# Influence of external electromagnetic field at mains frequency 50Hz on pacemakers

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***Abstract*—The rising prevalence of electronic devices increases electromagnetic field (EMF) emissions, potentially affecting implantable pacemakers. This study evaluates the impact of 50 Hz external EMF on pacemaker function through simulations and field measurements near power lines. Results show that electromagnetic interference (EMI) can cause temporary malfunctions, with risks dependent on electrode configuration and exposure level. While usually not critical, pacemaker-dependent patients may face clinically significant effects. The study highlights the need for improved shielding, optimized device programming, and greater awareness among healthcare providers and patients.**

***Keywords—Pacemakers; electromagnetic interference; numerical simulation.***

## I. Introduction

Advances in technology lead to an increasing number of sources of electromagnetic radiation, which may influence various devices, especially implantable electronic devices treating heart diseases, as these require precise sensing of intrinsic cardiac activity. Sensing of non-physiological signals may cause misinterpretation, leading to severe clinical conditions, including stimulation malfunction. This raises the issue of electromagnetic compatibility, where physicians, clinicians, and pacemaker manufacturers must identify possible sources of interference and provide solutions to reduce pacemaker susceptibility. Interaction with the pacemaker occurs mainly via the induction of an electric current in the conductive parts of the stimulation circuit. The induced voltage manifests as interference: low-level signals may be misinterpreted as heart activity, while high-level fields may be correctly recognized as interference, potentially switching pacing from synchronous to asynchronous and increasing arrhythmia risk. These effects are usually temporary and resolve after leaving the interference area. Although not always acutely risky, they may be clinically significant in pacemaker-dependent patients. Therefore, precautionary measures are necessary, including defining minimal environmental requirements and educating both health professionals and patients. In this context, the paper investigates the influence of a 50 Hz external electromagnetic field on an implanted pacemaker. The goal is to study risks associated with mains frequency fields influencing pacemaker function via induced voltage at the electrode, using simulations and measurements near external power lines and in areas with increased electromagnetic field sources.

## II. Clinical and Experimental Evidence of EMF Impact on Pacemakers

Pacemaker users face increasing EMF sources due to technological advances. Several studies examined pacemaker functionality under external EMF. Both in vivo and in vitro studies confirmed the connection between applied EMF and the implant. Clinically significant is a retrospective study by Hours et al. with 855 doctors: of 155 reported cases, 90 confirmed failures (74 abnormal pacing, nine transient inhibition, seven complete failures). Consequences were mostly insignificant but often required reset or replacement. Two EMI types were considered—electronic security systems and medical devices [1]. Medtronic reports 60,000 physician calls annually (8% EMI-related) and 6500 monthly patient calls (28% interference-related) [2,3]. In rare cases, pacemakers switch to “Power-on reset” or “back-up” mode [4,5]. Specific EMI sources were studied: Tiikkaja et al. confirmed interference in three unipolar pacemakers using a Helmholtz coil (2–200 Hz, up to 300 μT) [6]. In 2017, Stunder, Napp et al. exposed 119 patients to EMF from power lines, appliances, and workplace devices, determining the lowest interference level [4,7–9]. Korpinen et al. tested 31 pacemakers under a 400 kV line; one unipolar device switched to fixed frequency, with minor effects in others [10]. The German Cardiac Society and DGAUM (2019) emphasized EMI risks, workplace technologies, implant care, and device programming [11]. In the Czech Republic, Richter and Eichler recorded bipolar pacemaker responses [12]; in Slovakia, Smondrk et al. studied mobile phone effects [13–16]. Slovimpulz registry (2018) reported 3686 pacemakers implanted, 2843 first-time, 7% in patients under 60, more vulnerable to EM exposure [17]. Studies show that evaluating EMF effects only by induced voltage is insufficient; magnetic or electrical components predominate depending on source and distance. Pacemaker response depends on settings, diagnosis, patient predisposition, and manufacturer EMI protection. Available studies lack a comprehensive view, with few addressing network-frequency EM sources in real conditions. The presented research examines selected EMF quantities and induced electrode voltage, focusing on 50 Hz sources, particularly external power lines.

## III. Results

### *A. Induced voltage calculation – methodology*

Voltage is induced at the pacemaker electrode due to an exogenous electromagnetic field. The induced voltage is superimposed on the heart's signal, and the pacemaker may evaluate it as intrinsic, leading to inadequate response. Consequences include inhibition of stimulation or stimulation at the apex of the QRS complex, possibly resulting in life-threatening ventricular fibrillation. To calculate the induced voltage, values of electric and magnetic field quantities on a given integration path and area are required. Analytical or numerical methods and models provide the input for calculation. In a bipolar circuit arrangement, the induced voltage is determined from the spatial distribution of the electric field strength around the distal end of the electrode. Based on this distribution, the difference in electrical potentials between the tip and the ring of the pacemaker electrode is calculated. The RMS of the induced voltage $V_e$ [V] is given by the equation: