PICC - Replication Manual

2024 IEEE AP-S Student Design Contest

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I. Introduction

THE PICC is a fun and intuitive way of learning the concepts of impedance and polarisation of electromagnetic waves while playing with an RC-car. In Fig. 1 one can view a full picture of the the PICC. As seen in the picture the PICC consists of three main components; the antenna, the NanoVNA and the Raspberry Pi.
This replication manual describes how to assemble the PICC, what program installations are required as well as how to calibrate and use it.

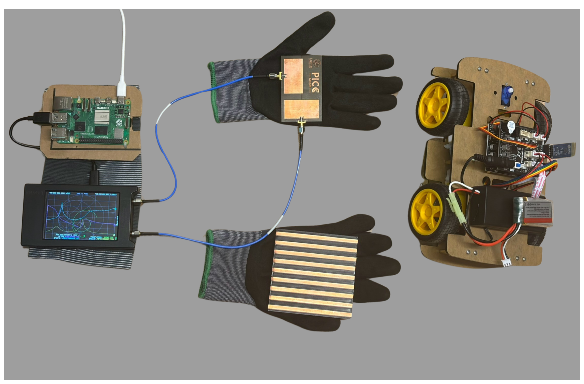


Figure 1: The PICC

II. Bill of materials

In table I all items needed to build the project are listed, including price at time of purchase.

III. Software

Our open source python library *pynanovna* [14] that is used to control the NanoVNA can be installed using pip: `pip install pynanovna`. A complete guide for installing the code for signal processing to steer the RC car can be found on the PICC group github at https://github.com/PICC-Group/picc-device.

Table I: Bill of the materials using convertion rates 1 SEK = 0.093 USD and 1 EUR = 1.08 USD as of May 3rd 2024.

Items:	Price:	Source:
RC car and controller	$73	Amazon [1]
LiteVNA 64	$184	Amazon [2]
Raspberry Pi 5	$78	Kjell & Company [3]
Raspberry Pi 5 Power Adapter	$17	Electrokit [4]
USB-A to USB-C cable	$17	Kjell & Company [5]
2x 18650-batteries	$12	Electrokit [6]
Gloves	$4	Biltema [7]
Elbow sleeve	$9	Biltema [8]
Micro SD card 64 GB	$30	Kjell & Company [9]
Patch Antenna (PCB)	$20	PCBWay [10]
SMA Connectors	$8	Amazon [11]
Strip Grid Plate (3D-printed)	$11	IKDC Lund University
Flat Copper Wire	$13	Amazon [12]
Hook-and-loop tape	$10	Biltema [13]
Total:	$486	

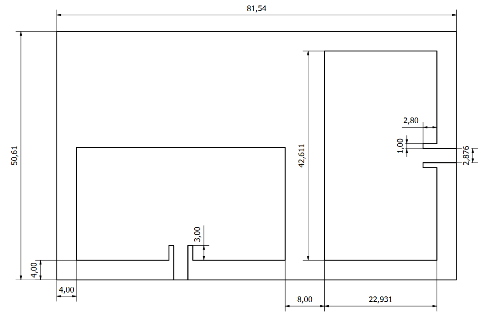
IV. Design and setup

In this section the design of the hardware parts is described and followed by the setup process.

A. Patch Antenna & Strip Grid

In Fig. 2a the schematics of the custom designed patch antenna can be viewed. The antenna is designed for the operating frequency of 3.0 GHz. Its dimensions are $22.9\,\mathrm{mm} \times 42.6\,\mathrm{mm} \times 1.6\,\mathrm{mm}$ and it is made with FR4 as substrate material, copper patches and SMA ports. The files for constructing the antenna can be found at https://github.com/PICC-Group/antenna. A picture of the complete antenna can be seen in Fig. 2b.

The strip grid is 3D printed with PLA plastic as background material with the dimensions $100\,\mathrm{mm} \times 100\,\mathrm{mm}$. The strips are 5mm wide and 0.2mm thick copper strips, see Fig. 3. The 3D printed plastic casing is designed so that the copper strips can be slid into place for a snug fit without need for glue. The 3D-printing stl files, including



(a) Schematic of antenna with dimensions in mm.

(b) Complete Patch Antenna

Figure 2: Antenna Design

the printer settings can be found at https://github.com/PICC-Group/strip-grid.

Figure 3: Strip grid

B. Raspberry Pi

The PICC uses a Raspberry Pi 5 for signal processing. It is the main hub, connecting the NanoVNA to the RC car. The Raspberry Pi can either be set-up using our pre-installed image or manually. A detailed guide on this as well as our pre-installed image can be found at https://github.com/PICC-Group/rpi-setup. The Raspberry Pi is then powered up and connected to the NanoVNA. If set-up correctly it will automatically try to connect to the RC car with Bluetooth and set up a local website that shows data from the PICC system. The website can be accessed at http://ip-adress:5000/ using the ip-address of the Raspberry Pi.

C. RC car

The RC car is constructed using a RC kit designed for easy modifications. The car can be controlled either using a standard RF signal or Bluetooth, where the Bluetooth option has better range and a more stable connection. The code used to control the car via Bluetooth, using the processed signals from the NanoVNA instead of the included controller can be found at https://github.com/PICC-Group/picc-device.

D. Setup

As seen in Fig. 1, the antenna and strip grid are fastened to the gloves on opposite hands using hook-and-loop tape. One side of the hook-and-loop tape is glued to the strip grid and antenna respectively, and the other side to the gloves. The hook-and-loop tape enables easy disassembly of the setup into its separate components.

For connectivity, the antenna is linked to the NanoVNA's SMA connectors via RG405 coaxial cables provided with the NanoVNA kit. Furthermore, the NanoVNA is connected to the Raspberry Pi utilizing a USB-A to USB-C cable. The NanoVNA and the Raspberry Pi is then attached to the forearm using hook-and-loop tape tape and an elbow sleeve. A Raspberry Pi Power Adapter is used to power the Raspberry Pi.

V. Usage

A. Operate the PICC

The PICC is started by powering up the Raspberry Pi. It will then host a website that can be used to control the settings of the system. The PICC can also be controlled with a command line interface over ssh for the more technical users.

The PICC will automatically try to pair with the RC car. Make sure the car is turned on, has the Bluetooth module installed and is in pairing mode.

The NanoVNA needs to be calibrated before every use of the PICC to get accurate results. The calibration is done with the four calibration tools that come together with the NanoVNA: short, open, load and through. The calibration is easily done by following the guide in the web interface at http://ip-adress:5000/.

After the calibration, five reference measurements need to be taken. The first one is without the strip grid in front of the antenna. Then the others are taken at the minimum and maximum distance and angle. This is also easily done by following the instructions in the web interface.

The PICC works between distances $10\,\mathrm{mm}$ to $100\,\mathrm{mm}$ and angles between $0°$ and $45°$. Start by holding the strip grid and antenna planes parallel to each other. When the distance is $10\,\mathrm{mm}$ between grid and antenna the RC car will drive as fast as it can. If the distance is increased the car will drive slower and slower, up to $100\,\mathrm{mm}$ where the car will stand still. Turning the car is done by either rotating the grid, antenna or both. To drive straight the angle should be $22.5°$. For smaller angles the car will turn left and for greater angles it will turn right. Exceeding the maximum turning angle ($< 0°$ or $> 45°$) will result in the turning angle reversing. This is due to the physics that the PICC is based on and can be a great discussion topic for the classroom.

B. Limitations

When using the PICC it is important to hold the strip grid facing the antennas as parallel and centered as possible. Small diversions in angle may lead to more noisy signal due to a smaller portion of the reflected signals hitting the antenna. A diversion in angle for a shorter time will not affect the output signal, but if the strip grid is held at a bad angle for a longer time the measurements will be off and it will be harder to control the RC car.

Other factors that can distort the output signal, which should be considered when using the PICC, include: ensuring the NanoVNA is calibrated correctly, avoiding the presence of other materials nearby that could reflect the signal similarly to the copper strips and setting the reference values at the start of the PICC carefully.

C. In the classroom

For teachers, the RC car can be used as an eye-capturing device showing students the functionality of electromagnetic field theory and the possibilities it brings. For students or others of interest, the PICC offers a splendid chance to build your first technical project and apply theoretical knowledge in antenna and electromagnetic field theory in real life. The project showcases the challenges of applying theoretical concepts in real life, and how they can be solved. There is also room for extending the functionality of the PICC by using multiple NanoVNAs. This way, more control parameters can be obtained and more complex systems can be controlled, for example a drone.

REFERENCES

[1] Amazon, “Freenove 4wd car kit,” (Last visited 2024-05-08). [Online]. Available: https://www.amazon.se/dp/B07YBPTXHG?ref=ppx_yo2ov_dt_b_product_details&th=1

[2] ——, “Litevna 64,” (Last visited 2024-05-08). [Online]. Available: https://www.amazon.se/dp/B0BBFCD4Y1?psc=1&ref=ppx_yo2ov_dt_b_product_details

[3] Kjell & Company, “Raspberry pi 4 model b enkortsdator 8 gb ram,” (Last visited 2023-12-15). [Online]. Available: https://www.kjell.com/se/produkter/dator/enkortsdator/raspberry-pi-4-model-b-enkortsdator-8-gb-ram-p88159?gad_source=1

[4] Electrokit, “Nätadapter 27w usb-c pd raspberry pi 5 vit,” (Last visited 2024-05-13). [Online]. Available: https://www.electrokit.com/stromforsorjning-27w-usb-c-raspberry-pi-vit

[5] Kjell & Company, “Linocell flätad usb-a- till usb-c-kabel svart 0,5 m,” (Last visited 2024-05-13). [Online]. Available: https://www.kjell.com/se/produkter/mobilt/ladda-koppla/kablar-adaptrar/usb-c-kablar/linocell-flatad-usb-a-till-usb-c-kabel-svart-05-m-p24403

[6] Electrokit, “Batteri li-ion 18650,” (Last visited 2024-05-13). [Online]. Available: https://www.electrokit.com/batteri-li-ion-18650-3.7v-3200mah-lg-inr18650-mh1

[7] Biltema, “Montagehandske,” (Last ,visited 2024-05-17). [Online]. Available: https://www.biltema.se/bygg/arbetskladar/arbetshandskar/montagehandskar/montagehandske-2000042644

[8] ——, “Armbågsskydd,” (Last visited 2024-05-17). [Online]. Available: https://www.biltema.se/fritid/traning/stretching-och-behandling/armbagsskydd-2000046487

[9] Kjell & Company, “Sandisk ultra micro-sd-kort 64 gb sdxc,” (Last visited 2023-12-15). [Online]. Available: https://www.kjell.com/se/produkter/mobilt/minneskort/sandisk-ultra-micro-sd-kort-64-gb-sdxc-p65991

[10] PCBWay, “Pcbway pcb cost calculator,” (Last visited 2023-12-15). [Online]. Available: https://www.pcbway.com/orderonline.aspx

[11] Amazon, “Sma female pcb panel edge mount plug with 4 pins stand straight connector rf coax coaxial adapter,” (Last visited 2024-05-13). [Online]. Available: https://www.amazon.com/QMseller-Straight-Connector-Coaxial-Adapter/dp/B07XWL597P

[12] ——, “Benecreat 6 m platt koppartråd, 5 mm,” (Last visited 2024-05-08). [Online]. Available: https://www.amazon.se/dp/B0CGJ2TKF6?psc=1&ref=ppx_yo2ov_dt_b_product_details

[13] Biltema, “Kardborreband svart,” (Last visited 2023-12-15). [Online]. Available: https://www.biltema.se/hem/kladvard/kladvardsrullar/kardborreband-svart-3-m-x-25-mm-2000053541

[14] P. group, “pynanovna,” (Last visited 2024-05-17). [Online]. Available: https://pypi.org/project/pynanovna/