Implantable Medical Devices

ECE, UA

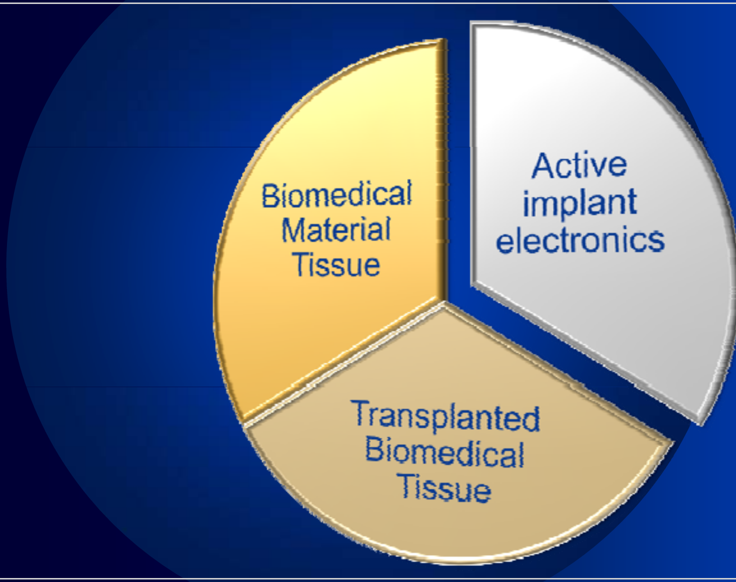
IMD

- **Implant:**

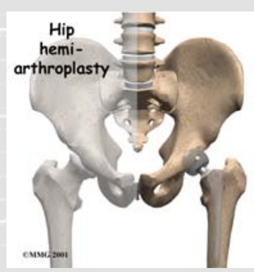
Man-made Medical Devices

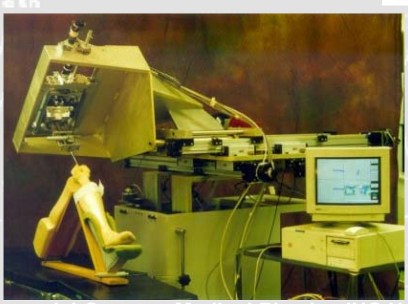
- **R**eplace a missing biological structure
- **S**upport a damaged biological structure
- **E**nhance an existing biological structure

IMD



Prosthetic Devices - Implants





Robotic device for knee prosthesis implantation

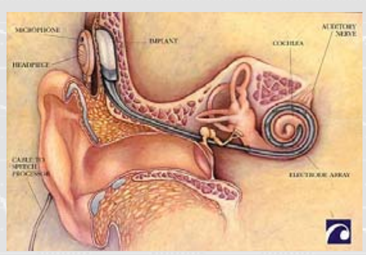
IMD

Applications

- **Electrically-powered implants** → **Active implants:** Pacemaker…
- **Bio-implants** → Biomaterial tissues: skin cornea…
- **Dental implants** → Artificial tooth
- **Orthopedic implants** → Correct the affected joint …

Prosthetic Devices – „Artificial Organs“

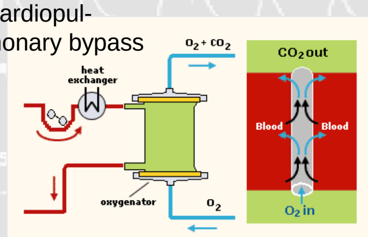
Artificial heart

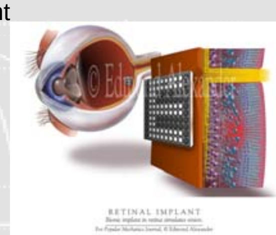


Cochlear implant

Ventilator

Cardiopul-monary bypass





Retinal implant

6

IMD

❖Medical Device Definition

An instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or other similar or related article, including a component part, or accessory which is:

-Recognized in the official National Formulary

-Intended for use in the diagnosis of disease or other conditions

-Intended to affect the structure or any function of the body of man or other animals

IMD

❖Classification:

- **Class I: General controls**
- **Class II: General controls with special controls** (infusion pumps, and surgical drapes…)
- **Class III: General controls and premarket approval** (implantable pacemaker, pulse generators, automated external defibrillators…)

IMD

- Four components of information security

Implantable Medical Devices
AT-A-GLANCE

American Heart Association
Learn and Live

Name of Device	What the Device Does	Reason for Device
Left Ventricular Assist Device (Also known as LVAD)	The left ventricle is the large, muscular chamber of the heart that pumps blood out to the body. A left ventricular assist device (LVAD) is a battery-operated, mechanical pump-type device that's surgically implanted.	Helps maintain the pumping ability of a heart that can't effectively work on its own. Sometimes used as a "bridge to transplant" for patients waiting for a heart transplant.
Pacemaker (Also known as Artificial Pacemaker)	A small device that has wires which are implanted in the heart tissue to send electrical impulses that help the heart beat in a regular rhythm. The device is powered by a battery.	When the heart's "natural pacemaker" is defective and causes the heart to beat too fast, too slow or irregularly, a pacemaker helps the heart beat in a regular rhythm.
Implantable Cardioverter Defibrillator (Also known as ICD)	A device that has wires which are implanted into the heart tissue and can deliver electrical shocks, detect the rhythm of the heart and sometimes "pace" the heart's rhythms, as needed.	Used in patients at risk for recurrent, sustained ventricular tachycardia or fibrillation. Restores the heart to normal rhythm. Helps prevent sudden cardiac death.

To see an illustration of an implantable medical device from this chart, visit:

Implantable Medical System

Implantable Devices (ID)

They have two main functions:

- Applying a therapy, usually by delivering electrical signals to some organs or tissues.
- Monitoring relevant parameters or signals in order to avoid risks to the patient or to optimize his treatment.

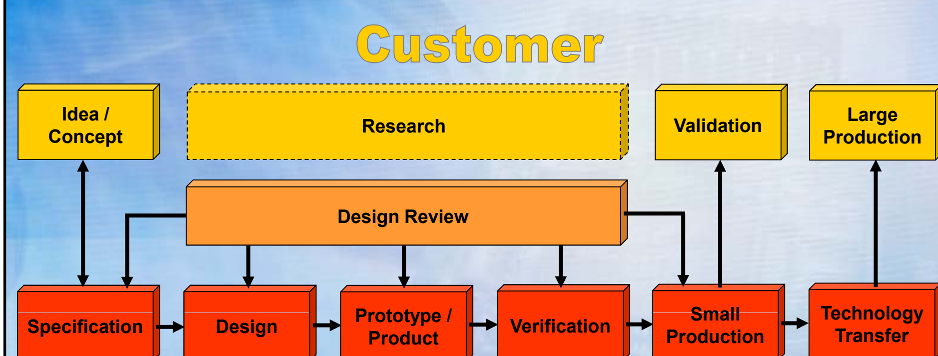
They usually are capable of measuring and analyzing electrical and mechanical physiological signals. They transmit this information (monitoring function) or use it as input data for the therapy.

Development Platform

- Communication protocols and modules
- Sensing modules
- Pacing modules
- Wireless battery recharge module
- Lead impedance measurement modules
- Accelerometer modules
- FW download module
- RTC module

medical devices

Design Process



medical devices

Application Fields of Some Systems Developed by CCC

- Heart Failure
- Obesity
- Diabetes
- Neurostimulation
- Blood pressure control
- Foot drop correction
- Urinary incontinence
- Patient monitoring
- Sleep apnea

CCC medical devices

medical devices

Implantable Systems Market

- 5 big companies:
  - share more than 98% of the market (mainly pacemakers and ICDs).
  - design and manufacture their products but do not act as contract designers or manufacturers.
  - buy patents and technology from small companies in the field or eventually buy the companies.
- Start –up companies created to check the feasibility of treating a disease using an implantable device implementing a therapy conceived by themselves:
  - few per year, mainly from US, Israel and Canada
  - without capacity to develop and manufacture the devices

CCC medical devices

medical devices

EMC for Active Implantable Medical Devices

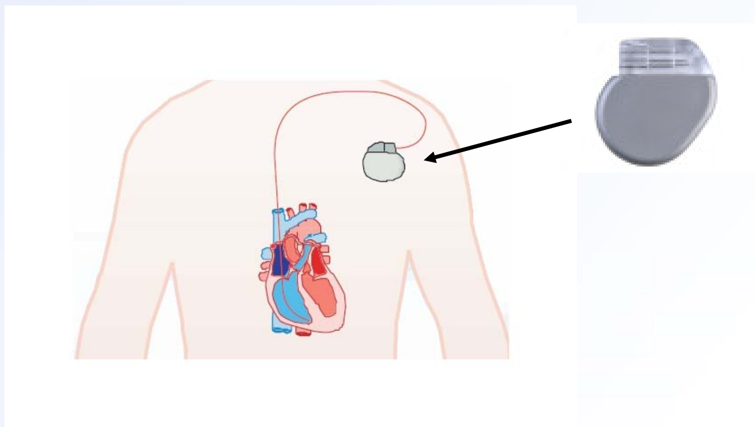
Active implantable medical devices

Types

- Implantable cardiac pacemakers
- Implantable defibrillators
- Cochlear implants
- Implantable nerve stimulators (FES)
  - Limb function stimulation
  - Bladder stimulators
  - Sphincter stimulators
  - Diaphragm stimulators
  - Analgesia
- Implantable infusion pumps
- Implantable active monitoring devices

Active implantable medical devices

Implantable cardiac pacemaker



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History

- On February 3, 1960, Dr. Orestes Fiandra performed the first effective pacemaker implant to a human being in the world.
- In 1970, Dr. Orestes Fiandra founded CCC, to develop and manufacture pacemakers.
- So up to date this means 48 years working with implantable medical devices 38 years of experience in manufacturing.

Carmel J Caruana Medical Physics IHC Univ of Malta

Active implantable medical devices

Cochlear Implant

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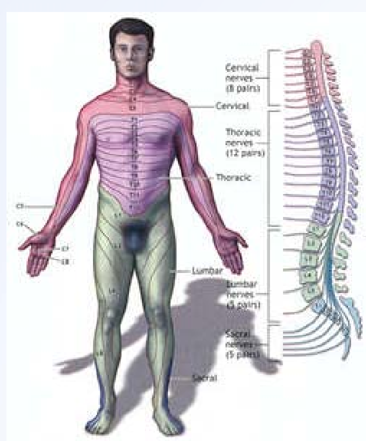
Active implantable medical devices

Functional Electrical Stimulation



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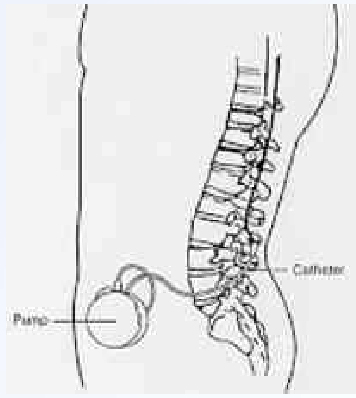
Active implantable medical devices

Implantable infusion pump



EMC Background - Definitions

Electromagnetic Compatibility (EMC) -

the condition which exists when equipment is performing its designed functions without causing or suffering unacceptable degradation due to electromagnetic interference to or from other equipment.

Background – Sources of interference

- **intentional radiators**
  - radio/TV stations
  - remote controls
  - paging, cell phones
- **unintentional radiators**
  - digital electronics
  - microwave ovens
  - appliances
  - lamp dimmers

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Background - Definitions

Electromagnetic compatibility

- **Electromagnetic emissions**
- **Electromagnetic susceptibility**

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Background - Definitions

	radiated emission limits	RF immunity fields
residential	100-500 μV/m *Class B (3m)*	3 V/m
industrial	300-700 μV/m *Class A (3m)*	10 V/m

EMC Standards & Regulations – History

1844 Morse, telegraph
1892 Law of telegraph in Germany (EMC)
1895 Marconi, first radio transmission
1927 German Hochfrequenzgerätegesetz
1933 CISPR founded
1934 USA Communications Act, FCC
1972 Altair 8800, first PC
1979 FCC Part 15, subpart J (ITE)
1985 IEC CISPR 22 (ITE)
1989 EMC Directive, EU

Standards – Res/Comm/Ind. Immunity

Electrostatic discharge	IEC 61000-4-2
RF radiated immunity	IEC 61000-4-3
Fast transient burst (EFT/B)	IEC 61000-4-4
Lightning induced surge	IEC 61000-4-5
RF conducted immunity	IEC 61000-4-6
*Harmonics/interharmonics**	*IEC 61000-4-7*
Radiated magnetic immunity	IEC 61000-4-8
Pulsed magnetic immunity	IEC 61000-4-9
Damped oscillatory magnetic	IEC 61000-4-10
Voltage dips/interrupts	IEC 61000-4-11

* a guide, not a standard

Medical Standards & Regulations – History

1895	X-ray, by Röntgen
1903	Electrocardiograph
1906	USA Pure Food & Drug Act (FDA)
1930	FDA name formalized
1958	Implanted pacemaker
1967	Cochlear implant
1979	FDA MDS-201-0004 (EMC)
1990	AIMD 90/385/EEC
1993	MDD 93/42/EEC
1993	IEC 60601-1-2 1st edition
1997	Brain pacemaker

Standards – Medical equipment Immunity (IEC 60601-1-2 2nd edition)

Electrostatic discharge	IEC 61000-4-2
RF radiated immunity	IEC 61000-4-3
Fast transient burst (EFT/B)	IEC 61000-4-4
Lightning induced surge	IEC 61000-4-5
RF conducted immunity	IEC 61000-4-6
Radiated magnetic immunity	IEC 61000-4-8
Voltage dips/interrupts	IEC 61000-4-11

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Standards – Implant Immunity

RF radiated immunity	IEC 61000-4-3
Radiated magnetic immunity	IEC 61000-4-8

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Active implantable medical devices

Environments - general

Active implantable medical devices

EMC threats - general

Device Type	Power (W)	Frequency (MHz)	In Vivo Studies			In Vitro Studies
			Health Canada	Univ. of Oklahoma	U.S. FDA	
Analog Cellular Phone	0.6	828	0%	0%	0	0.5%
TDMA-50	0.6	835	3.4%	4.7%	10%	4.2%
TDMA-11	0.6	—	—	—	36.7%	10.5%
CDMA	0.6	—	—	2.8%	—	3.1%
PCS	0.6	1810	0%	0.6%	—	0.2%
GSM	0.6	—	—	—	0	—
FRS	0.1	468	0%	—	—	—
Number of Pacemakers	—	—	20	29	30	975 patients
Incidence of Interference	—	—	3.4%	4.7%	—	20%

Table II. Effects of various wireless telecommunications devices on pacemakers (in vitro and in vivo studies).

Active implantable medical devices

Environments - special

Active implantable medical devices

EMC threats – EAS samples (HC survey)

Type	Mode	Carrier Frequency	Magnetic Field Strength (μT)*	Effects on Pacemakers	
				Inhibition	Reactivation
EAS	Continuous	535 Hz	450	23%	55%
	Modulated pulse	Carrier: 58.4 KHz modulation:60 Hz	400	36%	68%
	Sweep	7.4–9.1 MHz	0.1	0	0
WTMD	Pulse	250–500 Hz	4.5–10	5%	9%
	Pulse	89 Hz	45	36%	64%
	Modulated pulse	250–909 Hz	18–22	5%	9%
	Modulated pulse	210 Hz	12	9%	14%
HHMD	Continuous	14 kHz–1.8 MHz	0.2–10	0	0

*Measured at 15 cm from the transmission panel of EAS and WTMD systems and 2.5 cm from HHMDs; 0 indicates no interference effects.

Table III. Effects of security systems on pacemakers.

Active implantable medical devices

EMC threats – RFID*

Carrier frequency	peak field	modulation
134 kHz	65 A/m	10 – 14 Hz
13.56 MHz	7 A/m	2 – 11 Hz
915 MHz	-	56 kHz

*ISO/IEC JTC1 SC31 study January 2006

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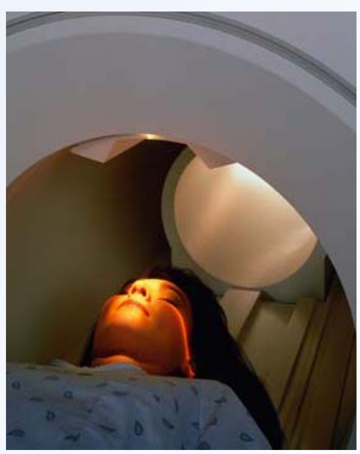
Active implantable medical devices

Environments - special



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Active implantable medical devices

EMC threats – MRI

Implant → Potential Interferer ↓	Implanted Cardiac Pacemaker	Implanted Cardiac Defibrillator	Implanted Neurostimulator
Shortwave and Microwave Diathermy	Absolute contraindication	Absolute contraindication	Absolute contraindication
Ultrasound Diathermy	Take Precaution*	Take Precaution*	Absolute contraindication
Electromagnetic Stimulation Device	Take Precaution*	Take Precaution*	Absolute contraindication
MRI	Absolute contraindication	Absolute contraindication	Absolute contraindication
Electrosurgery Device	Take Precaution*	Take Precaution*	Take Precaution*
External Defibrillator	Take Precaution*	Take Precaution*	Take Precaution*
Radiotherapy Device	Take Precaution*	Take Precaution*	Take Precaution*
Lithotripsy or Ultrasound Therapy Device	Take Precaution*	Take Precaution*	Take Precaution*
Fluoroscopy or other X-ray Devices	No contraindication	No contraindication	No contraindication
Echography	No contraindication	No contraindication	No contraindication

Agence française de sécurité sanitaire des produits de santé (AFSSAPS)(1995) as adopted by Health Canada.

Active implantable medical devices

EMC threats – MRI

- **Magnetic field strengths of 0.3T to 3T (earth's magnetic field is ~ 50 μT).**
- **Magnetic field gradients of 20 mT/m to 100 mT/m.**
- **Pulse repetition time 16 – 500 ms.**

Active implantable medical devices

EMC threats – MRI

2006 classification for implant and ancillary device safety (ASTM/FDA):

- ***MR-Safe*** **–** device or implant is completely non-magnetic, non-electrically conductive, and non-RF reactive.
- ***MR-conditional*** **–** may contain magnetic, electrically-conductive or RF-reactive components found safe in tested conditions ("tested safe to 1.5T")
- ***MR-unsafe***

Active implantable medical devices

EMC standards in place

	USA FDA	EU MDD/AIMD
Cochlear implants	**IEC 60601-1-2** **ANSI C63.19** **FDA Guidance 8-1-03**	***EN 60118-13 (MDD)***
Cardiac pacemakers	**IEC 60601-1-2** **AAMI PC69**	***EN 45502-2-1 (AIMD)*** **ISO 14708-2**
Infusion pumps		

Active implantable medical devices

EMC draft standards

	USA FDA	EU MDD/AIMD
Cochlear implants	IEC 60601-1-2 ANSI C63.19 FDA Guidance 8-1-03	*EN 60118-13 (MDD)* prEN 45502-2-3 (AIMD)
Cardiac pacemakers	IEC 60601-1-2 AAMI PC69	*EN 45502-2-1 (AIMD)* ISO 14708-2
Infusion pumps	dr ISO 14708-4 (AAMI)	dr ISO 14708-4

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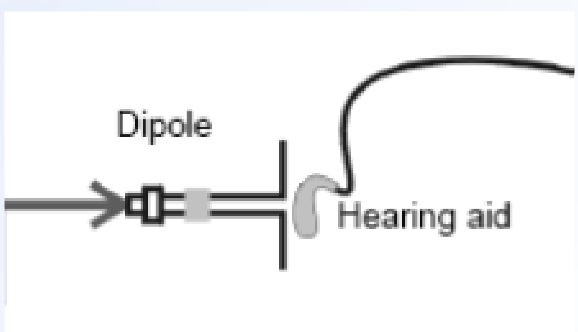
EMC standards – cochlear implants



From: EN 60118-13

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EMC standards – cochlear implants

	USA FDA ANSI C63.19	EU EN 60118-13
frequency range	835-1880 MHz	800 – 2000 MHz
Field strengths	E: 31.6 – 177.7 V/m H: 0.071 – 0.4 A/m	E: 50 – 75 V/m

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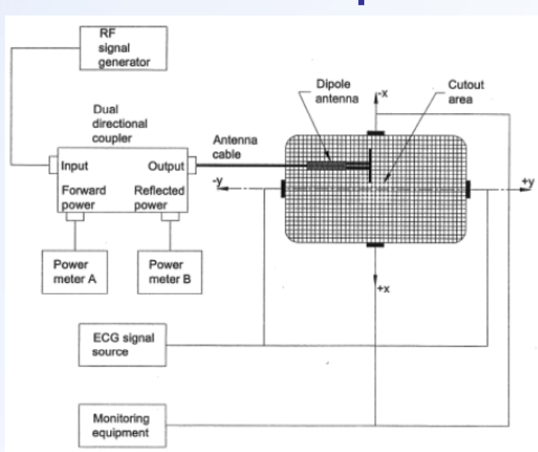
Active implantable medical devices

EMC standards – cardiac pacemaker



From: AAMI PC69

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Active implantable medical devices

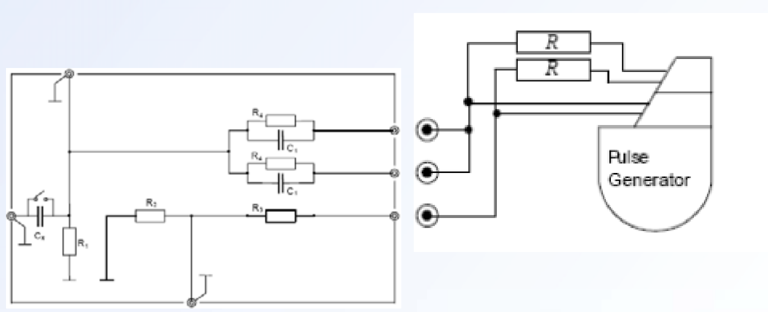
EMC standards – cardiac pacemaker

	USA FDA AAMI PC69	EU and international ISO 14708-2/EN 45502-2-1
frequency range	450 – 3000 MHz	E: 16.6 Hz – 3000 MHz H: 1 – 140 kHz
Field strengths	40 mW (~ 10 V/m no fluid) optional 2W and 8W	1 – 10 V p-p* 107 – 150 A/m

*For ISO 14708-2/EN 45502-2-1, applied through a tissue equivalent interface circuit.

Active implantable medical devices

EMC standards – cardiac pacemaker



ISO 14708-2/EN 45502-2-1 Connection of tissue equivalent interface circuit (left) and multichannel bipolar cardiac pacemaker (right).

Testing 450 MHz – 3 GHz is deleted if feed-through insertion loss is 30 dB or greater.

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Pacemakers

- **Products**:
  - TEROS pacemakers
  - ALUS Programming System
  - Leads
  - Circuits & Parts

CCC medical devices

medical devices

Active implantable medical devices

EMC standards – infusion pump

parameter	USA FDA and EU draft ISO 14708-4
Static magnetic fields	1 mT (10 G)
Magnetic fields, 10 Hz – 30 MHz	A: 795 – 0.053 A/m (1 mT – 0.067 µT) B: 159 – 0.53 A/m (0.2 mT – 0.67 µT)
30 MHz – 450 MHz	A: 16 V/m, swept B: 140 V/m, spot
450 MHz – 3000 MHz	A: 40 mW, per AAMI PC69

Performance criteria

- A: during test, operates as intended; no degradation
- B: during test, may be loss of function; lost functions are self-recoverable after test.

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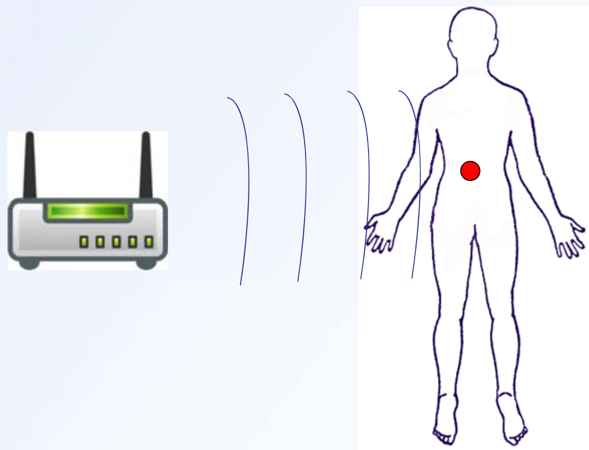
EMC – how much field attenuation does the human body provide?



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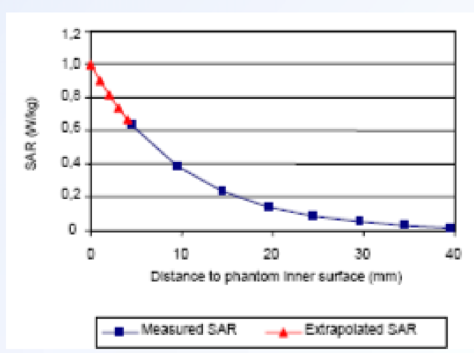
EMC standards – SAR measurement



From: EN 62209-1

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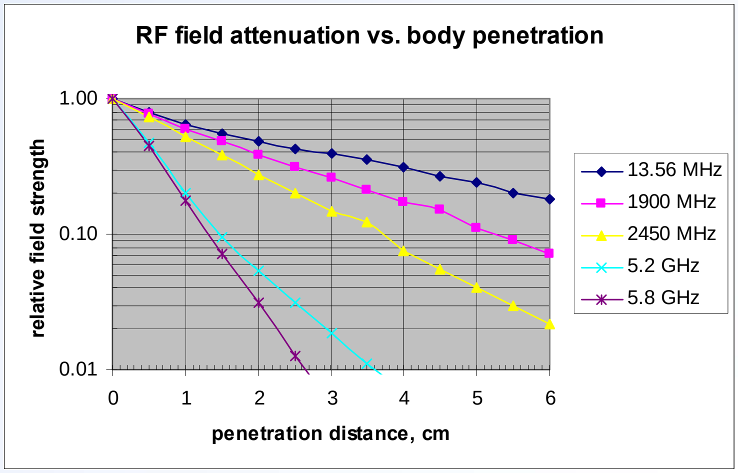
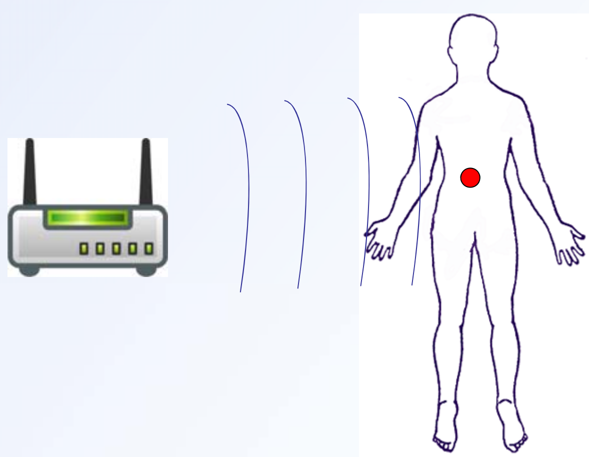
EMC standards



Active implantable medical devices

Radio standards – programming the implant



Active implantable medical devices

Radio standards – programming the implant

Global Frequency bands	Category	Comments
9 – 315 kHz	EU medical implant	not so allocated outside EU
13.56 MHz	ISM and SRD	RFID frequency*
27.12 MHz	ISM and R/C	congested
40.68 MHz	ISM and SRD	protocol restrictions in USA
402 – 405 MHz	Medical Implant Comm.	Reserved for implants
2.45 GHz	ISM and SRD and microwave oven	802.11b/g (BT, Wi-Fi)
5.8 GHz	ISM	802.11a

* See FDA Guidance 12-10-2004 on RFID transponders for patient ID.

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Active implantable medical devices

Radio standards – programming the implant

Global Frequency bands	FCC regulation	EU regulation
9 – 315 kHz	15.209 general (not 90-110 kHz)	EN 302 195-1, -2 (radio) EN 301 489-1, -31 (EMC)
13.56 MHz	15.225 general	EN 300 330-1, -2 (radio) EN 302 291-1, -2 (inductive)
27.12 MHz	15.227 and 95C	EN 300 220-1, -2 (radio) EN 301 489-1, -3 (EMC)
40.68 MHz	15.231	EN 300 220-1, -2 (radio) EN 301 489-1, -3 (EMC)
402 – 405 MHz	95I	EN 301 839-1, -2
2.45 GHz	14.247, 15.249	EN 300 440-1, -2; EN 300 328
5.8 GHz	15.247; 15.407	EN 300 440-1, -2; EN 301 893

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Active implantable medical devices

Radio standards – Medical Implant Communications (MICS), 402 – 405 MHz

Jurisdiction	Regulation
USA	47 CFR Part 95 subpart I
EU	EN 301 839-1, -2 EMC per EN 301 489-1, -27
Japan	Ordinance regulating radio equipment, article 49.14
Australia	Radiocommunications (Low Interference Potential) Class License, item 48

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Active implantable medical devices

Radio standards – Medical Implant Communications (MICS)

Key parameters

Frequency band	402 – 405 MHz.
Transmitter power	25 µW or 9.1 mV/m at 3m on anechoic site (if implant, measured in torso simulator.
Bandwidth	300 kHz maximum.
Frequency stability	100 ppm.
Programmer access protocol	listen-before-talk.

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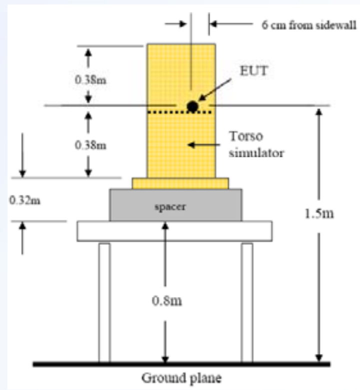
Active implantable medical devices

Radio standards – Medical Implant Communications (MICS)

Torso simulator



From FCC 95I and EN 301 489-27

Active implantable medical devices

EMC design considerations

- EM disturbances for implants are much more severe than non-medical industrial ones - but there may be some mitigation of high-frequency RF fields owing to body attenuation.
- EM disturbances are limited in type to RF electric and magnetic fields, DC and suitably modulated. (Be careful: EN 45502-2-1/ISO 14708-2 for pacemakers use special coupling networks).
- Influence of MRI on patients can arise from presence of implant leads, separate from any direct effect on implant.

Active implantable medical devices

EMC design considerations (continued)

- **In many cases, the recognized EMC tests for a given active implant will differ between jurisdictions. Be careful to cover all tests, or obtain prior regulatory assent to a single method of testing.**
- **RF communications with implants takes place with lowest loss at lowest RF frequencies – but operation at these frequencies is also most susceptible to ambient disturbances such as RFID. Therefore, a robust protocol is needed. See FDA draft guidance "Radio-Frequency Wireless Technology in Medical Devices" to augment IEC 60601-1-2 compliance testing.**

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IMPLANT CIRCUIT DESIGN

- Wireless Power and Data Transmission with ASK Demodulator and Power Regulator for a Biomedical Implantable SOC

Chen-Hua Kao, Kea-Tiong Tang 2009 IEEE

Implant circuit design

- **Outline**
  - **Abstract**
  - **Introduction**
  - **ASK Structure**
  - **Power Regulator**
  - **Results**
  - **Conclusion**

Implant circuit design

- **Abstract**
- Bio-medical implantable devices have appeared for more than fifty years.
- Wireless implantable devices could transmit power and data by magnetic coupling.
- This paper presents an efficient power and data transmission- LDO & ASK

IMPLANT CIRCUIT DESIGN

- **Introduction**

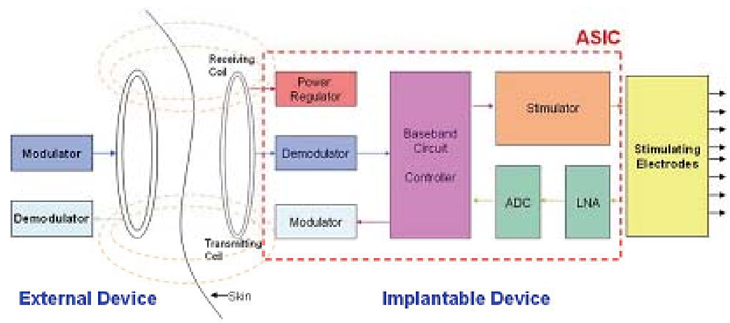


Fig. 1 Block diagram of a stimulation device

IMPLANT CIRCUIT DESIGN

- Introduction

- Widely used implantable stimulator:
  →cochlea implant, pacemaker, auditory brainstem …

- Size and Power consumption is much concerned
  → wireless power and data combining transmission

Power regulator   ASK

IMPLANT CIRCUIT DESIGN

- ASK Demodulation Structure

<low power, small area, high efficiency, low cost and feasibility>

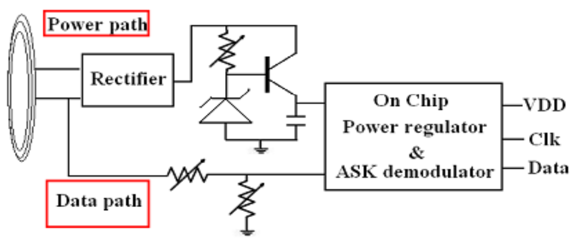
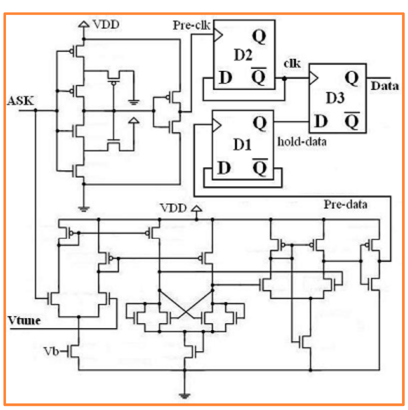


Fig.2 Receiver block

IMPLANT CIRCUIT DESIGN

- ASK Demodulation Structure



self-sampling

50% modulation rate

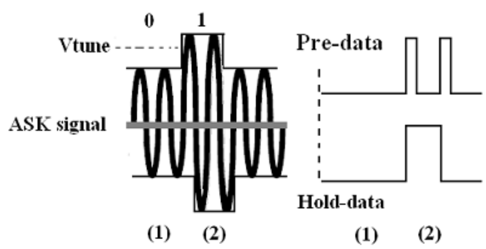
tunable modulation index

IMPLANT CIRCUIT DESIGN

- ASK Demodulation Structure

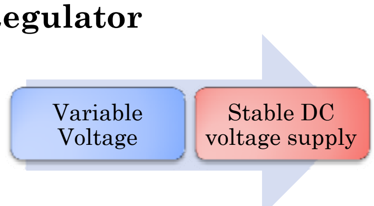
  (1)Low level sensing

  (2)High level sensing



IMPLANT CIRCUIT DESIGN

- **Power Regulator**



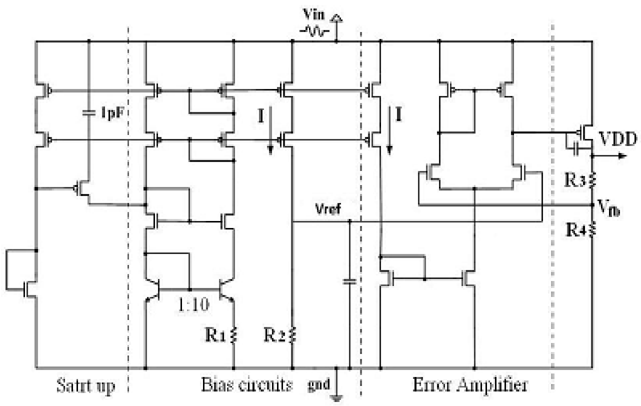
$$I = \frac{V_T \times \ln 10}{R_1}$$

$$V_{ref} = I \times R_2 = \frac{R_2}{R_1} \times V_T \ln 10$$

IMPLANT CIRCUIT DESIGN

- **Power Regulator**

$$VDD = \frac{V_{fb}}{R_4} \times (R_3 + R_4)$$



IMPLANT CIRCUIT DESIGN

- **Results**

  // carrier is set as 2M Hz with a 1M Hz random binary data rate

  // 2.86% modulation index 1.8V supply

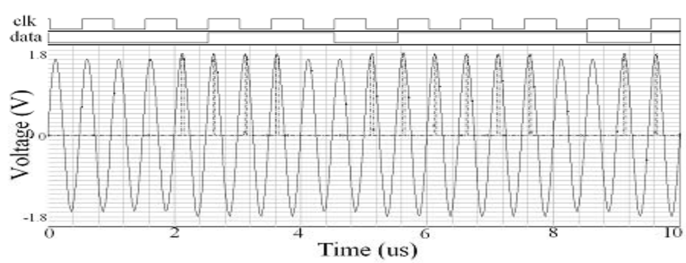


Fig. 6 Modulation index=2.86% (VH=1.8V, Vtune=1.75V, VL=1.7V), Modulation rate=50% (2M Hz carrier and 1M Hz data), Input ASK data are 0011011101, Output "data" are Correctly 0011011101 with "clk" sampling.

IMPLANT CIRCUIT DESIGN

- Results

Table I
Characteristics of ASK demodulator and power regulator

	Specification	Results
Power Regulator	Power supply	4V~5V 2M Hz
	VDD (with RC load 0.1nF and 10kΩ)	1.802V~1.803V
ASK Demodulation	Modulation Index*	2.86%~38.46%
	Operated Carrier	2M Hz
	Data Rate	1M Hz
	Modulation Rate**	50%

$$* \; Modulation \;\; Index = \frac{VH - VL}{VH + VL} \times 100\%$$

$$* \; Modulation \;\; Rate = \frac{Data \;\; Rate}{Operated \;\; Carrier} \times 100\%$$

IMPLANT CIRCUIT DESIGN

- **Conclusion**

  - This work presents a new ASK demodulator structure with a regulated power supply.
  - we find this ASK demodulator having better modulation rate and controllable modulation index.
  - This architecture is flexible for biomedical applications.
  - Simulation results of this work are very appealing to these applications.

IMPLANT CIRCUIT DESIGN

- **Using Pulse Width Modulation for Wireless Transmission of Neural Signals in Multichannel Neural Recording Systems**

Ming Yin, Maysam Ghovanloo

IEEE Transactions on Neural Systems and Rehabilitation engineering, august2009

IMPLANT CIRCUIT DESIGN

- **Outline**
  - Introduction
  - WINER System Architecture
  - Evaluation of the wireless PWM technique
  - Simulation and Measurement Results
  - Conclusion

IMPLANT CIRCUIT DESIGN

- Introduction
  - The accelerating pace of research has created a considerable demand for data acquisition systems
  - Commutator is a delicate mechanical component and one of the most expensive items in the system
  - Size, power consumption, robustness, input referred noise,and bandwidth are the main concerns in developing WNR system

IMPLANT CIRCUIT DESIGN

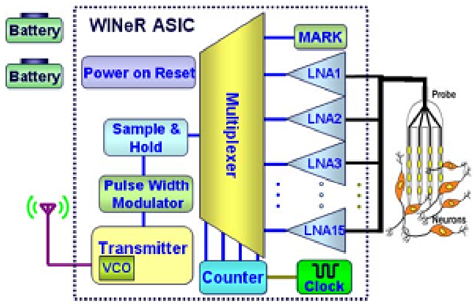
- Introduction
  - ✓ neural signal spectrum 0.1 Hz -10 kHz
  - ✓ 50 to 1 mV, supply range of 1.5V
  - ✓ > 10 uV of background noise
  - ✓ resolution of 8–10 bits
  - ✓ 160 kb/s of bandwidth is needed

PWM of TDM signal in WINeR system

IMPLANT CIRCUIT DESIGN

- **WINER System Architecture**

A. Implantable Transmitter Unit



(a)

a. gain of 100 amplifier

b. 0.1 Hz to 10 kHz using an array of LNA

c. 16:1 TDM combines 15 channels

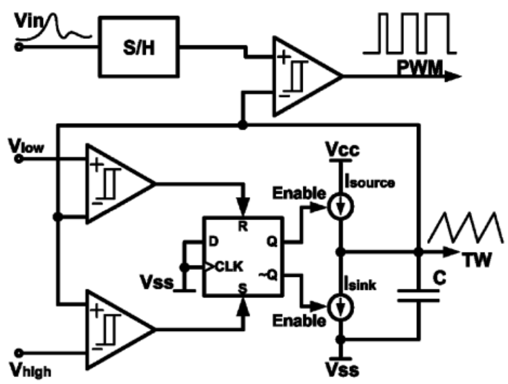
IMPLANT CIRCUIT DESIGN

- **WINER System Architecture**
  - **PWM** (Pulse width modulator)

- A sample and hold (S/H) circuit follows the TDM to stabilize samples for PWM.
- The PWM block compares the S/H output with a triangular waveform generator (TWG) output through a high speed rail-to-rail comparator C, resulting in a PWM-TDM signal
- PWM-TDM duty cycle is robust against noise and interference (ATC)
- Complexity and power consumption of a single comparator is far less than ADC

IMPLANT CIRCUIT DESIGN

- **WINER System Architecture**
  - **PWM** (Pulse width modulator)



IMPLANT CIRCUIT DESIGN

- **WINER System Architecture**

B. External Receiver Unit

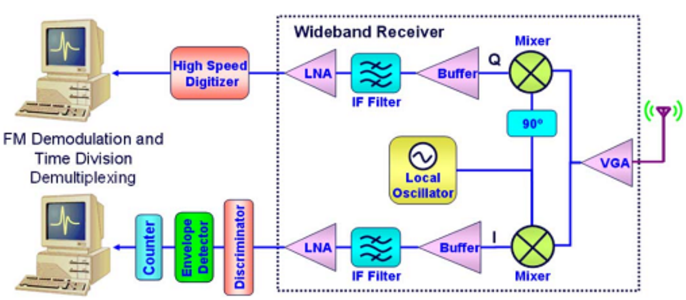


Fig. 2. Block diagram of the external receiver unit in the WINeR system.

IF-PWM-FSK

IMPLANT CIRCUIT DESIGN

- **Evaluation of the wireless PWM technique**

A. Implantable Transmitter Errors

1) PWM Noise:

$$w = CV_{\text{in}}\left(\frac{1}{I_{\text{Source}}} + \frac{1}{I_{\text{Sink}}}\right).$$

$$\frac{dw}{T} = D\left(\frac{dC}{C} - \frac{I_{\text{Sink}}I_{\text{Source}}}{I_{\text{Source}} + I_{\text{Sink}}}\left(\frac{dI_{\text{Source}}}{I_{\text{Source}}^2} + \frac{dI_{\text{Sink}}}{I_{\text{Sink}}^2}\right)\right) + \frac{dV_{\text{in}}}{V_{\text{high}} - V_{\text{low}}}$$

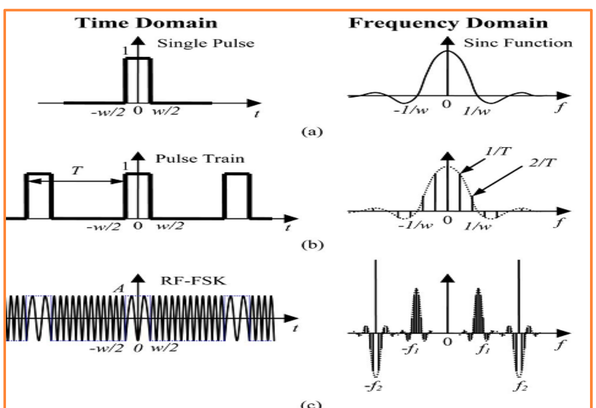
$$\frac{w_{n,\text{PWM}}^2}{T^2} = \left(\frac{DI_{\text{Sink}}I_{\text{Source}}}{I_{\text{Source}} + I_{\text{Sink}}}\right)^2\left(\frac{i_{n,\text{Source}}^2}{I_{\text{Source}}^4} + \frac{i_{n,\text{Sink}}^2}{I_{\text{Sink}}^4}\right) + 3\left(\frac{V_{n,\text{comp}}}{V_{\text{high}} - V_{\text{low}}}\right)^2$$

IMPLANT CIRCUIT DESIGN

- **Evaluation of the wireless PWM technique**

A. Implantable Transmitter Errors

2) VCO Noise:



4. Transmitter FSK-PWM-TDM signal in time and frequency domains.

IMPLANT CIRCUIT DESIGN

- **Evaluation of the wireless PWM technique**

B. External Receiver Errors

1) Receiver Thermal Noise:

Maximum noise power transfer happens when there is impedance matching between successive blocks.

$$P_{n,Rx,\mathrm{dBm}} = P_{n,\mathrm{dBm}} + 10\log(F-1) = [-174 + 10\log(\Delta f) + 10\log(F-1)]\ \mathrm{dBm}.$$

$$\mathrm{SNR}_{\mathrm{PWM}} = \left(\frac{T}{\Delta w}\right)^2 = \frac{1}{\Delta D^2}.$$

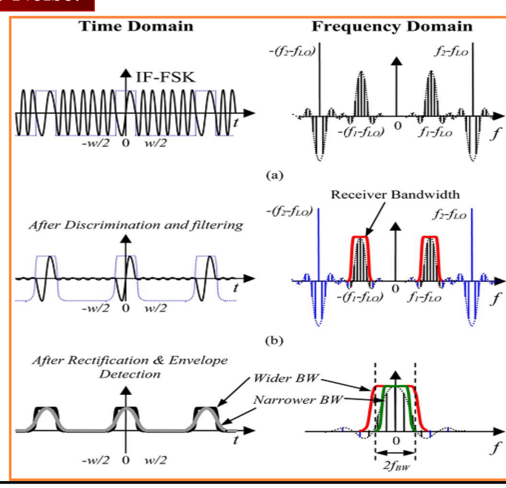
IMPLANT CIRCUIT DESIGN

- **Evaluation of the wireless PWM technique**

B. External Receiver Errors

2) Local Oscillator Phase Noise:

3) RBW Limitation:



IMPLANT CIRCUIT DESIGN

- **Simulation and Measurement Results**

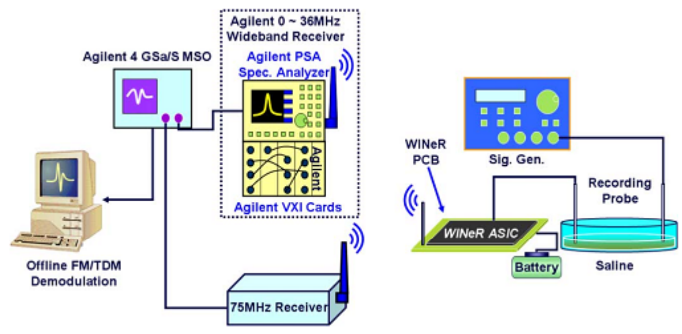
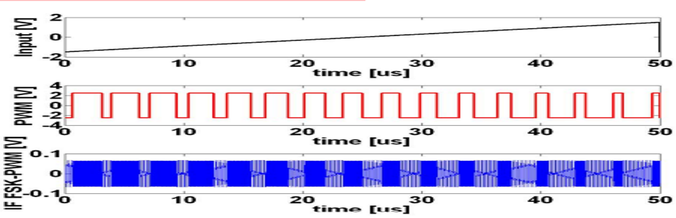


Fig. 9. Experimental setup for the wireless PWM technique using the WINeR ASIC as the transmitter, and wideband receivers from 5 to 75 MHz.

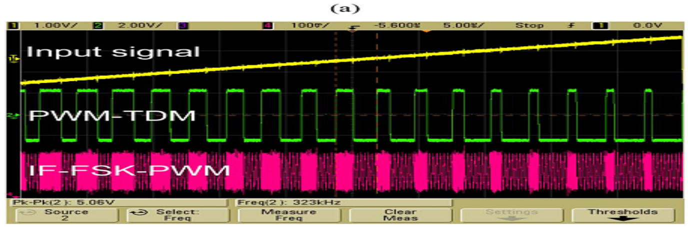
IMPLANT CIRCUIT DESIGN

- **Simulation and Measurement Results**

A. *Matlab-Simulink Modeling*



(a)



IMPLANT CIRCUIT DESIGN

- **Simulation and Measurement Results**

B. Measurements

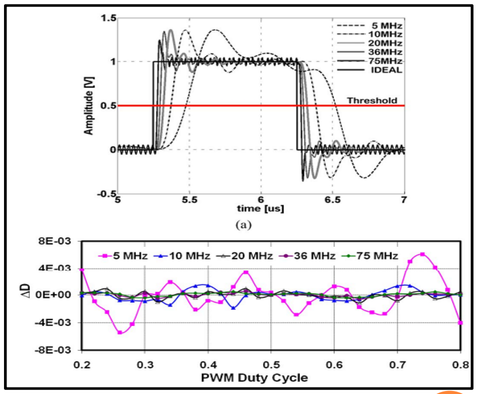
1) Comparator Error

2) TWG Error

3) VCO Error

4) Receiver Thermal Noise

5) Receiver Bandwidth Limitation Error



IMPLANT CIRCUIT DESIGN

- **Conclusion**
  - Presented an effective architecture for simultaneously acquiring wideband neural signals from a large number of sites.
  - WINeR operates based on pulse width modulation of time division multiplexed samples (PWM-TDM)
  - Identified various sources of error in the proposed architecture
  - It turns out that the receiver bandwidth limitation is the dominant source of inaccuracy followed by SNR at the receiver RF front-end output.

IMPLANT CIRCUIT DESIGN (ANTENNA)

- **Design of Implantable Microstrip Antenna for Communication With Medical Implants**

Pichitpong Soontornpipit, Cynthia M. Furse

IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, AUG 2004

IMPLANT CIRCUIT DESIGN

- Outline
  - Introduction
  - Method of analysis and evaluation
  - Parametric Study
  - Analysis of the antenna in the realistic shoulder
  - Conclusion

IMPLANT CIRCUIT DESIGN

- **Introduction**
  - **where the antennas are "embedded" in lossy material reduced antenna efficiency**
  - **the need to reduce antenna size, and the very strong effect of multipath losses.**
  - **This paper provides a better understanding of microstrip antennas embedded in lossy environments.**

IMPLANT CIRCUIT DESIGN

- **Intruduction**
  - I. ***Coaxial antennas***
  - II. ***wire antennas***
  - III. ***arrays embedded in various lossy materials***

Embedded microstrip antennas

IMPLANT CIRCUIT DESIGN

Embedded microstrip antennas

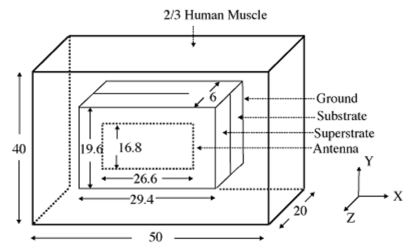
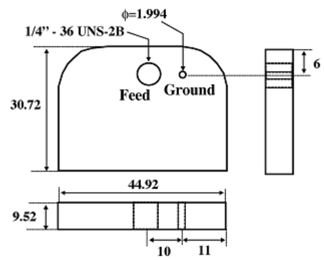


Fig. 1. Simulation model (in millimeters).



IMPLANT CIRCUIT DESIGN

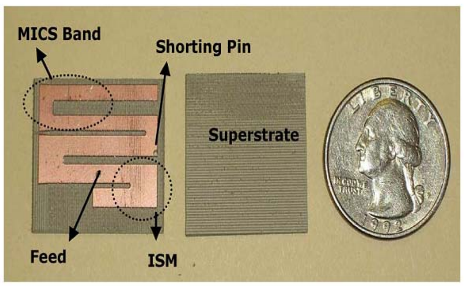
- Method of analysis and evaluation

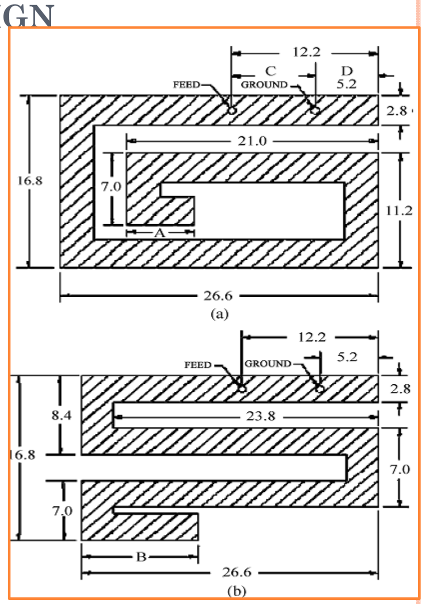
TABLE I
EFFECTIVE ELECTRICAL PARAMETERS OF DIFFERENT SUBSTRATES AND SUPERSTRATES (POWER IS GIVEN AT 1 m WHEN MAX 1-g SAR = 1.6 W/kg)

	Substrate			Superstrate Parameters (substrate is Macor)		
	Teflon	Macor	Alumina			
ε_r	2.1	6.1	9.4	3.1	6.2	9.3
ε_{r_eff}	2.28	5.54	8.24	5.54	6.12	6.69
λ_{eff} (m)	0.115	0.179	0.218	0.115	0.188	0.197
Power (dBw)	-29.51	-31.60	-18.69	-31.60	-10.97	-6.28
Eff. (%)	4.16	21.37	35.18	21.37	9.62	6.36

IMPLANT CIRCUIT DESIGN

- Parametric Study
  - A. Effect of Shape





IMPLANT CIRCUIT DESIGN

- Parametric Study
  - B. Effect of Length

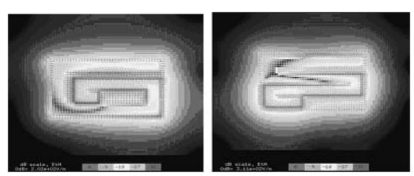
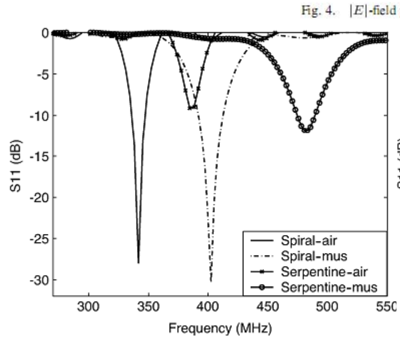
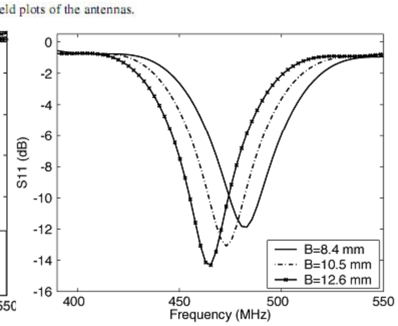


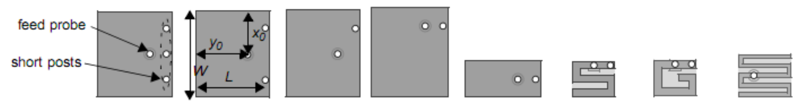
Fig. 4. |E|-field plots of the antennas.





IMPLANT CIRCUIT DESIGN

- C. Effect of Feed and Ground Point Locations



- D. Effect of Substrate and Superstrate Materials
- E. Effect of Substrate and Superstrate Thickness
- F. Effect of Nonuniform Superstrate

IMPLANT CIRCUIT DESIGN

- In realistic shoulder

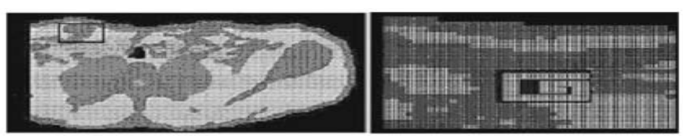


Fig. 13. X—Y section of realistic shoulder (370 mm × 170 mm) used in the design.

TABLE II
PERMITTIVITIES AND CONDUCTIVITIES FOR TISSUES OF THE REALISTIC SHOULDER AT 433 MHz FROM [32]

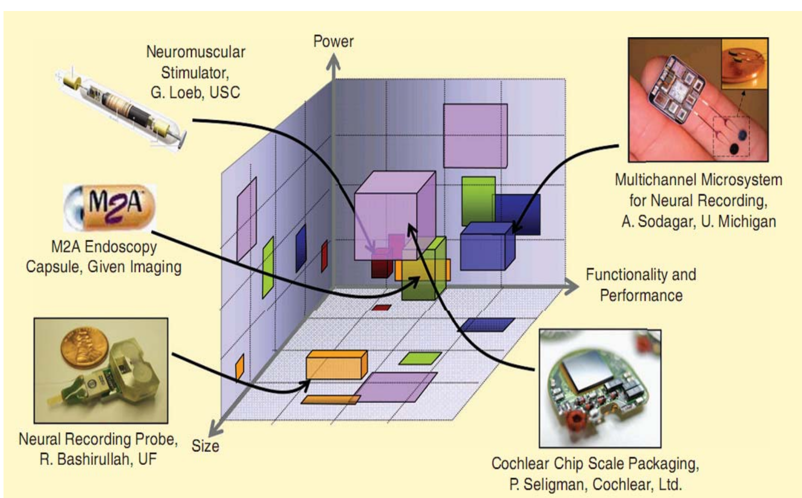
Material	ε_r	σ
Fat	5.028	0.04502 S/m
Bone	17.35	0.16725 S/m
Cartilage	43.64	0.65 S/m
Skin	46.68	0.64 S/m
Nerve	35.7	0.5 S/m
Blood	57.29	1.72 S/m
Muscle	42.807	0.64633 S/m
Lung	21.58	0.3561 S/m

IMPLANT CIRCUIT DESIGN

- **Conclusion**

- Spiral and serpentine microstrip antennas that can be used or communication with medical devices have been analyzed.
- The spiral design was the smaller of the two designs and both were significantly smaller
- The best design can be found by first choosing the substrate and superstrate materials, then optimizing the length to provide approximately the size
- Finally, the antenna should be tuned by varying the location of the feed point with the ground point fixed very near one end of the antenna.

IMPLANT CIRCUIT DESIGN



IMPLANT CIRCUIT DESIGN

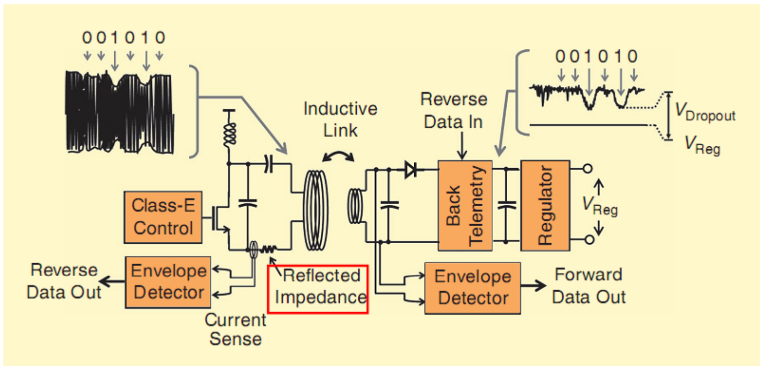


Figure 2. *Basic inductive link components and architecture for wireless power and data transfer.*

IMPLANT CIRCUIT DESIGN

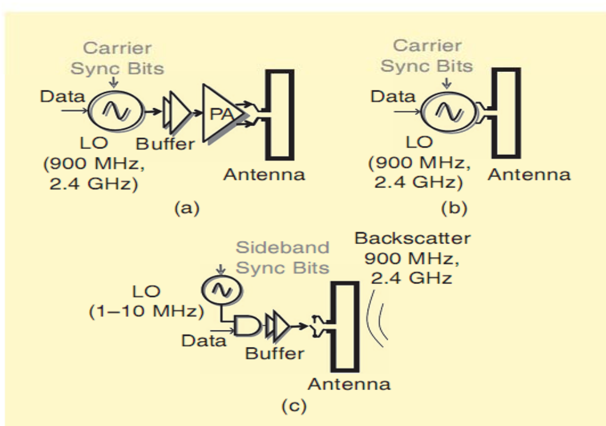
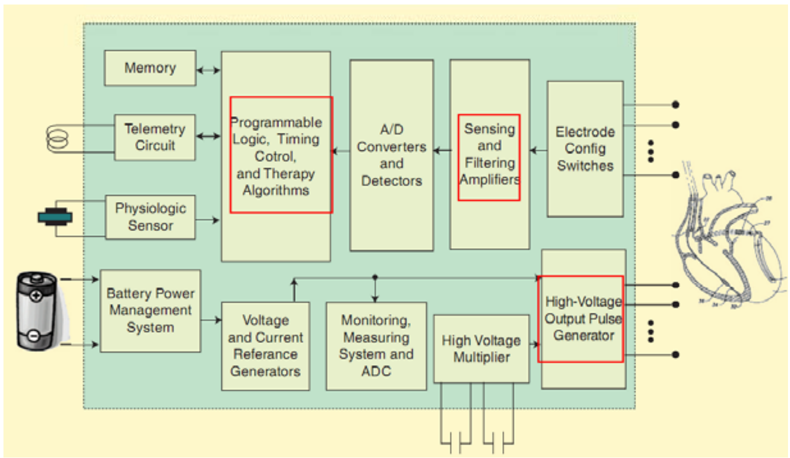
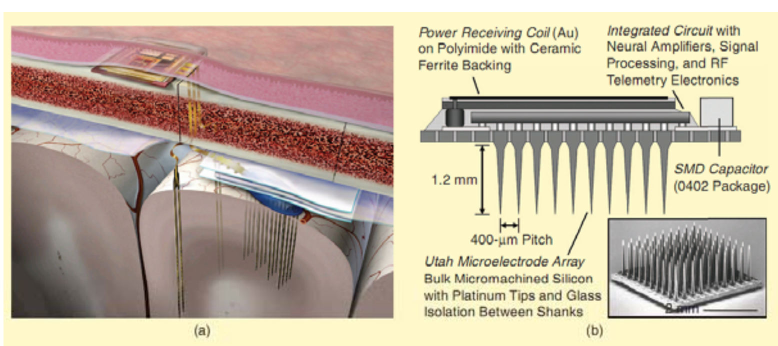


Figure 3. *Simplified block diagrams of data transmission strategies for biomedical devices.*

IMPLANT CIRCUIT DESIGN



IMPLANT CIRCUIT DESIGN



igure 8. *Conceptual diagrams of neural microsystems for brain computer interfaces: (a) two-dimensional and three-imensional arrays of cortically implanted electrodes with ribbon cables connecting them to a subcutaneous electronics [41] nd (b) neural interface (INI) assembly concept with Utah Microelectrode Array [42].*

Implant circuit design

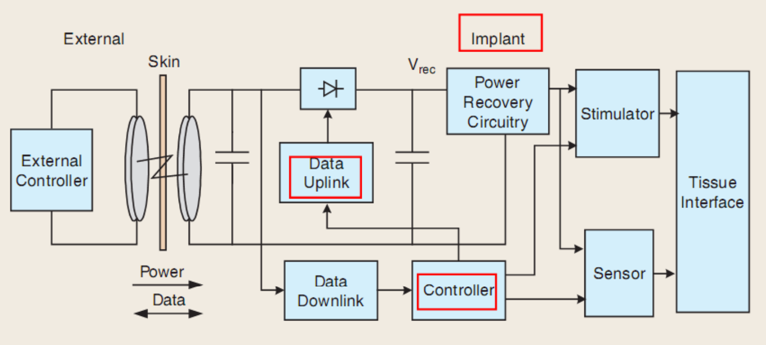
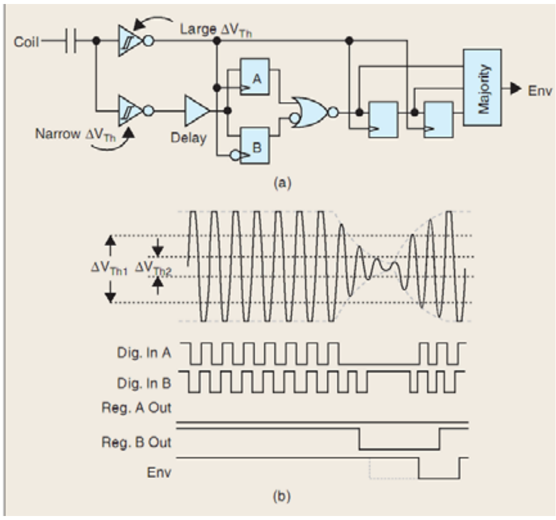


Figure 1. Inductive link to transmit power/data.

Implant circuit design



Implant circuit design

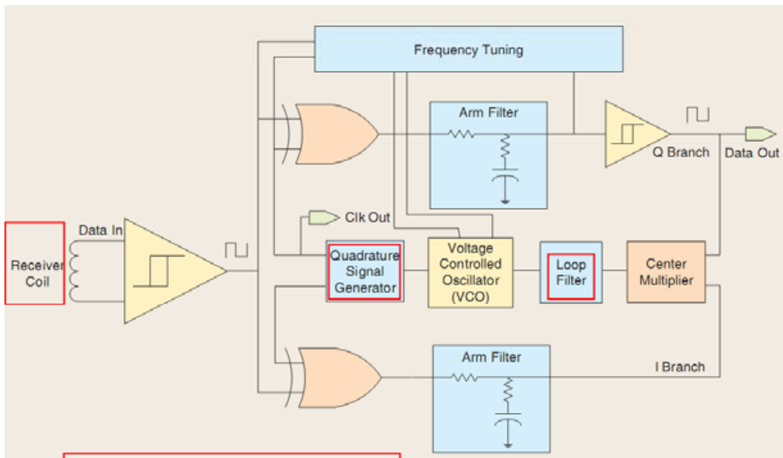


Figure 6. Block diagram of the proposed BPSK demodulator.

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