SENCITY™LINK 60 – A WIRELESS POINT-TO-POINT TRANSPARENT ETHERNET BRIDGE

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Abstract: The paper highlights the key technological aspects of the recently introduced SENCITY™Link 60 millimeter wave communication system. The basic system design choices are explained as driven from regulatory and technological constraints. The technological approach to the implementation of the key building blocks is outlined. Metalized injection molded plastics has been used to realize the planar antenna and the transmit/receive filter. The active millimeter wave subunit is based on low temperature co-fired ceramics. The corresponding building blocks are discussed and their integration into the overall system is shown.

Keywords: communication systems, Ethernet, electronic systems, telecommunications, waveguides.

1. INTRODUCTION

Wireless communication systems are well behind fiberoptic alternatives in terms of data rate and communication range. Several approaches to implement wireless communication at speeds of 100Mbps or even Gbps are currently being followed by industry, research and standardization bodies.

HUBER+SUHNER developed a system that uses the 60GHz band (license-free under FCC Part 15 regulation), providing 100Mbps speed and seamless integration into Fast Ethernet networks as a “transparent bridge”. It makes use of Huber+Suhner's experience in the field of communication antennas as well as microwave oscillators. Leading edge technologies as Metalized Injection Molded Plastics and Low Temperature Co-fired Ceramics have been combined to overcome traditional design constraints.

This paper explains how the application of these advanced technologies resulted in a point-to-point data link, which combines both ease of use and cost efficiency.

2. SYSTEM CONSIDERATIONS

2.1 Application Scenario

From a user perspective, the SL60 system behaves as a simple Ethernet patch cable extended to the link distance. The units are powered over the data port by an IEEE 802.3af Power-over-Ethernet (PoE) compatible power sourcing equipment, e.g. an accordingly equipped switch. There is no need for a dedicated power cord to operate the outdoor unit. After power-on and a short boot and synchronization period, two computers connected by the two SL60 terminals and separated by a distance of 700m can exchange data without further configuration. The system offers a full duplex connection running at full 100-Base-TX data rate.

The terminal’s status can be checked by a web-interface, which also helps during the alignment of the two terminals. The microwave signals are transmitted by high-gain planar antennas, which combine high gain and small unit size due to the short wavelength of the transmitted signals. The communication requires a line-of-sight arrangement of the two terminals.

The terminals are compact (16cm x 16cm x 8cm). They are suited for fixed rooftop installation and for quick “disaster recovery” i.e. temporary setups as well. The total weight is 1.75 kg only.
The selected transmission band between 57 GHz and 64GHz is open to unlicensed operation granted by the Federal Communications Commission (FCC) under "FCC Part 15" regulation in the US and in several other countries. A possible extension of this regime to the European and selected Asian countries is currently under consideration.
The unlicensed operation allows a quick and easy deployment without the involvement of a licensing body, while both the narrow beamwidth of the high gain antenna and the strong atmospheric damping ensure a reliable operation without any significant risk of interference induced black-outs as they are common with IEEE802.11 based bridges.

2.2 Technology Aspects

The main design goals were ease of use, low cost of ownership and excellent economy of scale. These attributes are crucially determined by the proper choice and combination of technologies, prominently influencing the implementation of active and passive millimeter wave blocks as well as the baseband subsystem.
For the passive millimeter wave components, i.e. the antenna and the transmit/receive duplex filter, a novel approach using plastic injection molding has been pursued. This results in a substantial amount of tooling costs, but it overcomes the impediments of conventional millimeter wave equipment, which were caused by the low-volume fabrication with extensive application of precision machining and hermetic packaging. The corresponding building blocks are explicated in separate chapters below.
The active millimeter wave frontend is based on Low Temperature Co-fired Ceramics (LTCC) technology previously explored in a millimeter wave oscillator development (Geist *et al*., 2003, Hesselbarth *et al*., 2003, 2004). A specially designed blind-mate waveguide transition between duplex filter and LTCC-based frontend is used for direct EM-coupling to the up- and downconverting mixer structures. The key features of the mixer stages are outlined in the chapter on the millimeter wave unit.
The terminal control and user interface is implemented in a System-on-a-Chip (SoC), which is readily available in the context of Ethernet appliances. Thus the complexity of the user interface and terminal control units are completely separated from the transceiver design.
A comparatively conservative approach has been selected for the implementation of the modulator and demodulator units. The IF-sections have been realized using commercially available SMT components. Crucial blocks of carrier and clock recovery have been integrated into Field Programmable Gate Arrays (FPGAs), which allowed further system optimization after printed circuit design freeze.

2.3 Regulatory Constraints

The frequency band that has been selected for the operation of the SL60 system provides plenty of bandwidth, so that the spectral efficiency of the applied modulation scheme is no longer the primary design goal. The Equivalent Isotropic Radiated Power (EIRP) however is effectively limited to 40 dBm.
The path loss L_s

$$L_s = \left(\frac{4p\, d}{l} \right)^2 \cdot 10^{\frac{1}{10}\left(15dB \cdot \frac{d}{1km}\right)}$$

for the projected link distance d of *700 m* is as high as *135 dB* at the wavelength l of *5 mm*. The second term reflects the excess loss introduced by oxygen molecular absorption. Thus the received power in a system using omnidirectional antennas would be approximately *–95 dBm*. Using a directional antenna increases the value – but only proportional to the receive antenna gain, as the EIRP value is fixed.
The minimum required receive power for a system operating at the data rate r having the receiver noise figure NF is

$$P_{\min} = N_0 + NF + SNR_{\min} + 10 \log \frac{r}{1Hz} \quad ,$$

where N_0 is the thermal noise floor (-174 dBm/Hz). SNR_{min} is the minimum required signal-to-noise ratio that allows a satisfactory signal reception. Primarily this value is depending on the modulation scheme. It can be reduced by forward error correction techniques, however at the cost of additional system complexity.
The SL60 system is operated at a gross symbol rate of *62.5 Mbps*. A typical noise figure for a direct downconversion receiver operating at 60 GHz is *10dB*. Coherent detection of Quaternary Phase Shift Keying QPSK requires a minimum SNR of approximately *12 dB*, which assumes a small margin compared to the theoretical limit when operating at a bit error rate of 10^{-6}. Hence *–74 dBm* receive power is necessary at the input of the system. Additional margins are required for receive and transmit path loss (e.g. in duplex filters and waveguides) and variable rain attenuation. This demands for a receive antenna gain of more than 35 dB.
For the SL60 system a planar array antenna providing a gain of 38 dBi has been selected. This leads to cost savings in the transmit amplifier, as only 1 mW of transmit power must be supplied. On the other hand, the gain is high enough to supply the demodulator with a satisfactory input signal at a maximum link distance of 700m at a BER of 10^{-6}.
Obviously inefficient modulation schemes, e.g. like On-Off-Keying (OOK) would require increased antenna sizes that would result in noticeably increased system and deployment cost.

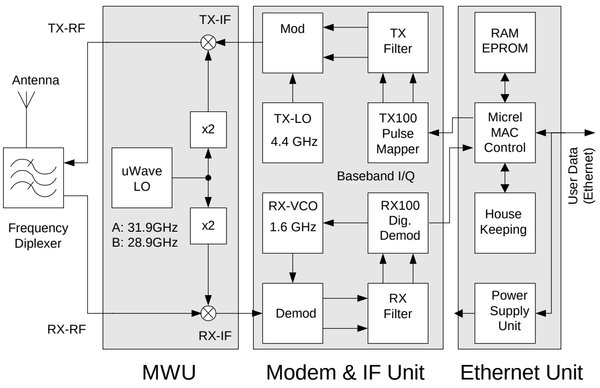

Fig. 1. Principle diagram SL60 communication system. The system comprises the a digital Ethernet unit, a modem unit, that handles the analog baseband and IF signals, and a millimeter wave unit (MWU). Further key building blocks are the frequency duplex filter and the planar high gain antenna.

2.4 The Selected Approach

Apart from the inherent necessity to use a modulation scheme of modest SNR demand the system design needs to address additional characteristics of the available millimeter wave components. First there is a substantial amount of non-linear distortion, which is intrinsic to many active millimeter wave components. In order to maximize the possible link distance the ability to tolerate a nearly saturated operation of the transmitter's output stage is highly desired. Again QPSK is a good candidate, as it is much more resistant to that kind of imperfection than most of the more sophisticated modulation schemes.
Second the receiver topology should be lean enough to allow a cost-effective implementation. Last but not least, the receiver should be capable to deal with a substantial amount of frequency offset, which facilitates the use of free running oscillators in the millimeter wave units. This approach fits perfectly in the lean system concept followed since the initial planning of the system. The overall system diagram resulting from these considerations is shown in fig. 1.
The SL60 receiver is realized in a feedback topology, which is a slightly modified variant of the well-known Costas Loop. The main issue of those feedback receivers is the trade-off between acquisition time and performance on noisy signals. While this is a serious issue for any burst mode communication system it is irrelevant to the SL60 system, which operates on the continuous Ethernet data stream. Thus the dynamics of the loop controller could be optimized for noise performance. The frequency acquisition is aided by a quadri-correlator type frequency offset detector.
To keep the complexity of the millimeter wave subunit small a frequency plan has been devised, that allows the reduction to only one free running millimeter wave oscillator per terminal. Thus two distinct terminal types are required to make up the communication system. While the structure of both is identical, one of them got an RF local oscillator running at a frequency near the upper edge of the frequency band, the other one's frequency is near the lower edge. Thus the intermediate frequencies are the same for both terminals, e.g. 4.5 GHz for the transmitter and 1.6 GHz for the receiver.
The actual microwave local oscillators are operating in the range of 30 GHz, since the RF mixers are designed for subharmonical operation.

3. TECHNOLOGY DRIVEN BUILDING BLOCKS

3.1 High Gain Planar Antenna

The SL60 system applies a high gain planar antenna that is realized in Injection Molded Metalized Plastics technology. The metalization on the plastics acts as the conducting boundary of the antenna's waveguide structure, i.e. the millimeter waves are propagating through the air filled conduits that are constituted between the three plates of the antenna (see fig. 2). The latter feature complimentary grooves and ridges that are mechanically and electrically joined in a high precision soldering process.
The antenna is performing well at frequencies between 53 and 68 GHz. It incorporates an array of radiators with 32 x 32 elements fed by a waveguide divider network.

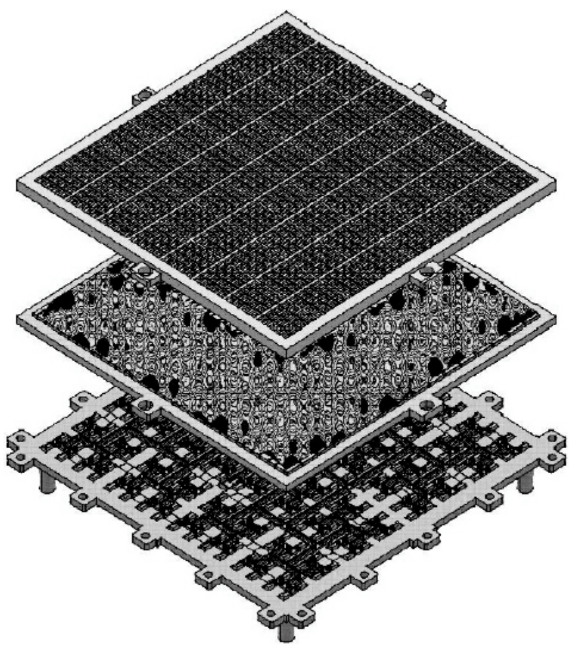

Fig. 2.Exploded view of the SL60 high gain planar waveguide antenna. The upper plate realizes the slot radiators and the final 1 by 4 dividers. The middle and lower plates make up the waveguide divider network. Moreover the lower plate is part of the receiver shielding.

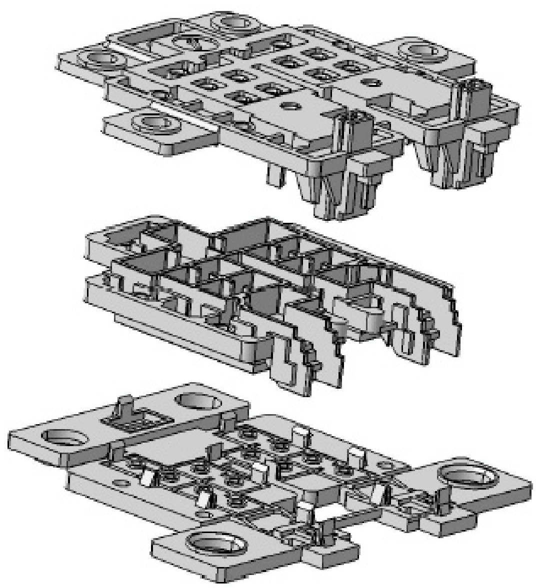

Fig. 3. Exploded view of the SL60 frequency duplex filter. The lower part forms the connector structure of the antenna port and the bottom lid of the lower resonator cavities. The central part is mainly required to establish the resonator cavities, 2x6 on the lower, 2x4 on the upper face. The top part contains the waveguide connectors to the millimeter wave unit (MWU).

The antenna consists of three major functional blocks. The first one is a 3D transition from rectangular to ridge waveguide. The second block is a tree of ridged waveguide power dividers distributing the microwave signal to the radiator unit. The radiator unit is the third major constituent of the antenna, an array of 256 cavities, which each feeds 4 slot radiators. The highly symmetrical parallel-branch antenna architecture yields an excellent pointing accuracy.

The entire radiating surface of the antenna is covered by a radome foil, which is an intrinsic part of the overall matching circuit design. A thin water-repellent layer covers the radome.

The rear face of the antenna is providing shielded cabinets for both receiver and transmitter.

3.2 Frequency Duplex Filter

The frequency duplex filter separates the two frequency bands that are used for transmit and receive signals. This is a crucial functionality for the frequency division approach used to establish the full duplex link of the SL60 system. The TX- to RX-isolation is as high as 80 dB.

The duplex filter consists of three main blocks. The first block is a T-junction with matching stubs. The base of the T-junction is connected to the antenna port by the means of a specially designed blind-mate waveguide flange technique.

The side arms of the T-junction are each connected to a filter block. Each filter consists of 10 iris coupled rectangular cavities. On the opposite end each filter features a specially designed transition from rectangular waveguide to ridge waveguide that composes a choke structure with the cover of the millimeter wave module.

The first bandpass filter exhibits a passband in the lower frequency band ranging from 58 GHz to 60 GHz. Its stopband starts at 61GHz and extends well beyond the second filter's passband (61 to 63 GHz). By employing alternating inductive and capacitve couplings, this filter type exhibits excellent far-off rejection, avoiding spurious passbands.

Mechanically the duplex filter consists of three metalized thermoplastic parts that are joined by a combined press-fit and soldering process.

The thermoplastic parts have a very high reproducibility in mass production, but initial tolerances are relatively high. Therefore the final performance is obtained in a two step process. In a first step the resonance frequencies of the 20 cavities of a prototype filter and the coupling coefficients of its input- and output apertures are tuned by specially designed tuning screws. In the second step the tuning screws are substituted by small protrusions that are integral parts of the thermoplastic top and lower filter parts.

3.3 Millimeter Wave Unit

The 60GHz Millimeter Wave Unit (MWU) comprises the passive and active discrete and monolithically integrated millimeter wave devices.

The local oscillator is running at about 30 GHz, since a sub-harmonically pumped single sideband mixer topology is used, which offers an intrinsic frequency doubling of the LO signal. There is no active component operated at 60 GHz except the mixing diodes. Two single mixers are operated in a push-pull mode by simultaneously coupling their upconverted signals into the double-ridge input of the duplex filter. The resulting power combination yields an output power of approximately 1mW at 60GHz. On the receive side, the electro-magnetic field coupling results in a conversion loss comparable to discrete waveguide integrated mixers, despite the use of lossy Low Temperature Co-fired Ceramics (LTCC) material for the planar circuit.

The MWU is based on a LTCC substrate, which carries the Monolithically Integrated Millimeter-Wave (MMIC) amplifiers of the microwave LO and the sub-harmonically pumped microwave mixers, which are based on discrete GaAs Schottky diode pairs.

A metal base plate is both used for transferring the dissipated heat to the backplane and to form the cavity for the microwave oscillator’s high-Q resonator with patent pending temperature stabilization. On the opposite side a cover is attached to the unit, which realizes both shielded compartments for the individual building blocks of the MWU and is part of the choke structure interfacing to the frequency duplex filter.

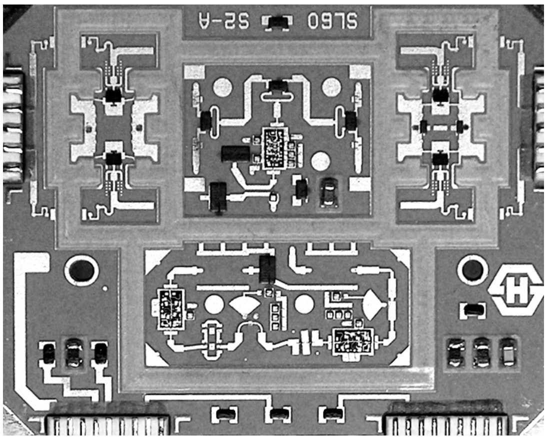

Fig. 4. Microphotograph of the SL60 millimeter wave unit. The picture shows the component side of the LTCC containing the millimeter wave oscillator in the lower center region. The upper region contains the amplifier delivering each 13 dBm power to the millimeter wave mixer, which are on the outer topsides. The lighter traces are the footprint of the shielding compartments.

3.4 Baseband and IF Electronics

The Modem. The SL60 System uses QPSK modulation with a roll-off factor of approx. 50%. The transmit side IF is around 4.5 GHz. The high transmit IF has been selected to minimize interference to the lower receive IF at around 1.6 GHz. In this way, transmit IF spurious signals can be removed by lowpass filtering and harmonic locking of the carrier recovery circuit is mitigated due to the choice of non-commensurate frequencies.

The second block in the receiver chain is the automatic gain control (AGC) that is also used to monitor the actual receive power level.

The demodulation process requires the reconstruction of the received signal's clock and carrier phase. Both the symbol clock and the carrier phase are recovered in feedback control loops. The error detectors operate on the sampled receive signal and are implemented in a FPGA chip. The remaining parts of the control loops are realized in a conventional analog manner.

The sampled operation of the carrier phase and symbol timing recovery loops poses some issues with respect to the initial acquisition. The acquisition is a chaotic process that can be described by trajectories representing the error signals of the corresponding control loops. Depending on the unknown, stochastic starting point and on the loop characteristics both control loops can enter a stable point without being locked to the received data signal. This effect is called "hang-up" – a catastrophic failure that needs to be carefully addressed. The severity of this issue is even increased by the fact, that most of the digital methods of carrier phase and clock timing estimation are not independent from each other. One possible approach to this issue is the joint estimation of both carrier phase and clock timing.

The implementation cost of a joint estimation is however enormous and was not feasible for the SL60 system. To overcome the issue, the time constants of the interfering loops have been selected vastly different. Thus a possible interaction is made impossible, as the slower loop can't react on the faster one. This can be interpreted as a kind of a spectral separation.

Ethernet Subsystem. This unit establishes the Ethernet connectivity of the SL60 system. It consists of a highly integrated System-on-a-Chip (SoC), which both implements the user data interface and the web server that assists in terminal alignment and system setup. It also provides continuous information on the system's operating state, relevant system temperatures, and the receive signal's power level. Moreover the unit performs some housekeeping, e.g. assisting in the initial frequency acquisition of the demodulator unit, automatic offset compensation, supervising the receiver locking state, etc..

The SL60 system is designed for operation in a professional environment. Automated management is possible through the SNMP agent running on the SL60 terminals. It is easily possible to manage daisy-chained SL60 terminals that would be needed to overcome the link distance limitation of a single system.

Upon request modified SL60 links can be made available that are suited to be part of an aggregated link installation. Up to four terminals can be co-located by the reuse of frequency and polarization.

Exceptional security requirements can be addressed by external cryptographic equipment that needs to be installed in an in-house secure area.

The unit also features an IEEE 802.3af PoE compatible power-conditioning unit and a highly efficient DC-DC power converter. Besides the lean overall concept the latter helps to achieve an overall power consumption of approx. 10 W, staying well below the IEEE 802.3af allowance of 12.95 W.

4. CONCLUSION

A novel electronic system for wireless transparent transmission of Fast Ethernet data was presented in both the aspects observable by the user and the internal system aspects. A contribution is made to the discussion of opportunities to exploit the recently opened spectrum at 60GHz in the United States. European regulatory authorities are discussing an adaptation of “FCC Part 15” – this application demonstrates the bright opportunities that open up with unlicensed frequency allocation.

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BIOGRAPHY

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Mr. Goebel studied electrical engineering at University of Braunschweig. He worked in several positions in microwave and millimeter-wave circuit and system design. As the department head of the Research and Advanced Development department of Huber+Suhner AG, Switzerland he initiated the development of millimeter wave system design and laid the technological foundations of the SencityLink transparent Ethernet bridge. Since January 2007 he is holding the position of CTO of the RF Technology Sector of HUBER+SUHNER AG, Switzerland.