AUSTRALIAN RADIATION PROTECTION AND NUCLEAR SAFETY AGENCY

Measurement of Residential
Power Frequency Magnetic Fields

by

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ABSTRACT

Residential magnetic field measurements are needed in order to assess power frequency magnetic field exposure in private dwellings. A standard methodology that includes a measurement protocol improves the reliability and comparability of such measurements. A number of protocols have been developed internationally in the past as stand alone articles (eg Bowman, 1998) or as part of epidemiological studies (eg Kaune *et al*, 1987; Bracken, 1993; Schuz *et al*, 2000; etc). In Australia, a measurement protocol was developed by the Electricity Supply Association of Australia in 1996 (Dovan, 1996) to use for measurements in residences and other locations. This report has been developed from a review of these earlier references.

CONTENTS

1. INTRODUCTION

Exposure measurement is defined as the determination (or approximation) of the magnitude of exposure for an individual or group to an agent in the environment. The agents of interest in this case are residential magnetic fields at the power frequency of 50 Hz.

Magnetic fields are complex physical agents whose measurement has been the subject of much investigation. Various methodologies for the measurement of residential magnetic fields have been developed by different organisations corresponding to their specific requirements.

1.1 Purpose

The purpose of this report is to standardise the various measurement methodologies regarding residential magnetic fields at 50 Hz and to:

- provide simple and clear instructions to the qualified testing and/or power utility personnel on how to perform these measurements and record their results.
- To provide a standardised measurement format that allows for comparison of data collected by different individuals at different locations and at different times.
- To provide a structured and consistent method of measurement that can be used in any State and Territory of Australia.

Surveyors, engineers, epidemiologists and other investigators with a knowledge of magnetic field exposure can use the information provided to define the exposure characteristics that should be assessed and assemble measurement methods to suit their requirements. Residents and lay persons wanting these measurements to be performed in their home can use the information to clearly understand the issues related to magnetic field measurements.

1.2 Scope

The scope of this report is to describe the measurement of residential magnetic fields at 50 Hz. The content is limited to quantitative field measurement and does not consider magnetic field exposure surrogates such as wire-coding. Finally, the methods described only measure physical characteristics of magnetic field exposure, and not dosimetric quantities, which must be evaluated with bio-interaction models.

2. BACKGROUND AND APPLIANCE FIELDS

Residential power frequency magnetic fields consist of two components:

Background Field

The background or "ambient" field (as it is sometimes referred to) is present away from any operating appliances. It is generally produced by the paired and unpaired electrical cabling, supplying electricity throughout the home or by power lines in close proximity to the residence. The background field strength and its uniformity depend on current-carrying wiring arrangements. Background field levels may be significantly affected by ground currents in the earth return path (eg. via earth stake or water pipe). In particular, substantial ground currents can arise where circumstances allow significant currents to flow through multiple conductive paths.

Appliance Field

Every major appliance in the home produces an elevated magnetic field in its immediate vicinity while operating. Usually the intensity of this "appliance" field drops off rapidly and is therefore significant only within a close distance to the appliance. Electrical equipment that is continually left on within the vicinity of the residence (including appliances from neighbouring homes eg hot-water system) may also contribute to background fields.

In general, background fields are the predominant contribution to residential magnetic field exposure. For that purpose measurement methodologies for background fields should mainly be considered. Appliance fields are a factor in the overall exposure only when a resident is in close proximity to an electrical appliance for a prolonged period of time (eg using a computer, sitting next to a radiant heater, using an electric blanket etc).

3. MEASUREMENTS

Magnetic fields in the home are produced by electrical currents[1], which vary widely and experience instantaneous, hourly, daily or seasonal variability. Therefore, residential magnetic fields are also highly variable not only at different locations but also over time at

the same location. When describing the measurement of a magnetic field the following concepts need to be considered:

3.1 Units of Measurement

Magnetic fields or H-fields are expressed in units of amperes per metre (A/m). When evaluating a magnetic field we measure the magnetic flux density or B-field, which is given in units of tesla (T) or microtesla (μT). Another unit for magnetic field that has been used historically and whose practice has persisted among the scientific/engineering community is the gauss (G) or milligauss (mG) where 1 G is equivalent to 10^{-4}T (or 1 mG = 0.1 μT).

3.2 Duration

In general, residential magnetic field measurements summarise the average magnetic field over a specified sampling period. They can be classified into three main categories:

Spot measurements (also referred to as "point-in-time measurements")

This term refers to measurements made in one or more places, over a short period of time, and yielding a single answer at each location.

Long-term measurements

These are measurements made by a meter and recorded by a logger placed in one position for, usually, at least 24 h. The actual period can be longer, although if the period is not an integral multiple of 24 h, the average field over the period may be a biased estimate of the average field over 24 h. Long-term measurements are usually summarised with the arithmetic mean or sometimes the median of the individual measurements.

Personal-exposure measurements

These are made by the resident concerned wearing a small, portable meter and data logger for, usually, at least 24 h. This logger will often record magnetic fields encountered inside as well as outside the home. For assessing residential exposure, personal-exposure measurements can be restricted to periods where the resident is inside the home.

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[1] Electrical currents are produced by the movement of charges in a conductor

3.3 Location

Measurements should be conducted at the following locations:

Background fields

For spot and long-term measurements of background fields, assessments should be made at 1 metre above the ground/floor level by placing the meter on a non-conducting stand[2]. Measurements should be made as near as possible to the geometric centre of a room.

Appliance fields

For spot measurements of appliance fields, measurements should be made at a distance similar to that taken when using the relevant appliance. The location of the measurements should simulate the position of the human torso.

Personal monitoring

For the assessment of personal exposure, measurements should be made at the torso.

3.4 Conditions at time of measurement (spot measurements only)

The amount of electrical power used in the home affects magnetic field levels. Therefore, spot measurements in rooms and external locations of the residence should be made under "low", "high" and "normal" power use conditions in the home, which are defined as follows:

Low power condition

This condition simulates a time of very low power use, such as when sleeping at night-time and is therefore an approximate measure of the fields produced by nearby power lines and other external sources. The low-power condition is obtained by turning off most electric-power-consuming systems within the residence including heating and air conditioning, lights and electrical appliances. Appliances, which operate continually such as refrigerators and freezers should be left on to avoid resetting at the end of the measurement period.

[2] As per ANSI/IEEE Std 644-1987 for measurements of power frequency magnetic fields

High power condition

The high-power condition simulates a time of very high power use and is therefore indicative of combined fields from outside and localised sources inside the home. The high power condition can also identify the contribution of the house "ground-current", which can be a major magnetic field density source in some instances. This is accomplished by turning on most electric-power-consuming systems including lights and electrical appliances.

Normal power condition (optional)

The normal-power condition is most representative of magnetic fields normally existing in the home. It is achieved by turning all appliances on (or off) to simulate conditions that would exist during normal usage of a room when a resident(s) is present. If normal-power condition measurements are not performed, a low-power assessment is probably closer to average conditions than a high-power one.

These measurements are to be performed with the assistance of the resident, due to his/her knowledge of the appliance layout and usage. The measurement results under these conditions will broadly indicate the relative contribution of internal and external magnetic field sources.

3.5 Other Data

Other information, which may be used in assessing residential magnetic fields exposure is:

- Magnetic field source characteristics (type, voltage, power, etc)
- Location of utility service entrances including power and water meters
- Existence, type and location of any power lines, transformers or substations in the vicinity of the home
- The electricity consumption of the residence (annual, quarterly etc)
- Information on appliance use by the resident (including length of time and frequency of use, and proximity to the equipment when in use)
- Measurements of magnetic fields produced by ground currents, for example, magnetic fields associated with or in proximity to the earth stake

4. EQUIPMENT

4.1 Measurement Instrumentation

A measurement of a linearly polarised magnetic field consists of recording the maximum magnetic field intensity in three orthogonal directions and calculating the resultant magnitude as a root mean square (rms) value. As such, the measuring instrument should be a three-axis magnetic field meter that records the three orthogonal components of the field, and subsequently calculates the resultant rms value. For a meter that measures the magnetic field in one direction only, each orthogonal component of the field must be assessed separately and the resultant value calculated and recorded accordingly. The calculation should be done using the following equation:

$$B = \sqrt{B_x^2 + B_y^2 + B_z^2}$$

where, Bx, By and Bz are the magnetic flux densities measured at one point in space in three orthogonal directions. It must be noted that one-axis devices require a careful orientation to prevent missing the main vector component, especially near appliances.

Where practicable, and where a three-axis meter displays the individual field components, it is also recommended to record all three orthogonal components of the field as well as its resultant value. This approach, among other advantages, allows to simplify identification of the major contributing source of the magnetic field in a complex multi-source environment if the field mitigation work will follow at a later stage.

If the magnetic field is elliptically polarised, the calculation of the resultant from three orthogonal directions will give a higher value than the actual maximum field, rising to 41% in the limit of circular polarisation. Background fields are reported to have limited elliptical polarisation, although probably not enough to produce substantial differences between maximum and resultant values.

Other factors related to the performance of the meter are:

Magnetic field sensor

For the measurement of power frequency magnetic fields, an instrument with an induction coil probe is normally used.

Frequency response

The instrument's frequency response should be in the range 30Hz – 1kHz. A traceable calibration at 50 Hz is desirable.

Harmonics

It has been shown that magnetic fields contain moderate amounts of harmonics, primarily the third harmonic. In theory, the result of the field measurement will depend on whether the meter used is sensitive to harmonics or not. Instruments with a frequency response can include the relevant harmonics, although, in general, the harmonic content adds a negligible contribution to the total rms value.

Sampling

For long-term measurements, meters need to have a digital-logging capability in order to record the measurements over a specified period. The sampling period of the logger can be programmed.

Dynamic range

The dynamic range represents the instrument's range of response to magnetic field amplitudes. The instrument's dynamic range should be sufficient (eg 0 – 200 μT or greater) in order to measure high fields.

Output

Meters may display the measured level in a digital or analog format. When a spot measurement is taken on an analog display, the needle will often fluctuate. In that event the measurement recorded should be the estimated average and not the highest value.

Accuracy

The instrument error should be limited to ±10% at 50Hz.

Environmental factors

The instrument should be immune to other environmental factors such as heat, radio-frequency (RF) radiation, humidity, temperature etc.

Calibration

Prior to obtaining measurements for a given residence, the traceable calibration[3] and proper functioning of the meters should be checked. Attention should be paid to calibration at low-level fields (eg 0.04 μT or less) due to the influence of background fields.

4.2 Auxiliary Equipment

Other equipment, which is required in assisting the on-site measurements, is listed below:

- 1 metre high non-conducting stand
- Distance measurement device
- Lab book
- Clamp-on current meter (desirable - minimum of 50mm jaw opening capability, minimum current measuring range of 0 - 100 A and resolution of 0.1A)
- Lap-top computer (optional)
- Camera (optional)
- Portable calibration check unit (optional)

4.3 Personal-exposure Equipment

When conducting personal-exposure measurements the following equipment is required:

- A fabric pouch with non-conducting suspender or belt attachments for positioning the meter
- An activity diary for recording all the daily activities of the resident including the time and location of the activity and the use and proximity of any electrical appliances

4.4 Information

It is important to disclose the measurements to the resident(s) as well as any additional information relating to residential magnetic fields. Consequently, the following items should be made available to the resident(s) upon completion of the measurements:

- Measurement forms (a pro-forma for a measurement form is shown in Appendix A)
- Information brochure(s) on the measurements performed

[3] As per ANSI/IEEE Std 644-1987 for measurements of power frequency magnetic fields

4.5 Credentials

The intrusive nature of performing measurements in private residences requires the clear identification of the people conducting the measurements. Field officers should, therefore, possess identification (photo ID) and business cards that clearly identify them as the person that the resident is expecting.

5. ETIQUETTE

Residential measurement procedures of any type are intrusive by nature. Every step should be taken to minimise any inconvenience to the residents and promote the positive aspects of performing such measurements in their home. To that effect, field officers employed to perform the measurements must be well trained not only in the technical issues but also in liasing with the resident(s) in the correct decorum.

All on-site measurements should be performed at a scheduled time, pre-arranged via appointment.

All information obtained when performing magnetic field measurements should be treated as confidential material and must comply with privacy legislation under state and federal laws. The *Privacy Act 1988* provides legislative standards for the handling of personal information by Commonwealth and ACT Government agencies and since 21 December 2001 it also regulates the handling of personal information by private sector organisations[4] (Commonwealth of Australia, 2001).

6. MEASUREMENT PROTOCOLS

After an initial introduction, the field officer conducting the measurements is to give the resident a general overview of the measurement procedure. Next, with the assistance of the resident, the field officer is to inspect the interior and exterior measurement areas and record the outline of the residence including electrical facilities within a 50-metre proximity and the

[4] Further information on the Privacy Act 1988 can be obtained from the Federal Commissioner's website at: *http://www.privacy.gov.au*

locations of the meter box, the service drop and the water meter. The procedure is then to follow the methodology for spot, long-term and personal-exposure measurements separately:

Spot measurements

- The residence is to be prepared for "low-power" condition and the measurements are to be conducted at/near the centres of rooms and other locations. Results are to be recorded accordingly.
- Following the low-power measurements, the residence is to be prepared for "high-power" condition and the measurements are to be repeated and recorded. The electrical usage in the home is to be reset to the original or low-power condition.
- Next, measurements associated with appliances that the resident(s) spends considerable time in the immediate vicinity of are to be performed as suggested by the resident.
- Finally, other measurements as requested by the resident are to be conducted.

Long-term measurements

- Meters with data loggers are to be set up in the living room and the appointed bedrooms (or any other rooms where a significant amount of time is spent by the resident(s)). The meters are to be placed in/near the centres of the rooms standing 1 metre from the floor on a non-conducting stand.
- The meters are to remain in that position for 24 hours and are to be subsequently retrieved by the field officer the following day.
- If only one meter is available, different rooms are to be measured on different days via arrangement with the resident, making sure that the conditions of measurement are similar for all days.

Personal-exposure measurements

- The resident concerned is to be familiarised with the operation of the meter.
- The resident is to be instructed on the recording of the activity diary.
- The meter is to be worn in a fabric pouch, which is to be attached to suspenders or a belt.
- The meter is to be worn by the resident continuously while awake in a 24-hour period and is to be subsequently retrieved by the field officer the following day.

- While the resident is sleeping the meter is to be placed on or near the bed-head of the bed.
- The activities of the resident are to be recorded in the activity diary by the resident, including the time and location of the activity and the use and proximity of an electrical appliance.

In all types of measurement the recordings are to be entered on a measurement form and, together with a measurement report, they are to be presented to the resident. The report is to be discussed with the resident indicating any high exposures and advice should be given (where possible) on ways of reducing it. Finally, as part of the consultative process, any additional information should be provided to the resident.

7. CONCLUSION

With the advancement of technological progress, society has seen the proliferation of environmental exposures. Magnetic fields produce environmental exposures that may be significant in indoor environments such as residences.

The possibility of adverse health effects associated with exposure to power frequency magnetic fields is still partly unknown. As research into any potential risk continues, it is important to measure the actual exposure to magnetic fields in homes.

The various measurement methodologies that were described may be used according to the specific requirements of the exposure assessment undertaken. The cost of assessing exposure in terms of time and money may also play a significant role in the choice of the measurement methodology. For people who are interested in their average exposure due to background fields, however, the most practical, widely-used and effective method is the quantification of long-term exposure using a logger over a 24-hour period.

GLOSSARY

arithmetic mean

Also known as the average. The arithmetic mean is obtained by adding several quantities together and dividing the sum by the number of quantities.

calibration

Calibration is the setting or correcting of a measuring device or base level, usually by adjusting it to match or conform to a dependably known and unvarying measure.

charge

Quantity of unbalanced "electricity" in a body, ie an excess or deficiency of electrons. Charge can be either positive or negative and always exists in multiples of the fundamental amount of charge on an electron.

conductor

A material that easily conducts an electric current because some electrons in the material are free to move.

earth stake

Also known as ground rod, ground stake or earth bar. Metal stake driven into the ground for establishing an electrical connection to ground.

electrical current

Rate of flow of electrical charge in a substance, solid, liquid or gas. Practical unit of current is the Ampere (A).

elliptical polarisation

Polarisation such that the tip of the electric field vector describes an ellipse in any fixed plane intersecting, and normal to, the direction of propagation.

exposure

That which occurs whenever a person is subject to the influence of an agent (in this case a magnetic field).

frequency

The number of cycles or completed alternations per unit of time, usually measured in Hertz (Hz).

frequency response

The range of frequencies over which the measured level remains within the limits of ± 3dB.

ground current

In the presence of an electrical fault, the current that flows in the protective ground wire of a power distribution system.

harmonic

A signal or wave, whose frequency is an integral (whole-number) multiple of the frequency of some reference signal or wave. The term can also refer to the ratio of the frequency of such a signal or wave to the frequency of the reference signal or wave.

linear polarisation

The confinement of the electric field vector or the magnetic field vector to a given plane (*see also* "polarisation").

magnetic field

A field of force that exists around a magnetic body or a current-carrying conductor.

magnetic field sensor

A sensor whose output changes based on changes in the magnetic field.

magnetic flux density

The number of magnetic lines of force passing through per unit area of a surface. The SI unit for magnetic flux density is the Tesla (T).

median

The median is the middle number in a given ordered sequence of numbers. (If the sequence has an even number of items, then there is no unique 'middle' number; in that case, the median is taken as the average of the two middle numbers.)

mitigation

Any action taken to permanently eliminate or reduce the long-term risk to human life, property, and function from perceived hazards (in this case magnetic field exposure).

orthogonal

Intersecting or lying at right angles.

polarisation

The property that describes the orientation, ie time-varying direction and amplitude, of the electric field vector.

radiofrequency (RF) radiation

Electromagnetic energy with frequencies in the range 300 Hz to 300 GHz.

root-mean-square (rms)

The square root of the mean of the square of a function over a specified time period. It is derived by first squaring the function and then determining the mean value of the squares obtained, and taking the square root of that mean value, i.e.

$$\mathbf{F_{rms}} = \sqrt{\frac{1}{\mathbf{t_1 - t_2}} \int_{\mathbf{t_1}}^{\mathbf{t_2}} \mathbf{[F(t)]^2\, dt}}$$

substation

Equipment that switches or modifies voltage, frequency, or other characteristics of electrical power.

traceability

Traceability is the ability to trace the history, application or location of an entity by means of recorded identifications.

torso

The trunk of a human body (in terms of magnetic field measurements the torso includes the head).

transformer

An apparatus for producing from a given electrical current another current of different voltage.

vector

A quantity that has two independent properties: magnitude and direction. The term also denotes the mathematical or geometrical representation of such a quantity.

voltage

Also known as the potential difference. The difference in potential energy between two points. Voltage is measured in Volts (V).

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APPENDIX A: Pro-forma for a measurement form

Organisation/Company Name
Address
Phone
Fax
E-mail
Web

Field Officer: _____
Measurement Date: _____
Measurement Time: _____
Start Time - ☐ am ☐ pm
End Time - ☐ am ☐ pm
Reference Number: _____

Resident's Details
Name: _____
Address: _____
_____
Phone: ( ) _____

Instrument Details
Manufacturer: _____
Model: _____
Serial No: _____
☐ Single – Axis (maximum recorded)
☐ Three – Axis (resultant recorded)
Last calibrated: _____

Residence Details

Type of house

☐ Detached House ☐ Town House ☐ Flat/Apartment ☐ Other: _____

no. of storeys: ____ floor no.: ____

Proximity to powerline(s)

List the type of powerline(s) within a 50m radius of the residence
1. _____
2. _____
3. _____
4. _____

NOTE: Type of powerlines may include –
- *Distribution line with open type high voltage and low voltage mains*
- *Distribution line with aerial bundle cable mains*
- *Underground distribution cable (if known to be buried in proximity to the residence)*
- *Sub-transmission line (66kV and above)*
- *Transmission line (220 kV and above)*

Proximity to a substation

Is there a substation within 50m of the residence?

☐ YES ☐ NO

If YES, specify:

☐ Pole mounted distribution substation
☐ Pad mounted distribution substation
☐ Kiosk type distribution substation
☐ Indoor type distribution substation
☐ Zone substation (usually substation with 66kV and 132kV primary supply voltage)
☐ Terminal station (usually substation with 220kV and above primary supply voltage)

Is there a main power distribution board within 50m of the residence?

☐ YES ☐ NO

(Usually for flats/apartments in a multi-storey building)

Are there main and sub-main cables or a cable riser within 50m of the residence?

☐ YES ☐ NO

(Usually for flats/apartments in a multi-storey building)

MEASUREMENTS Of 50 Hz MAGNETIC FIELDS

(All units are in ☐ μT ☐ mG, 1μT = 10 mG)

SPOT MEASUREMENTS

(Sampling rate____ sec)

Background Fields					
Location	Magnetic Field		Location	Magnetic Field	
	Low-power	High-power		Low-power	High-power
Front Door			Under distribution line / Above cable		
Living/Family			Centre Front Yard		
Kitchen			Centre Back Yard		
Master Bedroom			Meter Box		
Bedroom 2			Water Meter		
Bedroom 3			Other:		
Bedroom 4/Study					

Appliance Fields						
Appliance	Magnetic Field			Appliance	Magnetic Field		
	At 30 cm	At 1 m	At 2 m		At 30 cm	At 1 m	At 2 m
Television				Dishwasher			
Electric Heater				Clock Radio			
Microwave Oven				Hair Dryer			
Electric Kettle				Computer			
Electric Range				Other:			

LONG-TERM MEASUREMENTS

(24-hour average, sampling rate____ sec,☐ arithmetic mean, ☐ geometric mean)

Location	Magnetic Field	Location	Magnetic Field
Living/Family		Bedroom 3	
Master Bedroom		Bedroom 4/Study	
Bedroom 2		Other:	

PERSONAL EXPOSURE MEASUREMENTS

(24-hour average, sampling rate ____ sec, ☐ arithmetic mean, ☐ geometric mean)

Name of person	Magnetic Field	

Activity Diary Completed (tick box)

NOTE: 1. All background field (both spot and long term) measurements are 1 m above ground/floor level and at or near the centre of the room.

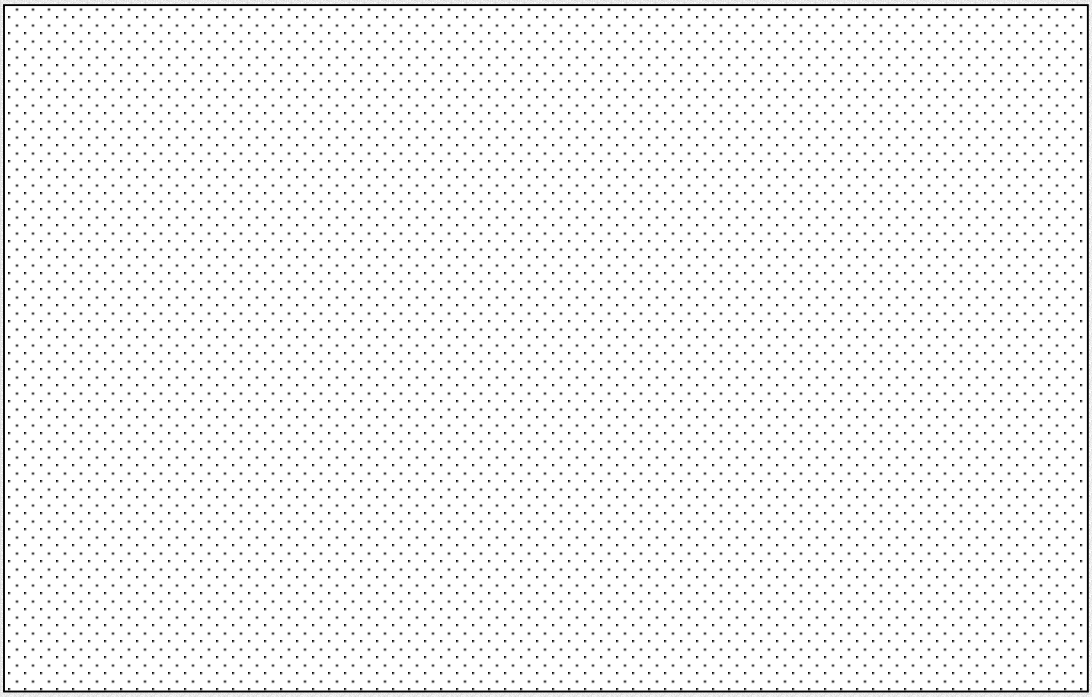
2. Low power usage = most electrical items turned off (except refrigerators/freezers)

3. High power usage = most electrical items turned on

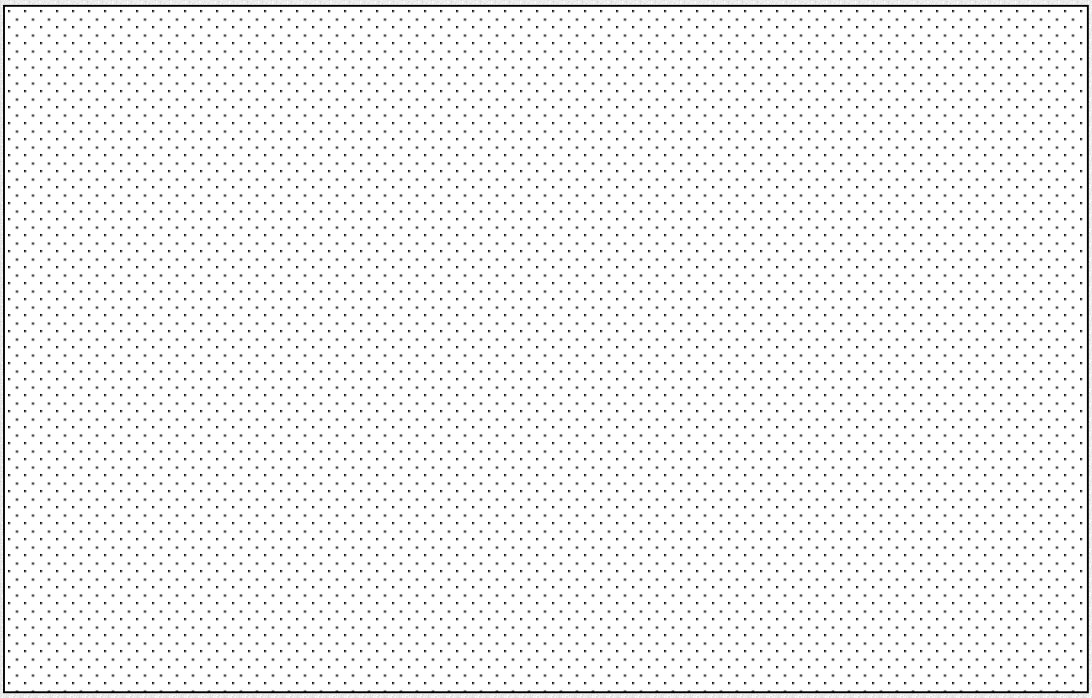
SKETCH OF HOUSE

(Generally 50m radius however in certain situations 100m radius may be required)

Plan View



Elevation View



NOTE: Indicate distances to electrical facilities.
Indicate locations of meter box, service drop and water meter

NOTES

(eg additional measurements)