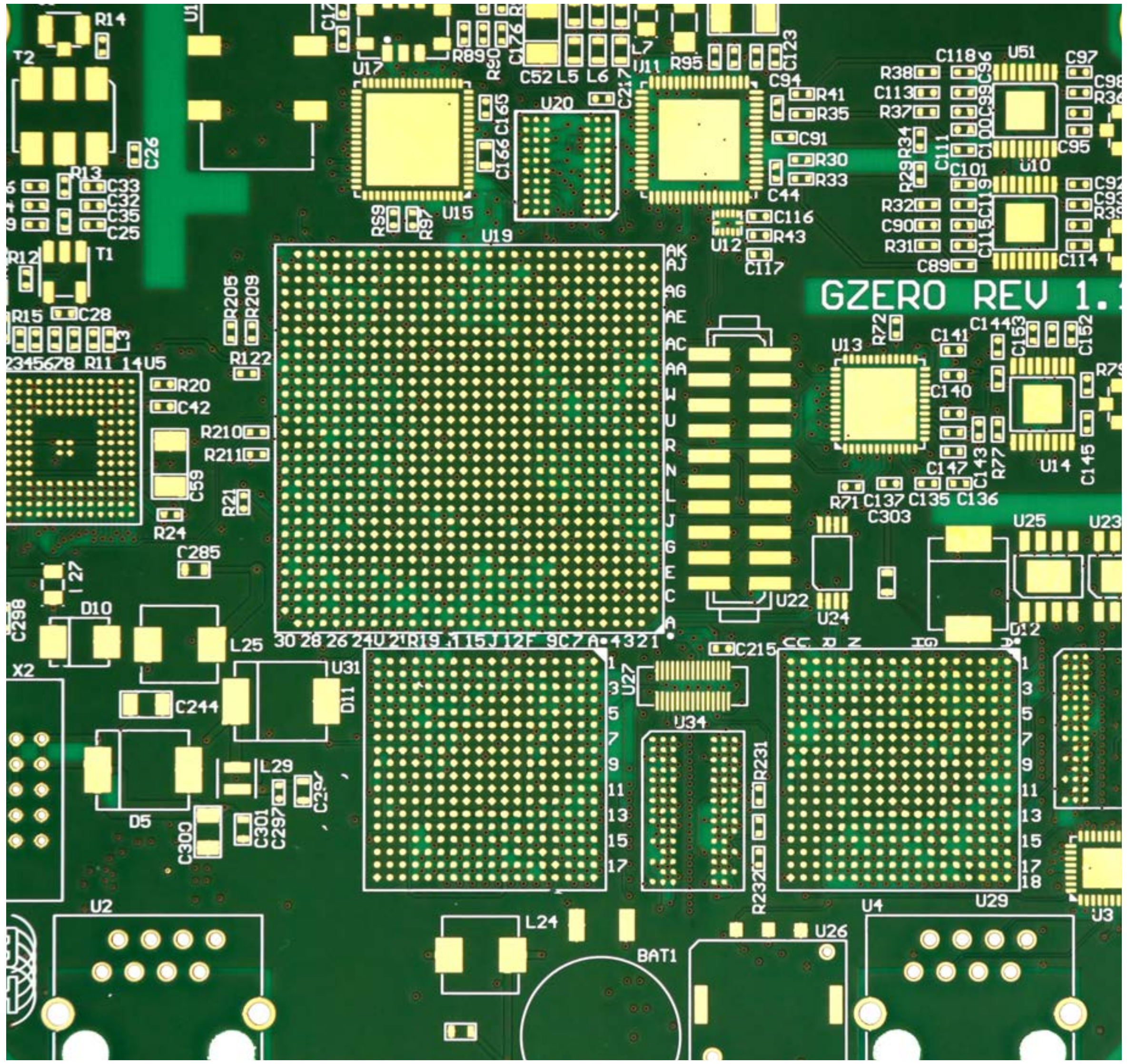


Depending on the frequency, EtherNudge's communication range exceeds 100km with less than one Watt of mean transmission power and can provide up to worldwide coverage with increased power. The available, software controlled, frequency spectrum can be selected seamlessly from 20 MHz to 500 MHz. Maximum bandwidth is 200 kHz, optionally 400kHz, with a net spectral efficiency of up to 10 Bit/Hz/sec, so the maximum available bandwidth for data is up to 2, respectively 4 Mbit per second.

EtherNudge is designed for maximum reliability and quality. Specifically its RF performance is highly optimized for mobile applications, and even under the worst channel conditions found in rough environments, it performs near theoretical limits, in line-of-sight as well as non-line-of-sight. It uniquely qualifies as a key communication tool in order to instantly deploy network infrastructure.

EtherNudge is easy to add into existing networks with no structural change. No additional software or protocol is required, nor is any additional set-up or configuration within an existing infrastructure needed.

02 DEVELOPMENT PERFORMANCE



EtherNudge significantly benefits from ModulaTeam's excellent development history.

Over 100 man-years of development, especially OFDM modem technologies, hardware design and radio know-how is integrated into this product.

The overall system design, with highly integrated components, delivers an outstanding software defined radio solution.

This enables important technical features such as ultra rapid modem synchronization.

A unique combination of different skill-sets in one company enabled clean room implementations in all areas.

100

man-years of development

Modem

Based on research at a European university the development started in the mid-90s in Germany and Austria leading to a product and successful OEM sales of this stand-alone component.
These assets have been taken over by ModulaTeam and further developed to create today's solution.

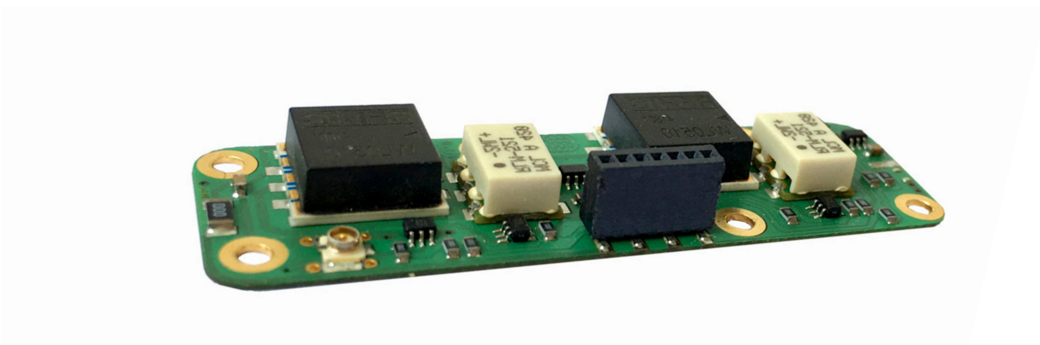
Radio

The unique radio design has been developed by ModulaTeam based on core developments acquired from international companies and supported by experts from Germany and the Netherlands.

Hardware

Complete hardware design has been accomplished in-house, especially the unique design of the data path from the physical network to the signal processors and digital-analog converters. Local experts created the layout and routing of the final circuit boards.

03 TECHNICAL COMPONENTS & FEATURES



- Radio
  - Best in class Non-loss Automatic Gain Control (patent pending)
  - Software controlled radio seamlessly covering 20 to 500 MHz with bandwidth as low as 6.25 kHz up to 200 kHz, optionally 400 kHz, in steps of 6.25 kHz, in a single device
  - Most innovative Micro Footprint Filter Architecture
- Modulator/Demodulator (MODEM)
  - In-house implementation; no standard chipsets or 3rd party solutions
  - Highly optimized for mobile applications, stable operation at velocities up to 300 km/h, robustness against Doppler shift/spread and multipath signal aggregation
  - Ultra-fast synchronization time in 6-100 milliseconds depending on bandwidth
  - Adaptive Coding and Modulation (ACM)
- Digital Interface
  - Covering 10BASE-T and 100BASE-T with Negative Overhead Synchronization (NOS)
  - No configuration or IP address needed
  - Automatic data rate adaption on-the-fly
- System
  - Ultra-fast power up operation readiness in one second
  - Optimized for IP communication
  - Minimized setup procedure
- Operation Mode
  - Frequency Division Duplex, Time Division Duplex, Simplex
- Network Setups
  - Point-to-multipoint (Broadcasting), Point-to-point, multiple peers (swarm)

Parameters*

* Depend on licensed functionality and are subject to change without notice.

Radio

Transmission Mode	Frequency Division Duplex, Time Division Duplex, Simplex
Frequency Range	20MHz-500MHz seamless
Power	+36dBm (peak)
External Amplifier Control	External booster controlled over PTT
Bandwidth ordering options	200 kHz, 400kHz
Channel Spacing	N x 6.25 kHz (N=1-64)
Carrier frequency configuration	Configurable 1 Hz steps
Receiver Sensitivity	>95dB
Diversity	Antenna diversity x2

Modem

Topology	PtP, PtMP, MPtP, Mesh, Swarm
Modulation	COFDM, QAM-4 to QAM-65536
Coding	Trellis code
TX signal synthesis, DAC	Full digital signal synthesis with digital up conversion to carrier frequency
RX signal path, ADC	12/14-Bit ADC, RF direct sampling with 3x ADC
AGC	Direct, non-loss automatic controlled

Common

Hardware Core	DSP ADSP-21469 SoC SmartFusion2 M2S050
Built in data interfaces (transparent cable replacement)	10/100-BaseT, RJ-45
Built in management interface (local and remote)	10/100-BaseT, RJ-45
GUI	Web-based, SNMP optional
Antenna Connector	SMA
Power Connector	M12, 4-pole
External PPT Connector	M5, 4-pole
DC input range	9VDC-36VDC
Typical Power consumption	>35W
Firmware Upgrade	Via web interface
Temperature range and environment	Environment: -indoor or outdoor cabinet with direct sun protection. -Operating temperature: -30°C to +50°C
Storage, Transport	Temperature –40°C to 85°C Humidity 95%, non condensing
Mechanical Dimensions	175x160x65mm
Weight	2.3 kg

04 UNIQUE SELLING PROPOSITION

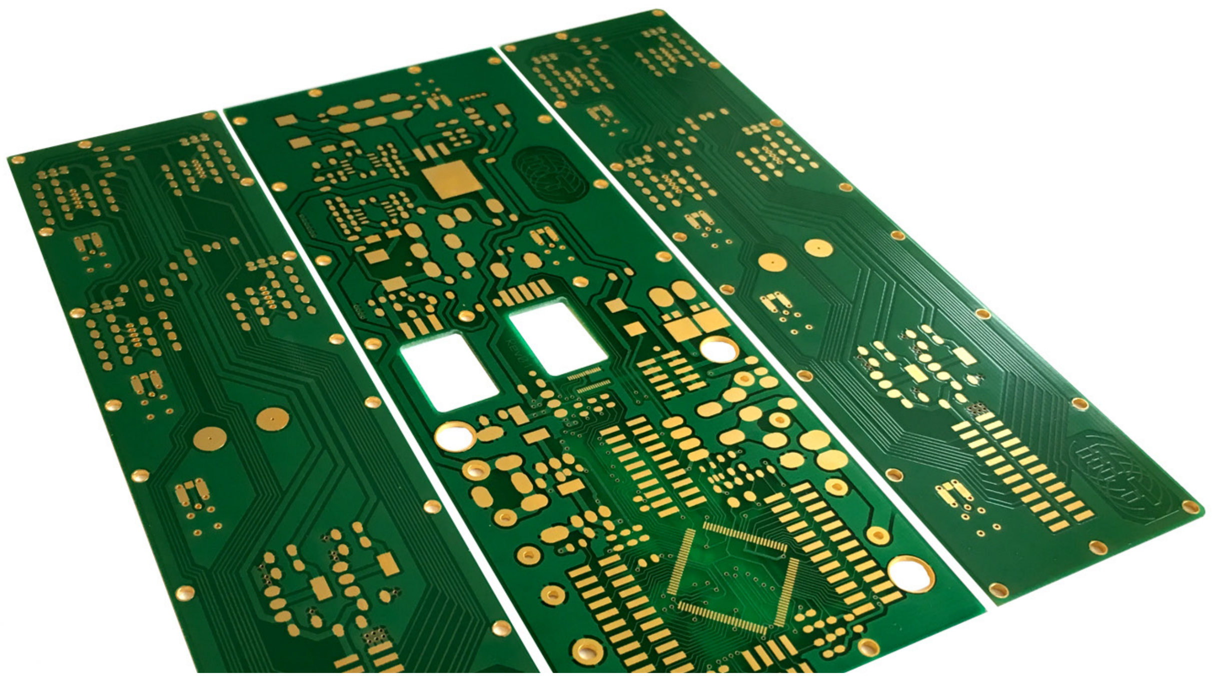
1. EtherNudge provides *instant deployment* of communication networks in areas with outdated, insufficient, damaged or even no infrastructure.

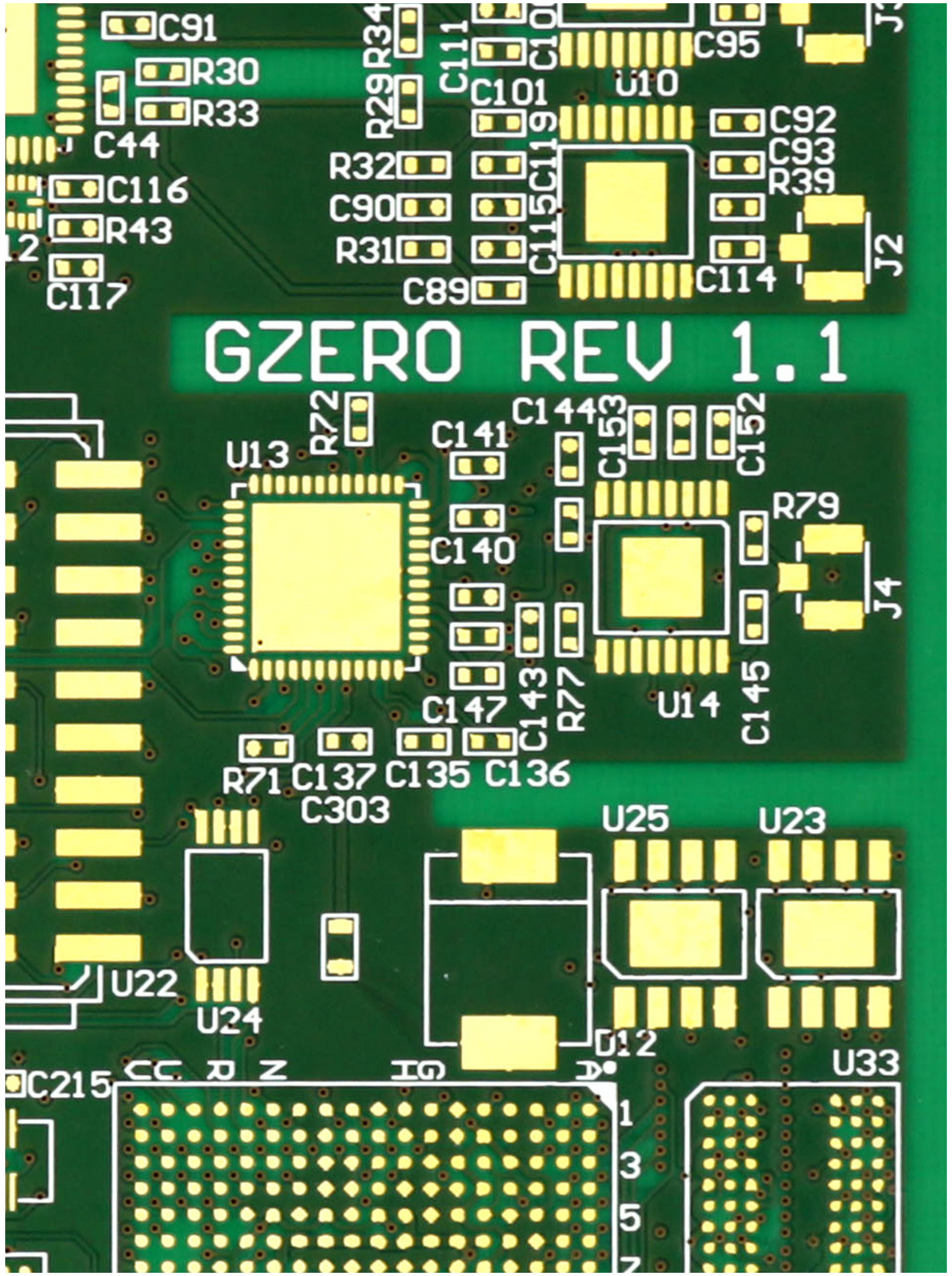
2. EtherNudge *performs completely free* within and outside regulated frequency ranges due to its software configurable frequency spectrum, ranging from 20 – 500 MHz in a single device

3. EtherNudge *works with no single point of failure*, due to its swarm communication capabilities

4. EtherNudge is highly *optimized for real mobility,* performing on-the-fly data rate adaption near theoretical limits.

5. EtherNudge is a wireless cable replacement that is invisible to the application and-needs *no data link configuration.*





05 SECURITY

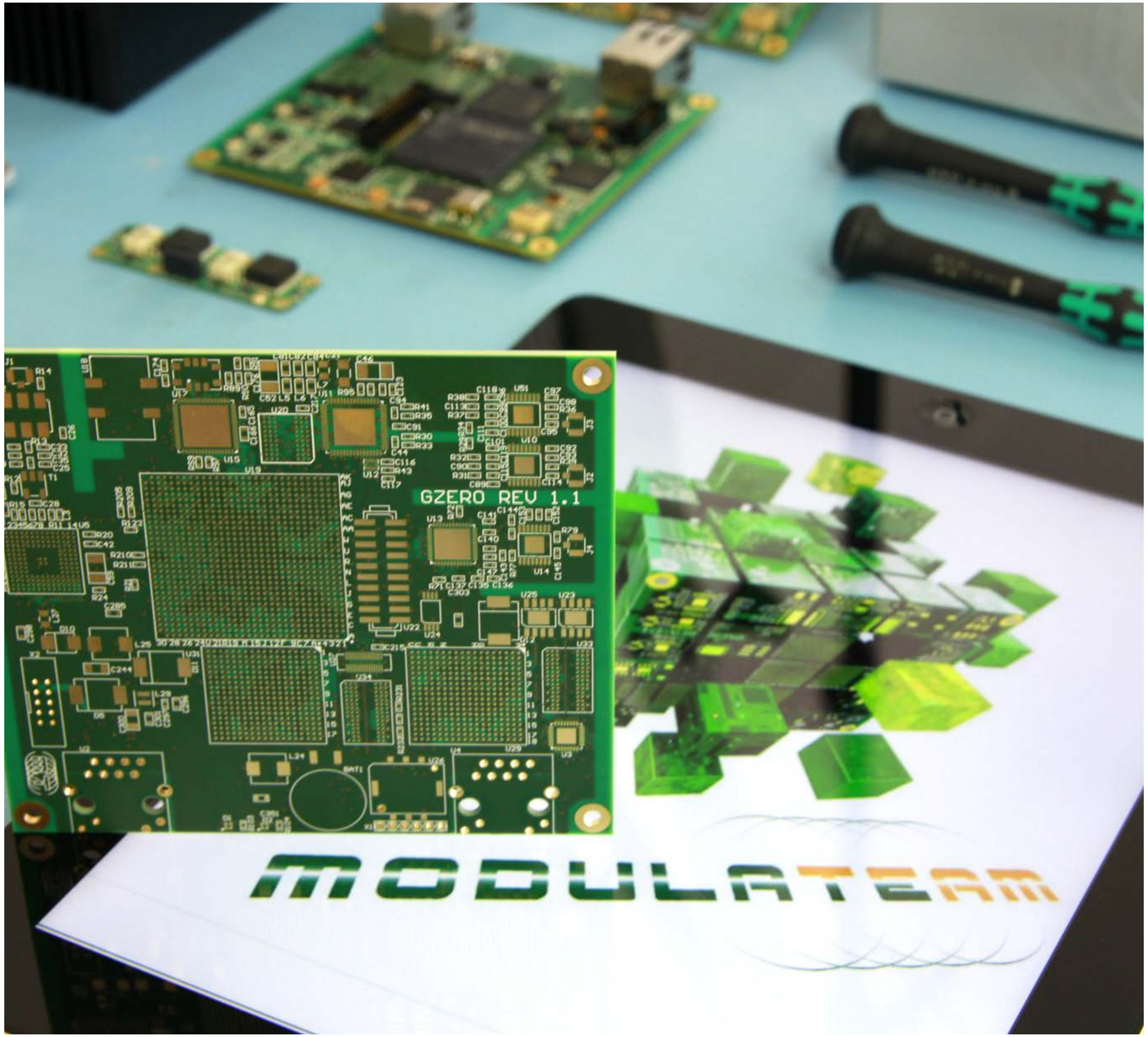
The software is stored in an onboard flash memory protected by latest encryption algorithms executed in the SoC Field Programmable Gate Arrays (FPGA). Most advanced security features of the respective chipsets in combination with military-grade smartcard technology are incorporated to avoid cloning or the copying of software.

In order to avoid the abuse of communication on non-assigned frequencies and bundles, EtherNudge is comprised of a sophisticated access control mechanism to protect users and regulators.

In addition, EtherNudge uses the latest PCB layout methods in order to harden/counteract hardware cloning and hijacking.

06 MANUFACTURING

EtherNudge is designed and assembled entirely in-house in order to ensure the highest level of quality. Printed circuit boards and mechanics are built and assembled exclusively by selected suppliers in Germany.



EtherNudge is designed for use in mobile environments.
In these environments, different aspects are of interest that are described in detail in the following pages.

Spectral Efficiency

Spectrum efficiency is the net data rate per bandwidth (bit/s/Hz), where data rate is measured by the number of bits actually transferred from end to end, excluding the overhead of error-correction codes. EtherNudge uses modulation schemes 4QAM to 65kQAM. The theoretical limit of spectral efficiency in this case is

DataRatePerHz = SymbolRate * CodeRate

where SymbolRate denotes the number of bits transmitted by a symbol and CodeRate denotes the code rate. The following Table 1 gives an overview on modulation schemes, code rates and resulting net symbol rates technically available in EtherNudge in bit/s/Hz.

Symbol	Symbol rate	Code rate	DataRate
QPSK	2	1/2	1
16QAM	4	1/2	2
64QAM	6	2/3	4
256QAM	8	3/4	6
1024QAM	10	4/5	8
4096QAM	12	5/6	10
16384QAM	14	6/7	12
65536QAM	16	7/8	14

Table 1 Net symbol rates

As restrictions on out of band (OoB) emissions have to be considered, the number of OFDM carriers actually used in general is smaller than the FFT size. The frequency spectrum, covered by carriers not used at both sides of the band is called the guard band. Beside code rate, spectral efficiency is influenced by the guard band, the length of cyclic prefix (CP) and the number of pilot tones.

Denoting the guard band and the number of pilot tones as ratios of the total number of carriers: Rguard, Rpilot and CP length as ratio of the symbol length (in time) RCP, spectral efficiency is calculated by

DataRatePerHz=

SymbolRate * CodeRate * (1 - Rpilot) * (1 – Rguard) * (1 – RCP)

The guard band ratio typically has a value of 0.25. The following table gives an overview on spectral efficiency reduction depending on pilot configuration and CP ratio.

Pilot spacing Rpilot RCP	2 0.5	4 0.25	6 0.16	8 0.125	12 0.083	16 0.0625	24 0.0416	32 0.03125
0.0625	0.352	0.527	0.586	0.615	0.645	0.659	0.674	0.681
0.125	0.328	0.492	0.547	0.574	0.602	0.615	0.629	0.636
0.25	0.281	0.422	0.469	0.492	0.516	0.527	0.539	0.545
0.33	0.250	0.375	0.417	0.438	0.458	0.469	0.479	0.484

Table 2 Reduction of spectral efficiency depending on pilot spacing and CP length

Example 1:
In mobile use, where the maximum symbol data rate achievable is 4096QAM, combined with the values in Table 2, maximum spectral efficiency of EtherNudge is

DataRatePerHzmax = 12 * 5/6 * 0.574 ≈ 5,74 bit/s/Hz

Example 2:
In stationary use, where the maximum symbol data rate achievable is 65kQAM, combined with the values in Table 2, maximum spectral efficiency of EtherNudge is

DataRatePerHzmax = 16 * 7/8 * 0.674 ≈ 9,53 bit/s/Hz

Maximum Velocities

The main restricting factor for velocities is the Doppler Effect. The system has to compensate for two impacts, Doppler shift and Doppler spread.

The first is the shift of the center frequency caused by the movement, resulting in shifts of the OFDM carrier frequencies. The second describes the difference between the carrier frequencies of different incoming multipath signals. The worst case scenario occurs when a vehicle is moving away from signal source along the line of sight with velocity V in the direction of a reflecting object. Doppler shift reduces the center frequency F of the direct signal by a value Fshift depending on V and F. The center frequency of the reflected signal is increased by the same value, resulting in a Doppler spread twice the value of the Doppler shift Fshift. Thus, Doppler spread has a more restricting impact on velocities than Doppler shift.

In this paper, maximum velocity is determined by assuming that the Doppler spread is not greater than half of the OFDM carrier spacing. It thus depends on the bandwidth and the number of OFDM carriers (or OFDM FFT size, respectively).

The following table gives an overview on maximum velocities for different bandwidth and different center frequencies.

Center Frequency Bandwidth	20 MHz	50 MHz	100 MHz	250 MHz	500 MHz
6.25 kHz	531.2 km/h	531.2 km/h *	132.8 km/h **	212.5 km/h **	106.2 km/h **
12.50 kHz	1062.5 km/h	531.2 km/h	531.2 km/h *	425.0 km/h **	212.5 km/h **
25.00 kHz	2124.9 km/h	1062.5 km/h	531.2 km/h	425.0 km/h *	425.0 km/h **
50.00 kHz	4249.8 km/h	2124.9 km/h	1062.5 km/h	425.0 km/h	425.0 km/h *
100.00 kHz	8499.6 km/h	4249.8 km/h	2124.9 km/h	850.0 km/h	425.0 km/h
200.00 kHz	16999.2 km/h	8499.6 km/h	4249.8 km/h	1699.9 km/h	850.0 km/h
400.00 kHz	33998.1 km/h	16999.2 km/h	8499.6 km/h	3399.9 km/h	1699.9 km/h

Table 3 Maximum velocity depending on center frequencies and bandwidth, FFT size 128, 64*, 32**

Number of carriers (FFT size) is 128 in general. Values in fields marked by * and ** are calculated for FFT sizes of 64 and 32 respectively.

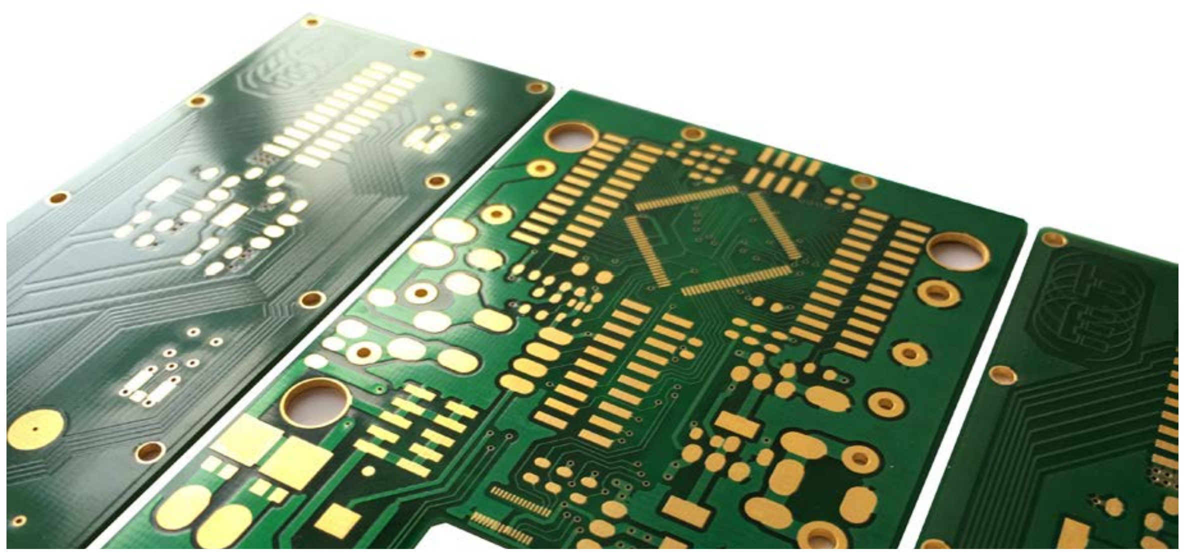
Theoretically Required Signal to Noise Ratios

For modulation M-QAM (M € {4,16,64,256,1024,4096,16384,65536}) and given signal to noise ratio (SNR), a theoretical calculation of the symbol error rate (SER) vs. signal to noise ratio is given by formula:

$$SER(M,SNR) = 2\left(1-\frac{1}{\sqrt{M}}\right)erfc\left(\sqrt{\frac{3}{2(M-1)}SNR}\right)-\left(1-\frac{2}{\sqrt{M}}+\frac{1}{M}\right)erfc^2\left(\left(\sqrt{\frac{3}{2(M-1)}SNR}\right)\right)$$

M	min SNR [dB]
4	11,8
16	19,0
64	25,3
256	31,4
1024	37,5
4096	43,5
16384	49,5
65536	55,6

Table 4 Min. required SNR for given M-QAM at SER 10-4



Multipath Properties

Difference in Multipath Lengths

Cyclic prefix length determines the size of the time interval in which different multipath signals do not interfere with each other but can be aggregated. Differences in time delay can also be expressed as differences of path lengths which may be a more descriptive entity.

It is used in the following tables, where maximum path length differences are shown depending on CP ratio (related to symbol length) and bandwidth for FFT sizes 128, 64 and 32.

CP ratio Bandwidth	0.0625	0.125	0.25	0.333
6.25 kHz	368.4 km	736.8 km	132.8 km	1962.8 km
12.50 kHz	184.2 km	368.4 km	736.8 km	981.4 km
25.00 kHz	92.1 km	184.2 km	368.4 km	490.7 km
50.00 kHz	46.0 km	92.1 km	184.2 km	245.3 km
100.00 kHz	23.0 km	46.0 km	92.1 km	122.7 km
200.00 kHz	11.5 km	23.0 km	46.0 km	61.3 km
400.00 kHz	5.8 km	11.5 km	23.0 km	30.7 km

Table 5 Maximum path length differences depending on center frequencies and bandwidth, FFT size 128

CP factor Bandwidth	0.0625	0.125	0.25	0.333
6.25 kHz	184.2 km	368.4 km	736.8 km	981.4 km
12.50 kHz	92.1 km	184.2 km	368.4 km	490.7 km
25.00 kHz	46.0 km	92.1 km	184.2 km	245.3 km
50.00 kHz	23.0 km	46.0 km	92.1 km	122.7 km

Table 6 Maximum path length differences depending on center frequencies and bandwidth, FFT size 64

CP factor Bandwidth	0.0625	0.125	0.25	0.333
6.25 kHz	92.1 km	184.2 km	368.4 km	490.7 km
12.50 kHz	46.0 km	92.1 km	184.2 km	245.3 km
25.00 kHz	23.0 km	46.0 km	92.1 km	122.7 km

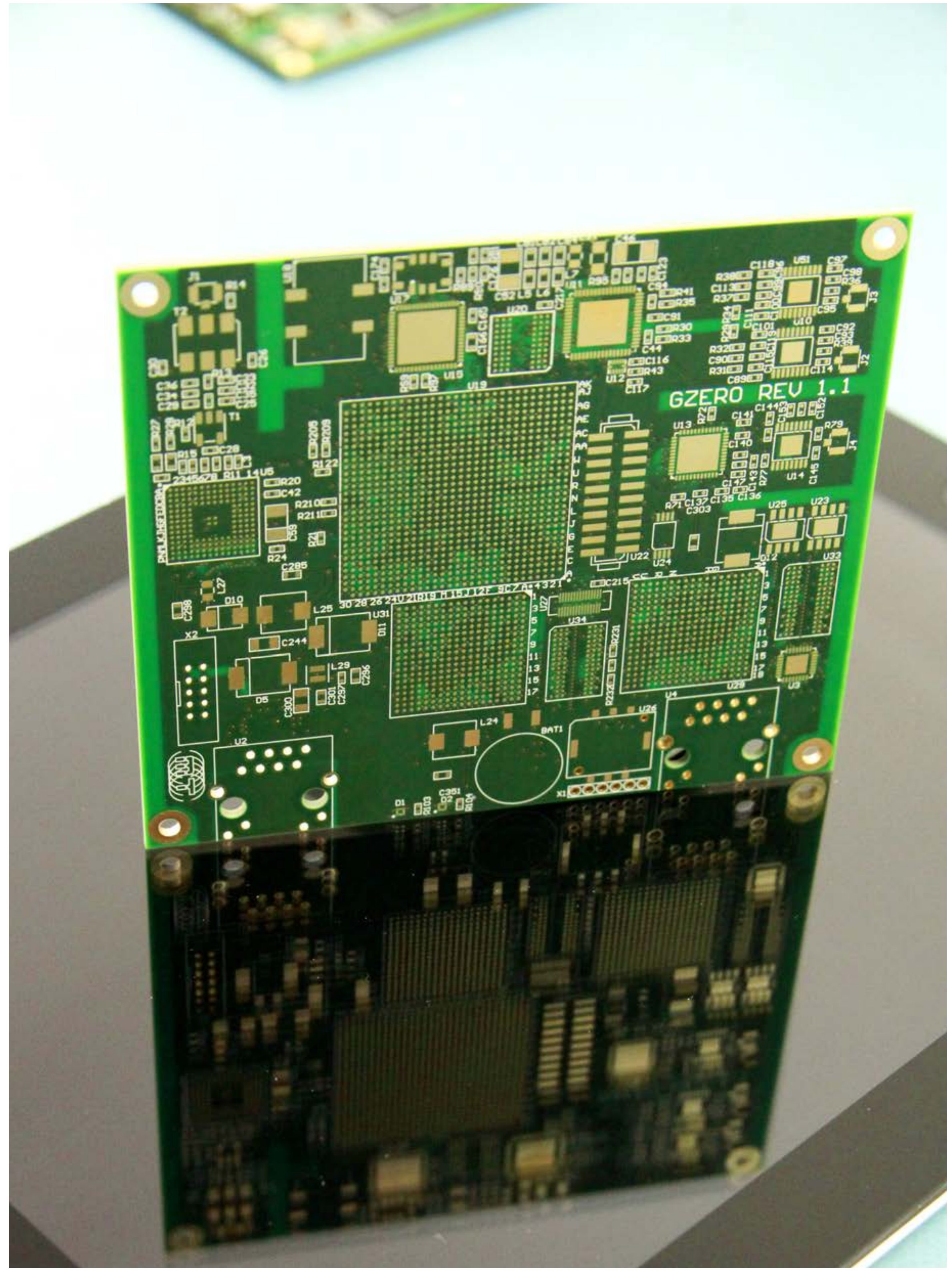
Table 7 Maximum path length differences depending on center frequencies and bandwidth, FFT size 32

Maximum Number of Usable Multipath Signals

The maximum number of different multipath signals that can be aggregated by the algorithm used in EtherNudge is half the number of carriers allocated for pilot tones. In EtherNudge at least 2 multipath signals are able to be processed. Assuming a guard band of 25% (s. section 3.1), the following Table 8 shows the maximum number of identifiable multipath signals depending on the carrier spacing between pilot tones and FFT size.

Pilot spacing FFT Size	2	4	6	8	12	16	24	32
128	24	12	8	6	4	3	2	1
64	12	6	4	3	2	1	1	—
32	6	3	2	1	1	—	—	—

Table 8 Maximum number of multipath signals depending on pilot spacing and FFT size



BSS MATERIEL

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