WearTactile: An Electrotactile Research Platform to Support Exploration of Nuanced Electrotactile Control for Wearable Devices

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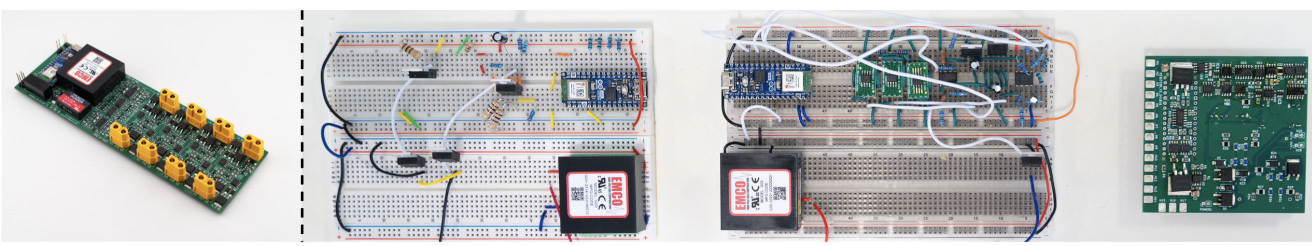

Figure 1: We contribute an open-access research platform, designed to enable non-specialists, researchers and designers to easily implement nuanced on-body electrotactile control, minimising the need for specialised electronics knowledge. (left) The final iteration of the WearTactile research platform as a robust, reliable, open-access multichannel PCB. (right) Chronological iterations in development.

Abstract

In this project we present a customised research platform to enable easy implementation of Electrotactile feedback specifically for on-body applications. Electrotactility is often seen as an unstable technology with the interplay between ranged input variables such as pulse width, intensity, and frequency being under explored. We identify that this is partially due to a lack of access to complicated electrotactile technology. To facilitate investigations in this area, complementing general-purpose ET platforms like eTactileKit, we developed a customised research platform tailored to the specific constraints and parameters of on-body ET applications. We present the research platform itself, its on-body-optimised features, and a set of performance evaluations exploring the functionality of the platform.

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CCS Concepts

• **Hardware → PCB design and layout**; *Emerging interfaces*; *Board- and system-level test*; • **Human-centered computing → User interface toolkits**; *Haptic devices.*

Keywords

electrotactile feedback, haptics, wearable devices, open-source hardware, on-body interaction; hardware prototyping.

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1 Introduction and Related Work

Through controlled electrical currents, Electrotactile (ET) stimulation activates cutaneous mechanoreceptors to elicit sensations such as tingling, buzzing, tapping or pressure-like feelings [4]. Compared to mechanical actuators, ET systems can be lightweight, silent, fast in response and mechanically simple. Additionally, ET systems support distributed architectures where control circuitry can be physically separated from electrodes by thin unobtrusive wires. This enables actuation at body locations with limited clearance or broad movement ranges, such as joints or fingers. Further, modulations in the type of ET can drastically change the perception: changes in frequency, pulse width, amplitude, and waveform can substantially alter the perceived quality of sensation [1, 3]. This potential for expressive, fine-grained control suggests that ET could support nuanced, information-dense, and even spatially structured forms of tactile communication on the body.

Despite this promise, ET feedback remains relatively underutilised and under-explored within HCI research and commercial digital devices. A key reason is that ET systems are difficult to design, calibrate, and reproduce. Sensation is highly sensitive to electrode geometry, skin condition, placement on the body, and individual physiology [6, 7, 9]. Small changes in electrical parameters can shift sensations from subtle to uncomfortable, and different body sites often require different stimulation ranges. As a result, ET implementations are frequently bespoke, fragile, and difficult to replicate across labs or applications. In contrast to vibrotactile actuators, which are widely available as standard components with well-understood behaviour, ET requires careful tuning, specialised electronics knowledge, and non-trivial safety considerations.

Furthermore, while recent work has made important progress toward making ET technology readily available, most notably through comprehensive ecosystems like eTactileKit [10], existing control circuits have constraints resulting from the balance between design trade-offs, notably: usability by the non-specialist; size; multiplexing; and timing. These constrictions introduce practical limits on ET output such as truly concurrent multi-channel output, fully independent control of frequency and pulse parameters per channel as well as the range of skin impedances that can be supported. We extend this existing work, focusing specifically on the control electronics, by building a targeted hardware with a balance of design trade-offs optimised for wearable on-body devices. In particular the WearTactile platform enables multichannel control, high-voltage output, and has a compact wearable form factor. This positions the WearTactile platform optimally for systematic exploration of the nuanced, high-dimensional electrotactile design space, specifically in a wearable context.

We present the WearTactile research platform in an open-access format for use by the haptics community, including its hardware architecture, safety features, and control capabilities, and we report a set of performance evaluations that characterise its electrical behaviour and reliability. Our aim is to provide a shared, transparent infrastructure that lowers the barrier to working with on-body electrotactile feedback and supports further research, design and optimisation of electro-tactile as a haptic technology. We propose the use of WearTactile in scenarios not enabled by generalised solutions. By making the circuit design and control architecture open and accessible, we seek to enable a broader community of HCI researchers, designers, and practitioners to engage with electrotactile interaction and to integrate it into future wearable systems. We contribute:

- WearTactile, an open-access, multi-channel electrotactile hardware platform designed for wearable and on-body interaction, supporting fine-grained control over frequency, pulse width, and intensity.
- A set of technical characterisations, including a brief user study (n=6) evaluating and validating the circuit's accuracy, stability, and limits.

2 The WearTactile Research Platform

We have developed a open-access research platform that allows for fully-configurable nuanced ET control. This platform was developed in response to the limited technical information regarding ET circuit implementation and design, particularly with regard to nuanced control and configurability, and the ensuing limitations for non-specialists. We were motivated by the limitations in existing platforms and we carried out a targeted literature review of 41 papers to verify existing constraints on both the parameters of ET control circuits and the transparency of their implementation (see Supplementary Materials). Inspired by works such as Illumipaper [8], our platform follows the principles of adaptability, interoperability, and usability to enable research into nuanced ET control and associated applications, while encouraging further development of the platform itself through transparency and an open-access design.

2.1 Research platform features

The physical research platform shown in Figure 1 has 8 independent output channels, each capable of providing nuanced, controllable electrical output characteristics. We highlight 6 key features of our research platform that showcase its design for application in wearables and tangible devices:

(1) **Complex control over concurrent electrical output:** Per-channel electrical output characteristics include current level (0 – 3800 μA), frequency (1 – 1500 Hz), and pulse width (0 – ∞ μs). This allows the platform to be used in complex studies that require distinct concurrent stimulations at different sites. Each channel also includes both high and low side controls, which is crucial for localised delivery of stimulation.
(2) **Inbuilt safety features:** The platform includes a built-in isolator, removing the need for an isolated power supply. It further has a safety cut off, requiring the shorting of two pins to operate. As such, a user can connect the two pins to a normally closed deactivation button, ensuring no accidental activation. Crucially, while the system operates at a high

voltage (500 V), it is strictly power- and current-limited both by the control circuit itself and the high-voltage supply that produces the high voltage from a 12 V input source. The high voltage is necessary to overcome skin impedance, but the power supply cannot sustain high currents, and the hardware strictly limits maximum current output to 3.8 mA, well below the threshold for harm [2].

(3) **Compactness:** The platform is compact and rectangular (195 mm by 63 mm), allowing it to be mounted on and be aligned with human limbs. It can be powered with a single 12 V source, eliminating the need for a variable power supply. This reduces cost and bulkiness, and allows the circuit to be powered by off-the-shelf chargers or 12 V DC converter boards.

(4) **Wireless:** Control of the platform is enabled seamlessly via remote control through Bluetooth Low Energy via a custom text-based protocol, enabling all output characteristics of each channel to be altered simultaneously.

(5) **Ease of platform recreation:** The platform is built around an Arduino Nano ESP32. It has a low cost (190 GBP per 8-channel board including all components) and the information is open access (see Supplementary Materials). The physical research platform is built using commonplace and readily available components.

(6) **Ease of use by a non-specialist:** The use of the ESP32 allows users to benefit from the existing support communities of microcontroller hobbyists. Further, we designed and built an easy-to-use API for setting frequencies, intensities and pulse widths (of multiple channels simultaneously).

2.2 Technical functionality

We provide an overview of the technical ET output of the research platform. These figures are validated and tested through performance characterisations. We provide a further breakdown of functionality within the Supplementary Materials. The signal-related specifications of the WearTactile research platform include:

The platform is driven by control signals generated by an Arduino Nano ESP32 and two MCP4728 Digital-to-Analogue Converters (DACs). The theoretical control range is 0 to 4800 μA at 500 V. The 500 V is provided by the XP Power (formerly EMCO) G05 from the 12 V input. The G05 is limited to 3 mA [12], but is complemented by a 0.47uF Polypropylene Film Capacitor to allow for higher momentary peak currents. The platform provides:

- **Eight concurrent output channels** with individually controllable pulse width and current. Each channel can be assigned in software to one of four independent timers, allowing for up to **four unique frequencies simultaneously**.
- An **absolute current range** of 0 μA − 3800 μA
- A **frequency range** of 1 Hz − 1500 Hz
- A **pulse width range** of 0 − ∞, ±2.4 μs @ 100 Hz native

Our circuit builds upon the architecture suggested by Kajimoto et al. [6]. The most important part of the circuit is the V-I Converter, which provides constant current output signal proportional to the input voltage level. This allows for an exact amount of current to be demanded at the output. The signal provided to the V-I converter is a combination of the *Current Control Signal*, the analogue voltage level proportional to the required current, and the *Pulse Control Signal*, the fast switching signal at the required frequency and pulse width. This allows for a high-frequency pulsed signal but at a precisely controlled pulse height. The flow of control signals for each channel in the circuit is shown in a flowchart included in the Supplementary Materials.

2.3 Delineation from EtactileKit

eTactileKit [10] provides a highly capable and generalisable solution for electrotactile research. However, each platform makes different engineering trade-offs suited for distinct contexts. While eTactileKit excels in scalability, easily supporting large channel counts essential for many applications, and offers a highly compact footprint, WearTactile prioritises true concurrent multi-channel output and high-voltage driving for distributed, on-body wearable applications beyond the fingertip.

A primary distinction lies in the signal generation architecture. eTactileKit utilises a single signal generator multiplexed across different channels. Because of this shared architecture, pulses across multiple channels are delivered sequentially rather than simultaneously. Whilst this sequential delivery can be circumvented through rapid switching between settings to create the illusion of concurrency, it does not provide true concurrent pulsing and can lead to unreliability as pulses can coincide at their common multiples. Additionally, this pseudo-multi-channel setup applies a lower cap on the maximum frequencies, namely $f \leq \frac{1}{\text{Pulse Width} + \text{Switching Delay}}$ which could limit explorations of high frequency ET when multiple channels are used. Previous works are known to use higher frequencies, abeit in single-channel applications, including works by Duente el al. [3] and Radivojevic et al. [11] which utilises up to 1000 Hz and 1500 Hz respectively. WearTactile's hardware-level concurrency is advantageous when providing strictly simultaneous, varied feedback with independent frequencies, pulse widths, and amplitudes to multiple locations on the body, though it comes at the cost of the channel scalability offered by eTactileKit.

eTactileKit has demonstrated highly compact boards in its evolving open-source hardware, while WearTactile's true concurrent multi-channel design uses eight separate control/drive subcircuits, which necessarily increases component count and routing demands, thus increasing the minimum footprint for the same goals. As on-body electrotactile studies may require participants to move freely within a space, simulating typical conditions of use for wearable devices, it is important for the circuit to be portable and fit on a range of body parts. We therefore optimised the circuit's dimensions within these constraints and chose a limb-friendly geometry that remains practical for on-body studies. This resulted in a larger, but still practical form factor.

Finally, skin impedance, which affects perceptual thresholds for electrotactile signals [5], is known to vary significantly with body location. Our own experimentation confirmed that lower voltages were often unable to produce noticeable electrotactile sensations at particular parts of the body, such as the legs and feet. For this reason, our platform is capable of outputting up to 3.8 mA signals at 500 V (configurable up to 650 V), delivering stronger and more noticeable ET feedback to high-impedance body locations compared to eTactileKit, whose output is also limited to 3.8 mA but at 270 V.

3 Performance Characterisations and Validation Through User Engagement

We evaluate and demonstrate the functionality of our research platform through 4 performance characterisations and a brief validation study.

Test 1: Pulse Width Range

Overview: We evaluate the ability of the research platform to reproduce short pulse widths as a factor affecting nuanced ET sensation. This test showed a linear relationship between actual and expected pulse width, with a slight offset occurring after reaching the minimum pulse width for the given frequency.

Results: As shown in Figure 2, the research platform was able to generate pulse widths as small as 3.8 µs at 100 Hz and 1.33 µs at 1000 Hz. Beyond the minimum pulse width, the relationship between the actual pulse width and expected pulse width was linear, with a small offset likely caused by the ESP32's internal rounding and delays. Without this offset, the pulse width has an RMS error of 38 ns and 98 ns at 100 Hz and 1000 Hz respectively.

Test 2: Current Delivery Accuracy

Overview: We test the ability of the research platform to accurately match current output with demanded current. While the platform performs well, we observed that high electrode resistance has an impact on pulse shape.

Experimental set-up: We set the research platform to output increasing current and measured the actual output current using an oscilloscope through a 10 kΩ shunt resistor.

Results: As shown in Figure 3 (left), the actual current closely matches the demanded current before flattening out at distinct thresholds determined by load resistance. This limiting behaviour arises from two distinct mechanisms. First, for lower resistances (5.7 kΩ to 57 kΩ), the current output is capped by the power supply's wattage capacity; despite remaining below the voltage saturation limit, the supply cannot deliver sufficient power to sustain higher currents. Second, for higher resistances, the output is limited by voltage saturation, as the required voltage for the demanded current exceeds the platform's 500 V maximum. In addition to voltage saturation, higher resistance also affects the shape of the pulse; this is shown in Figure 3 (right), which depicts a low-resistance pulse shape (purple) alongside a high-resistance pulse shape (blue). Here, both traces show the anode voltage when set to deliver 300 µA current and 300 µs pulse width signal at 100 Hz. The channel corresponding to the purple trace is connected to a 10 kΩ load whilst the one with the blue trace is connected to a 1 MΩ load. The higher resistance has led to an expected much higher voltage and also a less square pulse, although the pulse area, corresponding to charge, remains approximately the same.

Test 3: Frequency Range

Overview: We tested the range of actual frequencies generated by the research platform and identified that it is capable of delivering a broad range of frequencies with high accuracy.

Results: Figure 4 (left) shows error between the actual and expected frequency within our test range of 0 – 1500 Hz. The research platform frequency output can reach frequencies of 1500 Hz, which is the 95^{th} percentile of frequency range found in our literature analysis (see Supplementary Materials). Output frequency remains very accurate throughout this range, with percentage error below 0.03%.

Test 4: Multi-channel Operation

Overview: We tested the research platform's ability to simultaneously utilise all 8 of its channels, demonstrating high performance with all channels active.

Results: The 8 channel oscilloscope readings, shown in Figure 4 (right) showed consistent pulse shapes, indicating stable functionality across all 8 channels when used in tandem. Channels 1–4 are on four independent timers (Timer 1–4) and are consequently not aligned. Conversely, channels 5–6 both share Timer 1 and channels 7–8 share Timer 2, and are thus aligned. To avoid overlapping pulse shapes, channels that share a timer were set to different current levels. The timer used by each channel can be selected in software.

Test 5: User Engagement

We performed a user study (n=6, approved by our institutional ethics review process) on the WearTactile platform to validate its use across participants beyond the author team. We implemented ET output through forearm and leg electrodes revealing that users were able to distinguish between different frequencies and intensities of electrotactile feedback on the examined body locations. We present this brief overview to provide credence to the WearTactile platform's functionality with future work involving extending this study to 48 participants, with formal publication of methodologies and results.

4 Discussion and Conclusion

We present WearTactile, an open-access electrotactile research platform with eight concurrent output channels optimised for on-body applications. Performance characterisations demonstrated high accuracy in pulse width (98 ns RMS error at 1000 Hz), current delivery (42 µA RMS error), and frequency output (<0.03% error across 0-1500 Hz). Preliminary user engagement (n=6) validated users' ability to distinguish frequencies and intensities at varied body locations including forearm and leg, confirming the platform's suitability for nuanced ET perception research. WearTactile's independent channel control, compact wearable form factor, and high-voltage capability specifically address on-body application challenges. These hardware capabilities pave the way for future explorations into wearable applications of ET that require nuanced pulse control distributed across the whole body, such as full-body posture correction for physical rehabilitation or immersive, multi-location tactile feedback in virtual reality. By providing open-access, specialised infrastructure for wearable ET research, we hope to lower barriers for HCI researchers exploring expressive haptic feedback in future wearable systems.

References

[1] Yosuef Alotaibi, John H Williamson, and Stephen Anthony Brewster. 2022. First Steps Towards Designing Electrotactons: Investigating Intensity and Pulse Frequency as Parameters for Electrotactile Cues. In *CHI Conference on Human Factors in Computing Systems*. ACM, New Orleans LA USA, 1–11. doi:10.1145/3491102.3501863

[2] British Standards Institution. 2018. BS IEC 60479-1:2018 Effects of current on human beings and livestock.

[3] Tim Duente, Justin Schulte, Malte Lucius, and Michael Rohs. 2023. Colorful Electrotactile Feedback on the Wrist. In *Proceedings of the 22nd International Conference on Mobile and Ubiquitous Multimedia (MUM '23)*. Association for Computing Machinery, New York, NY, USA, 172–184. doi:10.1145/3626705.3627800

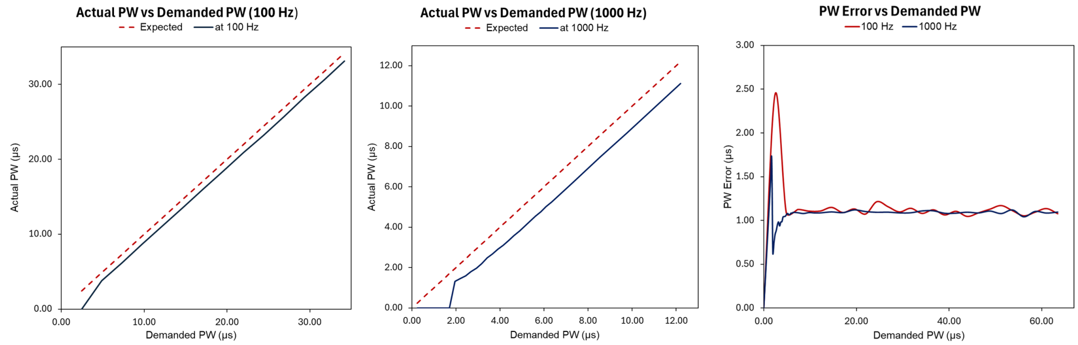

Figure 2: Left, Middle: Measured outputted pulse width (through an oscilloscope) compared to the expected pulse width at 100 and 1000 Hz. Right: Pulse width deviation at different expected pulse widths.

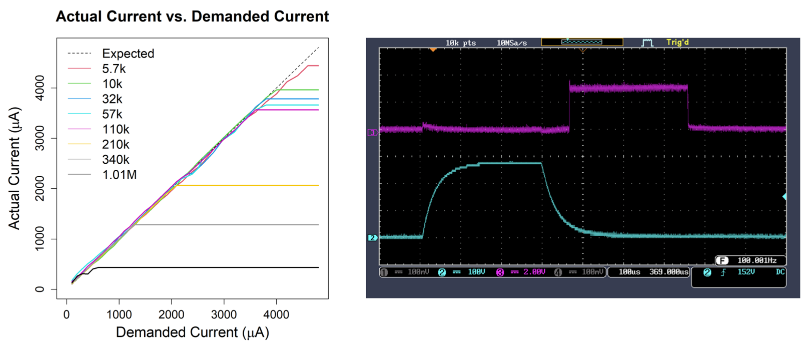

Figure 3: Left: Actual current delivered (µA) versus demanded current (µA) for multiple series resistances from 5.7 kΩ to 1.01 MΩ. Solid lines show measured currents by resistance, and the dashed line indicates the expected 1-to-1 relationship. Right: Oscilloscope trace showing differences between pulse shapes when connected to low resistance (purple) and high resistance (blue).

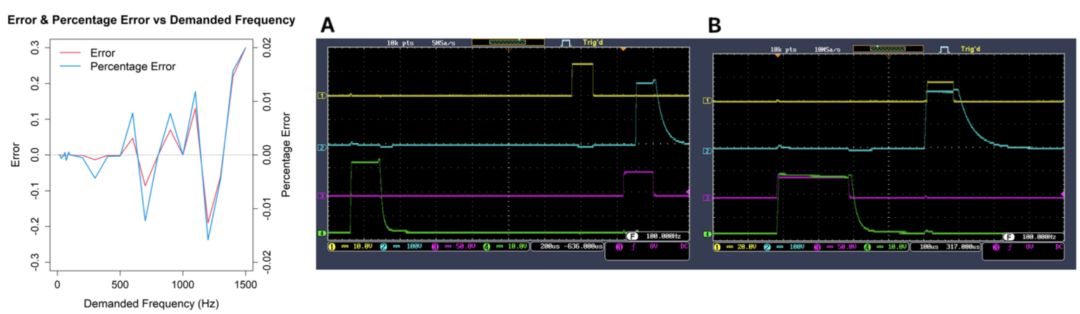

Figure 4: Left: Error in actual frequency versus demanded frequency, collected during Test 3. Absolute error shown in red (left axis, Hz); percentage error shown in blue (right axis, %). Right: Oscilloscope readings showing consistent pulse shapes across 8 concurrently active channels, collected during Test 4. Sub-figure A shows channels 1-4, which are controlled by four independent timers. Sub-figure B shows channels 5-8; two independent timers are shared between channel pairs 5/6 and 7/8.

[4] K.A. Kaczmarek, J.G. Webster, P. Bach-y Rita, and W.J. Tompkins. 1991. Electrotactile and vibrotactile displays for sensory substitution systems. *IEEE Transactions on Biomedical Engineering* 38, 1 (Jan. 1991), 1–16. doi:10.1109/10.68204

[5] Hiroyuki Kajimoto. 2012. Electrotactile Display with Real-Time Impedance Feedback Using Pulse Width Modulation. *IEEE Transactions on Haptics* 5, 2 (2012), 184–188. doi:10.1109/TOH.2011.39

[6] Hiroyuki Kajimoto. 2016. Electro-tactile Display: Principle and Hardware. In *Pervasive Haptics: Science, Design, and Application*, Hiroyuki Kajimoto, Satoshi Saga, and Masashi Konyo (Eds.). Springer Japan, Tokyo, 79–96. doi:10.1007/978-4-431-55772-2_5

[7] Thierry Keller and Andreas Kuhn. 2008. Electrodes for transcutaneous (surface) electrical stimulation. *Journal of Automatic Control* 18 (Jan. 2008). doi:10.2298/JAC0802035K

[8] Konstantin Klamka and Raimund Dachselt. 2017. IllumiPaper: Illuminated Interactive Paper. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York,

NY, USA, 5605–5618. doi:10.1145/3025453.3025525

[9] P. Li, G. H. Chai, K. H. Zhu, N. Lan, and X.H. Sui. 2015. Effects of electrode size and spacing on sensory modalities in the phantom thumb perception area for the forearm amputees. In *2015 37th Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*. 3383–3386. doi:10.1109/EMBC.2015.7319118

[10] Praneeth Bimsara Perera, Ravindu Madhushan Pushpakumara, Hiroyuki Kajimoto, Arata Jingu, Jürgen Steimle, and Anusha Withana. 2025. eTactileKit: A Toolkit for Design Exploration and Rapid Prototyping of Electro-Tactile Interfaces. In *Proceedings of the 38th Annual ACM Symposium on User Interface Software and Technology (UIST '25)*. Association for Computing Machinery, New York, NY, USA, 1–17. doi:10.1145/3746059.3747796

[11] Z. Radivojevic, P. Beecher, C. Bower, S. Haque, P. Andrew, T. Hasan, F. Bonaccorso, A. C. Ferrari, and B. Henson. 2012. Electrotactile touch surface by using transparent graphene. In *Proceedings of the 2012 Virtual Reality International Conference*. ACM, Laval France, 1–3. doi:10.1145/2331714.2331733

[12] XP Power. 2024. G Series DC-HVDC Converter Datasheet.