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RF Radiation Measurements in Selected Locations
In Kokomo, Indiana

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1.0   Introduction:

We were asked by James P. Cowan of Acentech to make radiofrequency (RF) radiation measurements and low frequency electric and magnetic field measurements to supplement the acoustic measurements his team is making to determine the source of the "Kokomo Hum." On Wednesday May 21, 2003, we arrived in Kokomo in the afternoon to make RF radiation measurements at four preselected locations. The intent of this measurement program was to determine whether the type and sources of RF radiation in the area were consistent with the hypothesis that auditory perception of pulsed RF radiation, absorbed by the residents might account for the Kokomo Hum. Among the limited sample of the population that we visited, a few general observations could be made before the onset of measurements: 1) At two locations, the residents heard a high pitched tone that one person described as being like the tones heard in a hearing test and another person described as being like the sound of a TV set with the sound turned off, but with a high pitched sound emanating from the transformer. (We assume he meant flyback transformer, part of the mechanism for raster scanning the electron beam across the face of the picture tube and producing a high voltage pulse, and not power transformer – because a high pitched sound emanates from the flyback coil, but only 60 Hz sound comes from the power transformer.) 2) At two other locations, residents heard low pitched, rumbling – sometimes booming – sounds, which one person described as being like an idling diesel locomotive and another person described as being like a heavy truck. People with these sensations also sometimes perceived vibrations of their houses. Without strain gauges or some other vibration measurement, we cannot say whether structural vibrations actually occurred or were just perceived by the residents. People who heard the low frequency, booming sounds also often endured physical symptoms such as headaches, nausea, aggravated insomnia, etc.   In many respects, their symptoms are a subset of the types of symptoms experienced by victims of radiofrequency (RF) sickness syndrome, as chronicled by scientists in the Former Soviet Union in studies lasting over 40 years, some of which were recently reexamined by U.S. scientists[1].

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[1] Ana G. Johnson Lyacouris, "Radiofrequency (RF) Sickness in the Lilienfeld Study: An Effect of Modulated Microwaves?" *Archives of Environmental Health,* Vol. 53, No. 3 (1998)

2.0   Sources of RF radiation in and around Kokomo:

The Kokomo region has a fairly complex electromagnetic environment for a small city. Since 1990, at least 18 cellular or Personal Communications System (PCS) towers have been erected in and very near Kokomo.[2] Kokomo policy permits and encourages collocation of up to three service providers on each tower. In addition, Indiana State Police and civic and commercial offices use trunked radio communications involving pulsed RF systems. ("Trunking" is a telecommunications term that denotes the manner in which many simultaneous conversations can be handled by a few communications channels. Trunking requires the use of a control channel to manage the transmissions, and this channel sends pulsed data transmissions.) Nextel pulsed digital wireless phone transmissions also take place in a region of the spectrum that shares adjacent wavelength bands with some Kokomo trunking radio systems (near the frequency 858 Megahertz, MHz). All other pulsed digital wireless phone services in Kokomo use frequencies that are in a completely different spectral region (1900-2000 MHz).

In addition to the wireless telephone systems, Kokomo has a number of commercial broadcast systems. There is a strong AM radio station just south of Kokomo on Route 26, south of the community of Indian Heights. This station operates with 5 kilowatts (kW) power during the day and 1 kW at night. More importantly, this station has a highly directional radiation pattern that is different at night from its daytime pattern. Thus, RF electric field strength (due to this station) at any given location varies from day to night.

Kokomo's TV station WTTK (southeast of Kokomo) operates on Channel 29 (frequency range 560-566) at Effective Radiated Power (ERP[3]) of 3.09 MW. This station has an application for a permanent digital TV station, and it is currently operating an experimental digital TV transmitter on a Special Temporary Authority for use of channel 54 (frequency range 710-716 MHz) with power level of 3.30 kW ERP. Further, there is a translator station that retransmits programs from a distant source. This is WKGK-LP, and it operates at 11.9 kW ERP on channel 48 (frequency range 674-680 MHz).

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[2] Glen Boise, Kokomo/Howard County Plan Commission, private communication, June 6, 2003

[3] ERP means the actual radiated power referenced to the power emitted by a standard dipole whose length is ½ wavelength. It is a measure of the antenna's ability to focus radiation.

All the Kokomo TV transmitters are horizontally polarized. This means that the plane formed by the electric field and the wave propagation direction is horizontal. For vertical polarization, the plane formed by the electric field and the propagation direction is vertical. The signal from the AM station WIOU is vertically polarized, and the signals from the FM stations in Kokomo have dual polarization – i.e., the polarization plane is oriented at 45 degrees with respect to either the horizontal or vertical plane. Thus, electric fields of the FM stations have equal components in both vertical and horizontal directions.

There are 3 FM broadcast stations in Kokomo. WIWC's transmitter is northwest of Kokomo, and it operates on 91.7 MHz at 2.1 kW ERP in both horizontal and vertical planes. WZWZ (owned by the organization that owns WIOU AM and WTTK TV) has a transmitting site on the western edge of Kokomo, slightly south of the center of town. WZWZ transmits on 92.5 MHz at 6 kW ERP with equal vertical and horizontal polarization. There is also a sister transmitter that is licensed as a backup at half the above power level. The highest power FM station in Kokomo is WWKI, and its transmitter is east-southeast of the city. WWKI operates on 100.5 MHz at 50 kW ERP with equal horizontal and vertical polarization. All these stations, except the backup transmitter, have radiating centers that are 93 – 147 meters above ground level. The radiating center of the backup station for WZWZ is 57 meters above ground level.

The RF radio environment is additionally complicated by aviation navigation and communications facilities nearby. Grissom Air Reserve Base is 15 miles north of Kokomo. This facility uses Airport Surveillance Radar (ASR) beams for approach and departure control, plus a number of communications channels, and pulsed navigational radio facilities. Weber[4] has tabulated the operating characteristics of several commonly used airport radars. Assuming this airport uses ASR-9 radar, its peak pulse output into the antenna is 1.1 Megawatts (MW), but the antenna gain is 34 decibels (dB), so the output power is 2.76 GW. Its pulse width is 1 microsecond, so that the energy per pulse of this radar is 2.76 kilojoules (kJ). This radar operates in the frequency range 2.7-2.9 GHz. Note: 1 GHz = 1,000 MHz.

A newer radar ASR-11 has been developed and is being deployed at airports that didn't previously have ASR-9. Antenna gain is the same as the

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[4] Mark E. Weber, "FAA Surveillance Radar Data as a Complement to the WSR-88D Network," MIT Lincoln Laboratory, Lexington, MA, available online (undated)

ASR-9. Peak power is 20 kW into the antenna, but its pulse widths are 1 microsecond and 80 microseconds. Thus, at 80 microseconds, its energy per pulse is 4.02 kJ. In addition, a Nexrad National Weather Service radar is at or near Grissom. These units have peak powers of 500 kW into the antenna. The Nexrad pulse widths are 1.57 microseconds and 4.5 microseconds. Assuming the same gain as the ASR-9 antenna, the energy per pulse of the Nexrad at 4.5 microseconds is 5.65 kJ. Thus, all three of these radars deliver pulse energies of a few kilojoules. ASR-9 and ASR-11 both have pulse repetition frequencies of about 1 kHz. Nexrad has a range of pulse repetition frequencies of 322-1,282 Hz.

Kokomo Municipal Airport is 4 miles northeast of the town. A VORTAC navigation radio facility is situated there, and another VORTAC is at Grissom ARB. (VOR means VHF Omnirange, and TACAN means Tactical Air Navigation. VHF is an acronym for Very High Frequency. VORTAC is a contraction of the terms that indicates the combination of the two facilities.) A typical VORTAC produces pulses into the antennas of 3.5 – 6 kW power. The gain of the antennas increases the effective power output several fold. These systems produce both omnidirectional pulsed beacons and continuous rotating beacons. The time delay between the reception of the two pulses provides position information relative to the fixed location of the VOR facility. Eight Navigation Directional Beacons (NDB's) are also in the area, but they are not considered significant contributors to the RF environmental complexity, because their output power level is only 25 watts. Further, nearby Muncie and Marion have VOR/DME facilities that have outputs of only a few watts. (DME means Distance Measuring Equipment.) Instrument flight operations at Kokomo Airport are all handled by Grissom ARB approach and departure controllers, so no additional radio transmitters are needed at Kokomo, except for a Unicom facility at 123.0 MHz. Unicom is a low power radio system used at airports without control towers to allow pilots access to wind and air traffic information by voice contact with someone at the airport. Finally, Glendale airport is 5 miles southwest of Kokomo, but it doesn't contribute significantly to the RF environment, as it has only a Unicom at 122.9 MHz.

A contributor to the RF environment is the Loran-C station at Dana, IN. Dana is about at the latitude of Indianapolis, but is quite close to the Indiana border with Illinois. It is 83 miles from Kokomo; however, its power is quite high, and its antenna is 625 feet high. Thus, its signal strength is probably non-negligible in Kokomo. Loran-C is a worldwide navigational system that

produces strong ground wave RF fields that can travel hundreds of miles with little attenuation. All Loran-C stations operate at 100 kHz frequency, and the Dana station emits pulses with 400 kW peak power level. (Loran is an acronym for Long Range Navigation.) The RF field strength in Kokomo of the Loran-C at Dana is comparable to the field strength from cell tower antennae, and we will later consider potential consequences of mixing of fields from the Loran-C system and cell tower antennae, as well as field mixing from the AM broadcast station and the cell tower antennae. This process is sometimes called "intermodulation," though that term is usually reserved for other situations of interference between RF signals.

3.0   Field Measurements at Four Kokomo Residences:

1) Measurements at 3030 Terrace Drive

Our first measurements in Kokomo were made at the residence at 3030 Terrace Drive. We used both our broadband RF instruments, a nonrecording instrument that covers the frequency range 500 kHz – 3 GHz (RF Field Strength Meter manufactured by Alphalab, Inc. Salt Lake City) and a data logging RF meter that covers the frequency range 2 MHz – 2 GHz (EM Eye CTM045 manufactured by Credence Technologies, Inc. Soquel, California). The Alphalab meter can be restricted to the more narrow range of frequencies 100 MHz – 3 GHz by switching to narrow bandwidth. Both instruments were calibrated by their respective manufacturers with NIST traceable procedures[5]. The Alphalab meter was calibrated prior to its purchase in Sept. 2002, and the EM Eye was last calibrated in July 2001. We have found in our own tests that the Alphalab and the EM Eye usually agree within a factor of two (3 dB) when the Alphalab is set on narrow bandwidth and the dominant sources are in the appropriate frequency range. Both instruments measure the RF electric field and then internally convert the results to radiation density measurements, using algorithms that invoke plane waves in the far-field of any RF source.

Upon arriving at the residence, we found that the Alphalab RF meter set on wide bandwidth registered about 15 microwatts per square centimeter ($\mu W/cm^2$) around the TV set, which was turned off. The EM Eye measured a much lower radiation density, suggesting that low frequency components were dominating the Alphalab meter's measurements. This conjecture was confirmed by turning on the internal speaker in the EM Eye. The EM Eye can

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[5] NIST means National Institute of Standards and Technology. It is the successor agency to the National Bureau of Standards.

detect amplitude modulated signals. We heard an AM radio station quite clearly. Later, we determined that the station's frequency was 1350 kHz. Since this frequency is well below the flat response range of the EM Eye, the contribution of this low frequency broadcast station to the radiation density measurements of the EM Eye is somewhat suppressed. Nevertheless, we made several sets of measurements with the EM Eye because of its directionality and its data recording capability. The meter was mounted with Velcro on a wooden block for electrical isolation, and the whole assembly was mounted on a camera tripod.

At this location, the TV cable, the residential power line, and the telephone line are all within about one foot of each other at a position in the back yard. In addition, these lines may be acting as receiving antennae. Thus, we made measurements to see whether the broadcast signal was appearing on the telephone line and the power line, as well as on the cable TV. With the cable unplugged from the TV set, we measured a very low background of 0.2 – 0.26 nW/cm^2, using the EM Eye set on RMS averaging mode. The sampling interval over which the averages were determined was one second. The instrument was oriented vertically (to maximize sensitivity to the higher frequencies) and it was located 3 inches down from the top of the picture tube and 9.5 inches toward the middle from the left edge of the picture tube. With the cable reconnected to the TV set and the meter pointed toward the picture tube from 2.5 inches away, we found radiation densities an order of magnitude larger than background – specifically 2.5 – 5 nW/cm^2, with the instrument set on peak measurement mode, sampling data over one second intervals and recording the highest value in each interval. The broadcast station could again be heard on the meter's internal speaker. We got a louder sound from the EM Eye's internal speaker when the instrument was placed behind the TV set, than when it was in front of the TV. Significantly, with the cable disconnected from the TV set, one resident could not hear the ubiquitous hum, but the other could. We also found broadcast signals from the EM Eye's speaker when we placed the instrument near the disconnected cable.

After these measurements, we took the instrument outside and in back of the house. There was a cell tower across the street. Because cellular systems use frequencies higher than 800 MHz, the instrument was oriented to get the highest signal strength, which occurs when the instrument is pointed along the radiated electric field. In this case, highest signal strength required vertical orientation. In some other installations, we have found highest signal strength

with almost 45 degree orientation. The instrument tripod was set up 8 feet away from the tree in the back yard. We obtained peak radiation densities varying from 1.2 – 8.8 nW/cm^2 in a pattern that strongly indicated a pulsing signal, as shown in Figure 1. The data shown here correspond to peak electric fields of 0.156-0.174 volts/meter (V/m). This graph is a composite of two data runs. The first 12 data points were recorded about 2 minutes before the rest of the data, because we examined the first set of data and then found the dramatic fluctuations shown here. The join point occurs at 12 seconds.
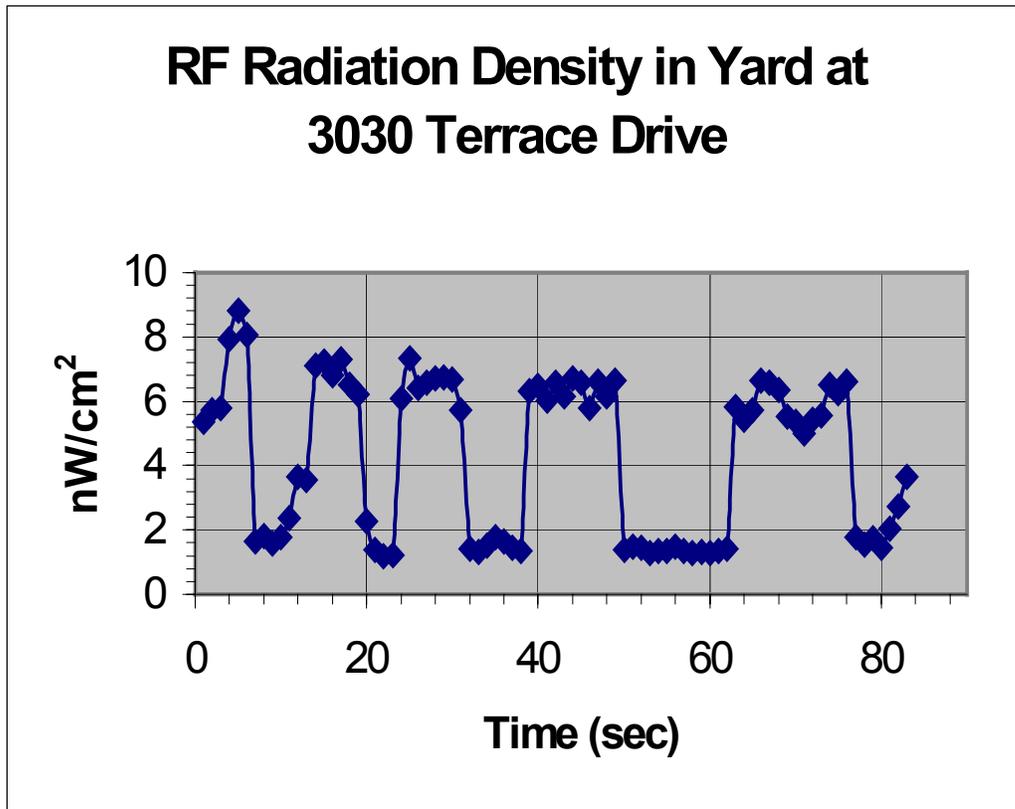
RF Radiation Density in Yard at 3030 Terrace Drive

y-axis: nW/cm^2 (0 to 10)
x-axis: Time (sec) (0 to 80)

Figure 1   Slow Pulsing Pattern of RF Radiation in Yard

We returned to the house to determine how extensively the RF that we had seen on the cable TV had contaminated the power line and the phone line. First, though, we repeated the measurements at the front of the TV set. This time, we took a data run with the cable initially not connected and then reconnected during the data taking. The meter's antenna was pointed at the screen, 1-1/2" from the screen, 3" down from the top, and 11"from the left side of the screen. This position was closer to the screen than before, and some RF reflections occurred, making the background when the cable was disconnected

somewhat higher than before. The background level varied from 0.65 – 1.0 nanowatt per square centimeter. When the cable was reconnected, there was an initial transient of about 19 nW/cm^2. Then, the signal settled down to 3 - 5 nW/cm^2 for some time, dipped down again to background level, with another transient in the 20 nW/cm^2 range, and then rose from 3 - 8 nW/cm^2 to a few seconds of data between 20 and 35 nW/cm^2 until the data run ended. We repeated this data series with the instrument in slightly different position: 1¼ inches from the picture tube, 2 inches down from the top and 11 inches from the left side toward the middle of the screen. Without the cable connected, the radiation densities ranged from 0.9 – 2.8 nW/cm^2. With the cable connected, the range was 5 – 14 nW/cm^2.

After the measurements at the TV set, we took the EM Eye into a bedroom and set it on the floor ½ inch from the telephone jack. The broadcast station was clearly audible on the EM Eye's internal speaker, and the meter recorded radiation densities of 12 – 18 nW/cm^2. Sound was also audible from the EM Eye, when it was placed near the TV jack in the room. Radiation density was about 52 nW/cm^2. At the electrical outlet, there was 0.29 microwatt per square centimeter (μW/cm^2). These measurements violate the far field restriction of the meter – so they should be considered only qualitative, but they clearly show that RF radiation was emitted by both the telephone jacks and the electrical outlets in this house.

We further tested the RF current on the power line, using an RMS voltage meter (Fluke Multimeter, model 79 III) connected to Dr. Martin Graham's circuit that isolates RF voltages from power line voltages.[6] This test set up is plugged into a residential power outlet and the meter reading is recorded. In tests in our own home and several other places, we have found that readings up to 30 millivolts (mV) are normal. This conclusion is also stated in Ref. 6. RF voltage significantly above this level suggests excessive RF current on the power line. RF currents on the power line will result in RF radiation to the inhabitants of the house. At this house, the RF voltage on the power line fluctuated in the range of 22 – 40 mV. When the residents turned on a light dimmer switch in the dining room and set it neither full on nor full off, the RF voltage increased to 80 mV. Dimmer switches are known RF sources when set at intermediate positions (see Ref. 6).

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[6] Martin Graham, "A Ubiquitous Pollutant," Memorandum No. UCB/ERL M00/55, Electronics Research Laboratory, College of Engineering, University of California, Berkeley, CA 94720, October 28, 2000

We set up our spectrum analyzer in the dining room and quickly sought to isolate the frequencies that appeared to be associated with the strongest RF signal. Figure 2 shows the portion of the spectrum centered on 859.11 MHz and spanning a range left to right of 0.8 MHz, using a step size of 5 kHz. This plot is from a BMP file generated by the instrument. In some other locations, we saved the data in a PC clipboard to be used in Excel charts, which are much more readable than this plot.

Our spectrum analyzer is a handheld unit manufactured in Korea and sold in the United States by Protek Corp. under several different brand names. Ours is Model RF-3200, sold under the brand name A.W. Sperry. It was calibrated and upgraded to model RF-3201 prior to purchase at the beginning of 2003.
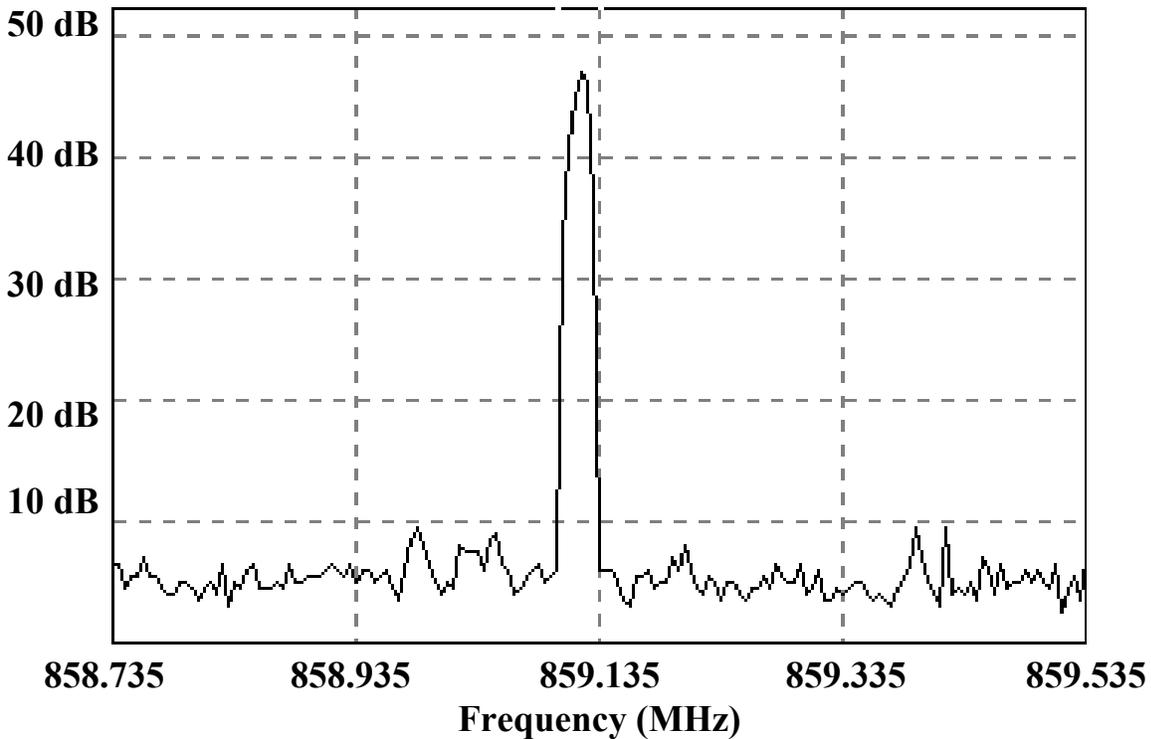

Figure 2   RF Spectrum near 859 MHz at 3030 Terrace Drive

The peak shown here is at 859.11 MHz and its strength is 47 dB above the reference level of – 117 dB. 0 dB corresponds to 1.0 milliwatt signal power across a 50 ohm impedance at the antenna input to the spectrum analyzer. We have made an effort to convert the relative signal strengths to absolute measurements. The instrument's antenna sits on a BNC connector of

4 mm radius. The average absolute electric field measurement should therefore be the voltage across the connector divided by the radius of the BNC connector. The voltage at 0 dB is the square root of the product of the power and the impedance – 0.2236 V. The average electric field corresponding to 0 dB is then 55.9 V/m. The corresponding radiation density equals the square of the electric field divided by the impedance of free space (120 pi ohms) and is equal to 828.9 μW/cm^2. The peak height is – 70 dB, so the absolute radiation density corresponding to this peak is 0.083 nW/cm^2. The scanning width is 5 kHz. There are 5 scanning widths across the entire peak, and the Full Width at Half Maximum (FWHM) is about 3 scanning widths at peak height of 44 dB, so the total radiation density from this peak is about 0.13 nW/cm^2.

The entire peak width is 25 kHz, indicating that this signal is from a pulsed digital phone system using Time Division Multiple Access (TDMA) technology to handle up to six conversations simultaneously[7].

Nextel uses TDMA technology combined with a proprietary Motorolla phase modulation technique. The combination is a proprietary Motorolla technology called Integrated Digital Enhanced Network (iDEN)[8]. Other wireless phone systems that use TDMA technology are within the frequency range assigned to PCS phone providers. These services use frequencies in the 1900-2000 MHz band. A few PCS providers use Code Division Multiple Access (CDMA), which has a different waveform from that of TDMA and also broader channel bandwidth, but most, if not all, of the providers in Kokomo use systems that have TDMA, instead of CDMA, on the basis of our spectral observations.

No other Indiana wireless phone system except Nextel has been assigned frequencies in the region of 858 MHz, because Nextel bought the frequencies that were previously designated Special Mobile Services (SMR) by the FCC. These frequencies were originally allocated for commercial dispatch services. Since they were under utilized, the FCC reallocated these frequencies to Nextel. They are interleaved with public service frequencies, including those of the Indiana State Police. There is a dispatch station for the State Police in nearby Bunker Hill. If some of the signal we have seen in the spectrum

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[7] On Line Tutorial on TDMA from International Engineering Consortium, Chicago (undated)

[8] iDEN Technical Overview, Motorola Network Solutions Sector, 1301 E. Algonquin Rd. Schaumburg, IL 60196 (1999) available online

measurements discussed above were due to this station, the signal would still be pulsed, because the police radio system uses Motorolla Smartnet type 2, a trunking radio system. However, the signal strength would be weaker than the signal from a Nextel base station. Trunking systems use a pulsed control channel to route the messages through the system. In fact, the Motorolla iDEN system has similarities to a trunking radio dispatch system and evolved from Motorolla's trunking radio experience. Further, the RF carrier frequency assignment used in iDEN is characteristic of trunking radio systems.

The spectral feature shown in Figure 2 is common to all four locations where we made measurements, but the precise position of the peak and its height varied with location. Outgoing iDEN frequencies are assigned by the control channel when a user's phone contacts the system by the algorithm: Outbound frequency = 851 MHz + 0.0125xcarrier number. At all four measurement locations, our spectral measurements agreed with this algorithm.

2) Measurements at 1040 South Lewis

Our second set of measurements in Kokomo was made at the residence at 1040 South Lewis Street. It should be noted that one of the residents of this house suffered some damage to his hearing apparatus when he was in the military and was subjected to a sudden, unexpected, very strong percussive blast close to him. He hears ringing sounds almost constantly.

We used all our instruments at this location. In addition to the instruments we previously described, we used a TriField meter (made by Alphalab, Inc.) to measure low frequency electric and magnetic fields. We began by making an informal survey of RF fields with the EM Eye to see what the RF environment looked like at this location. We did not record these data in the instrument memory, because we did not mount the instrument on its tripod. Thus, there are significant inaccuracies introduced by the operator's presence. Nevertheless, this survey was useful because it established that RMS averaged radiation level in the house was only 2-4 times background, that had been previously reported by the Environmental Protection Agency (EPA) to be a field strength of about 0.1 V/m, which converts into 2.65 nW/cm^2 radiation density[9]. This field strength was published in the 1990's, but it was based on

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[9] E.D. Mantiply, et al. "Summary of measured radiofrequency electric and magnetic fields (10 kHz to 30 GHz) in the general and work environment," *Bioelectromagnetics* 18:563-577 (1997)

measurements made in rural areas lacking obvious RF sources in the 1980's. In the case of the Shuck house, there were obvious RF sources: a cell tower visible from their property and the radio station at 1350 kHz. Turning on the EM Eye's internal speaker revealed that we again found a strong audible signal from this same radio station that was prominent at the first location.

We also did an informal magnetic field survey, finding significant fields only in the northwest corner of the kitchen. Typically, these fields were around 3 milligauss (mG) when appliance cords were plugged into the wall outlets. Under the desk the field was 100 mG, because the phone answering machine was plugged into an outlet there. Such a high field should be avoided, but it is unlikely to have sensitized the couple sufficiently to make them susceptible to microwave hearing effects. We also found 100 mG near the AC adapter for a computer plugged into a wall outlet in the study, even though the power supply was not connected to the computer. Because computers use switching power supplies, the power supply was apparently drawing current, even though the computer was not connected.

We made a number of RF measurements near the residents' personal computer using the Alphalab RF field meter, using both narrow and wide band settings of the meter, when the computer was turned on. Near the CPU, the wide band setting gave 180 nW/cm^2. The narrow band setting gave 20 nW/cm^2 at the same position. This reflects the effect of both the low frequency broadcast source and the RF radiation from the computer.

We also made RF measurements with the Alphalab meter near the PC's monitor. These measurements were made 6 inches from the surface of the monitor's screen. With the meter set on wide band, we measured 3 µW/cm^2. With it set on narrow band, we measured only 15-20 nW/cm^2. The computer was an IBM PC AT model. Likely, its processor speed (and, hence, the resultant RF radiation frequency) was only a few tens of MHz, so any radiation from this computer would have contributed significantly to the difference between the wide band and narrow band measurements.

We then made measurements to determine the amount of RF components that were on the house internal power lines. Using the Fluke RMS meter connected to Dr. Graham's filter circuit, we found 50 millivolts on the outlet connected to a Ground Fault Circuit Interruptor (GFCI). This occurred

when a radio was plugged into the GFCI, even though the radio wasn't turned on.

We took the EM Eye RF meter outside and found RF radiation reflected from the roof of the garage. The radiation density was about 10 nW/cm^2. A stronger signal of about 20 nW/cm^2 was coming from a nearby cell tower about two miles southeast of the house. We then set up the instrument tripod outside and back of the house on concrete in front of the garage about 30 feet in front of the west door. The tripod was elevated about 6-7/8 inches above its base. The instrument's azimuth was 260 degrees (west), and its elevation was 155 degrees. This means the instrument was pointed backwards from the vertical by 25 degrees. This was the direction that gave the highest signal strength. That is because the combination of antenna design and post installation mechanical adjustments were used by the telecommunications company to tilt the antenna radiation pattern slightly downward for optimum coverage of the desired area. Because the meter indicated some overload during these data collections, we took three data traces. Figure 3 is a composite of these data traces. The join points are at 29 and 42 seconds.
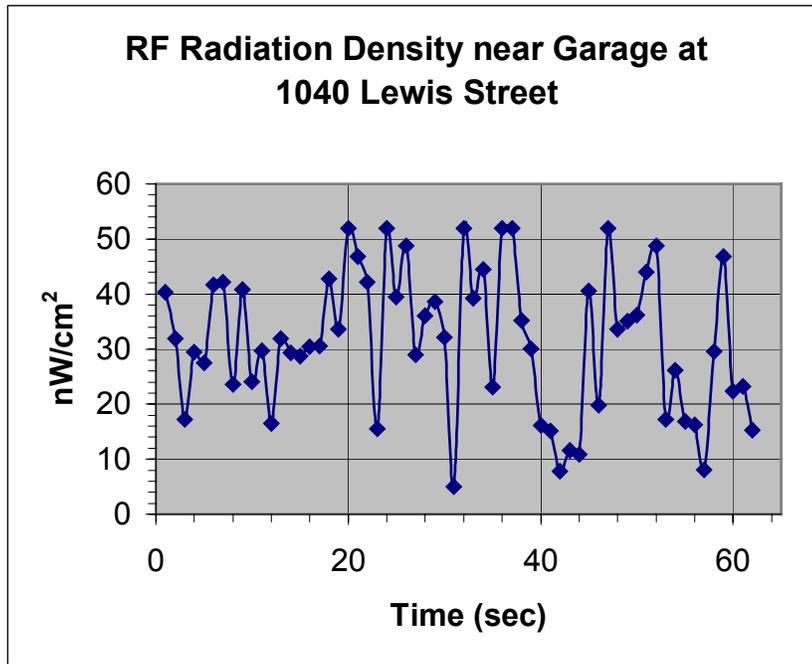

RF Radiation Density near Garage at 1040 Lewis Street

Figure 3   Pulsation Pattern of RF Radiation in the Yard

The fluctuation pattern shown in Figure 3 obviously differs considerably from the regular and slow apparent pulsations shown in Figure 1. Figure 3 is more typical of the pulsations we have previously found near cell towers for

pulsed, digital wireless phone systems than is Figure 1. The strength of the spectral peak near 858 MHz (described below) however, suggests that the results shown in Figure 3 are probably dominated by the (presumed) Nextel base station that we previously mentioned.

We set up the spectrum analyzer in the kitchen and measured spectral features in both the spectral region we had measured at the first location and in the spectral region that is characteristic of PCS pulsed digital phone systems. The spectrum around 858 MHz is shown in Figure 4.
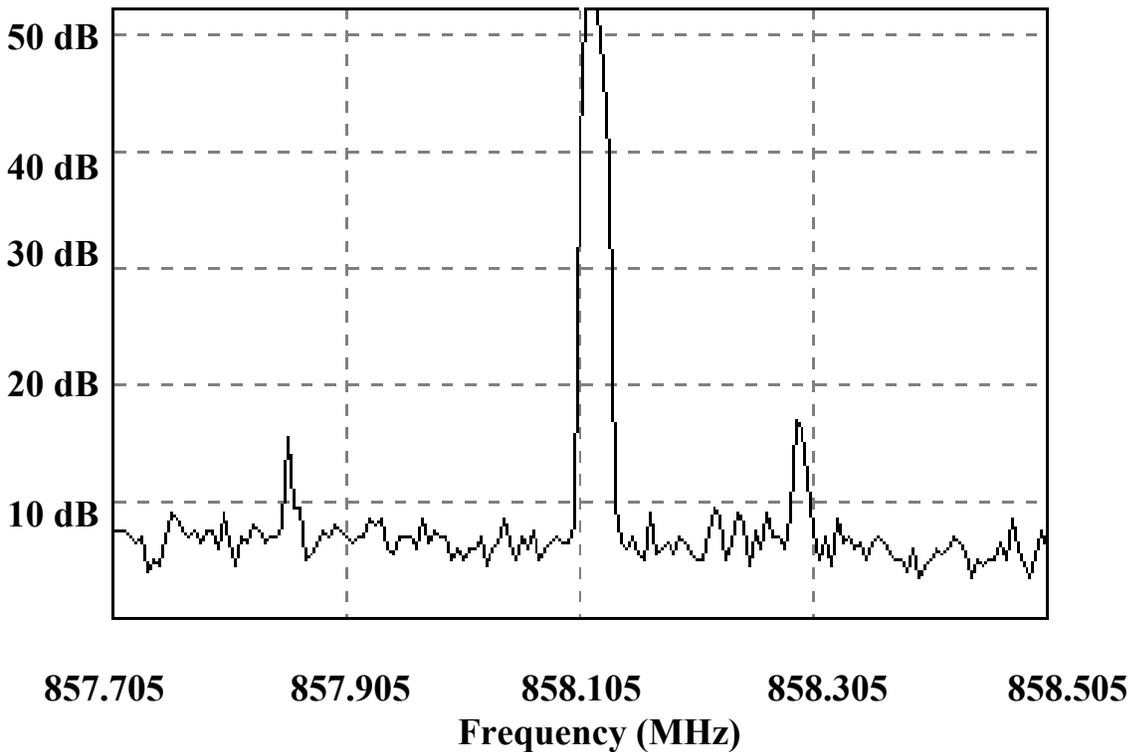
Figure 4   RF Spectrum near 858 MHz at 1040 South Lewis Street

There are obvious differences between the two spectra near 858/859 MHz shown in figures 2 and 4. The central peak is shifted in frequency and signal strength between these two cases. Also, there are two small side peaks in Figure 4 that don't appear in Figure 2. The width of the central peak is 25 kHz in both figures, however, indicating use of TDMA access technology for pulsed digital phone transmissions (see ref. 7). Thus, we believe that this is another Nextel channel, operating at a slightly different frequency from the one that produced the data shown in Figure 2. Though not shown here, we also found other peaks in the spectral region 874.7 – 889.4 MHz, and we heard sounds on the instrument's internal speaker at 856.3 MHz, though the signal strength was not as great as is shown here.

We also searched the spectral region 1800-2000 MHz, using a large scanning width of 100 kHz to examine the region where all other providers of pulsed, digital wireless services operate. We found strong signals only near 1960 MHz. The spectral region around 1960 MHz was then examined in detail, using a scanning width of 5 kHz. Figure 5 shows our results.
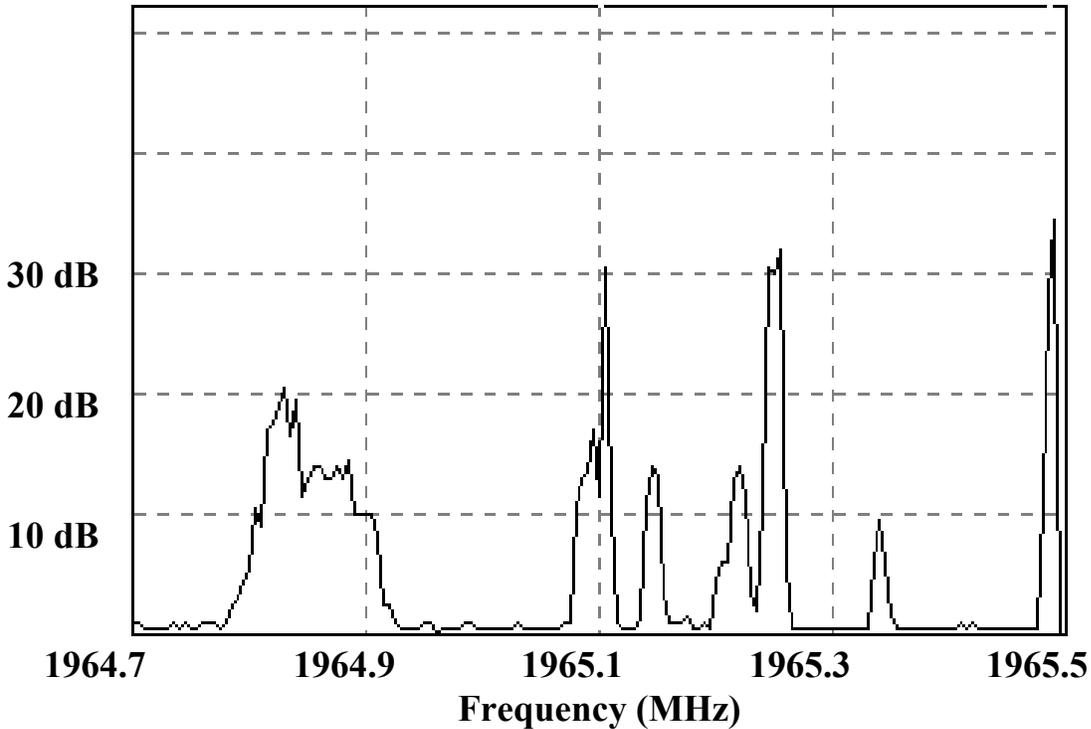
Figure 5   RF Spectrum near 1965 MHz at 1040 South Lewis Street

The prominent feature between 1964.8 and 1964.9 MHz may be a Global System for Mobile Communication (GSM) wireless phone provider's base station, because the spectral width is about 150 kHz, in contrast to the usual TDMA channel width of 25 kHz. GSM is the most prevalent wireless phone technology in the world, except the U.S. It uses channels with 200 kHz bandwidths. Recently companies such as T-Mobile and AT&T Wireless have begun using GSM technology in the U.S. One of the original providers in Kokomo was Omnipoint, which is now owned by T-Mobile. Presumably, the former Omnipoint base station now transmits GSM. GSM uses TDMA, but splits a time interval into 8 slots. It uses a different form of phase modulation called GMSK.   More will be said about the pulse structure of GSM transmissions later in this report. In addition to the spectrum in Figure 5, we found a peak at 1965.87 MHz that was about 34.5 dB in height. In general, this entire spectral region (1964 – 1966 MHz) was quite variable with time, probably a consequence of phone users going on and off the system, and with measurement location.

3) Measurements at 1615 Superior Street

This is one of the locations where the Kokomo Hum is perceived not as a high frequency sound, but as a low frequency rumbling, sometimes booming sound. The lady of the house reports headaches and neck aches and pressure like a vise. She described the sound as being like an idling locomotive. Her husband has trouble sleeping, but doesn't have other trouble from the hum. There is a cell tower about ½ mile away and a very close power line. We made measurements in this location, using all our instruments.

Using the TriField meter, we found that magnetic fields in the house were generally around and above 3 mG, slightly higher in specific locations – e.g., about 5 mG near the TV. Outside the house, we found about 5 mG next to a neighbor's driveway. There were inactive railway tracks at the side of the Smith property and a power line just across the tracks. Train traffic ceased about a mile farther down the tracks. The magnetic field increased as we approached and crossed the tracks. Close to the nearest tracks, the field was 10 mG close to the rails. Along the middle tracks the field was 13 mG close to the rails, and at the farthest tracks, the field was 15 mG close to the rails. Holding the meter over head pointing toward the power line west of the rails caused the reading to increase to 20 mG, so the field was clearly a consequence of the presence of the power line, although some compression of the field lines occurred near the steel rails, as the field there was higher than it was a couple of feet above the rails. Walking around the Smith yard revealed the field was consistently 3-4 mG outside the house.

Inside the house, we first set up the EM Eye RF meter about ½ inch from the telephone jack, measuring 100 nW/cm^2 and hearing a weak radio sound on the internal speaker. We also found some RF radiation from the power outlet in the dining room. These events prompted us to use the Fluke RMS meter equipped with the Graham filter to see how much RF voltage was present on the power line inside the house. At the electrical outlet in the dining room, we found 68 millivolts which eventually increased to 84 millivolts. On the basis of previous experience, we consider this amount of RF contamination of the power line somewhat excessive. We also found that, depending on the setting of the light dimmer switch, the RF contamination could be as high as 173 millivolts.

We next set up the EM Eye RF field meter in the back yard, pointing southwest at 218 degrees, with the instrument pointing almost vertically at 160 degrees, meaning that it is tipped from the vertical by 20 degrees. The instrument was located about 1 foot southwest of the walkway at the west side of the back stoop. The variation of the radiation density with time is shown in Figure 6. Clearly it would have been advisable to take data longer than we did, as the amplitude of the fluctuations seems to be increasing, perhaps an indication of increasing cell phone traffic at that time.
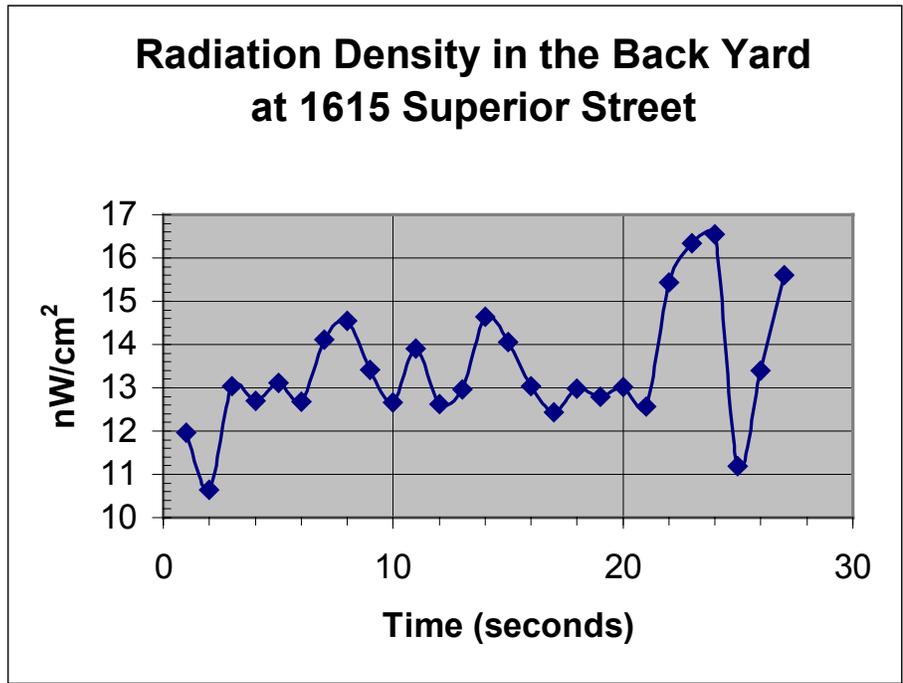
Radiation Density in the Back Yard at 1615 Superior Street

Figure shows a plot of nW/cm² (y-axis, 10 to 17) versus Time (seconds) (x-axis, 0 to 30).

Figure 6   Fluctuation Pattern of RF Radiation in the Yard

After we made the measurements shown above, we first made a frequency measurement with the instrument's internal frequency counter, finding that the radiation was dominated by lower frequencies than those from cell towers. Then we turned the instrument around, pointing it at an azimuth of 119 degrees and an elevation of 155 degrees (25 degrees tipped from the vertical). The results are very similar to the above plot, but smaller, and so they are not shown here. As a courtesy to the Smith family, we also measured the leakage through the door of their microwave oven, finding 19 μW/cm^2 four inches away from the door. This leakage is significant, but the residents can avoid significant exposure by standing three feet away from the oven.

Our final measurements at this location were made with the spectrum analyzer set up in the dining room. We again looked for the large peak near 858 MHz and found it at 858.495 MHz, as shown in Figure 7. The central peak width is 25 kHz, as before.
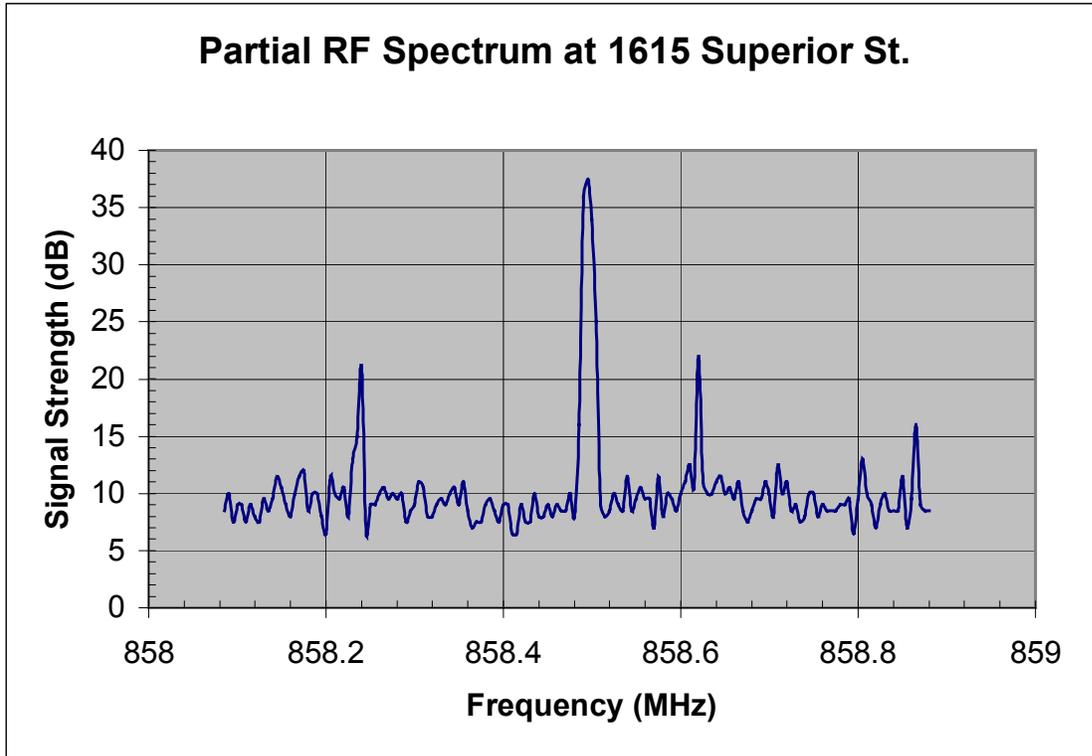
Partial RF Spectrum at 1615 Superior St.

Figure 7   RF Spectrum near 858 MHz at 1615 Superior Street

We also obtained a spectrum for the 1960 MHz region in Figure 8.
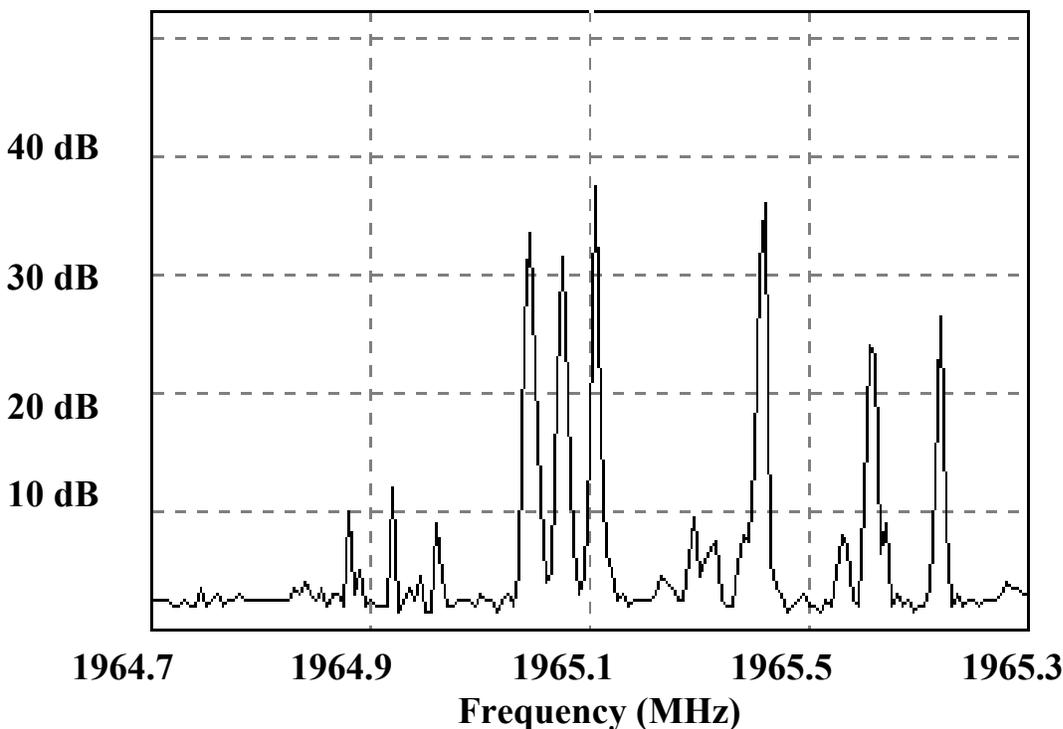

Figure 8   RF Spectrum near 1965 MHz at 1615 Superior Street

4) Measurements at 1717 Sussex on Berkeley

Our last set of measurements in Kokomo was taken at the home of a woman and her housemate at 1717 Sussex on Berkeley. Both women hear the hum and one suffers fairly drastic physical symptoms, nervousness, headaches, sleeplessness, nausea, and vomiting. Sound is usually worse at night than in daytime. One resident perceives low frequency sounds with vibrations. Her roommate suffers nausea, ear popping, pressure, and headaches. One perceives sounds in her left ear more strongly than in the right ear. The other hears the sounds mostly in her right ear.

Because of our having found RF current on powerlines at other residences, we first used the Fluke meter with Dr. Graham's circuit to measure the RF voltage on the line separately from the line voltage, obtaining only 14.8 millivolts. This RF level on the powerline is quite low, in our opinion. We

next made magnetic field measurements, obtaining 3 – 3.5 mG fairly consistently, except for 100 mG about 6 inches from the back of the stove and 35 mG at the back of the refrigerator right at the power outlet. The field vanished when the refrigerator turned off. We also checked the microwave oven for leakage with the EM Eye RF meter, obtaining only 1.0 µW/cm^{2}close to the oven.

We set up the spectrum analyzer in the kitchen and obtained the results in the 858 MHz spectral region shown in Figure 9. The strong central peak has 39.5 dB height, and it is centered at 858.105 MHz. This peak is more narrow than in previous spectra. It is 5 kHz wide (FWHM), instead of the standard 25 kHz width of a TDMA channel.
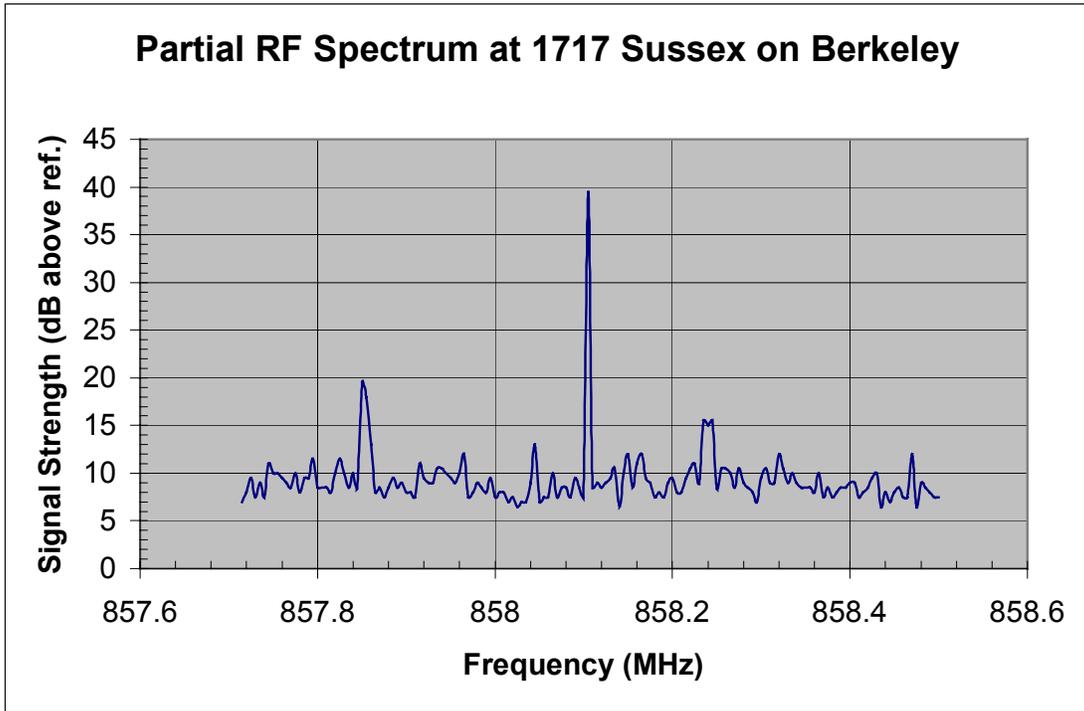

Figure 9   RF Spectrum near 858 MHz at 1717 Sussex on Berkeley

We also examined the spectrum that is associated with PCS pulsed digital wireless phone systems, as we have previously. Figure 10 shows the spectrum.
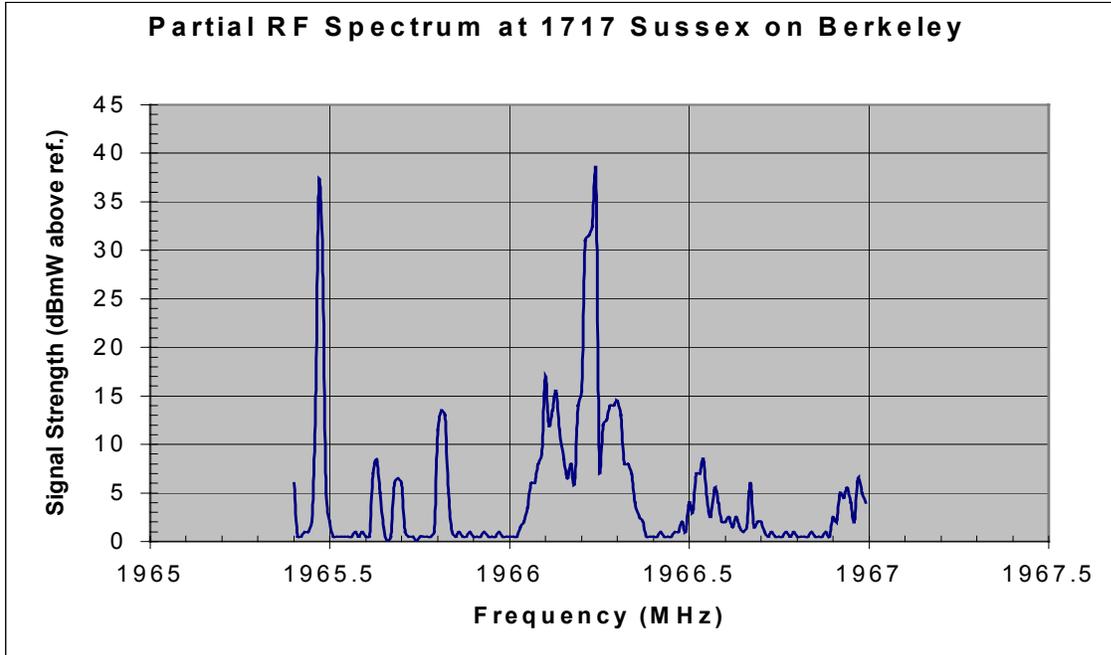

Figure 10   RF Spectrum near 1965 MHz at 1717 Sussex on Berkeley

In addition to the spectrum measurements, we made broadband RF measurements, as well. With the Alphalab RF meter, we found radiation densities on the wide band setting that ranged from 36 nW/cm^2 to 40 nW/cm^2.

Pointing the meter toward Haynes International resulted in the higher of the two numbers above, but we do not consider that increase significant in the light of signal variability that we shall discuss shortly. What is significant is the lack of correlation of our measurements with the feelings that one resident expressed. She told us that the feeling was intensifying, at a time when our measurements did not simultaneously increase.

We took a data trace with the EM Eye RF meter, and it is shown in Figure 11. The meter was set up in front of and to the right of the bedroom window. The meter was elevated 6 inches above the tripod base. Its azimuth was east 73 degrees, and its elevation angle was 130 degrees. Thus, it was tipped from the vertical by 50 degrees. The trace shows definite pulsing, though the signal level is low. Probably, the signal has been attenuated quite a bit, since it was measured inside the house. Typically, walls attenuate RF

radiation considerably, but windows hardly attenuate at all. Unfortunately, we took these measurements at a time when the resident said that she felt very little sensation. These measurements are about 10 times smaller than those obtained from the Alphalab meter, but it was set on wide band, so some of the discrepancy is due to sources below 100 MHz, probably FM radio. Note that we did not receive the AM radio station at 1350 kHz on either of our instruments that have internal speakers.
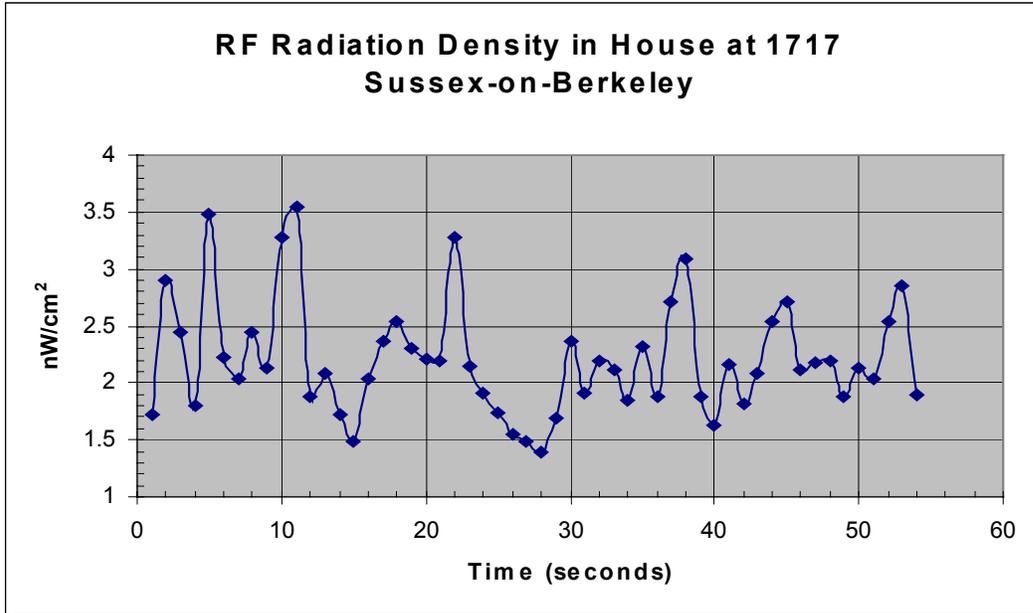

Figure 11   RF Radiation Density in the Bedroom

4.0   Discussion of Results and Relevance to Microwave Hearing

In many respects, the attempts to relate the Kokomo Hum to RF radiation amount to a search for common factors that might occur in laboratory and field observations of microwave hearing (or auditory perception of RF absorption). Here, we shall consider some results indicated by our measurements to be common to all the measurement sites.

Clearly, the spectral peak shown in Figures 2, 4, 7, and 9 occurs with different height and slightly different frequencies at all locations. What is common to these measurements is the fact that they fit the iDEN freqeuncy assignment algorithm (quoted previously) within the resolution of our spectral measurements (5 kHz). In fact using the algorithm shows that carriers number

649, 569, 600, and 568, respectively, fit the central peak positions in Figures 2, 4, 7, and 9 within 5 kHz. This seems to us to be conclusive evidence that a Nextel base station is operating in Kokomo.

Using the method for converting decibels to absolute measurements that we previously described, the peak heights in the above mentioned figures are 0.083 nW/cm^2, 0.42 nW/cm^2, 0.0094 nW/cm^2, and 0.041 nW/cm^2. We can get the field strength corresponding to these radiation densities from the proportionality between the radiation density and the square of the electric field strength. The field strengths corresponding to the maxima of the peaks are .018 V/m, 0.040 V/m, 0.0060 V/m, and 0.012 V/m.

We can also associate radiation densities and field strengths with each entire peak, not just its maximum value. The FWHM of each peak, except the last one, is three scanning widths (15 kHz) at 3 dB below the maximum. Therefore, the entire radiation density is approximately three times the value of radiation density at half maximum. Thus, the radiation levels of the 858-859 MHz peaks in all four locations are 0.13 nW/cm^2, 0.62 nW/cm^2, 0.016 nW/cm^2, and 0.041 nW/cm^2. The corresponding field strengths are 0.022 V/m, 0.048 V/m, 0.0078 V/m, and 0.012 V/m. Note that these fields are either vertically polarized or else shifted from the vertical by an unspecified amount determined by the design characteristics of the antennas and the adjustments made by technicians at each tower site. In fact, for the composite RF signal we measured at the four locations, the apparent polarization directions were vertical, vertical minus 25 degrees, vertical minus 20 degrees, and vertical minus 50 degrees.

We also have the composite electric fields measured by the EM Eye at each location. These fields are, of course, the sum of the contributions of all the RF sources in the vicinity, and they have the previously stated polarization directions. The maximum values measured at the four locations are 0.17 V/m, 0.44 V/m, 0.25 V/m, and 0.11 V/m.

It is useful to compare these electric field strengths with those of two other ubiquitous RF radiation sources. These are the AM broadcast station WIOU and the signal from the Dana, IN Loran-C facility. The broadcast station has an unusually strong signal, considering that its daytime transmission power is 5 kW and its nighttime transmission power is only 1 kW. This station has four separate towers that transmit different relative fields and a number of

other directional augmentations that result in a directional propagation pattern which changes from day to night broadcasting. Calculations of the electric field at each of the four residential locations were made for both day and night conditions. Propagation at these distances is almost entirely due to the ground wave of WIOU. Calculated electric field strengths are shown in Table 1, along with the estimated distances and bearings of these locations from the radio station. These field strengths are larger than the field strengths resulting from the (presumed) Nextel base station discussed previously, and they are comparable with the measured fields due to multiple unknown sources.

Table 1.   Electric Field Strength of WIOU (1350 kHz) at four locations in Kokomo

Location	Distance (km)	Bearing (Deg.)	Electric Field (V/m)	
			(Day)	(Night)
1	3.6	355	0.35	0.11
2	6.8	20	0.15	0.050
3	8.1	340	0.13	0.042
4	9.7	342	0.10	0.034

Parameters for this calculation were obtained from the AM Querry at the Telecommunications and Information FCC web site www.fcc.gov. The calculations were carried out, using the Low, Medium Frequency (propagation) Model, System 1, developed by Nicholas Deminco at the Institute for Telecommunication Sciences, National Administration (NTIA), Dept. of Commerce, Boulder, CO 80303

The composite field resulting from WIOU and the measured fields is the vector sum of the vertical fields in Table 1 and the measured fields and polarization directions previously stated. Since the wavelength of WIOU's radiation is 222 m, all the cell towers are submerged in its field. It is, therefore, appropriate to add the fields vectorially, instead of adding the scalar radiation densities of the separate sources, as is usually done when considering composite radiation densities far from the sources. The vertical component of the total field due to both WIOU and the measured field from the other RF sources is shown in Table 2. Since the EM Eye has flat response only in the frequency interval 2 MHz – 2 GHz, the measured fields can be assumed to have little, if any contribution from WIOU. Thus, we are simulating the result of adding the signal from WIOU to our measurements.

Table 2 Composite Vertical Electric Field of WIOU and Measurements in Kokomo

Location	Measured Peak Field	Composite Vertical Field	Rad. Density
1	0.17 V/m	0.52 V/m	72 nW/cm^2
2	0.44 V/m	0.55 V/m	80 nW/cm^2
3	0.25 V/m	0.37 V/m	36 nW/cm^2
4	0.11 V/m	0.17 V/m	7.7 nW/cm^2

What is remarkable about these results is the similarity of the composite field strengths in the first two locations, even though the measured fields (presumably excluding WIOU) differ by a factor of 2.6. This is because the WIOU field variation with observer location compensates for the increased strength of the (presumed) Nextel signal at location 2. Note that WIOU has such low frequency that mixing of its signal with that of the wireless phone base stations would not change appreciably the base station frequencies or the nature of their pulse waveforms or repetition rates.

Another source of long wavelength radiation that might interact with the RF sources that we measured is the Loran-C station in Dana, Indiana. This station has output power of 400 kW at 100 kHz frequency. It is 134.8 km from Kokomo, but it still has signal strength in Kokomo that should be compared with the presumed Nextel signals. Interest in the Loran-C signal characteristics stems from the unusual pulse shape shown in Figure 12 and the fact that the pulse repetition rate is about 10 pulses per second.
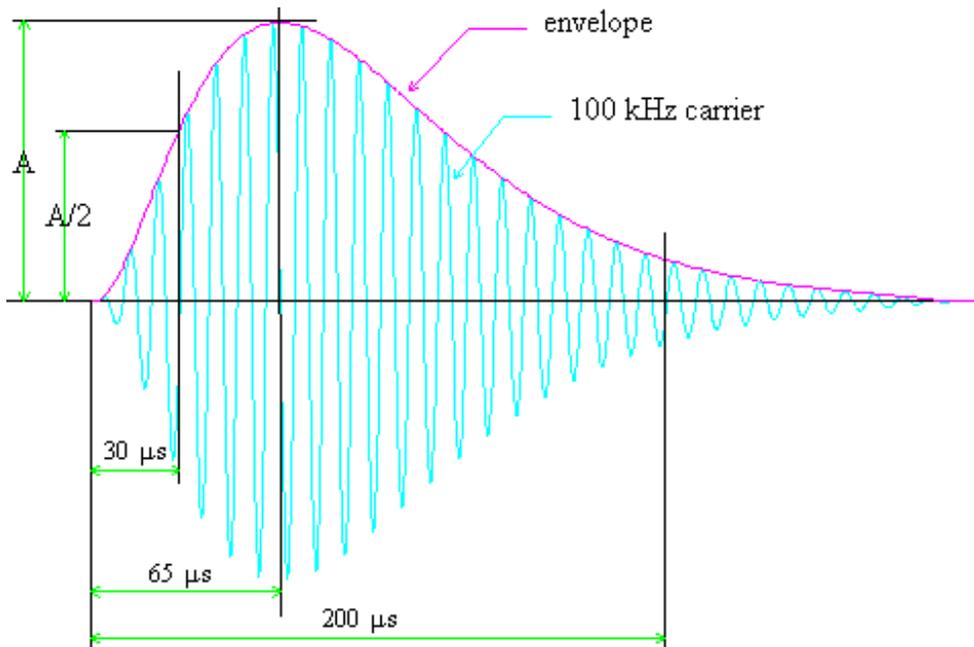

Figure 12   Loran-C Pulse Characteristics

To calculate Loran-C signal characteristic in Kokomo, we again used the propagation computer code (from the NTIA) that we previously used to calculate characteristics of the WIOU signal. Because of the distance between Dana and Kokomo, both sky wave and ground wave propagation were taken into account in these calculations. The results were field strength in Kokomo of Loran-C signal of 0.022 V/m in daytime and 0.025 V/m at night. These fields are comparable with the fields associated with the (presumed) Nextel spectral peaks, but they appear to be too small for the Loran-C waves to add significantly to the total fields from all the RF sources that are included in our broadband measurements, and the Loran-C has too low frequency to be detected by our instruments with sufficient sensitivity. However, should they so mix, the pulsing rate of the Loran-C signal would be superimposed on the pulsed signals from the wireless phone base stations, in our opinion.

It is not necessary to invoke the Loran-C signal to understand the occurrence of a pulse pattern that might cause auditory perception of RF. The pulse characteristics of any wireless phone system using TDMA access technology are complex enough to supply several pulse repetition structures that include audio frequencies. In the iDEN system, the bit rate is 64 kilobits per second, however TDMA is used to permit up to six simultaneous users on a 25 kHz channel (see ref. 8). Since a bit is either the presence or absence of a pulse, the maximum pulse rate is 64,000 pulses per second Thus, the width of each rectangular pulse cannot exceed 15.6 microseconds. iDEN divides the pulse train into six slots of 15 milliseconds each. These six slots constitute a frame. We have been unable to find any additional information on the burst pattern of iDEN, however the burst pattern of other forms of TDMA are well known.

There are three forms of TDMA in current use: iDEN, GSM, and the system described by the international standard IS-136. A burst of pulses in the TDMA technology used in the GSM phone system lasts 0.577 milliseconds[10], and the time between bursts is 4.6 milliseconds. The pulse rate is 270,000 pulses per second. After 25 combinations of burst and pause, the 26th is absent.

[10] V. Kraz, A. Wallash, and C. Chang, "Can Mobile Phones Damage GMR Heads by Electromagnetic Interference (EMI)?" paper presented at IDEMA, April 2000

On account of these pulse timing characteristics, G.J. Hyland[11] says "The signals emitted by a GSM Base-station are characterized by a number of frequencies in the audio range, specifically, 4.26Hz, 8.33Hz, 217Hz, and 1.73kHz, the first two of which lie in the range of the human brain-wave activity (delta and alpha bands, respectively)." The alpha brain wave is associated with productive activity, and the delta brain wave is associated with sleep. Hyland compares the effect of exposure to pulsing signals at brain wave frequencies to flashing a strobe light at the same frequencies on a photosensitive epileptic person, and he says that seizures can result from such exposures. Similar frequency combinations are likely to occur in iDEN transmissions, as well, but we have found little information concerning the specific pulsing frequencies, because iDEN is proprietary.

iDEN uses a combination of pulses for embedded signaling, forward error correction, and voice coding that totals to a pulse rate of 15,288 pulses per second (see ref. 8). Allan Frey, the pioneer researcher on microwave hearing has said that the perceived frequencies will correspond to the pulsing rate, within the range of carrier frequencies of 400 MHz – 1800 MHz, if the subject has unimpaired high frequency hearing[12]. The current most accepted model for microwave hearing, the thermoexpansion model[13], which has been developed over many years, is disputed by Frey to have much relevance to microwave hearing at low levels of radiation. The thermoexpansion model requires energy deposition density of at least 2.3 microjoules per square centimeter in the first 10 microseconds of a pulse. According to this model, tiny localized heating of soft tissues in the head (producing a temperature rise of no more than 5E-06 degrees C) causes an acoustic wave to propagate, mostly by bone conduction, to the cochlea. In the cochlea, electric potentials imaging the acoustic pulse are propagated via the acoustic nerve to the brain, where the perception of an external sound is registered. Frey says that this mechanism is correct at sufficiently high energy deposition, but he thinks that the threshold associated with the thermoexpansion model is not necessarily correct. He implied (in a series of 4 papers he sent us) that opening of the blood brain barrier may play a role. If so, experiments by Persson, et al at

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[11] G.J. Hyland, "How Exposure to GSM & TETRA Base-station Radiation can Adversely Affect Humans," Dept. of Physics, Warwick University, Coventry, U.K. and Executive Member, International Institute of Biophysics, Neuss-Holzheim, Germany

[12] Allan Frey, private communication, May 2003

[13] J.A. Elder and C.K. Chou, "Auditory Response to Pulsed Radiofrequency Energy," *Bioelectromagnetics,* in press

Lund University in Sweden indicate that the BBB can be opened at absorbed power levels (SAR) as low as 4E-04 W/kg. This is 4,000 times less than the SAR value that the FCC considers "safe." The same group has found brain damage in rats exposed to GSM phone radiation at SAR values 800 times lower than the FCC limit[14]. Thus, power densities shown in Table 2 for pulsing radiation streams may be sufficient to cause microwave hearing in susceptible individuals. Some support to this conclusion is given in a recent study of tinnitus and schwannoma in people exposed to cell phone radiation.[15] Schwannoma is a benign brain tumor (acoustic neuroma). Frey has noted the similarity between tinnitus and RF auditory perception. Frey has also suggested making a large "hat" of screen wire and placing it over the head of subjects to see whether the perceived sounds will diminish when they are so shielded.

Before going on to the conclusions of our study, we wish to demonstrate that the radars at Grissom ARB apparently have little or no role in the Kokomo Hum, nor in our measurements. We have already stated that the energies of the possible radars at Grissom are several kilojoules per pulse. As we previously stated, the energy density per pulse is important to the thermoexpansion model of microwave hearing. Both ASR-9 and ASR-11 have elevation and azimuth beamwidths of 5 degrees and 1.4 degrees, respectively. The area perpendicular to the beam axis at 15 miles distance from the radar is 1.25×10^{10} cm^2. Thus, even if the radar beam struck a person in Kokomo, the beam energy density would be less than 0.5 microjoule per square centimeter. This is 4 - 20 times below the threshold of microwave hearing, according to experiments that support the thermoexpansion model. However, in the time it takes the beam to scan past a person, about 19 milliseconds, there will have been 19 pulses. Thus the total energy density due to all 19 pulses will be 8.6 microjoules per square centimeter, and that energy will have been delivered in 19 milliseconds. Thus the average power density during the sweep period is 463 µW/cm^2, which is close to the average power density threshold found by Ingals (see ref. 13). Nevertheless, since Dr. Allan Frey, the first laboratory investigator of microwave hearing, thinks that the limits imposed by the thermoexpansion model are inappropriate, we state another argument by which to eliminate the

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[14] L.G. Salford, et al., "Nerve Cell Damage in Mammalian Brain after Exposure to Microwaves from GSM Mobile Phones," *Environmental Health Perspectives,* online edition, Jan. 2003

[15] L. Hardell, K.H. Mild, M. Sandstrom, M. Carlberg, A. Hallquist, and A. Pahlson, "Vestibular schwannoma, tinnitus and cellular telephones," *Neuroepidemiology*. 22(2):124-9, Mar-Apr 2003.

Grissom ARB radars as potential sources of the Kokomo hum – specifically, the radar pulse timing. During most of the radar's revolution period, its beam will not be intercepting a particular person. In fact, after the burst of 19 pulses, there will be silence for 4.8 seconds until the next burst. This pattern is not consistent with the descriptions of the Kokomo hum by the people who have experienced it.

5.0   Conclusions:

As a consequence of our measurements and subsequent analyses, we have come to the following conclusions:

1) The strongest pulsating RF source is probably a Nextel base station with channel frequencies in the 858-859 MHz range. This source is stronger at all locations where we made measurements by 10-20 decibels than sources in the 1900-2000 MHz range. Its spectrum at the measurement locales corresponds to the Motorola iDEN scheme for assigning carrier frequencies, within the resolution capability of our spectrum analyzer.

2) The strongest steady state RF source is AM radio station WIOU. Its daytime directional pattern results in RF electric field strengths twice as large as most omnidirectional radio stations produce. In three out of the four locations where we made measurements, there were significant induced fields radiating from the telephone lines, residential power lines, and CATV cables. The field from this station is strong enough to enhance the fields from the pulsed sources. The resultant enhanced field will differ negligibly in frequency, but will have the pulse pattern of the original pulsed source.

3) The broadband RF field and power density measurement profiles show pulsing signals at all measurement locales. The identified cellular and PCS system sources produce pulsed waveforms. The Motorola iDEN communications system for wireless providers is used in this country solely by Nextel and Southern Linc. The system for carrier access by multiple users is TDMA, which produces a pattern of multiple pulsing rates. Some of these rates, if perceived as acoustical signals, are in the high frequency range of several kHz, others are in the very low frequency range of several Hz.

4) None of the RF signals, whether from the cell towers alone or enhanced by the AM broadcast field, meets the threshold energy deposition requirements for the thermoexpansion mechanism of microwave hearing, but the possible participation of subthermal response mechanisms cannot be dismissed, according to noted researcher Allan Frey. If blood brain barrier opening by RF absorption plays a role in the acoustic transduction process, the radiation levels found here may be sufficient to excite auditory responses.