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Citation for published version (APA):

Lee, S. C. J., Breyer, F., Cárdenas, D., Randel, S., & Koonen, A. M. J. (2009). Real-time gigabit DMT transmission over plastic optical fibre. *Electronics Letters*, 45(25), 1342-1343.
<https://doi.org/10.1049/el.2009.1803>

DOI:

[10.1049/el.2009.1803](https://doi.org/10.1049/el.2009.1803)

Document status and date:

Published: 01/01/2009

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
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Real-time gigabit DMT transmission over plastic optical fibre

S.C.J. Lee, F. Breyer, D. Cárdenas, S. Randel and A.M.J. Koonen

For the first time, a real-time 1.25 Gbit/s discrete multitone (DMT) transmitter implemented in a field-programmable gate array is demonstrated for use in low-cost, standard 1 mm step-index plastic optical fibre applications based on a commercial resonant-cavity LED and a large-diameter Si-photodiode.

Introduction: Derived from the more general orthogonal frequency division multiplexing (OFDM), discrete multitone (DMT) is a baseband version that is widely applied in Digital Subscriber Line (DSL) systems such as ADSL and VDSL [1]. Recently, it has been shown that DMT can also be employed to enable high-speed transmission over dispersive optical channels such as plastic fibre, demonstrating gigabit transmission over bandwidth-limited, LED-based step-index plastic optical fibre (SI-POF) links with conventional transceivers [2]. Such applications are useful in automotive networks, owing to low cost and better robustness and stability in terms of temperature behaviour and lifetime of LEDs. Until now, only offline signal processing has been used for proving the concept of gigabit transmission with DMT. Commercial VDSL DMT chipsets only provide transmission rates of up to several tens of Mbit/s. Although a real-time multi-gigabit OFDM receiver was reported in [3], details about hardware resources and implementation complexity were not given.

This Letter reports the implementation of a 1.25 Gbit/s DMT transmitter in a field programmable gate array (FPGA) and investigates the feasibility of real-time gigabit transmission with DMT in terms of hardware resources. First, experimental results over a 10 m SI-POF link for application in automotive networks are presented.

System implementation: Fig. 1 shows a functional block diagram of the implementation of the DMT transmitter in an FPGA (Xilinx Virtex-4 FX100). A PRBS sequence is generated as input source to the DMT modulator. This serial input sequence is serial-to-parallel converted and mapped onto different quadrature amplitude modulation (QAM) constellation points, implemented using read-only memory cells. After this, the parallel QAM symbols are serialised because the pipelined IFFT-core expects serial input data. A demultiplexer (DEMUX) is needed to split the serial data into two parallel processing streams clocked at 312.5 MHz each because the FPGA cannot support a high clock frequency of 625 MHz. As a result, two IFFT-cores (clocked at 312.5 MHz each) are needed to process the data which is sent to the digital-to-analogue converter (DAC) at double data rate after reordering of the DMT frames and insertion of training preambles. The DAC samples at a speed of 625 MSamples/s.

Fig. 1 FPGA implementation of DMT transmitter and experimental setup for performance evaluation

Fig. 2 depicts the relative amount of resources needed for each of the functional blocks when everything was to be implemented using only FPGA slices. A Virtex-4 slice consists of two flip-flops and two four-input look-up tables. In the actual implementation, FPGA-specific

hardware such as embedded multipliers and block RAMs are used so that full performance can be achieved. As expected, it can be seen from Fig. 2 that the IFFT core demands most resources. Depending on the bandwidth of the DMT signal and the sampling speed of the DAC, parallelisation is needed because of the limited FPGA chip rate. For a bit rate of 1.25 Gbit/s, implementation in an application-specific integrated circuit (ASIC) will allow higher chip rates and discard the need for parallelisation. However, for higher bit rate OFDM/DMT systems which are currently being proposed for >10 Gbit/s transmission over singlemode and multimode silica fibre [3], parallelisation will nevertheless be needed because ASICs will not be able to handle such high chip rates. Therefore, for such applications, more resources for IFFT processing will be required because of the need for (several orders of) parallelisation. This is an important issue which should be considered when implementation complexity of digital signal processing techniques in high-speed fibre-optic transmission systems are studied.

Fig. 2 Virtex-4 FPGA slices utilised in DMT transmitter according to functionality (normalised)

Fig. 3 Bit-allocation per subcarrier (Fig. 3a), measured SNR per subcarrier for electrical back-to-back and after transmission over 10 m SI-POF (Fig. 3b), spectrum of DMT signal measured for electrical back-to-back (Fig. 3c) and after 10 m SI-POF (Fig. 3d)

Experimental results: The experimental setup for evaluating the performance of the DMT modulator is shown in Fig. 1. The DMT sequence generated by the DAC is used to drive an RC-LED for transmission over 10 m of SI-POF. Such distances are typical for automotive networks and the main limitation originates from the low bandwidth of the LED-based transmitter. The received optical power after 10 m of SI-POF is -3 dBm and the modulation index is approximately 0.6. A large diameter (540 μ m) Si-photodiode with an integrated transimpedance amplifier is used to receive the optical signal and a digital storage oscilloscope sampling at 2.5 GSamples/s is used for demodulation and evaluation of the received DMT sequence. Fig. 3 shows the results of the real-time DMT transmitter. A 128-point IFFT is used for the DMT modulator where the first and last subcarriers are set to 0. Therefore, a total of 62 subcarriers are available and used for information transmission. The bit allocation is depicted in Fig. 3a. A four-point cyclic prefix is used and 10 preambles per 100 DMT frames are transmitted for training and channel estimation purposes. The bandwidth of the DMT signal is

approximately 303 MHz, resulting in a bit rate of 1.25 Gbit/s (1.125 Gbit/s after deduction of preamble overhead). The signal-to-noise ratio (SNR) per subcarrier of the DMT transmitter was measured and is plotted in Fig. 3b for both electrical back-to-back and transmission over 10 m of SI-POF. The bandwidth limitation of the SI-POF channel can clearly be seen. The spectrum of the DMT signal is measured and depicted in Fig. 3c, where its aliasing product can be observed at frequencies beyond 312.5 MHz. Unlike in wireless communications, this aliasing product does not need to be filtered away before transmission over the SI-POF because it does not interfere with other communication bands. Observe in Fig. 3d that the aliasing product is suppressed by the low-bandwidth SI-POF channel. In Figs. 4a–d, the received constellation diagrams (after the 10 m SI-POF) are plotted for the subcarriers indicated by the arrows in Fig. 3a.

Fig. 4 Received constellation diagrams after 10 m SI-POF for subcarriers indicated by arrows in Fig. 3a

Conclusion: An analysis of hardware resources needed for implementing gigabit DMT transmission shows that parallelisation of signal processing functions plays an important role in defining hardware complexity when operating at high bit rates. Experimental results verify successful implementation of a real-time 1.25 Gbit/s DMT transmitter over 10 m of SI-POF with an RC-LED. The results prove that DMT is a promising candidate for upgrading conventional LED-based SI-POF networks to enable gigabit transmission.

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23 June 2009

doi: 10.1049/el.2009.1803

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