ARTICLE

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Maternal Exposure to Magnetic Fields During Pregnancy in Relation to the Risk of Asthma in Offspring

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Objective: To determine whether maternal exposure to high levels of magnetic fields (MFs) during pregnancy is associated with the risk of asthma in offspring.

Design: A prospective cohort study.

Setting: Kaiser Permanente Northern California.

Participants: Pregnant Kaiser Permanente Northern California members in the San Francisco area.

Main Outcome Measures: Asthma was clinically diagnosed among 626 children who were followed up for as long as 13 years. All participants carried a meter to measure their MF levels during pregnancy.

Results: After adjustment for potential confounders, a statistically significant linear dose-response relationship was observed between increasing maternal median daily MF exposure level in pregnancy and an increased risk of asthma in offspring: every 1-mG increase of maternal MF level during pregnancy was associated with a 15% increased rate of asthma in offspring (adjusted hazard ratio [aHR], 1.15; 95% confidence interval [CI], 1.04-1.27). Using the categorical MF level, the results showed a similar dose-response relationship: compared with the children whose mothers had a low MF level (median 24-hour MF level, ≤0.3 mG) during pregnancy, children whose mothers had a high MF level (>2.0 mG) had more than a 3.5-fold increased rate of asthma (aHR, 3.52; 95% CI, 1.68-7.35), while children whose mothers had a medium MF level (>0.3-2.0 mG) had a 74% increased rate of asthma (aHR, 1.74; 95% CI, 0.93-3.25). A statistically significant synergistic interaction was observed between the MF effect and a maternal history of asthma and birth order (firstborn).

Conclusion: Our findings provide new epidemiological evidence that high maternal MF levels in pregnancy may increase the risk of asthma in offspring.

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Asthma is the most common chronic condition among children. Approximately 13% of children younger than 18 years (9.4 million children in the United States) have asthma.[1] Based on reports from the Centers for Disease Control and Prevention, asthma is a leading cause of hospitalization and emergency department visits for children younger than 18 years in the United States, with staggering annual costs of more than $30 billion (http://www.cdc.gov/HealthyYouth/asthma).[1] The prevalence of asthma has been steadily rising during the last several decades, with an increase of about 74% from 1980 to 1996. While not ruling out genetic susceptibility, such a secular increase indicates the presence of important environmental risk factors that remain elusive.

Environmental exposures during pregnancy could affect fetal development of the immune system and lungs and thus have an impact on the risk of asthma in offspring.[2-5] Among the limited research, chemical exposures have represented much of the focus, while the potential of environmental physical exposures has rarely been examined. One such physical exposure is increasing man-made electromagnetic fields (EMFs). In addition to traditional low-frequency EMFs from power lines and appliances, the buildup of increasingly stronger wireless networks both inside and outside living and work spaces and the proliferation of cell phones and other wireless devices have led to human populations being surrounded by EMFs of increasing intensity. This parallel increase in both EMF exposure and asthma prevalence in the past several decades warrants examination.

Studies have shown that EMFs could adversely affect reproductive outcomes and the immune system.[6-15] A recent study also

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showed an EMF effect on brain cell activities.[16,17] Therefore, it is conceivable that exposure to high EMFs, especially during pregnancy (the period of fetal development), may have an impact on the risk of asthma in offspring. To examine this hypothesis, we conducted a prospective study based on a cohort of pregnant women whose daily exposure to magnetic fields (MFs) was captured objectively by a meter during their pregnancy and whose offspring from the index pregnancy were followed up for as long as 13 years for their asthma diagnosis.

METHODS

A prospective cohort study was conducted to examine the effect of EMF exposure on the risk of miscarriage among pregnant members of Kaiser Permanente Northern California (KPNC) in the San Francisco area who were recruited from 1996 to 1998.[6] The members of KPNC are representative of the racially/ethnically diverse underlying population. All pregnant women who submitted a pregnancy test in the KPNC facilities of the San Francisco area were informed of the study, and those with a positive pregnancy test result were recruited for their possible participation. The study was approved by the KPNC institutional review board, and all participants signed an informed consent form.

RECRUITMENT

Women who spoke English and intended to carry the pregnancy to term at the time of recruitment were eligible for participation in the study. We recruited pregnant women early in gestation (5-13 weeks) because miscarriage usually occurs during the first trimester.[6] All participants were interviewed in person during pregnancy to ascertain risk factors for adverse pregnancy outcomes and potential confounders. Of the original 1063 recruited women, 829 delivered a live birth. Of these offspring, 28 did not have medical records in our KPNC system, which means that they likely received their pediatric care outside the KPNC system and therefore were not included in the study.

EXPOSURE MEASUREMENT: MFs

Electromagnetic field refers to both electric fields and MFs. In this study, because the instrument we used (EMDEX-II meter; Enertech Consultants, Campbell, California) measures only MFs, hereafter we will refer to our exposure as *MFs*. All participants were asked to wear an EMDEX-II meter for 24 hours during the first or second trimester so that their actual MF exposure level throughout the day from all sources could be measured objectively. The EMDEX-II meter collected MF measurements in the frequency range of 40 to 800 Hz every 10 seconds. The MF level was measured in milligauss. The meter was programmed to show only the time of day, without displaying any MF exposure level, so that participants were not aware of their MF exposure during the measurement period. This design was implemented to avoid changes of any routine daily activities due to the MF level displayed. At the end of the measurement period, the women were asked to rate their activity patterns during the measurement period as either similar to or quite different from those during a typical day of their pregnancy. Of 801 participants whose children had pediatric care at KPNC, 67 did not have complete 24-hour MF measurements. These mother-child pairs were excluded from the study.

OUTCOME MEASUREMENT: ASTHMA IN OFFSPRING

The children of the remaining 734 pairs with complete maternal 24-hour MF measurements during pregnancy were followed up until (1) they received a diagnosis of asthma, (2) they left the KPNC system (no longer a KPNC member), or (3) the end of the study period (August 31, 2010). To be considered as having a case of asthma, a child had to have received a clinical diagnosis of asthma (*International Classification of Diseases, Ninth Revision*, codes 493.00-493.99) on at least 2 occasions within a 1-year period during follow-up. We excluded those who had either only 1 diagnosis (n=67) or 2 diagnoses that were more than 1 year apart (n=17) or those who used antiasthmatic medications without a clinical diagnosis of asthma (n=24). These children were considered to have suspected asthma and formed a separate outcome group. They were not included in the main analyses but were analyzed separately for comparison. The final analyses included 626 mother-child pairs with both maternal MF measurements and a known asthma status.

POTENTIAL CONFOUNDERS

Although the number of known potential confounders are likely limited because of (1) a lack of association between MF exposure and many commonly known social, demographic, and behavioral factors and (2) the small number of known risk factors for asthma,[24] we evaluated many common sociodemographic characteristics and known prenatal and postnatal risk factors for asthma to ensure that they truly did not confound the association between maternal MF exposure during pregnancy and the risk of asthma in offspring. Because most variables evaluated were not confounders, we included the common sociodemographic variables such as maternal age, education, and race/ethnicity as well as the main risk factors for asthma such as a maternal history of asthma and smoking during pregnancy in the final model.

DATA ANALYSIS

We used the Cox proportional hazard regression model to examine the relationship between in utero MF exposure and the risk of asthma in offspring after controlling for potential confounders. Survival analysis has the advantage of taking into account different follow-up times for the offspring with regard to asthma diagnosis. All children were followed up starting from birth until (1) they received diagnoses of asthma (failed), (2) they left the KPNC system (censored), or (3) the end of the study (censored).

To quantify a woman's overall daily MF exposure burden, we used median 24-hour MF exposure to reflect her overall MF exposure during pregnancy to reduce the impact of outliers. Because everyone is exposed to MF at some level, we examined whether an increasing MF exposure during pregnancy is associated with an increased risk of asthma in offspring, a dose-response relationship rather than a dichotomized variable of yes/no. We first examined the dose-response relationship using the median MF level as a continuous variable. To present the association as categorical MF exposure for an easier interpretation, we divided the median MF level into 3 categories: low (≤10th percentile [≤0.3 mG]), medium (>10th-90th percentile [>0.3-2.0 mG]), and high (>90th percentile [>2.0 mG]).

RESULTS

Table 1 presents the characteristics of the study population according to their MF exposure level during pregnancy. We examined maternal, prenatal, genetic, and

Table 1. Characteristics of the Study Population

Characteristic	Median Magnetic Field (MF) Level, %			χ^2 Test (*P* Value)
	Low,[a] (n=81)[d]	Medium,[b] (n=482)[d]	High,[c] (n=63)[d]	
Sociodemographic factors				
Maternal age, y				.91
≤25	19.7	18.3	19.1	
26-30	32.1	31.5	31.7	
31-35	30.9	32.8	38.1	
>35	17.3	17.4	11.1	
Maternal education				.93
<College	51.8	55.8	57.1	
College	32.1	27.8	28.6	
Postgraduate	16.1	16.4	14.3	
Maternal race/ethnicity				.66
White	40.7	38.4	47.5	
Black	4.9	8.3	4.8	
Hispanic	21.0	19.5	17.5	
Asian/Pacific Islander	24.7	29.1	25.4	
Other	8.6	4.7	4.8	
Maternal prepregnancy BMI				.97
≤25	71.6	71.6	73.0	
>25	28.4	28.4	27.0	
Family income, $				.004
<30 000	24.4	18.4	13.3	
≥30 000	26.9	44.7	60.0	
≥60 000	48.7	36.8	26.7	
Prenatal factors				
Smoke during pregnancy				.90
Yes	8.6	9.5	7.9	
No	91.4	90.5	92.1	
Infection in pregnancy				.66
Yes	34.6	32.6	38.1	
No	65.4	67.4	61.9	
Antibiotic use in pregnancy				.48
Yes	34.6	41.3	42.9	
No	65.4	58.7	57.1	
Mode of delivery				.66
Vaginal birth	77.3	79.7	83.6	
Cesarean section	22.7	20.3	16.4	
Genetic factor				
Maternal history of asthma				.85
Yes	8.6	7.1	6.3	
No	91.4	92.9	93.7	
Infant factors				
Breastfed				.89
Yes	88.9	91.7	90.5	
No	11.1	8.3	9.5	
Sex				.66
Female	44.4	49.4	46.1	
Male	55.6	50.6	53.9	
Parity				.48
First child	51.9	45.6	50.8	
Not first child	48.1	54.4	49.2	
Low birthweight, <2500 g				.07
Yes	9.9	4.1	3.2	
No	90.1	95.9	96.8	
Preterm, <37 wk				.95
Yes	7.4	7.5	6.3	
No	92.6	92.5	93.7	
KPNC member at the end of follow-up				.92
Yes	58.0	60.4	60.3	
No	42.0	39.6	39.7	
NICU admission				34
Yes	11.8	7.9	5.1	
No	88.2	92.1	94.9	
Use of antibiotics before the first diagnosis of asthma				.10
Yes	84.8	87.3	77.4	
No	15.2	12.7	22.6	
Other factors				
MF level measured on a typical day				.99
Yes	64.2	63.9	63.5	
No	35.8	36.1	36.5	

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); NICU, neonatal intensive care unit; KPNC, Kaiser Permanente Northern California.

[a] Less than or equal to the 10th percentile (≤0.3 mG).

[b] Greater than the 10th percentile to the 90th percentile (>0.3-2.0 mG).

[c] Greater than the 90th percentile (>2.0 mG).

[d] The following 3 variables had missing data: family income (n=32), maternal mode of delivery (n=22), and NICU admission (n=24).

Part 3 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

Table 2. Maternal Exposure to Magnetic Fields (MFs) During Pregnancy and the Risk of Asthma in Offspring

Maternal Daily Median MF Level	Asthma in Children: Yes	Asthma in Children: No	cHR (95% CI)	aHR[a] (95% CI)
Continuous MF level, mean[b] (SD), mG	1.22 (1.22)	0.98 (1.09)	1.12 (1.02-1.23)	1.15 (1.04-1.27)
MF level in category, No. (%)				
Low, ≤10th percentile	11 (13.6)	70 (86.4)	1 [Reference]	1 [Reference]
Medium, >10th-90th percentile	98 (20.3)	384 (79.7)	1.65 (0.88-3.08)	1.74 (0.93-3.25)
High, >90th percentile	21 (33.3)	42 (66.7)	3.16 (1.52-6.57)	3.52 (1.68-7.35)

Abbreviations: aHR, adjusted hazard ratio (adjusted for maternal age, race, education, smoking during pregnancy, and a history of asthma; further adjustment for the remaining variables in Table 1 did not materially change the results); cHR, crude hazard ratio; CI, confidence interval.
[a]Trend test, $P<.001$.
[b]Mean of median.

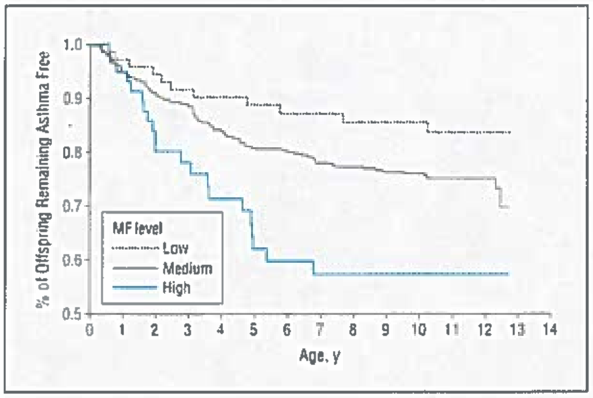

Figure. Kaplan-Meier estimates of asthma risk by maternal magnetic field (MF) exposure level during pregnancy.

infant factors that may be related to MF exposure, the risk of asthma, or both (ie, potential confounders). Of the 19 factors examined, none was related to MF exposure level except family income, which did not show a clear pattern of a relationship (Table 1). The percentages of children who were unavailable for follow-up at the end of the study because of their exiting KPNC membership and those whose MF exposure was measured on a typical day during pregnancy were quite similar among all MF exposure levels (Table 1).

Overall, 130 children (20.8%) of the study participants developed asthma during 13 years of follow-up, with most cases (>80%) diagnosed by 5 years of age. **Table 2** presents the results examining the dose-response relationship between increasing maternal MF exposure level in pregnancy and the risk of asthma in offspring using MF exposure level as both a continuous and a categorical variable. After adjustment for maternal age, race, education, smoking during pregnancy, and a history of asthma, a statistically significant linear dose-response relationship was observed between increasing maternal median daily MF exposure level in pregnancy and an increased risk of asthma in offspring (adjusted hazard ratio [aHR], 1.15; 95% confidence interval [CI], 1.04-1.27). In other words, 1 unit (1 mG) of increase in the maternal median MF exposure level during pregnancy was associated with a 15% increased rate of asthma in offspring (Table 2). Using the categorical MF level (low, medium, and high) as dummy variables, the results confirmed the linear dose-response relationship: compared with children whose mothers had a low MF level (<0.3 mG) during pregnancy, children whose mothers had a medium MF level (>0.3-2.0 mG) had a 74% increased rate of developing asthma (aHR, 1.74; 95% CI, 0.93-3.25). Furthermore, children whose mothers had a high MF level (>2.0 mG) during pregnancy had more than a 3.5-fold increased rate of developing asthma (aHR, 3.52; 95% CI, 1.68-7.35). Further adjustment for the remaining 14 factors, including family income, listed in Table 1 did not materially change the results. Finally, a similar association was also observed using suspected asthma cases, although the association was weaker, perhaps because of the misclassification of asthma cases. The aHRs were 1.24 and 1.41 for medium and high maternal MF exposure levels, respectively.

The **Figure** shows the Kaplan-Meier survival curves for the percentages of offspring who remained free of asthma during the 13-year follow-up period for 3 different maternal MF exposure levels in pregnancy. The cumulative asthma risks (1 − cumulative survival rate) in offspring were 0.16, 0.30, and 0.43 for low, medium, and high maternal MF exposure levels, respectively.

To determine whether other factors would modify the observed association, we examined the association stratified by 2 known risk factors for asthma: maternal history of asthma (a possible genetic risk factor) and firstborn child (a possible environmental risk factor, the hygiene hypothesis).[2-5] **Table 3** shows that the observed association was noticeably stronger among the children whose mothers had a history of asthma (aHR, 6.06; a more than 6-fold increased rate of asthma for 1 unit [1 mG] of increase in MF level in the maternal median MF exposure level during pregnancy) than among those whose mothers did not have a history of asthma (aHR, 1.12). Similarly, the association between increasing maternal MF exposure levels in pregnancy and the risk of asthma in offspring was stronger among firstborn children (aHR, 1.40; a 40% increased rate of asthma for every 1 unit [1 mG] of increase in MF level) than among later-born children (aHR, 1.07) (Table 3). The presence of these 2 risk factors (ie, history of maternal asthma [$P<.005$] and being a firstborn child [$P<.05$]) significantly exacerbated the adverse effect of maternal MF exposure in pregnancy on the risk of asthma in offspring.

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Table 3. Maternal Exposure to Magnetic Fields During Pregnancy and the Risk of Asthma in Offspring in Relation to Other Risk Factors for Asthma

		Asthma in Children, Mean (SD)			
Other Risk Factor for Asthma	Total No.	Yes	No	aHR (95% CI)	P Value
Maternal history of asthma					P<.005
Yes	45	1.17 (0.87)	0.65 (0.49)	6.06 (2.20-16.72)	
No	581	1.22 (1.25)	1.01 (1.11)	1.12 (1.01-1.25)	
Birth order					P<.05
First child	294	1.33 (1.31)	0.96 (0.88)	1.40 (1.16-1.70)	
Not first child	332	1.13 (1.14)	1.01 (1.25)	1.07 (0.92-1.25)	

Abbreviations: CI, confidence interval; aHR, adjusted hazard ratio (adjusted for maternal age, race, education, smoking during pregnancy, and a history of asthma; further adjustment for the remaining variables in Table 1 did not materially change the results).

Table 4. The Strengths of the Association in Relation to the Measurement Accuracy of Magnetic Fields (MFs)

	Asthma in Children, No. (%)		
Maternal Daily Median MF Level	Yes	No	aHR (95% CI)
Measured on a typical day			
Low, ≤10th percentile	5 (9.6)	47 (90.4)	1 [Reference]
Medium/high, >10th percentile	73 (21.0)	275 (79.0)	2.52 (1.01-6.30)
Measured on a nontypical day			
Low, ≤10th percentile	6 (20.7)	23 (79.3)	1 [Reference]
Medium/high, >10th percentile	46 (23.3)	151 (76.7)	1.31 (0.55-3.13)

Abbreviations: CI, confidence interval; aHR, hazard ratio (adjusted for maternal age, race, education, smoking during pregnancy, and a history of asthma).

COMMENT

In this prospective cohort study, we found that a high maternal MF exposure level in pregnancy is associated with a significantly increased risk of asthma in offspring. The observed association showed a dose-response relationship. Given the lack of understanding of the causes of asthma, our findings could open up a new research area to elucidate risk factors of asthma that are unknown and have not been examined before. Also, our study provides new findings for the potential adverse health effect of MF exposure on an end point (asthma) that, to our knowledge, has not been previously studied. While the public has been increasingly aware of EMF exposure owing to the increasing presence of infrastructure of wireless networks and the pervasive use of wireless devices, studies on EMF health effects remain limited. Because EMF exposure is ubiquitous and exposure to it is involuntary, these new findings have important public health implications. Nevertheless, they need to be replicated by other studies.

While prenatal risk factors for asthma are not well understood, pregnancy is one of the most influential periods when allergic sensitization (atopy) is developed in the fetus.[2,18,19] The underlying pathogenesis of asthma is likely structural and due to functional defects in epithelium and an impaired innate immune system.[3] Prenatal exposure to high MF levels could interfere with the development of both epithelial cells and normal immune systems. Research by multidisciplinary collaborative studies is needed to understand these mechanisms.

The current study has several methodological strengths that enhanced the validity of the new findings. First, it was a prospective cohort study in which MF exposure was measured in pregnancy, long before the diagnosis of asthma in offspring. This study design substantially reduces the likelihood of potential biases associated with participation influenced by the presence of outcomes. Second, both the exposure (MF levels) and the outcome (diagnosis of asthma) in this study were measured objectively without the knowledge of each other, thus reducing the concern of recall bias associated with the ascertainment of exposure and outcome variables that has existed in many epidemiological studies. Unlike many case-control studies of the MF health effect, in which MF exposure in the etiologically relevant period of the past was either reconstructed or surrogated by the current exposure measurement (eg, studies of childhood leukemia), MF exposure levels in this study were prospectively measured during the etiologically relevant period (eg, pregnancy). Also, while EMF exposure measurement in past studies was frequently based only on recalls, surrogate measures, and home spot measurements, the current study asked participants to carry an EMDEX-II meter that objectively captured their MF exposure from all sources during pregnancy. Furthermore, all diagnoses of asthma were based on clinical records, not on self-report by the participants, thereby reducing measurement errors of the outcome of interest. Finally, MF exposure is not related to most sociodemographic, behavioral, and commonly known risk factors (Table 1).[6,9] Given that confounders have to be associated with the exposure of interest, a lack of association between MF exposure and those factors limits the number of potential confounders, making the observed association robust against potential biases.

Part 3 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

While, compared with previous studies, we improved the accuracy of measuring MF exposure by asking participants to wear an EMDEX II meter for 24 hours, it was not feasible to measure MF exposure throughout pregnancy. Therefore, the accuracy of the MF measurement in reflecting the MF exposure in pregnancy may still be questioned, although one study has reported that MF exposure levels were relatively stable within 12 to 36 months.[20] Assuming that there was some misclassification of MF exposure because of measurement errors, given that this was a cohort study and MF was measured long before the diagnosis of asthma, such misclassification would be nondifferential (ie, the same degree of misclassification to both mothers of children with and without asthma). Nondifferential misclassification generally leads to attenuation of observed associations. Without such misclassification, the observed association could have been stronger. In fact, our reanalysis of the association, stratified by whether the MF measurement was conducted on a typical day of pregnancy (more representative of MF exposure in pregnancy) or a nontypical day (less representative of MF exposure in pregnancy, thus more measurement errors) provided evidence supporting this argument. As shown in **Table 4**, we indeed observed that less measurement error (ie, measured on a typical day) led to a stronger observed association (>2.5 times risk of asthma associated with a higher maternal MF exposure level during pregnancy) compared with more measurement error (ie, measured on a nontypical day), a nonstatistically significant 31% increased risk of asthma. Therefore, had we been able to measure participants throughout pregnancy, the observed association between maternal MF exposure in pregnancy and the risk of asthma might have been stronger than that presented in Table 2.

In addition to observing an association between high maternal MF exposure during pregnancy and the risk of asthma in offspring with a dose-response relationship, we also observed a statistically significant interaction between the MF effect on asthma and the other 2 risk factors for asthma: maternal history of asthma and birth order (firstborn). A maternal history of asthma is a well-established risk factor for genetic susceptibility that has been supported by the results of both genome-wide association studies and candidate gene studies.[2,3] Such an interaction with known risk factors for asthma not only revealed possible synergistic adverse effects between prenatal MF exposure and these 2 risk factors on the risk of asthma but also provided further support for the underlying association between maternal MF exposure in pregnancy and the risk of asthma in offspring. Synergistic factors themselves are often independent risk factors.

In conclusion, the findings of the present study open up a new area in understanding the risk factors for asthma and the health effects of ubiquitous MF exposure, especially during pregnancy. As with any epidemiological study, these findings need to be replicated. If confirmed, they have the potential to inform new intervention strategies to reduce asthma, the most prevalent chronic disease among children.

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LOW-FREQUENCY TRANSIENT ELECTRIC AND MAGNETIC FIELDS COUPLING TO CHILD BODY

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Much of the research related to residential electric and magnetic field exposure focuses on cancer risk for children. But until now only little knowledge about coupling of external transient electric and magnetic fields with the child's body at low frequency transients existed. In this study, current densities, in the frequency range from 50 Hz up to 100 kHz, induced by external electric and magnetic fields to child and adult human body, were investigated, as in residential areas, electric and magnetic fields become denser in this frequency band. For the calculations of induced fields and current density, the ellipsoidal body models are used. Current density induced by the external magnetic field (1 μT) and external electric field (1 V/m) is estimated. The results of this study show that the transient electric and magnetic fields would induce higher current density in the child body than power frequency fields with similar field strength.

INTRODUCTION

Some epidemiological studies in the past stated the existence of positive associations between cancer and leukaemia, occurring in children and the configuration of nearby residential electric power lines, often referred to as 'the wire code'[1,2]. Several reports on this subject have appeared since Wertheimer and Leeper[1] who first pointed out the possibility of an association between childhood mortality due to cancer and proximity of homes to power distribution lines with what is called 'high current configuration'. So far, there have been more than a dozen studies on childhood cancer and its possible causes by exposure to power frequency magnetic fields produced by nearby power lines[1,3–7]. The fact that the results for leukaemia that were based on proximity of homes to power lines had been relatively consistent led the U.S. National Academy of Sciences (NAS) Committee to conclude that children living near power lines appear to be at increased risk of leukaemia[8].

Over the years, there has also been substantial interest in whether there is an association between magnetic field exposure and childhood brain cancer, the second most frequent type of cancer found in children. However, the recent studies completed after the NAS Committee's review fail to provide support for an association between brain cancer and children's exposure to magnetic fields and also, whether the source was power lines or electric blankets. It is also not clear from the report whether magnetic fields were estimated by calculations or by wire codes[5,9,10].

The most intensively investigated environmental factor has been the time-weighted average magnetic fields associated with electric currents on power lines and grounding systems. A large U.S. Case Control Studies to test whether childhood acute lymphoblastic leukaemia is associated with exposure to 60-Hz magnetic field was published by Ref. (4). According to some workers in this field[11–13], the power lines were the most important source of exposure when the magnetic field due to line was greater than ~0.2 μT. The result of the study indicated that children who lived close to a power line had a higher magnetic field exposure than other children. Most of the research in this area has been associated with power frequencies and there are relatively few publications in the frequencies associated with transient fields and these are mostly studies of characteristic compositions of these fields.

In recent years, research has been conducted to characterise transient electric and magnetic fields in residential areas[14–16]. Transient fields in residential environments depend on the electric power lines, grounding systems, switch-gear and wire codes. According to Ref. (15), homes in urban areas had more transients than homes rural areas.

Transients occur with a large number of different waveforms that it did not seem feasible for us to identify a small number of standard waveforms on which to base our analysis. According to Ref. (17), any transient signal, $f(t)$, can be written as:

$$f(t) = \int_{-\infty}^{\infty} \mathrm{d}(\omega) f(\omega) e^{j\omega t} \quad (1)$$

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where ω is angular frequency, $j = \sqrt{-1}$, and $f(\omega)$ defines the frequency spectrum of $f(t)$. If this signal is passed through a linear system (e.g. electric or magnetic field coupling to a conducting body) whose transfer function for a sinusoidal input is $T(\omega)$, then the transient output signal $Q(t)$ can be defined as:

$$Q(t) = \int_{-\infty}^{\infty} \mathrm{d}(\omega) T(\omega) f(\omega) e^{j\omega t} \quad (2)$$

Hence, the response of the system to a transient input signal, $f(t)$, can be obtained by understanding its response to a sinusoidal input with frequency spanning 'frequency content' of the transient signal.

The present study analyses whole-body exposure of homogeneous ellipsoids shaped child models to uniform sinusoidal electric and magnetic fields with frequency up to 100 kHz. This frequency range was chosen as it is the practical upper limit for dosimetric concern because of the time constants (>10 µs) inherent to biological signalling within cell membranes[2].

The International Commission on Nonionizing Radiation Protection (ICNIRP) general public reference level for induced current J_{rms} is specified as 2 mA m^{-2} in the frequency range 4 Hz to 1 kHz, and $f/500$ mA m^{-2} in the frequency range 1–100 kHz (where f is the frequency in hertz)[18].

For the past 25 y, researchers have investigated a possible link between exposure to power frequency (50/60 Hz) of residential magnetic fields and childhood leukaemia cases. Thus, the International Agency for Research on Cancer (IARC) classified extremely low frequency magnetic fields as a 2B carcinogen. These classifications are for between average residential magnetic fields >0.3–0.4 µT and childhood leukaemia[12,19]. Presentation of a dosimetric approach about induced current density of transient electric and magnetic fields in the band of 50 Hz to 100 kHz was aimed

COUPLING MECHANISMS BETWEEN FIELDS AND THE BODY

The interaction of time-varying electric fields with the human body results in the flow of electric charge (i.e. electric current, the polarisation of bound charge, formation of electric dipoles), and the reorientation of electric dipoles already present in tissue. The relative magnitudes of these different effects depend on the electrical properties of the body (i.e. its electrical conductivity and permittivity). Electrical conductivity and permittivity vary with the type of body tissue and also depend on the frequency of the applied field. External electric fields induce a surface charge on the body. The results obtained for induced currents in the body and for the distribution of these currents depend on the exposure conditions, size and shape of the body, and on the body's position in the field.

The physical interaction of time-varying magnetic fields with the human body results in induced electric fields and circulating electric currents. The magnitudes of the induced fields and the current densities are proportional to the radius of the loop, the electrical conductivity of the tissue and the rate of change and magnitude of the magnetic flux density. For a given magnitude and frequency of a magnetic field, the strongest electric fields are induced where the loop dimensions are the greatest. The exact path and magnitude of the resulting current induced in any part of the body will depend on the electrical conductivity of the tissue.

METHODS AND MODELS OF ANALYSIS

The surface of an ellipsoid is defined by the equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \quad (3)$$

where x, y and z are rectangular coordinates, and the size and shape of the ellipsoid are determined by the three parameters a, b and c where $c \leq b \leq a$.

A basic ellipsoid child model is shown in Figure 1. When using an ellipsoid to model a person, $2a$ defines the person's height, $2b$ defines the person's width (measured from hip to hip) and $2c$ defines the person's 'depth' (measured approximately from the surface of the abdomen to buttocks). Table 1 gives the values of a, b and c in the ellipsoid models of children of various ages and average man[20]. Conductivity and dielectric constant of the selected homogeneous body model for various frequencies can be seen in Table 2[20].

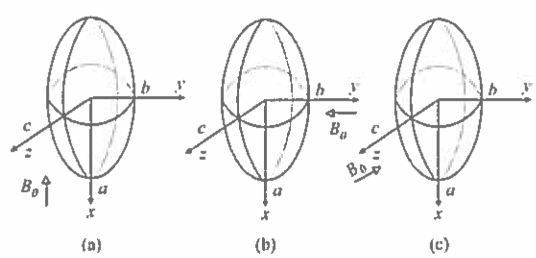

Figure 1. Ellipsoid models representation: (a) magnetic field is aligned with the major axis of the body ($B_0//a$), (b) magnetic field is aligned with the intermediate axis of the body ($B_0//b$) and (c) magnetic field is aligned with the minor axis of the body ($B_0//c$).

Table 1. Ellipsoid parameters for selected body models.

Selected models	a(m)	b(m)	c(m)
Ten-year-old child	0.69	0.143	0.078
Five-year-old child	0.56	0.12	0.069
One-year-old child	0.37	0.095	0.068
Average man	0.9	0.2	0.1

Table 2. Electrical properties of homogeneous body models.

Frequency	Dielectric constant ε_r	Conductivity σ (S m^{-1})
50 Hz	1×10^6	0.1
100 Hz	7×105	0.15
1 kHz	1×105	0.15
10 kHz	3×104	0.2
100 kHz	1×104	0.3

Current density and electric field induced by external electric field

The uniform electric field, E, induced inside an ellipsoid by external uniform vertical electric field, E_0, is given by equation (4):

$$E = \frac{j\omega\varepsilon_0}{\sigma^*}\frac{E_0}{A} \tag{4}$$

where $\sigma^* = \sigma + j w\varepsilon_r\ \varepsilon_0$ is the complex conductivity and

$$A = \frac{abc}{2}\int_0^\infty \frac{d\xi}{(\xi + a^2)\sqrt{(\xi + a^2)(\xi + b^2)(\xi + c^2)}} = abc\left(\frac{[F(\phi,k) - E(\phi,k)]}{((a^2 - b^2)(a^2 - c^2)^{1/2})}\right)$$

with

$$F(\phi,k) = \int_0^\phi (1 - k^2\sin^2\theta)^{-1/2}d\theta$$

$$E(\phi,k) = \int_0^\phi (1 - k^2\sin^2\theta)^{1/2}d\theta$$

and

$$k = \sqrt{\left(\frac{a^2 - b^2}{a^2 - c^2}\right)},\ \phi = \sin^{-1}\left(\frac{a^2 - c^2}{a^2}\right)^{1/2}$$

where $F(\phi, k)$ and $E(\phi\ k)$ are the incomplete elliptic integrals of the first and second kinds, respectively, and k is the modulus of these elliptic integrals. When the external electric field is vertical to the body, the induced electric field becomes maximum. For other orientations of external electric fields, mathematical details can be seen in the open literature[21].

The current density induced by electric field can be expressed as:

$$\vec{J} = \sigma\vec{E} \tag{5}$$

where σ is the electrical conductivity of the human model. Interactions of 50/60 Hz magnetic fields with a biological body can be considered, for the wavelength of the magnetic field is much larger in comparison to the size of the biological body. It can be shown from Faraday's and Ampere's laws that the secondary magnetic field produced in a biological object by the current flow induced by the external magnetic field can be neglected. So the magnetic field inside the biological body is considered uniform[22].

Mathematical relations for coupling of uniform magnetic field to ellipsoid

Consider a magnetic field, Bo, aligned parallel to the x axis. It can be shown that the induced electric field is in the y–z plane and is everywhere tangent to the ellipse $(y/b)^2 + (z/c)^2 = \eta^2$, where $1 \geq \eta \geq 0$[23,24]. The strength of the induced field E is[23]:

$$E = \frac{\omega B_0}{b^2 + c^2}\sqrt{b^4z^2 + c^4y^2} \tag{6}$$

The values of J_{max} and J_{rms} induced inside the ellipsoid are:

1. B_0 is aligned with a on x axis:

$$J_{max} = \sigma B_0\omega\frac{b^2c}{b^2 + c^2},\ J_{rms} = \sigma\frac{\omega B_0}{\sqrt{5}}\frac{bc}{\sqrt{b^2 + c^2}} \tag{7}$$

2. B_0 is aligned with b on y axis:

$$J_{max} = \sigma B_0\omega\frac{a^2c}{a^2 + c^2},\ J_{rms} = \sigma\frac{\omega B_0}{\sqrt{5}}\frac{ac}{\sqrt{a^2 + c^2}} \tag{8}$$

3. B_0 is aligned with c on z axis:

$$J_{max} = \sigma B_0\omega\frac{a^2b}{a^2 + b^2},$$

$$J_{rms} = \sigma\frac{\omega B_0}{\sqrt{5}}\frac{ab}{\sqrt{a^2 + b^2}} \tag{9}$$

INDUCED CURRENT DENSITIES

Table 3 depicts the calculated induced current densities when the ellipsoidal models are exposed to 1 V/m external electric field. Table 4 depicts the calculated induced current densities when the ellipsoidal models are exposed to 1 μT external magnetic field.

Figure 2 depicts results of the maximum induced current density in different body models versus different external magnetic field orientations for frequency of 50 Hz. Induced current density in all body models is the maximum for B_0 aligned with c on z axis. Table 5 shows calculated maximum induced current densities inside the ellipsoidal models exposed to 1 µT magnetic field for orientation of $B_0//b$. Table 6 depicts maximum induced current densities for the external magnetic field vertical to the body ($B_0//a$).

Table 7 presents the calculated induced current densities when the ellipsoidal models are exposed to 1 µT magnetic field for orientation of $B_0//c$

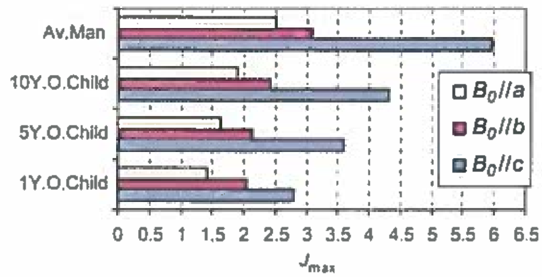

Figure 2. Results of the maximum current density values J_{max} [µA/m^2 /(µT)] in different body models for frequency of 50 Hz.

CONCLUSIONS

In this paper, for ellipsoidal body models, with 1 µT magnetic and 1 V/m electric field exposure, induced current densities have been analysed. Results vary with the orientation of field or the size of body. When the external magnetic field is applied in parallel to the long axis of body ($B_0//a$, i.e. aligned with the long

Table 3. Induced current density in body models by external electric field density value of 1 V/m which is vertical to the body.

Body models	J [µA/m^2/(V/m)]				
	50 Hz	100 Hz	1 kHz	10 kHz	100 kHz
Average man	0.0722	0.1443	1.443	14.392	142.0
Ten-year-old child	0.0744	0.1488	1.4878	14.836	146.38
Five-year-old child	0.068	0.1361	1.3604	13.567	133.86
One-year-old child	0.0448	0.0897	0.8967	8.942	88.2269

Table 4. Induced current density in body models by 1 µT external magnetic field which is perpendicular to front of the body.

Body models	J_{max} [µA/m^2/(µT)]				
	50 Hz	100 Hz	1 kHz	10 kHz	100 kHz
Average man	5.987	17.9625	179.6252	2395	35 925
Ten-year-old child	4.3075	12.9224	129.229	1723	25 845
Five-year-old child	3.6044	10.8132	108.1321	1441.8	21 626
One-year-old child	2.799	8.399	83.99	1120	16 800

Table 5. Induced current density in various body models by 1 µT external magnetic field which is perpendicular to the side of the body $B_0//b$.

Body models	J_{max} [µA/m^2/(µT)]				
	50 Hz	100 Hz	1 kHz	10 kHz	100 kHz
Average man	3.103	9.309	93.09	1241.3	18620
Ten-year-old child	2.42	7.258	72.58	967.8	14517
Five-year-old child	2.135	6.405	64.05	854.1	12 812
One-year-old child	2.06	6.02	61.99	826.6	12 399

Part 3 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

Table 6. Induced current density in body models by 1 μT external magnetic field which is vertical to the body $B_0//a$.

Body models	J_{max} [μA/m²/(μT)]				
	50 Hz	100 Hz	1 kHz	10 kHz	100 kHz
Average man	2.513	7.54	75.4	1005.3	15 080
Ten-year-old child	1.88	5.665	56.656	755.4	11 331
Five-year-old child	1.63	4.887	48.87	651.6	9774
One-year-old child	1.412	4.237	42.37	565	8475

Table 7. Induced current density in body models by 1 μT external magnetic field which is perpendicular to front of the body.

Body models	J_{rms} [μA/m²/(μT)]				
	50 Hz	100 Hz	1 kHz	10 kHz	100 kHz
Average man	2.743	8.23	82.3	1097.2	16 458
Ten-year-old child	1.967	5.9	59.018	786.9	118 004
Five-year-old child	1.648	4.945	49.45	659.4	9812
One-year-old child	1.3	3.878	38.78	517.113	7756.7

axis of the body), induced current density to the body is less than other field-body configurations ($B_0//b$ and $B_0//c$). As a result, induced current density may vary with shape and size of the body, exposure frequency and the orientation of the body relative to the field. Figure 2 and Tables 3–7 summarises the current densities in children's and adults' body when they are subject to external electric and magnetic fields. It is also easy to compare the exposures for field orientations. At exposure frequency, the induced current density varies in relation to the field orientation and the body models. The size and the shape of the body as well as the field orientation are the major parameters for induced current prediction.

The band of frequencies chosen for this study was between 50 Hz and 100 kHz. In this way, the densities of electrical currents induced in the body models of children and adults by the magnetic fields caused by the power frequencies and the frequencies contained in transient sparks were investigated. Transient fields may contain all three components of the magnetic field as well as at least one of the components of the electric field. In residential homes, these magnetic fields affect all the people living within. In bedrooms, these components of the fields may be parallel as well as perpendicular to the children's beds. The analysis indicates that the maximum induced current density occurs when the electric field component is parallel to the major axis of the body. In contrast, the induction of highest current density occurs when the external magnetic field component is parallel to the minor axis of the body. The results show that the transient electric and magnetic fields would induce higher current density in the child body than power frequency fields with similar field strength.

At this point it should be mentioned that frequency of external field appears to be an important parameter of the exposure as the induced current density increases with the frequency. Therefore the transients are of particular interest because they would induce higher current density in child body than power frequency fields with similar field strength. Induced current values of 75 and 100 nA/cm² were found on chest and abdominal areas of the anatomical man model (ungrounded), respectively, in the measurements which were performed at 60 Hz, 10 kV/m[25]. Calculated values of current densities in this study, 72.2 nA cm^{-2} in 50 Hz, 10 000 V/m (Table 3), are in good agreement with measured values.

Although the main aim of this study is not comparison of induced current densities with safety guidelines, current densities induced by 1 μT magnetic field and 1 V/m electric field stay under the basic ICNIRP restrictions.

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INTRODUCTION

In 1972 there was an oil embargo that forced countries to become more energy efficient. Energy efficient lightning, variable speed frequency drives, electronic motor starters, light dimmer switches, as well as a host of other electronic loads were rapidly being connected to the electrical grid. These devices use current in short pulses that create harmonics and high frequencies transients on the electrical circuits. Prior to this time the majority of the loads were linear loads. With Linear loads the current was drawn in a continuous manner. The electrical grid was designed for only 60-cycle linear loads like light bulbs and motors and not for the high frequency producing electronic loads that were being added rapidly after 1972. Most electric utilities have not update their obsolete lines to handle the technological load that started being connected to their system in the late 70's and continues to date. The electric utility's primary neutral wire that was designed to bring the current back to the substations was, and still is, no longer capable of handling the excess current and higher than 60-cycle currents now riding on the wire. The wire has too much impedance (Opposition to AC current) due to its inadequate size and causes overheating and a build up of voltage on the wire called Primary Neutral to Earth Voltage (PNEV). The Institute of Electric and Electronic Engineers (IEEE) recognized the problems caused by these changing loads and adopted a national standard, the IEEE-519, in 1981. The IEEE revised the standard in 1986 and again in 1992. It was a problem that was recognized and addressed by industry world wide, except for most electric utilities. It became the topic of most power quality magazines and publications through out the industry.

> "Harmonics: It surfaced as a buzzword in the early 1980's," (EC&M – June 1999).
>
> "When single phase electronic loads are supplied with a 3-phase, 4-wire circuit, there is a concern for the current magnitudes in the neutral conductor. Neutral current loading in the 3-phase circuits with linear loads is simply a function of the load balance among the three phases. With relatively balanced circuits, the neutral current magnitude is quite small. This has resulted in a practice of under sizing the neutral conductor in relation to the phase conductors.
>
> With electronic loads supplied by switch-mode power supplies, the harmonic components in the load currents can result in much higher neutral current magnitudes. This is because the odd triplen harmonics (3, 9, 15, etc.) produced by these loads is show up as zero sequence components for balanced circuits. Instead of canceling in the neutral (as is the case with positive and negative sequence components), zero sequence components add together in the neutral conductor. The third harmonic is usually the largest single harmonic component in single phase power supplies or electronic ballasts". (6.3.1 Neutral Conductor Overloading - Guide for Applying Harmonic Limits on Power Systems (63) – May 4, 1996)

> "Triplen harmonics do not cancel, but add together in the neutral conductor. In systems with many 1-phase nonlinear loads, neutral current can exceed an individual phase current. Generally, the amount of neutral current is between 125% and 225% of the highest phase current. The third harmonic current is usually responsible for most of the neutral current because the third harmonic typically represents the harmonic with the highest current value. High neutral current is dangerous because it causes overheating in the neutral. Because there is no CB in the neutral conductor to limit current, as in the phase conductors (A, B, and C), overheating of the neutral can become a fire hazard." (Power Quality Measurement and Troubleshooting, Glen A. Mazur-Author, 1992)

Because of the increased and higher frequency currents on the utilities' primary neutral, the electric utilities decided to use the earth as a return path to their substations for the excess currents they are responsible for. Once the currents are in the earth, they flow uncontrolled over the surface, across private property, and into homes and barns, through humans and animals. This was done despite national standards and electrical safety codes.

> "Ground connection points shall be arranged so that under normal circumstances there will be no objectionable flow of current over the grounding conductor." (National Electrical Safety Code, CS-1997 Rule 92D, Current in Grounding Conductor.)

> "Such flow may be disturbing to the service, as is sometimes the case around dairy barns in which cows are connected to milking systems… installations near areas that are often known to present specific problems (such as milking barns without adequate voltage gradient control, pipelines, electric railways, conduits, etc.) may need special attention to limit damage to equipment or uncomfortable conditions for personnel or animals." (NESC Handbook, Fourth Edition, "A Discussion of the National Electrical Safety Code").

Statement of Facts and Supporting Documentation

The earth has been thought of as a sponge where the electrons that are put onto it are absorbed like water and never have to be dealt with again. Using this mind set, devices have been developed that electrically connect the human bodies with the earth with claims of discharging it, to measure "Body Voltage," or to maintain the body at the same electrical potential as the earth. The problem is that the earth is no longer at zero potential. It was reported that 70% of the current that went out on the electric utilities phase conductors returned via the earth in1998 by the Minnesota Science Advisors. Some of these devices use a remote rod driven into the earth somewhere in a person's yard with a wire connected to it and the other end of the wire connected to some sort of conductive electrical pad. Other devices use the 3rd (Ground) prong of the electrical outlet in the buildings wiring to connect their devices to the earth. This connection makes a direct mechanical as well as electrical connection to the electric utilities primary neutral wire at the utility transformer. Instead of getting rid of electrons from the body, the connection applies the voltage that was on the primary neutral system directly to the human body. Because the electrical loads have changed to non-linear there would be high frequencies applied to the body as well.

Figure 1 represents the electrical impedance model of the human body. The model shows the capacitance of the skin. Energy from frequencies above 1.7 kilo Hertz will cause the capacitors to short and be dissipated internal to the body.

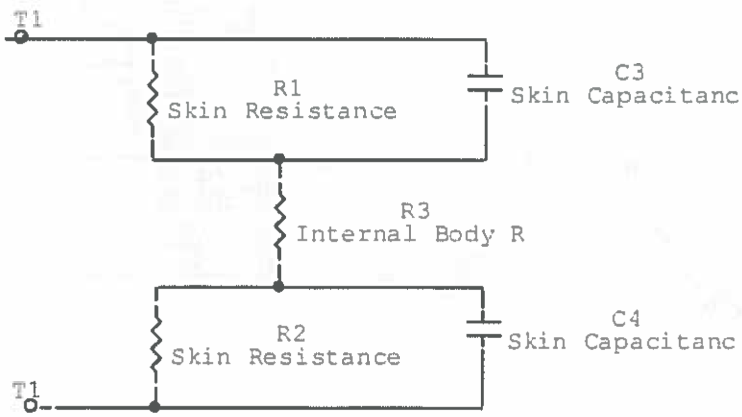


Figure 1 Five-component body impedance model. (UL. 1981.)

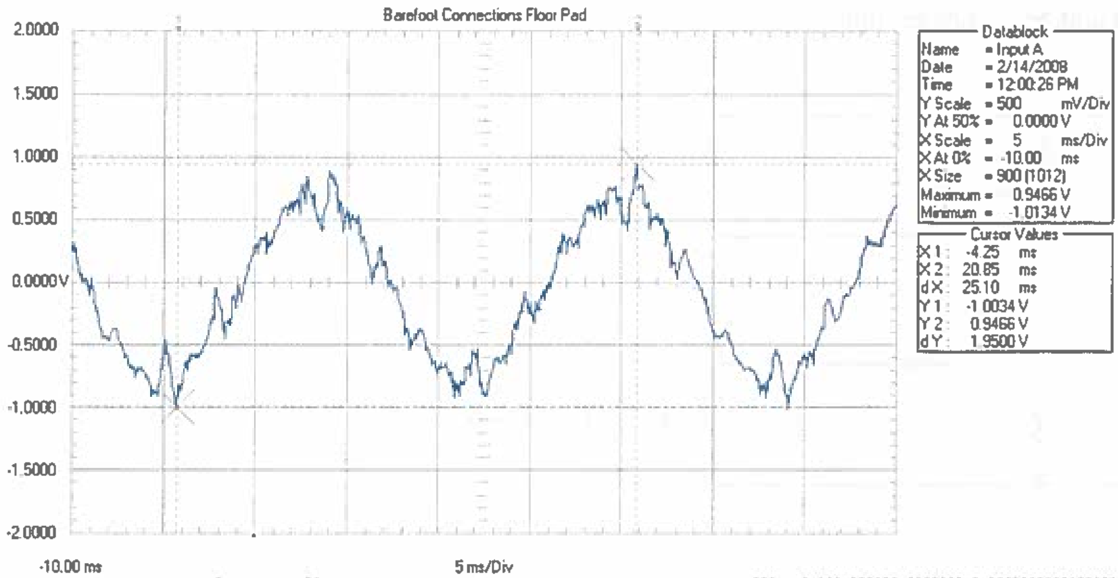
Figure 2 is a non-sinusoidal waveform measured between a conductive mat and the connecting wire that was plugged into grounding receptacle at a wall outlet. The waveform is distorted and is a sample of the voltages that were on the Primary Neutral wire at the time. These levels will change with time as the loads on the electrical grid change.

Figure 3 is a spectrum analysis of the waveform displayed in figure 2. Although it is difficult to see in this format, it shows frequencies above 9.8 kilo Hertz. These are a sample of the frequencies that would be applied to the person that would be in contact with such a device.

Conclusion

There have been anecdotal reports of changes in people's health after lying on such conductive devices such as mats, etc... There is no reason to doubt the reports. Being in contact with conductive surfaces may very well discharge the human body, or equalize some differences of electrical potentials, however those results may be difficult to achieve or duplicate when connected to high frequency ground currents or the electric utilities primary neutral return wire.

Exposing animals to this type of energy has been shown to affect their health, including decreased milk production in cows. (Hillman, Stetzer Graham, etal)



The didtorted 60 cycle waveform was measured between the connection pin on the Barefoot Connections Floor Pad and connecting wire that was plugged into the wallsocket. The readings were taken with a Fluke 196 Scopemeter, utilizing Flukeview software. The levels at the time are 1.9 volts AC Peak to Peak.

Figure 2

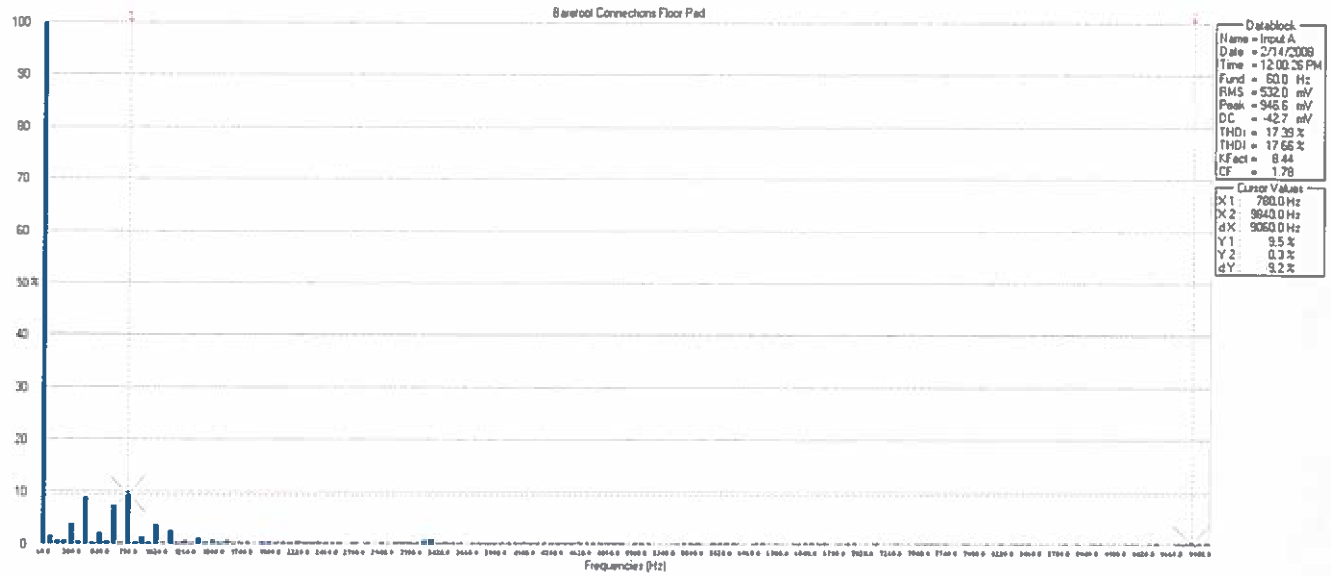
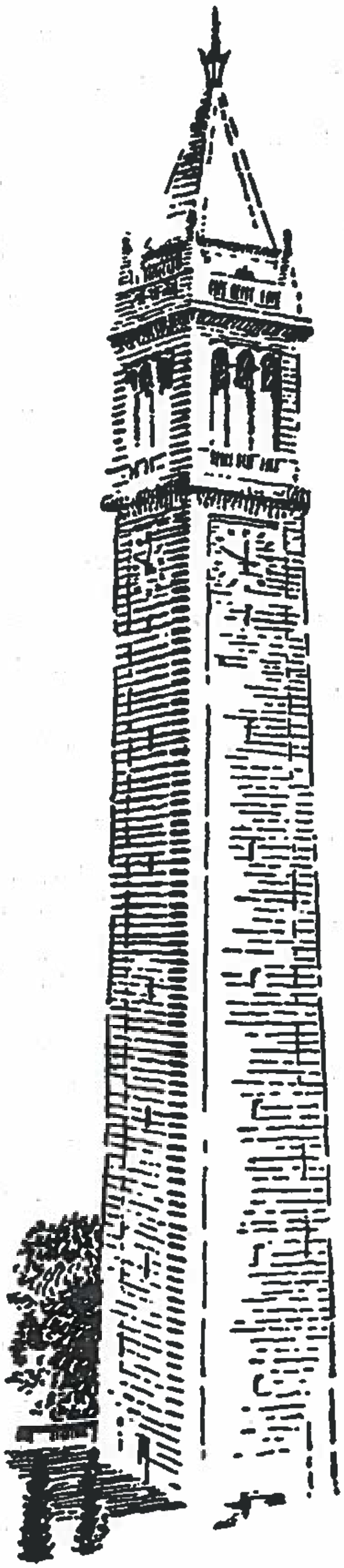

Barefoot Connections Floor Pad
Datablock
Name = Input A
Date = 2/14/2008
Time = 12:00:36 PM
Fund = 60.0 Hz
RMS = 532.0 mV
Peak = 946.6 mV
DC = -42.7 mV
THDi = 17.39 %
THDI = 17.66 %
KFact = 8.44
CF = 1.78
Cursor Values
X 1 780.0 Hz
X 2 9840.0 Hz
dX 9060.0 Hz
Y 1 9.5 %
Y 2 0.3 %
dY 9.2 %
100
90
80
70
60
50 %
40
30
20
10
0
Frequencies (Hz)

Figure 3



A MICROSURGE METER FOR ELECTRICAL POLLUTION RESEARCH

by

Martin Graham

Memorandum No. UCB/ERL M03/3

19 February 2003

ELECTRONICS RESEARCH LABORATORY

College of Engineering

University of California, Berkeley, CA 94720

Part 3 of 8, Additional information found TheBrainCan.com , SolomonSeries.com, and https://www.youtube.com/solomonseries

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A MICROSURGE METER FOR ELECTRICAL POLLUTION RESEARCH

Martin Graham

Professor Emeritus
Electrical Engineering and Computer Sciences Department
University of California, Berkeley

ABSTRACT

An inexpensive and simple to use instrument called a Microsurge Meter is described. It produces a digital reading related to how harmful the electrical pollution is to humans in that microenvironment.

A MICROSURGE METER FOR ELECTRICAL POLLUTION RESEARCH

Electrical pollution is an environmental problem in which the environment of concern is the space within a few feet of the human. Harmful currents flow through humans without humans making direct contact with conductors. The distance between humans and wires in homes is small compared to the distance between humans and the wires of the electric utility distribution systems. Since an electric field decreases rapidly with the distance from the conductor, measurement and mitigation should concentrate on the immediate environment, which might be referred to as a microenvironment.

Many homes have employed the mitigation techniques described in "Mitigation of Electrical Pollution in the Home" (Appendix A). Many of the occupants of these homes have reported a reduction of the symptoms described in "A Ubiquitous Pollutant" (Appendix B). The improvement usually occurred within days after the installation of the capacitors, which reduce the high frequency electric fields associated with the wiring in their homes without reducing the 60 Hz electric fields.

High frequency transients are often referred to as surges, and information on them and their harmful effect on electrical equipment, but not on humans, is on utility web sites (Appendix C). Information on the source of these surges and how to mitigate them is also on utility web sites (Appendix D).

The instrument described in "A Ubiquitous Pollutant" measures the heating effect of the transients. The effects of transient electrical fields on humans are related more to their peak amplitude and is cumulative. One large transient can convert a fibrillating heart to normal rhythm in seconds. Many small transients can have more subtle effects which develop over a period of time, and can be life threatening.

A combined filter and peak detector designed to measure the level of pollution is shown in Appendix E. It should cost less than $40. The total cost of the filter and peak detector together with the associated D.C. Voltmeter should be less than $90. This instrument can be used to determine the level of pollution at electrical outlets in a home and whether the pollution source is in the home or in a neighbor's home or in the electrical utility. When all the electrical loads in a home are turned off the pollution reading is due to sources outside the home. Steady readings of over 400 milivolts D.C. should be a cause for concern.

An individual can do research in electrical pollution be observing the relation of the electrical pollution level with how they feel. The observation is most meaningful when a large change in the electrical pollution level occurs over a short period of time. An individual can reduce the electrical pollution from a high level to a low level using the techniques described in "Mitigating Electrical Pollution in the Home." Some diabetic individuals experience a change in their monitored blood glucose levels when the electrical pollution level changes, and this is a recognized clinical measurement.

APPENDIX A

MITIGATION OF ELECTRICAL POLLUTION IN THE HOME

by

Martin Graham

Memorandum No. UCB/ERL M02/8

19 April 2002

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THE MITIGATION OF ELECTRICAL POLLUTION IN THE HOME

Martin Graham

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ABSTRACT

The electrical pollution that is mitigated is the electric fields produced by the ubiquitous Marconi Transmitters present in today's high technology environment. Individuals should be able to determine if this mitigation in their home is beneficial to them.

THE MITIGATION OF ELECTRICAL POLLUTION IN THE HOME

The electrical pollution considered in this report is electrostatic fields that vary rapidly in a random or noiselike pattern. When Guglielmo Marconi transmitted wireless signals from Polphu, England to St. John's, New Foundland on December 12, 1901 he used a spark transmitter that generated fields of this type. The antenna and the ground were connected to the spark gap. The wireless signals used today are much more orderly, since this is the basic way to enable multiple communication channels that share a common medium [1]. These modern signals have sinusoidal waveforms that are similar to those in the electrical distribution systems. However, there are millions of transmitters in the electrical power system that are the equivalent of Marconi's transmitter, and the power distribution wires are the antennas and grounds that couple these noiselike signals to humans. An inexpensive hand held AM radio receiver will detect these signals. Tune the receiver to the lowest frequency on the dial (about 500 kilohertz) which is below the lowest frequency broadcast station, turn up the volume, and you will hear a noise. As the receiver comes closer to a transmitter, the noise becomes louder. Try it near dimmer switches at various settings, personal computer displays and keyboards, fax machines, microwave ovens, electronic telephones, high efficiency fluorescent lamp bulbs, video tape recorders, and hand held hair dryers. The effects on humans depend on the path the currents produced by these fields takes through the humans, on the sensitivity of the individual, and on the amplitude, waveform, and duration of the fields. There is strong evidence that these currents may cause cancers, but this report is concerned with reducing the symptoms that humans can directly observe in themselves, such as poor short-term memory, chronic fatigue, depression, nausea, and rashes.

The Marconi Transmitters may be there because of the customer, or they may be there because of the utility. Some of the transmitters belonging to the customer are

- Hair dryers
- Dimmer switches
- Electronic transformers in low voltage halogen reading lamps
- Loose electrical connections
- High efficiency electronic systems

Some transmitters belonging to the utility are

- Switches controlling the power factor correction capacitors
- Tap switches on transformers for voltage regulation
- Deteriorated wires and connectors

There are transmitters which belong to other customers that are connected by the utility distribution system to your house. One such case is the strobe lights located on radio towers for aircraft warning purposes. The signals generated by these transmitters can travel considerable distances. The electric fields produced by these noise voltages between the power wires in a home can be reduced by lowering the impedance between the wires. Connecting a large capacitance between the wires has been effective in many cases in reducing the symptoms experienced by the occupants of the home. The capacitances used in these tests were about 200 microfarads across each 120 Volt circuit in the usual 240 Volt utility distribution system. In most cases these were installed at the main distribution in the home by a licensed electrician. Appendix A describes how an individual can evaluate the effectiveness of this mitigation technique on their symptoms.

APPENDIX A

An individual can install a capacitor across the 120 Volt circuit by electrically connecting it to a plug that is inserted into a 120 Volt electrical outlet, which is the type used in homes for appliances such as lamps, television sets, toasters, etc. A good arrangements for individuals is to plug in ten to twenty 20 microfarad motor run AC capacitors into a number of different outlets. Suppliers of these capacitors can be found in the telephone yellow pages under electric motors and/or electrical supplies. The newer A.C. dry film capacitors in epoxy cases are better for this use by nonprofessionals than the older style oil filled capacitors in metal cases, but either will mitigate the pollution. The mitigation is somewhat more effective if the capacitors are plugged into outlets used for appliances that individuals are close to for extended periods of time, such as reading lamps, radios and television receivers, and kitchen appliances.

Particular attention should be paid to safety.

- There should be no exposed electrical conductors.
- The components should be in a enclosure that prevents children from tampering with the device.
- Whenever a capacitor is disconnected from the outlet, it may have energy stored in it which will remain there for hours. A 27 kilohm 2 watt resistor permanently connected directly across the 20-microfarad capacitor will remove the stored energy within a few seconds without wasting appreciable power while the capacitor is connected to the outlet. Some sparking may occur at the plug when the capacitor is connected. This is normal.

REFERENCE

[1] Sungook Hong, *Wireless (from Marconi's black-box to the audion)*, The MIT Press, Massachusetts Institute of Technology, Cambridge, MA 02142, 2001.

APPENDIX B

A UBIQUITOUS POLLUTANT

by

Martin Graham

Memorandum No. UCB/ERL M00/55

28 October 2000

ELECTRONICS RESEARCH LABORATORY

College of Engineering
University of California, Berkeley
94720

A Ubiquitous Pollutant

Martin Graham

Professor Emeritus
Electrical Engineering and Computer Sciences Department
University of California, Berkeley

ABSTRACT

High frequency voltages present on the electrical power wires in homes, offices, schools and factories should be considered a potential pollutant. An inexpensive and simple to use instrument is described for measuring these voltages.

The letter of May 4, 1999 by Kenneth Olden which accompanied the *NIEHS Report on Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields*[1] contains the following paragraph:

> The lack of connection between the human data and the experimental data (animal and mechanistic) severely complicates the interpretation of these results. The human data are in the "right" species, are tied to "real life" exposures and show some consistency that is difficult to ignore. This assessment is tempered by the observation that given the weak magnitude of these increased risks, some other factor or common source of error could explain these findings. However, no consistent explanation other than exposure to ELF-EMF has been identified.

This report suggests that the "some other factor" is high frequency currents, i.e., much higher frequency than the power line frequency. High frequency voltage can cause currents to flow in humans by direct contact, or by capacitive coupling. The effects on humans will depend on the magnitude, waveform, duration, and path taken through the body. The voltage causing these currents should be considered a pollutant.

The presence of a pollutant is often obscured by the presence of much larger quantities of non-pollutants. Low level high frequency voltages are often obscured by the large power frequency voltages, but low level high frequency voltage compared to the power line voltage does not imply that they do not cause detrimental health effects in humans.

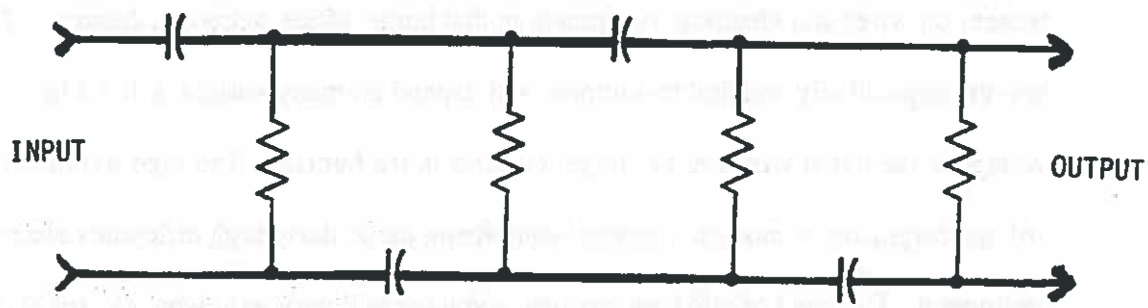
It is always a problem as to where to measure a pollutant such as high frequency electric fields. An instrument has been developed to do a very simple measurement. The measured voltage is that present at the standard household electrical outlet. A filter

(Figure 1) is used to remove the power line frequency and its harmonics. The remaining voltage is applied to an RMS digital voltmeter. The frequencies that are measured are determined by the filter and the characteristic of the meter. The FLUKE 79 III meter responds to frequencies above 10,000 Hz. The voltage amplitude measured will be that present on wires and electrical equipment in that home, office, school or factory.[2] The amount capacitively coupled to a human will depend on many variables, but a larger voltage at the outlet will result in larger currents in the humans. The high frequency voltage originates in modern electrical equipment, particularly high efficiency electrical equipment. The level of this high frequency voltage will vary with what electrical equipment is on at that location and with the time of day, due to the varying load on the electrical utility system which also contributes to this pollution.

Experiments are being performed to improve the design of this instrument and the interpretation of the readings.

If the effect on humans is caused by the high frequency voltages and currents, it would be important that the experiments with 60 Hz voltages and currents use voltages and currents that are not contaminated with these high frequencies.

FILTER



INPUT from Ubiquitous AC Outlet

OUTPUT to FLUKE 79 III meter set to VOLTS AC

All capacitors are .01 microfarad

All resistors are 10 kilohm

Figure 1

Footnotes

[1] *NIEHS Report on Health Effects from Exposure to Power-Line Frequency Electric and Magnetic Fields, Prepared in Response to the 1992 Energy Policy Act (PL 102-486, Section 2118),* National Institute of Environmental Health Sciences, National Institutes of Health Publication No. 99-4493.

[2] Exploratory measurements of this voltage varied from tens of millivolts to hundreds of millivolts. The voltage induced by a two milligauss 60 Hz magnetic field passing through a one square meter area is less than .1 millivolt.

ALLIANT ENERGY

Energy Basics: Power Surges
The Causes

Power surges occur when the flow of electricity is interrupted, then started again, or when something sends electricity flowing back into the system.

Surges can range from five or ten volts when you turn on your hair dryer to thousands of volts if lightning strikes a transformer.

Internal power surges

More than half of household power surges are internal. These happen dozens of times of day, usually when devices with motors start up or shut off, diverting electricity to and from other appliances.

Refrigerators and air conditioners are the biggest culprits, but smaller devices like hair dryers and power tools can also cause problems.

External power surges

An external power surge, stemming from outside your home, is most commonly caused by a tree limb touching a power line, lightning striking utility equipment or a small animal getting into a transformer.

Surges can also occur when the power comes back on after an outage, and can even come into your home through telephone and cable TV lines.

Energy Basics: Power Surges
The Consequences

Your home is filled with items susceptible to power surges. Anything containing a **microprocessor** is especially vulnerable - the tiny digital components are so sensitive that even a 10-volt fluctuation can disrupt proper functioning.

Microprocessors are found in **hundreds of consumer items**, including TVs, cordless phones, computers, microwaves, and even seemingly "low-tech" large appliances like dishwashers, washing machines and refrigerators.

Large power surges, as with a lightning strike, can cause **instantaneous damage**, "frying" circuits and melting plastic and metal parts. Fortunately, these types of power surges are rare.

Low-level power surges won't melt parts or blow fuses, but they can cause **"electronic rust,"** gradually degrading internal circuitry until it ultimately fails.

Small surges won't leave any outward evidence, so you may not even be aware they're happening - even though they may occur **dozens or even hundreds of times each day**.

Did you know?

A power surge usually lasts less than 1/120th of a second.

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Energy Basics: Power Surges

Preventing Power Surges

The first line of defense against power surges is **prevention**. While most external surges can't be controlled, you can eliminate some common causes of internal surges.

Did you know?

Your home may experience dozens or even hundreds of low-level internal power surges every day.

Unplug devices you aren't using

The easiest way to avoid power surge problems is to unplug devices that aren't being used. Take a look around your home, and you'll likely find dozens of idle items plugged in.

There's no need to leave toasters, power tools or other small appliances plugged in; if you rarely use the programming features on your microwave or VCR, unplug those as well.

Inadequate wiring

If you have an older home, inadequate wiring could be the cause. Electrical systems in homes built before the 1980s weren't designed to handle large-capacity refrigerators, entertainment systems and computer equipment.

Some visible signs of inadequate wiring are frequent blown fuses or tripped circuit breakers, or lights that flicker or dim when the refrigerator or another large appliance kicks on.

Don't ignore these symptoms - they're a signal that something is wrong, and the problem may become a fire hazard.

Overloaded circuits

If your home is newer, you may have a problem with an overloaded circuit. Look for two (or more) large appliances drawing power from the same circuit, especially in the kitchen.

Another troublespot might be a circuit with many smaller devices, such as a family room filled with computer and entertainment equipment.

Ask your electrician to establish dedicated circuits for each large appliance, and to divide rooms with multiple devices into separate circuits.