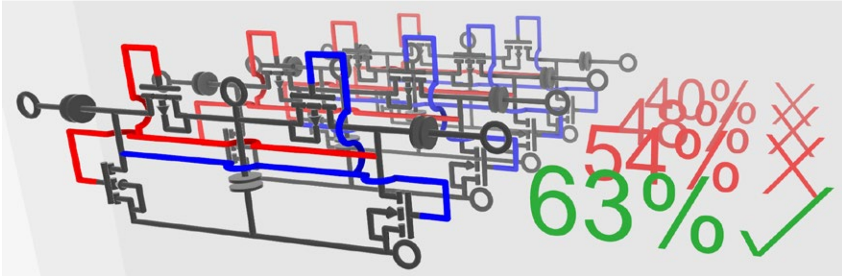
A wireless, battery-free world: how do we power it?

Our digital world depends on the interconnectivity between wireless devices, often battery-free with no direct power supply. Such devices include wireless passive sensors, designed to receive and respond to signals from the environment. These devices can be powered by electromagnetic waves, provided their antenna can efficiently convert waves to energy. By employing optimisation algorithms and introducing a more accurate measure of efficiency in these systems, Dominik Mair and a team of scientists from the University of Innsbruck in Austria have designed and simulated highly efficient circuits for wireless passive sensors.

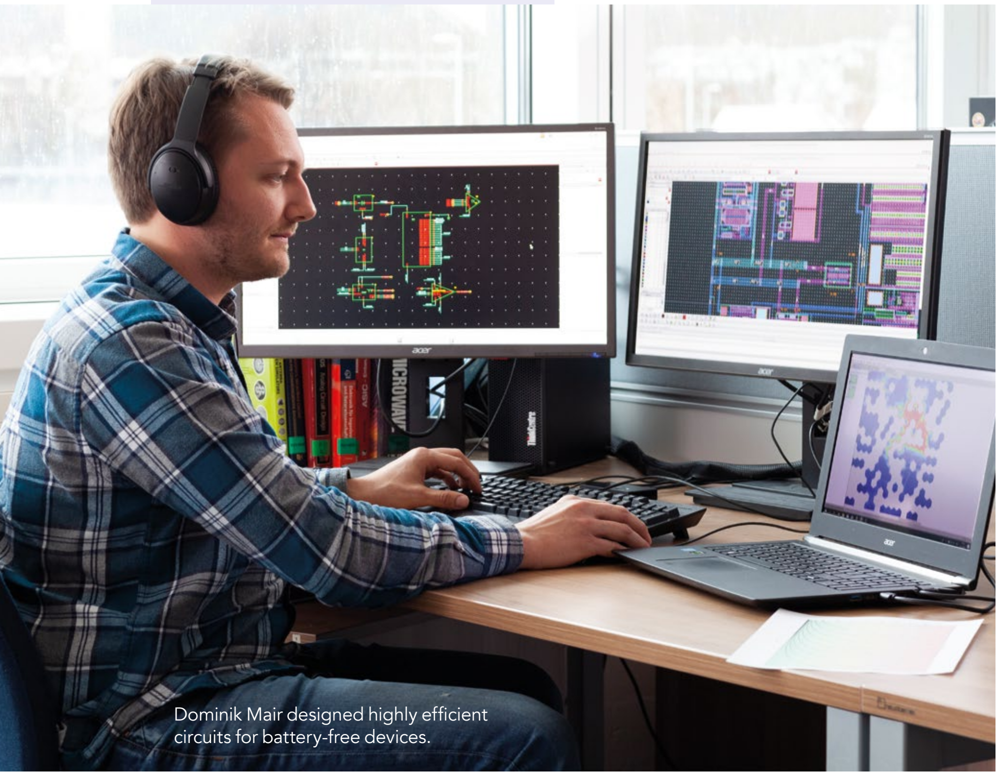


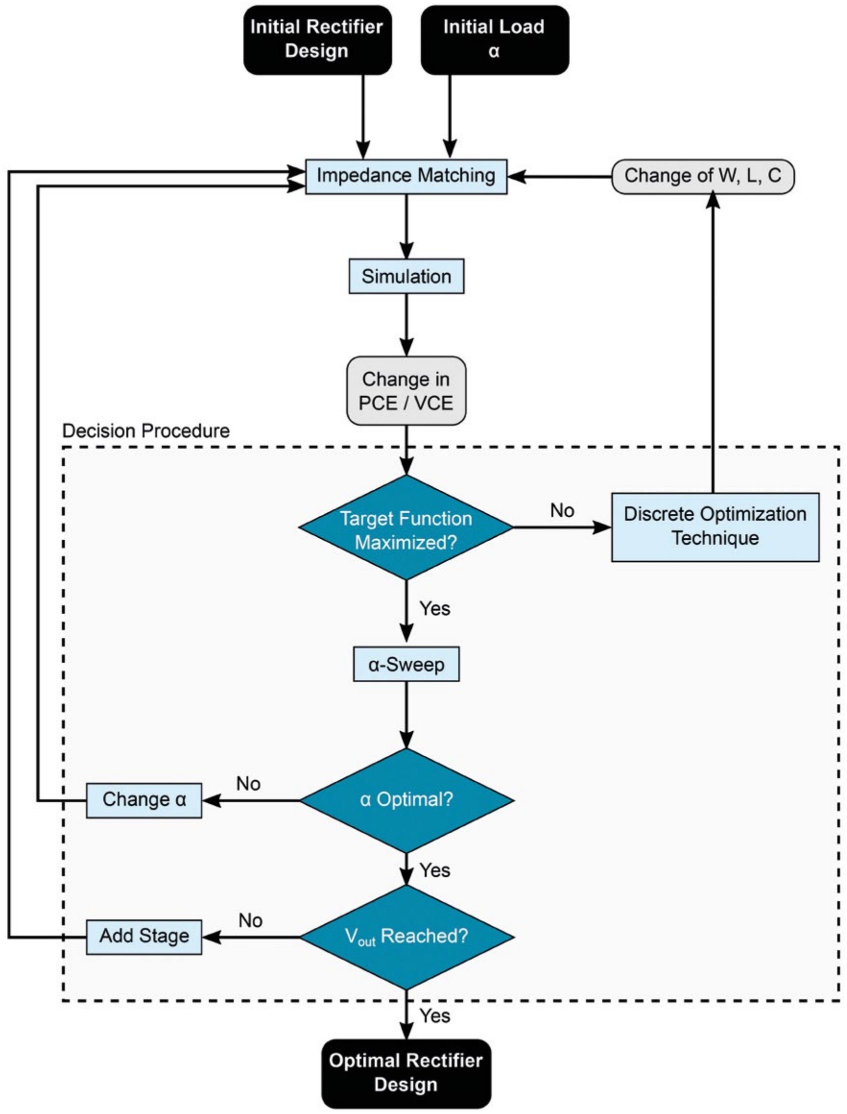
Graphical abstract of the optimised rectifier design.

When Alexander Graham Bell made the first-ever phone call in 1876, calling his assistant to meet him, the connectivity of today's world would have been well beyond his wildest dreams. Perhaps even in the late 1980s and early 1990s, when the internet as we know it started to emerge, the digital world we have since built would have been unimaginable. Today, we don't just use technology to communicate with each other: we are also finding ways to make devices communicate between themselves to allow us to control our environments.

The 'Internet of Things', as it is now called, is the combination of the immense web of sensors, devices, apps, and other technology that are connected and sharing information between them. The smartwatch that reads your emails, monitors your heart rate and 'talks' to the app on your phone, the app that lets you switch the lights off or turn the heating on at home while at work, your Alexa, or even a fridge that creates a virtual shopping list you can sync to your phone – these are all examples of how we are using the Internet of Things to control our environments. There are currently over 17 billion connected 'Internet of Things' devices in the world, and the number is expected to rise to 125 Giga (125,000,000,000) in the next ten years. The high demand for this type of device is driving the technology forward towards smaller, smarter, more efficient, more autonomous devices.

To control our world, however, we need to be able to interconnect many devices which, for ease of installation and pleasing design, are usually wireless, including no power supply cables. For environmental reasons, it is also beneficial that these devices are battery-free. Battery-free devices can instead be powered by the electromagnetic waves they receive from the powered devices they are connected to. For example, if you wanted to install a motion sensor on your front door capable of automatically sending a live video stream to your phone when activated, the sensor could simply be powered by your Wi-Fi router, with no need for any cables or batteries. With the right equipment, the electromagnetic waves sent by the Wi-Fi router could be enough to supply the energy needed to power the motion sensor.


Dominik Mair designed highly efficient circuits for battery-free devices.



The team employed optimisation algorithms that accelerate the design of new rectifier circuits.

CONVERTING WAVES TO POWER

Devices whose function is to detect and respond to physical signals from the surrounding environment are called passive sensors. The ability of a passive sensor to harvest energy from the environment depends heavily on the ability of its antenna – which receives electromagnetic waves – to efficiently turn waves into electricity that can power it.

Battery-free devices can be powered by the electromagnetic waves they receive from the powered devices they are connected to.

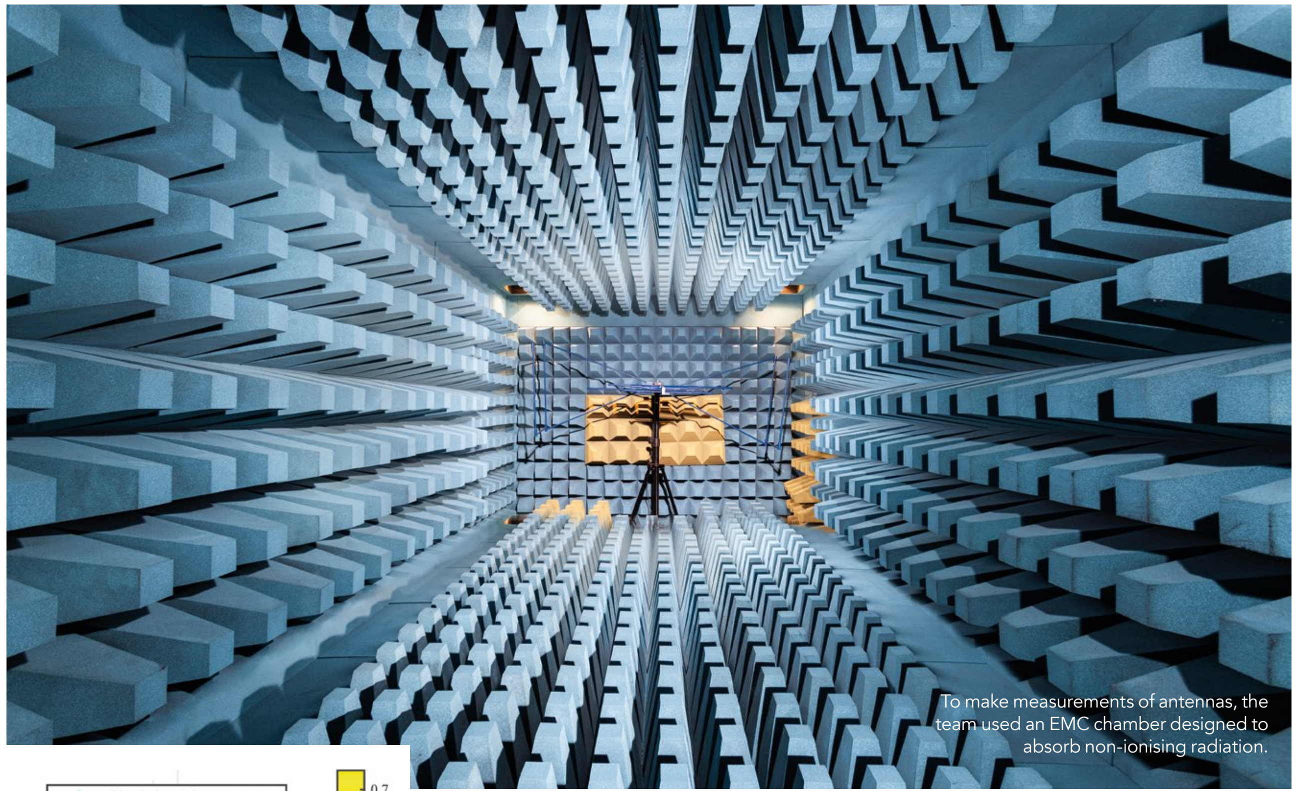
As such, a crucial part of improving this remote powering technology involves making the rectifier (the part of the antenna responsible for converting waves to power) work as efficiently as possible. The efficiency of the rectifier depends on a number of factors, including the antenna's characteristics. In addition, the efficiency of the wave-to-power process also depends on the distance between transponders and readers. Using the earlier example, that means that the further away the motion sensor on your front door is from your Wi-Fi router, the much more difficult it becomes for the sensor's rectifier to convert waves into usable power. As such, optimising the wave-to-power conversion process is also a crucial step in increasing the working range of a remote sensor, a much-desired feature in this type of device. However, tackling the issue of wave-to-power efficiency can be time-consuming, making the development process expensive for these devices.

RE-DEFINING 'EFFICIENCY' FOR CIRCUIT DESIGN ALGORITHMS

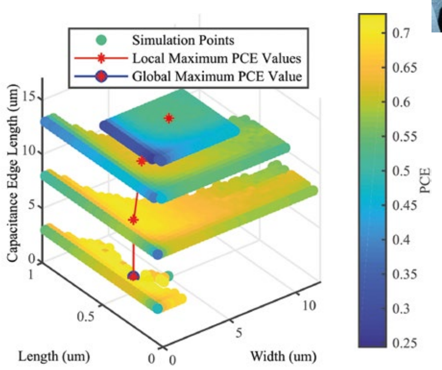
The rectifier performance can be measured in terms of its voltage conversion efficiency, or its power conversion efficiency, where 'voltage' refers to an electrical potential, and 'power' here refers to the rate at which electrical energy is transferred through an electrical circuit. However, these two quantities are closely interlinked in complex ways, to such an extent that optimising one of these parameters is often done at the expense of the other, and it is not possible to optimise both parameters simultaneously.

Dominik Mair and his colleagues, working in the Department of Mechatronics of the University of Innsbruck in Austria, have shown in a recent publication that using either voltage or power conversion efficiency as measures of rectifier performance is not feasible. Instead, the team demonstrated that the concept of a 'mean conversion efficiency' (the average of the voltage and power conversion efficiencies) allows optimisation algorithms to find optimum rectifier circuit designs much quicker. Not only that, but the resulting designs also show superior overall performance when compared to previous ones, even with very low power from incoming waves.

But the chosen measure of efficiency is not the only thing complicating the design of rectifier circuits. More problems arise from the fact that the performance



To make measurements of antennas, the team used an EMC chamber designed to absorb non-ionising radiation.



Simulation of the performance of a rectifier for a given set of circuit conditions.

> ***To overcome these challenges, the team closely examined mutual dependencies and employed optimisation algorithms that accelerate the design of new rectifier circuits.***

of a rectifier depends on its components as well as on its application-specific environment. The development of rectifier designs involves changing a large number of parameters for a given circuit, most of them closely dependent on each other, resulting in a very complex optimisation process that can quickly turn into a time-consuming task that drives up development costs for these devices.

To overcome these challenges, the team closely examined mutual dependencies and employed optimisation algorithms that accelerate the design of new rectifier circuits. First, the algorithm simulates the performance of the circuit based on the initial design and set of parameters. With this starting point prepared, the algorithm then adjusts all other parameters in order to achieve a combination of power and voltage conversion efficiencies that yields an optimised mean conversion efficiency. The process is repeated in a loop, with many parameters being automatically evaluated and changed as needed until the maximum output power is generated, the point at which the rectifier circuit designed can be said to be optimum for the given conditions of the simulation. In this way, optimal systems that satisfy the demanding conditions of an efficient rectifier can be generated completely autonomously, both saving time and leading to better performances.

GETTING BETTER, FASTER

The growing demand for 'intelligent' devices that are interconnected with each other, allowing us to control our environment, is pushing the development of wireless, battery-free sensors which can gather information and even make decisions or control actuators. These devices need to be easy to install and maintain, being small and capable of powering themselves for the duration of their useful life.

The work developed by Mair and his team offers a robust optimisation method for automated and fast design of the rectifier circuits that allow passive sensors to harvest energy from their surroundings, avoiding cables and batteries. The approach proposed by the team accounts for several different factors simultaneously, quickly simulating and optimising performance for a given set of circuit conditions and therefore provides rectifier designers with crucial information to guide their work. The optimisation method presented also has the potential to yield better-performing circuit designs with significantly less development time, which is an essential contribution to the field of passive sensor technology and ultimately an important step towards a smarter, even more connected world.

Behind the Research

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Research Objectives

Dominik Mair presents a method for building rectifiers using optimisation algorithms.

Detail

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Bio

Dominik Mair received both his Bachelor's and Master's Degree in Mechatronics from the Leopold-Franzens-University of Innsbruck, Austria, in 2015 and 2017, respectively. His research interests include the development and optimisation of antennas and ultra-low power circuits. Besides his scientific activities he devotes himself to his family.

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Collaborators

• Michael Renzler

universität innsbruck

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Personal Response

Which piece of equipment that could potentially result from your work excites you the most?

" Due to the growing demand of wireless sensor networks used for various applications like building information modelling, smart home, industry 4.0 and telemedicine, the difficulty of powering all these application-specific sensors rises. Batteries lead to an unnecessary environmental impact and therefore technologies which work passively have to be pushed in my opinion. A battery-less sensor which can be read out with a range up to 60 meters fascinates me most. Such an enormous range could make passive sensors interesting for a variety of applications. "