Publications with LPKF Equipment, Part 1

Selection of internationally published scientific articles using LPKF equipment

February 2021

LPKF
Laser & Electronics

TOC: page, system, application

LPKF ProtoLaser U4

Material used:
Dupont Pyralux AP 8535R

Application area:
Medical Research

Published:
11/2019

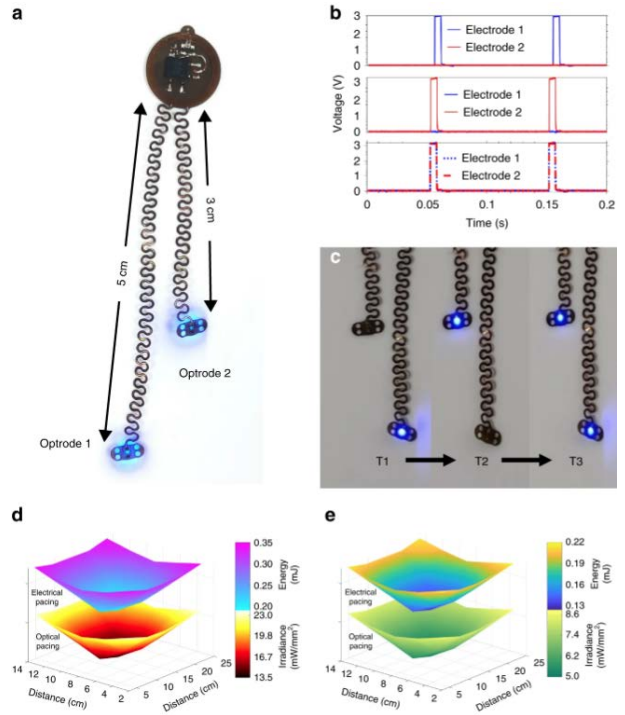
Wireless, battery-free, fully implantable multimodal and multisite pacemakers for applications in small animal models

wireless, battery-free, fully implantable

Small animals support a wide range of pathological phenotypes and genotypes as versatile, affordable models for pathogenesis of cardiovascular diseases and for exploration of strategies in electrotherapy, gene therapy, and optogenetics. Pacing tools in such contexts are currently limited to tethered embodiments that constrain animal behaviors and experimental designs. Here, we introduce a highly miniaturized wireless energy-harvesting and digital communication electronics for thin, miniaturized pacing platforms weighing 110 mg with capabilities for subdermal implantation and tolerance to over 200,000 multiaxial cycles of strain without degradation in electrical or ….

Device fabrication

Pyralux AP8535R served as a substrate for the circuit, the serpentine interconnect and the optrode. The top and bottom copper layers (17.5 µm thick) and via holes were structured via direct laser ablation (LPKF U4). Through-hole plating was performed via pulsed direct current electroplating of copper (LPKF Contac U4), to define the electrical connections between the top and bottom layers. Electron beam evaporation of 200 nm platinum defines the electrode surface.



Department of Biomedical Engineering, University of Arizona, Tucson, AZ, 85721, USA

https://www.nature.com/articles/s41467-019-13637-w

LPKF ProtoLaser U4

Material used:
Dupont Pyralux AP 8535R

Application area:
Neuroscience

Published:
12/2018

LPKF Laser & Electronics

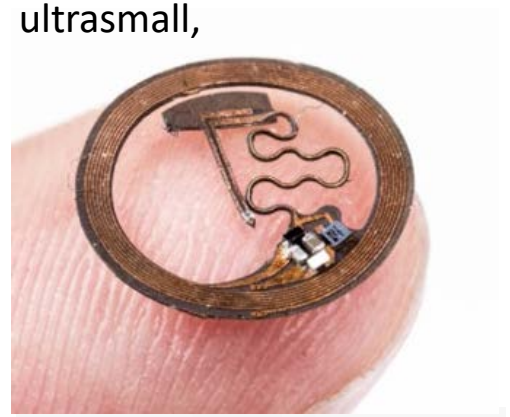
Fully implantable optoelectronic systems for battery-free, multimodal operation in neuroscience research

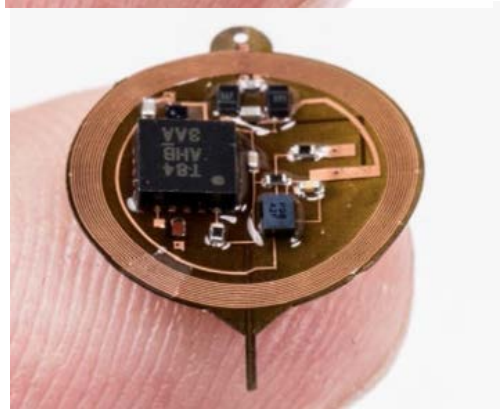
Recently developed ultrasmall, fully implantable devices for optogenetic neuromodulation eliminate the physical tethers associated with conventional set-ups and avoid the bulky head-stages and batteries found in alternative wireless technologies. The resulting systems allow behavioural studies without motion constraints and enable experiments in a range of environments and contexts, such as social interactions. However, these devices are purely passive in their electronic design, thereby precluding any form of active control or programmability; independent operation of multiple devices, or of multiple active components in a single device, is, in particular, impossible.

Device fabrication

Pyralux AP8535R served as a substrate for the flex circuit. The top and bottom copper layers (17.5 µ m thick) were structured via direct laser ablation (LPKF U4). Through hole plating via pulsed direct current electroplating of copper (LPKF Contac S4) defined the electrical connections between the top and bottom layers. Components with commercial packaging were attached via reflow soldering with low-temperature solder (IndiumCorp). The µ -ILEDs were mounted with a pick-and-place tool (Finetech Fineplacer pico ma) using defined force and temperature (180 °C) with an anisotropic…

battery-free, fully implantable, ultrasmall,





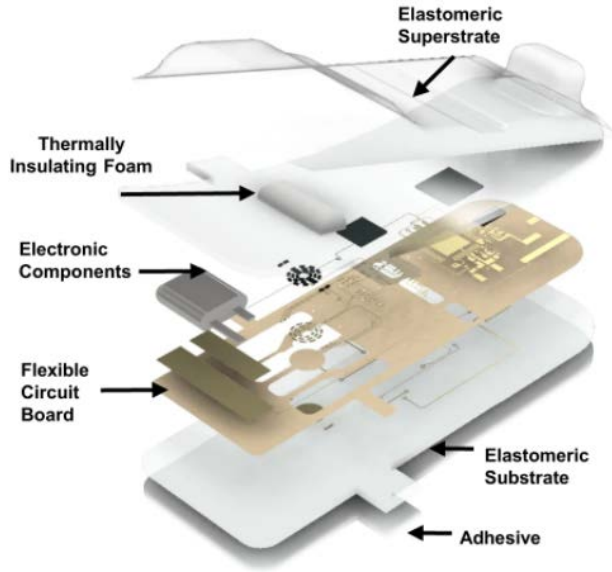
Center for Bio-Integrated Electronics at the Simpson Querrey Institute for BioNanotechnology and the Department of Materials Science and Engineering, Northwestern University, Evanston, IL, USA

https://www.nature.com/articles/s41928-018-0175-0

Continuous, noninvasive wireless monitoring of flow of cerebrospinal fluid through shunts in patients with hydrocephalus

wearable device, wireless,, continuous flow monitoring

Hydrocephalus is a common disorder caused by the buildup of cerebrospinal fluid (CSF) in the brain. Treatment typically involves the surgical implantation of a pressure-regulated silicone tube assembly, known as a shunt. Unfortunately, shunts have extremely high failure rates and diagnosing shunt malfunction is challenging due to a combination of vague symptoms and a lack of a convenient means to monitor flow. Here, we introduce a wireless, wearable device that enables precise measurements of CSF flow, continuously or intermittently, in hospitals, laboratories or even in home settings. The technology exploits measurements of thermal transport…



Fabrication and assembly of electronics

Fabrication of the sensor and supporting electronics began with processing of a trilayer film of copper/PI/copper (18 µm/75 µm/18 µm, Pyralux, DuPont Inc.) with a UV laser cutter (LPKF U4) to pattern traces, bond pads, and unplated vias. Successive washes in stainless steel flux (Worthington Inc), deionized water, and isopropanol (Fisher Scientific) removed surface oxides and prepared the resulting flexible PCB (fPCB) for assembly. Reflow soldering with low-temperature solder paste (TS391LT, ChipQuik) established electrical contacts between commercial-off-the-shelf components…

Department of Materials Science and Engineering, Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL, 61801, USA

https://www.nature.com/articles/s41746-020-0239-1

LPKF ProtoLaser U4

Material used: **FR4, 0.8mm 35/35**

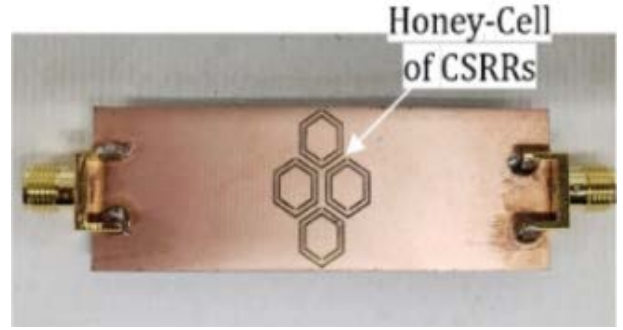
Application area: **RF / Medical Research**

Published: **09/2020**

Low-cost portable microwave sensor for non-invasive monitoring of blood glucose level: novel design utilizing a four-cell CSRR hexagonal configuration

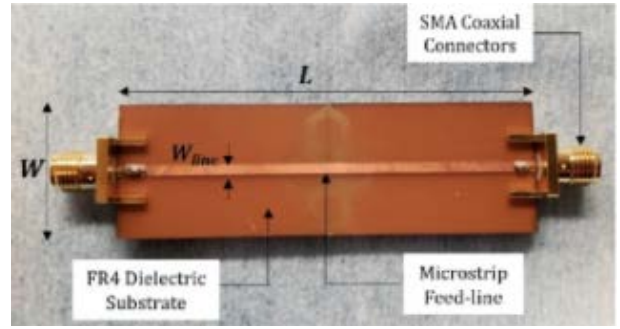
Microwave sensor, blood glucose measurement, non-invasive monitoring

This article presents a novel design of portable planar microwave sensor for fast, accurate, and non-invasive monitoring of the blood glucose level as an effective technique for diabetes control and prevention. The proposed sensor design incorporates four cells of hexagonal-shaped complementary split ring resonators (CSRRs), arranged in a honey-cell configuration, and fabricated on a thin sheet of an FR4 dielectric substrate. The CSRR sensing elements are coupled via a planar microstrip-line to a radar board operating in the ISM band 2.4–2.5 GHz. The integrated sensor shows an impressive detection capability and a remarkable sensitivity of blood glucose levels (BGLs).



Sensor fabrication

The sensor prototype was fabricated on an FR4 PCB of a copper thickness of 35 um and dielectric substrate of 0.8 mm thickness using the laser technology incorporated in the proto-laser machine (LPKF ProtoLaser U4). First, the DipTracer PCB layout software was used to generate the Gerber files (.gbr) from the DXF HFSS design files for the CSRR structure. A few fiducial points were added to the design to ease the alignment of top and bottom parts in fabrication. The CircuitPro software was used to control the laser micromachining when fabricating the CSRR device. On the top layer of…

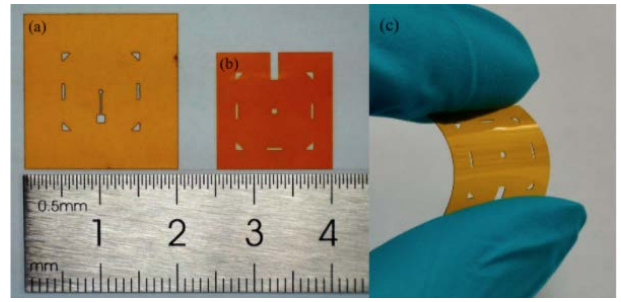


Department of Electrical and Computer Engineering, Centre for Intelligent Antenna and Radio Systems (CIARS), University of Waterloo, Waterloo, ON, Canada

https://www.nature.com/articles/s41598-020-72114-3

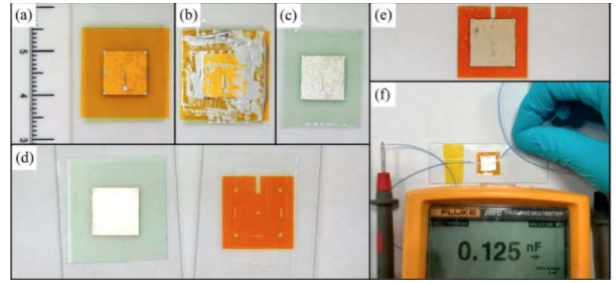
Low Temperature Adhesive Bonding-Based Fabrication of an Air-Borne Flexible Piezoelectric Micromachined Ultrasonic Transducer

Wearable devices, piezoelectric transducter, Kapton stencil



This paper presents the development of a flexible piezoelectric micromachined ultrasonic transducer (PMUT) that can conform to flat, concave, and convex surfaces and work in air. The PMUT consists of an Ag-coated polyvinylidene fluoride (PVDF) film mounted onto a laser-manipulated polymer substrate. A low temperature (<100 °C) adhesive bonding technique is adopted in the fabrication process. Finite element analysis (FEA) is implemented to confirm the capability of predicting the resonant frequency of composite diaphragms and optimizing the device. The manufactured PMUT exhibits a center frequency of 198 kHz with a wide operational bandwidth. Its acoustic …

Fabrication Process



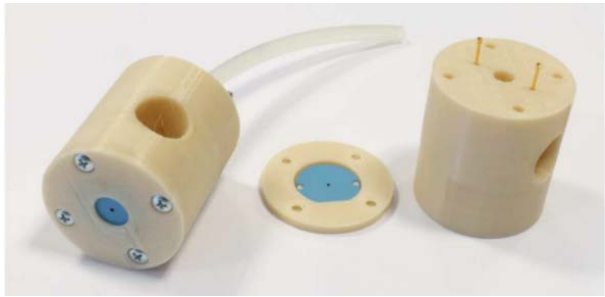
The low temperature adhesive bonding fabrication process is divided into pre-processing and main processing steps. A laser precision machining system (ProtoLaser U3, LPKF Tianjin Co., Ltd., Tianjin, China) is used to quickly pattern printing masks and flexible substrates in pre-processing. Compared with micromachining fabrication techniques such as standard photolithography, depositing, and etching, laser precision machining is convenient and time-saving. The diameter of focused laser beam is 30 µm, and the minimum space of ultra-fine structures can reach 45 µm, which will ….

State Key Laboratory of Mechanics and Control of Mechanical Structures, Nanjing University of Aeronautics

https://www.mdpi.com/1424-8220/20/11/3333/htm

Plasma Jets Fabricated in Low-Temperature Cofired Ceramics for Gold Nanoparticles Synthesis

atmospheric pressure plasma jets, low temperature cofired ceramics, gold nanoparticles synthesis



In this article, we present a development of atmospheric pressure plasma jets (APPJs) for modification of liquid solutions. APPJs were fabricated in low temperature cofired ceramics (LTCC) technology. During the measurements, plasma jets worked under various flowing gases, which can be used to produce plasma activated water. In addition, owing to the plasma treatment, it was possible to decrease the time of a synthesis of gold nanoparticles (AuNPs) without the use of additional hazardous reagents. The mechanism of gold nanoparticles formation in cold nitrogen plasma is also presented.

Fabrication

Ceramic structures were made of LTCC DuPont 951 (DuPont, Wilmington, NC, USA) ceramics and compatible pastes. The thickness of the ceramic foil used depended on the height of the recess and the thickness of the dielectric layers of the structure. The pattern of each layer was laser-cut using LPKF Proto Laser U (LPKF, Garbsen, Germany). Metal layers were screen-printed using Aurel vs. 1520A (Aurel Automation SPA, Modigliana FC, Italy). All the layers were laminated for 20 min under 20 MPa pressure in the isostatic press and then green plasma jets were fired in a typical LTCC …

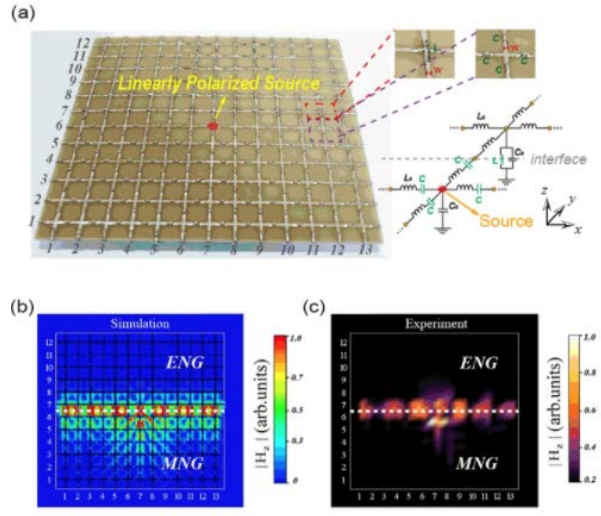
Faculty of Microsystem Electronics and Photonics, Wroclaw University of Science and Technology, 50-370 Wroclaw, Poland

https://www.mdpi.com/1996-1944/13/14/3191/htm

Photonic Spin Hall Effect in Waveguides Composed of Two Types of Single-Negative Metamaterials

optical signal routing, metamaterials, photonic spin Hall effect

The polarization controlled optical signal routing has many important applications in photonics such as polarization beam splitter. By using two-dimensional transmission lines with lumped elements, we experimentally demonstrate the selective excitation of guided modes in waveguides composed of two kinds of single-negative metamaterials. A localized, circularly polarized emitter placed near the interface of the two kinds of single-negative metamaterials only couples with one guided mode with a specific propagating direction determined by the polarization handedness of the source. Moreover, this optical spin-orbit locking phenomenon, also called the photonic spin Hall effect, …



Methods

A commercial software package (CST Microwave Studio) is used in designing the samples. The samples are all fabricated on copper-clad 1.6 mm thick FR4 substrates using laser direct structuring technology (LPKF ProtoLaser 200). In the experiment, the signal emission from the port one of vector network analyzer (Agilent PNA Network Analyzer N5222A) and another antenna (i.e., near-filed probe) connecting to the port 2 of analyzer are employed to measure the magnetic fields. A circular probe is vertically placed 1mm above the TLs to measure the signals of magnetic field of …

Key Laboratory of Advanced Micro-structure Materials, MOE, School of Physics Science and Engineering, Tongji University, Shanghai, 200092, China

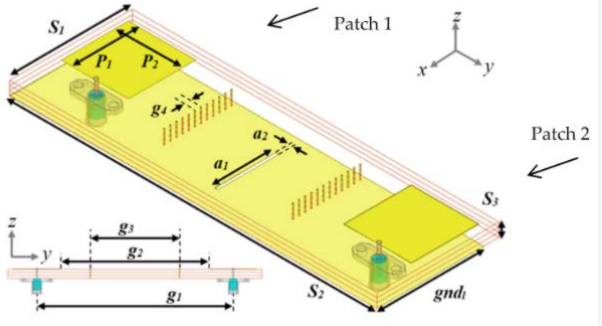
https://www.nature.com/articles/s41598-017-08171-y

Mutual Coupling Reduction between Finite Spaced Planar Antenna Elements Using Modified Ground Structure

In this paper, a modified ground structure capable of reducing mutual coupling to provide isolation between adjacent antenna elements is presented. The proposed modified ground structure is a combination of a strategically located ground slot, asymmetric partial ground and a substrate-integrated pin wall. The use of the modified ground structure causes a more than 28 dB (measured value) mutual coupling reduction. The modified ground structure has been optimized and validated with a finite spaced planar 2 × 1 antenna array operating at 4.16 GHz, intended for unmanned aerial vehicle radar altimeter applications.

For the **fabrication**, the LPKF ProtoMat H100 was used. In the first step, metallic traces were milled on RT duroid 5880 substrate. In the next step, a drilling bit with a diameter of 0.4 mm was used to create holes through the substrate. Since the required substrate thickness of 4.71 mm (S3) was not available as a standard thickness of RT duroid boards, three substrate sheets with thickness 1.57 mm were stacked together while the 0.4 mm holes were aligned. Copper wires of diameter 0.36 mm were passed through the aligned sheets via holes to finally develop the substrate-integrated pin wall as shown in Figure 5a.

mutual coupling reduction; altimeter; antenna array; modified ground structure



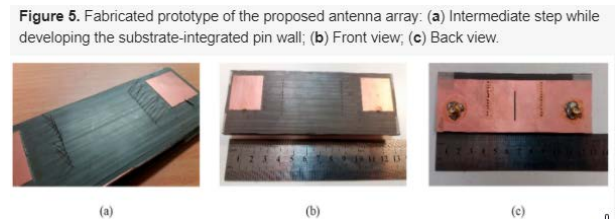


Figure 5. Fabricated prototype of the proposed antenna array: (**a**) Intermediate step while developing the substrate-integrated pin wall; (**b**) Front view; (**c**) Back view.

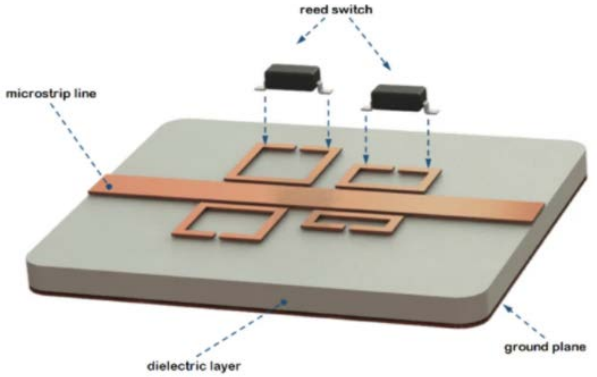
School of Electronic and Information Engineering, Beihang University, Beijing 100191, China

https://www.mdpi.com/2079-9292/10/1/19/htm

Design and implementation of magnetically–tunable quad–band filter utilizing split–ring resonators at microwave frequencies

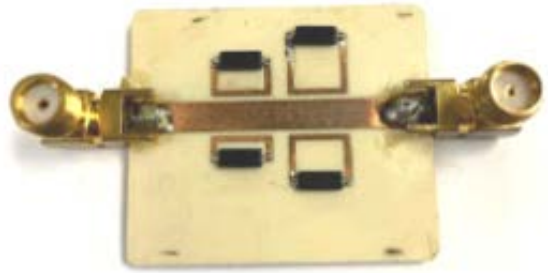
magnetically–tunable quad–band filter, split–ring resonator

In this article, we present a magnetically–tunable quad–band filter with high tunability in the frequency range of 2.1–3.9 GHz. A multi–band filter with four stop–bands comprises of a microstrip line coupled to four frequency–selective split–ring resonators (SRRs). We achieve tuning of individual frequency bands using magnetic reed switches connected in between the capacitive gaps of each split–ring resonator. Application of magnetic field tunes this capacitance affecting its resonance frequency. The measured reflection spectrum of the proposed device matches well with the simulation results. The results show more than 25% tunability for each of the four bands …



Experimental Results

Magnetically tunable quad–band microwave filters comprised of a microstrip line, split–ring resonators and reed switches have been implemented on commercially available double–sided Rogers RO4003C high–frequency boards patterned using LPKF Protomat S103 (LPKF Laser & Electronics AG, Garbsen, Germany) with standard printed circuit board (PCB) fabrication methods. After milling the board, magnetic MEMS reed switches (MK24–A–3, a SPST normally open (NO) switch from Standex Electronics, Cincinnati, OH, USA) are soldered in the gap of each individual …



Nano Lab, Advanced Technology Laboratory, 200 Boston Ave, Medford, MA, 02155, USA

https://www.nature.com/articles/s41598-020-57773-6

LPKF ProtoMat S103

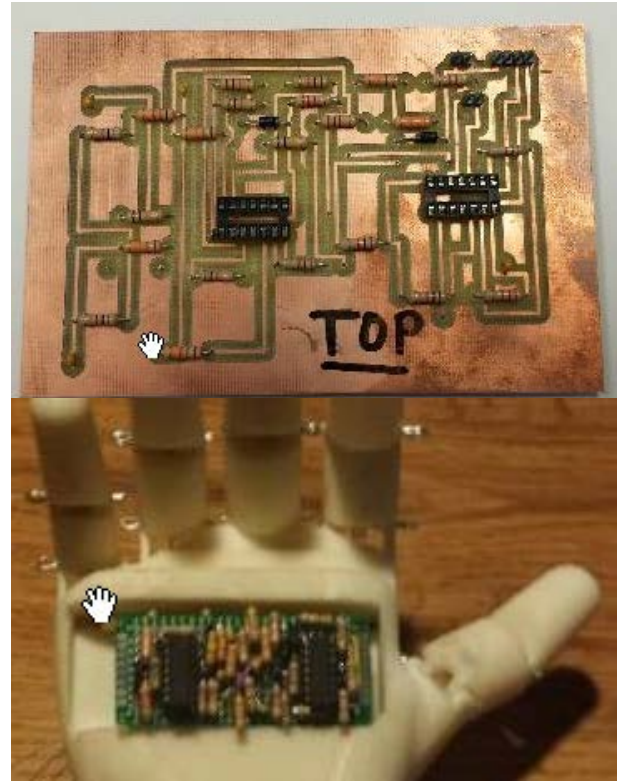
Material used: **FR4**

Application area: **Biomedical Engineering**

Published: **04/2017**

Development of an EMG Controlled Robotic Hand Prosthesis

Prosthetic hand, robotic hand



A robotic hand used as a prosthetic can be made using 3D printed material to replicate the normal anatomy and mechanical movement of the human hand using muscle signals associated with human finger movements. EMG electrodes were placed on the flexor carpi radialis, palmaris longus, flexor carpi ulnaris, flexor digitorum superficialis, and flexor policus longus to acquire EMG signals during finger movement. Analog integrated circuits were designed to amplify, filter and rectify the muscle signals with 4550 gain, 20-500 Hz cutoff frequencies for second order Butterworth bandpass filter, and a full wave rectifier circuit using LM324 quad operational amplifier.

A printed circuit board was designed using Cadence OrCAD software and PCBMaker. LPKF ProtoMat S103 plotter was used for milling and cutting the PCB board. An Arduino® Micro™ ATmega32U4 8-bit microcontroller board was used to convert analog signals into digital at 10 bits of resolution and generate pulse-width modulation (PWM) signals for servo motors of the 3D printed robotic hand. Siemens NX® 10.0 software was used to create a model for robotic hand and printed it in Stratasys® Dimension Elite 3D printer. The robotic hand was designed to be anatomically similar to the normal hand using anthropometric data. Real time control of an individual finger of the 3D printed robotic hand was achieved through Arduino programming.

Department of Biomedical Engineering, Indiana Institute of Technology, Fort Wayne, IN 46803Department of Biomedical Engineering, Indiana Institute of Technology, Fort Wayne, IN 46803

https://www.researchgate.net/publication/315736180_Development_of_an_EMG_Controlled_Robotic_Hand_Prosthesis

LPKF ProtoMat S63

Material used: **Rogers TMM4**

Application area: **RF**

Published: **05/2020**

LPKF Laser & Electronics

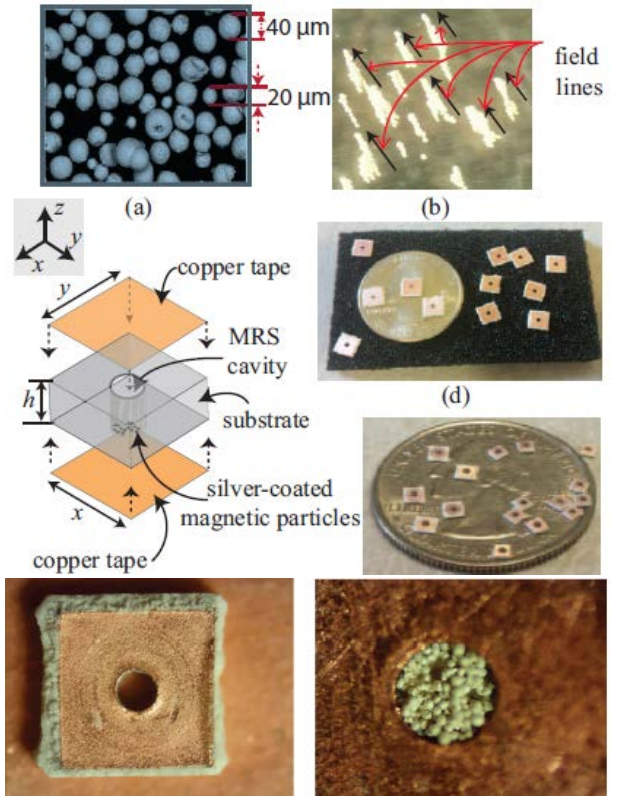
Characterization of Novel Structures Consisting of Micron-Sized Conductive Particles That Respond to Static Magnetic Field Lines for 4G/5G (Sub-6 GHz) Reconfigurable Antennas

Controlling Radio Frequency (RF) signals through switching technology is of interest to designers of modern wireless platforms such as Advanced Wireless services (AWS) from 2.18 GHz–2.2 GHz, mid-bands of sub-6 GHz 5G (2.5 GHz and 3.5 GHz), and 4G bands around 600 MHz/700 MHz, 1.7 GHz/2.1 GHz/2.3 GHz/2.5 GHz. This is because certain layout efficiencies can be achieved if suitable components are chosen to control these signals. The objective of this paper is to present a new model of an RF switch denoted as a Magnetostatic Responsive Structure (MRS) for achieving reconfigurable operation in 4G/5G antennas.

The **manufacturing** of the MRS was achieved in-house using the LPKF ProtoMat S63 PCB [13] milling machine. In particular, milling practices were used to make the cavities in a substrate and for accurate cutting of the MRSs. Initially, a 0.9 mm cavity diameter d on a 3.0 mm 3.0 mm substrate having a thickness of 0.508 mm h was accurately manufactured and is shown in Figure 1d. The substrate material used was a Rogers TMM4 with 1 oz. copper cladding on both the top and bottom. This practice validated the feasibility of milling practices and even smaller structures were manufactured using this milling machine process. Figure 1e shows the manufactured MRSs cavities with a diameter of 0.9 mm on a Rogers TMM4 substrate having a size of 1.5 mm x 1.5 mm x 0.508 mm.

Advanced Wireless services

Magnetostatic Responsive Structure

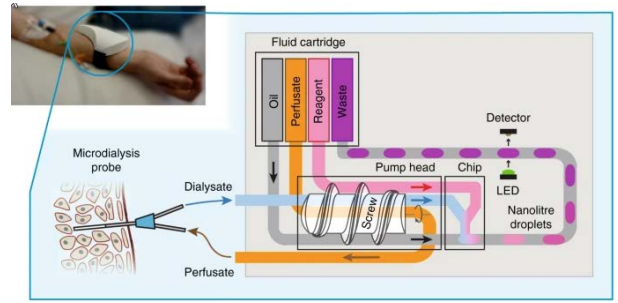


Department Electrical and Computer Engineering, COMSATS University Islamabad, Islamabad 45550, Pakistan

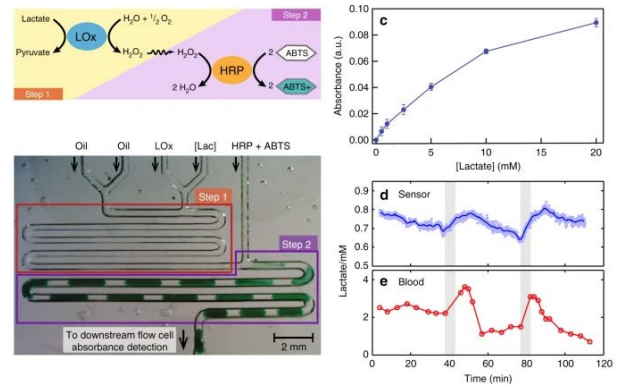
https://www.mdpi.com/2079-9292/9/6/903

Monitoring biomolecule concentrations in tissue using a wearable droplet microfluidic-based sensor

Wearable sensor, microfluidic, in situ analysis, biomarker



Knowing how biomarker levels vary within biological fluids over time can produce valuable insight into tissue physiology and pathology, and could inform personalized clinical treatment. We describe here a wearable sensor for monitoring biomolecule levels that combines continuous fluid sampling with in situ analysis using wet-chemical assays (with the specific assay interchangeable depending on the target biomolecule). The microfluidic device employs a droplet flow regime to maximize the temporal response of the device, using a screw-driven push-pull peristaltic micropump to robustly produce nanolitre-sized droplets. The fully integrated sensor is contained within a small …



Flow cell design and setup

The flow cell, shown in Supplementary Fig. 11, was based on a previously reported design31 and consisted of a black acrylic body which held the optical components and directed the light path through the fluid as it passed through PTFE tubing. The body was micromilled using a LPKF Protomat S100 micromill (LPKF Laser & Electronics Ltd., Berkshire, UK) from two 3 mm-thick black polymethylmethacrylate (PMMA) blocks. A straight centre groove of dimension 1.0 mm by 1.0 mm was milled to take the PTFE tubing. Perpendicular to the groove, a through-hole of square cross-section (0.4 mm) was milled to direct the light path. Recesses at each end of the through-hole …..

Faculty of Engineering and Physical Sciences, University of Southampton, Southampton, SO17 1BJ, UK

https://www.nature.com/articles/s41467-019-10401-y#MOESM1

ProtoMat C40

Material used: **FR4**

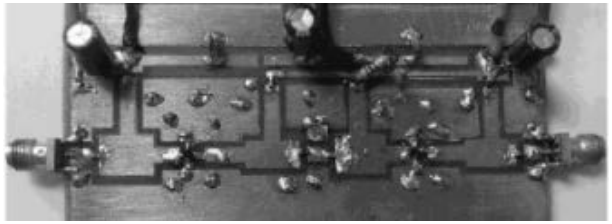
Application area: **RF**

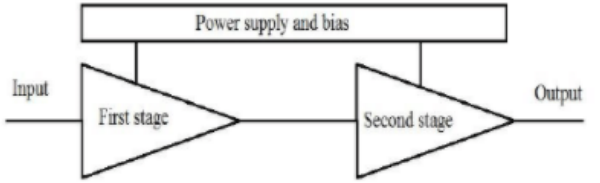
Published: **11/2013**

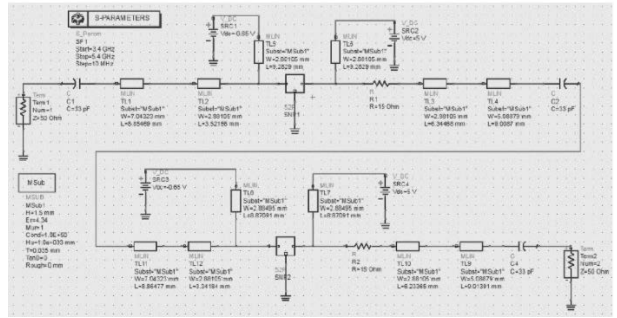
LPKF Laser & Electronics

High gain low noise amplifier design used for RF front end application

Low noise amplifier, C band, noise figure, satellite receiver, ADS







This paper presents the design and fabrication of a wideband low noise amplifier (LNA) at 4 - 5 GHz, which suitable for RF front end application. The design of the LNA uses diagram of two-stage cascade amplifier with different center frequency in order to create a good wideband performance and high gain. The LNA has been fabricated on a PCB board with FR4 subtrate using microstrip technology and pHEMT FET transistor amplifier with following specifications: Maximum overall gain of 26.046 dB, operating frequency from 4 GHz to 5 GHz, noise figure is about 1.515 dB, the reverse isolation of -29.5 dB, the LNA using a 5 V supply voltage respectively and total current consumptions of 20 mA. All the designed, simulated and fabricated processes were done using Agilent' ADS 2009 package and machine LPKF Protomat C40.

A two-stage LNA with spf-3043 is designed and demonstrated with simulations in ADS package as well as tuning for the optimum gain, noise figure and bandwidth. The design was fabricated and the board was measured and analyzed together with the simulated results. In summary, the measurement results of the LNB were compared to references with following its performances throughout the wideband frequency range, high gain, low noise and smaller PCB fabrication. Overall, this LNA could be used for the RF front end application working at 4 – 5GHz.

Faculty of Electronics Engineering, Broadcasting College 1, 136th Quy Luu, Phu Ly, Ha Nam, Viet Nam

https://www.researchgate.net/publication/303405737_High_gain_low_noise_amplifier_design_used_for_RF_front_end_application

LPKF ProtoMat E33

IS680

Design of a Broadband Coplanar Waveguide-Fed Antenna Incorporating Organic Solar Cells with 100% Insolation for Ku Band Satellite Communication

A broadband coplanar waveguide (CPW)-fed monopole antenna based on conventional CPW-fed integration with an organic solar cell (OSC) of 100% insolation is suggested for Ku band satellite communication. The proposed configuration was designed to allow for 100% insolation of the OSC, thereby improving the performance of the antenna. The device structure was fabricated using a Leiterplatten-Kopierfrasen (LPKF) prototyping Printed circuit board (PCB) machine, while a vector network analyzer was utilized to measure the return loss. The simulated results demonstrated that the proposed antenna was able to cover an interesting operating frequency band from 11.7 to 12.22

Fabrication and Measurement of the Proposed Antenna

The antenna structure was fabricated by using a E33 model LPKF prototyping PCB machine at Department of Electrical and Electronics, Iskenderun Technical University, Hatay, Turkey. In our research work, we had a chance to only fabricate the proposed antennas without organic solar cell due to the instrumentation limitation in our labs. A single sided copper covered the IS680 substrate with a thickness of 0.762 mm chosen in the manufacturing process for the proposed antenna. After the fabrication of the antenna, a 50 Ω SMA connector was soldered to the feeding line and ground plane, as illustrated in Figure 3.

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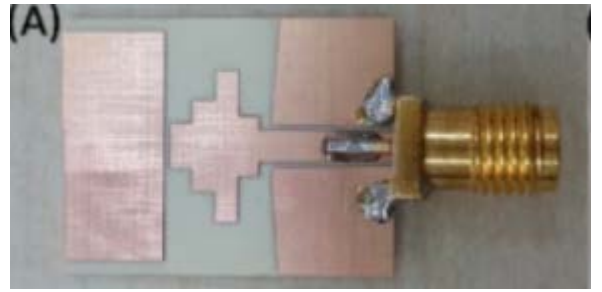
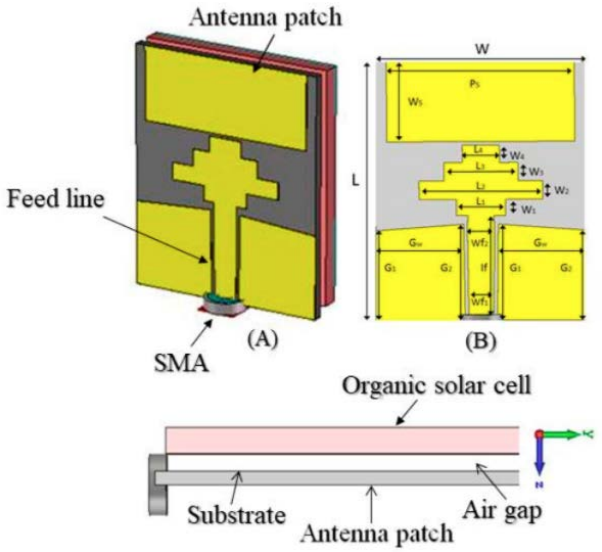
https://www.mdpi.com/1996-1944/13/1/142/htm

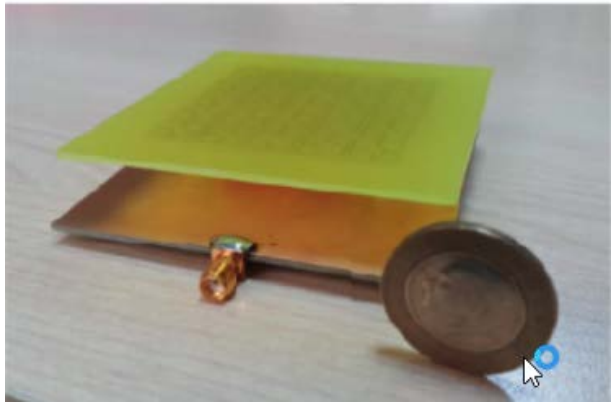
Ku Band, coplanar waveguide, organic solar cells





A Low-Profile Antenna Based on Single-Layer Metasurface for Ku-Band Applications

patch antenna, metasurface,



Improvement in the antenna gain is usually achieved at the expense of bandwidth and vice versa. This is where the realization of this enhancement can be made through compromising the antenna profile. In this work, we propose a new design of incorporating periodic metasurface array to enhance the bandwidth and gain while keeping the antenna to a low-profile scheme. The proposed antenna was simulated and fabricated in order to validate the results in the operating frequency range from 10 MHz to 43.5 GHz. Computer simulation technology (CST) microwave studio software was used to design and simulate the proposed antenna, while LPKF prototyping PCB machine was utilized to fabricate the antenna. Results showed that the antenna generated a gain and bandwidth of 14.2 dB and 2.13 GHz, respectively. Following the good agreement between the numerical and measurement results, it is believed that the proposed antenna can be potentially attractive for the application of satellite communications in Ku-band electromagnetic wave.

The utilization of a single-layer metasurface was successfully proposed to simulate and fabricate a high gain and band-width antenna of a reasonably low-profile scheme. The simulation results from CST microwave studio and HFSS tools were found to be in good agreement with the experimental one. Results showed the presence of three characteristic resonant frequencies of the antenna.

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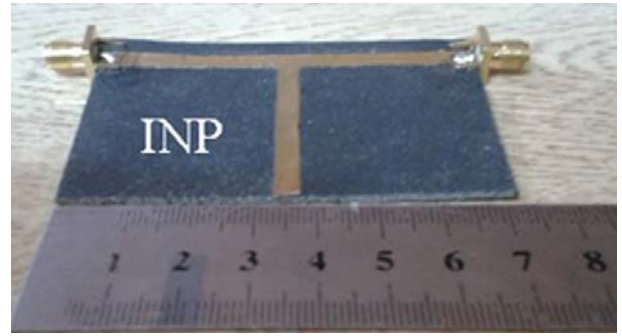
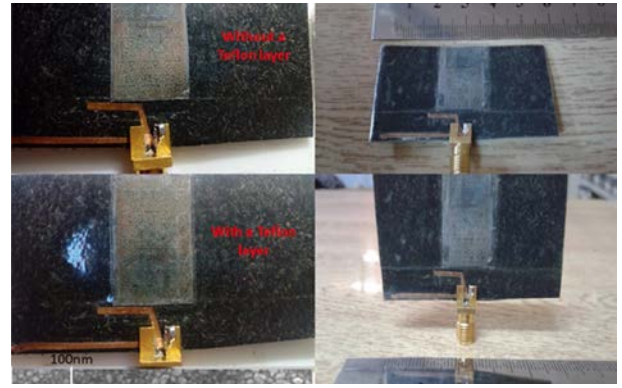
https://www.researchgate.net/publication/348193337_A_Low-Profile_Antenna_Based_on_Single-Layer_Metasurface_for_Ku-Band_Applications

Printed Microwave Metamaterial-Antenna Circuitries on Nickel Oxide Polymerized Palm Fiber Substrates

Iraqi Palm Tree Remnants (IPTR), Nickel Oxide Nanoparticles (NONP)



In this paper, the novelty of exploring the applications of the Iraqi Palm Tree Remnants (IPTR) mixed with Nickel Oxide Nanoparticles (NONP) hosted in Polyethylene (PE), called INP substrates, is utilized by printing metamaterial (MTM) based high gain microwave antennas on them. The proposed INP substrates are mainly created from pressed flexible organic fibers to suite the ink jet printing technologies. The complex relative constitutive parameters are characterized in terms of permittivity (ε) and permeability (μ) within the frequency range from 2 GHz up to 6 GHz using an open end dielectric probe and a T-stub transmission line technique. To validate the feasibility of the ….



MTM and dipole antenna structures fabrication

After accomplishing the printing process, an annealing progression inside a ProtoFlow LPKF's convection oven is curried out on the printed surface to avoid oxidization. Nevertheless, the annealing process is invoked to avoid the surface roughness due to the gaps between the nanoparticles. The annealing temperature is fixed at 100 °C for 12 hours to ensure good percolation channels by diminishing potential crakes due to glomeration of the nano structures that lead to conductivity reduction due to the surface roughness as depicted.

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