# INDUSTRIAL ASSESSMENT OF RADIOFREQUENCY AND MICROWAVE RADIATIONS: CASE STUDY AT ELECTRONIC MANUFACTURING INDUSTRIES IN PENANG

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## ABSTRACT

In electronic manufacturing industry, the applications of an equipment emitting radiofrequency radiation (RFR) are numerous and increasing. It is known that exposure to RFR at sufficiently high intensity and duration can produce a variety of adverse health effects. This paper presents some results from an extensive studies in the RFR field measurements at frequency range from 100 MHz to 1 GHz. All measurements were performed inside factories located at the Penang Free Trade Zone. In this case, the factories chosen are those that manufacture the electronic components whereby the applications of RFR equipment are likely to be intensive compared to other type of industries. The measurement system used in this study are the portable spectrum-analyzer, the passive log-periodic antenna and a desktop computer for data analysis. Results from this study have indicated that the RFR exposure levels in most factories are in the range of $7.7 \times 10^{-4} - 4.31 \times 10^{-3}\,\mathrm{Wm}^{-2}$ and $0.01 - 0.741\,\mathrm{Vm}^{-1}$ for power density and electric strength measurement respectively. These ranges are at least 100 times lower compared to the RFR protection guidelines proposed by the American National Standard Institute (ANSI). However, the exposure levels inside the factory are consistently $10^3 - 10^4$ higher than the levels caused by natural sources and is about $10^2 - 10^6$ higher than the levels measured at a distance of 30 m from a low-power output mobile phone transmitter. In the case of the health effect assessment, no sufficient evidence has been found to indicate the potential consequences resulting from excessive RFR exposure. Nonetheless, many factories surveyed are unaware of the existence of the international guidelines and codes on the safe use of radiofrequency energy eventhough, some measures are being taken to protect their employees against RFR.

Key words
Non-Ionizing Radiation, Electromagnetic Emissions,

## INTRODUCTION

During the past decade, due to the rapid industrialization process, the use of an equipment capable of emitting radiofrequency (RF) radiation is steadily on the rise. For example, numerous uses have been found for microwave devices in the manufacturing sector ranging from foods to process-based industries. In Penang particularly, the 1990s are now seen as a period of transformation whereby the industrial sectors especially the electronic component manufacturers, in adapting new technologies and deepen their activities, have introduced more automation and mechanization in the production process through re-investment of more capital-intensive equipments including those that utilize the RF energy. As a result, the occupational exposure levels due RFR had, over the years, proliferated. Although the widespread use of RF equipments provide significant benefits to the industrial sectors, they may also constitute hazards to the individual through uncontrolled and excessive emissions of radiation energy. This has aroused growing interest in the general public and scientific community since at sufficiently high levels of intensity and duration, exposure to microwave and RF fields can produce not only biological effects but pose a definite risk to health. For the electronic manufacturing sectors in particular, the potential consequences of exposure to RFR caused by the automatic test and microwave moulding instruments has not been widely reported.

Automatic test equipment (ATE) produce electromagnetic emissions predominantly at the extremely high frequency range (800MHz - 1GHz) or at frequencies from 300 to 400 MHz which belongs to the RF range. The electromagnetic field emissions at both ranges are due to the ATE acting as a transmitter during product testing cycles. In this case, the radiation is a leakage one since the bulk of the RF energy is ransmitted directly to the device under test using a common shielded cabling system. Thus, for the ATE, the stray radiation can be considered the principal concern with respect to irradiation of humans. In contrast, the moulding equipment emits radiation at frequencies from 50 to 300 MHz which belongs to very high frequency range. Similar to the operation of the commercial or domestic microwave instrument, this type of instrument is intensively been used at the electronic manufacturing industries for heating purposes. Since the moulding machine utilize the RF energy to produce heat, it is also a radiating instrument and the exposure levels in vicinity to the machine can be very high.

In the RF range, measurements have usually been performed on electric field strength only, since for plane waves, the magnetic field strength is related to the former by the impedance of wave propagation. Its value in free space is equal to 377 $\Omega$. To optimise measurement sensitivity, the directional sensitive antenna such as the dipole and log periodic antennas are normally be recommended (IRPA, 1988). Furthermore, the use of spectrum anaylyzer for signal analysis is very effective in identifying and measuring the RFR. The use of this instrument also allows RF measurement been conducted in the baseband region since many of the ATE generally emit RF energy which is frequency-multiplexed onto several different subcarriers.

The American National Standards Institute Committee on Radiofrequency Radiation Hazards (now IEEE Standards Coordinating Committee 28, "SCC-28") have recently published standard proposals which cover the whole RF range from 30kHz to 300 GHz (Petersen 1991). Since the standard gives different guidelines for controlled and uncontrolled environment, it can be utilized for assessing the RFR level in the manufacturing environment which falls under the former category.

## EXPOSURE STANDARD

Figure 1 shows the ANSI exposure guideline available in the frequency range relevant to the ATE and moulding equipment emissions. The standard has been defined as the maximum permissible unperturbed electric field strength $\vec{E}, (V\,m^{-1})$ , magnetic field strength $\vec{H}, (A\,m^{-1})$ and power flux density $\vec{P}, (W\,m^{-2})$. In order to effectively use Figure 1, the normalized exposure indices have been introduced. The indices are defined as

$$\vec{E}_{ind} = \left[ \sum_{n=1}^{\infty} \frac{\vec{E}_n^2}{EL_n^2} \right]^{\frac{1}{2}} \quad (1)$$

for the $\vec{E}$ field strength and

$$\vec{P}_{ind} = \left[ \sum_{n=1}^{\infty} \frac{\vec{P}_n^2}{PL_n^2} \right]^{\frac{1}{2}} \quad (2)$$

for the power flux density where $\vec{E}_n$ and $\vec{P}_n$ are the nth harmonic component of the $\vec{E}$ field and power flux density respectively while $EL_n$ and $PL_n$ are their corresponding exposure limits. Since all measurements have been performed in the *xyz* coordinates system, the component which showed the maximum value was used in (1) and (2). However, an alternative and more laborious method would be to measure all the xyz components $\vec{E}_{nx}$, $\vec{E}_{ny}$, $\vec{E}_{nz}$ and compute the resultant field strength magnitude. Since, in most cases, there is only one component which substantially larger than the others, the discrepancy between measuring the single maximum field component and all *xyz* components is not decisive and hence the simplified version in (1) and (2) is justified. Both the normalized indices, $\vec{E}_{ind}$ and $\vec{P}_{ind}$ are dimensionless quantities which should fulfil the condition

$$\vec{E}_{ind} \leq 1 \quad \text{or} \quad \vec{P}_{ind} \leq 1 \quad (3)$$

in order not to exceed the ANSI requirement for the exposure limitation. Accidentally, this is the way in which the American Conference of Governmental Industrial Hygienist (ACGIH) standards limit multi-frequency exposure.

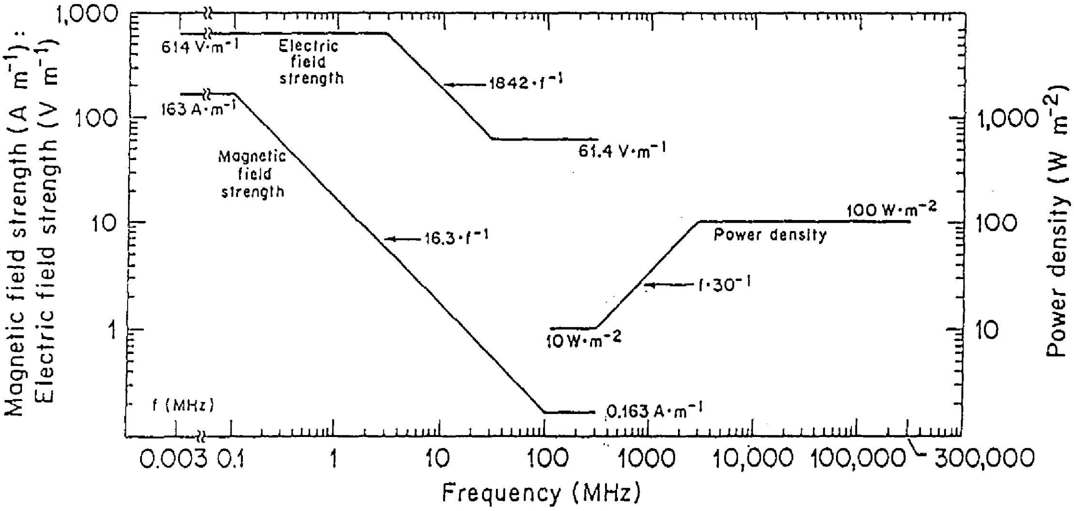


FIGURE 1 Proposed ANSI Exposure Limit For Controlled Environment

## INSTRUMENTATION AND MEASUREMENT SYSTEM

Figure 2 shows the general layout of the measurement system used in this study. The heart of the system is AVCOM's PSA-65A portable microwave spectrum analyzer and high performance precision machined log-periodic antenna which covers a frequency range from 100 MHz through 1 GHz. The signal from the antenna is fed into the RF preamplifier with 20db gain to enhance performance of the log-periodic and improve the sensitivity of the spectrum analyzer.

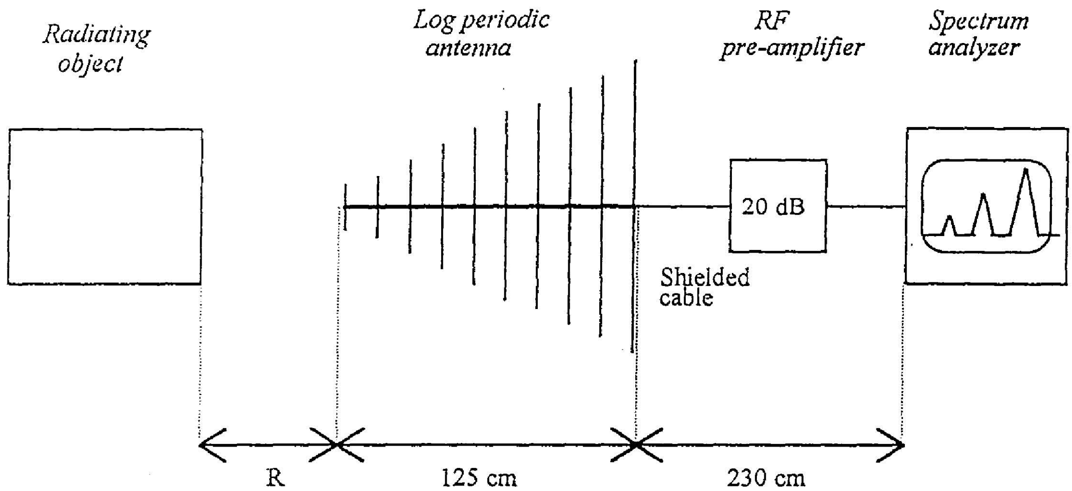


FIGURE 2 RFR Measurement Arrangement and Apparatus

For a given frequency, the distant R shown in Figure 2 was chosen to enable the measurement be performed at the far field region. When this condition is satisfy, the electric field intensity, $\overline{E}$ and power flux density $\overline{P}$ can be calculated using

$$\vec{E} = \log^{-1}\left[ \frac{P_{dbm} + 107 + AF}{20} \right] \ \mu v m^{-1} \tag{4}$$

and,

$$\vec{P} = (1 \times 10^{-12}) \frac{\overline{E}^2}{Z_o} \ \ Wm^{-2} \tag{5}$$

where $P_{dbm}$ is the power relative to 1 mW recorded by the analyzer and $Z_o = 120\pi$. Using the system in Figure 2 the RFR has been surveyed in major and international-based electronic industries located at Penang Free Trade Zone (FTZ). Due to the difficulty in getting access to some of the factories, the surveyed results reported here were summarized from a total of 6 factories constituting a large pool of established foreign-based operators at Penang's FTZ areas. For comparison purpose, a few measurements were also conducted near a mobile phone transmitter operating at 900 MHz. The results obtained will be discussed in the next section.

## RESULTS AND DISCUSSION

The main result from this study has been summarized in Table 1 which present measured field strengths, fundamental frequencies and computed exposure indices. The $P_{dbm}$ values were obtained straight from the frequency domain recordings whereas the power density were calculated from the spectrum data.

| Radiation source | Fundamental frequency (MHz) | $P_{dbm}$ (dbm) | Field strength | Exposure indices | |
|---|---|---|---|---|---|
| | | | | $\vec{E}_{ind}$ | $\vec{P}_{ind}$ |
| ATE | 418.0 | -25 | $1.06 \times 10^{-4}$ W/m$^2$ | - | $10^{-6}$ |
| | 880.0 | -28 | $7.7 \times 10^{-4}$ W/m$^2$ | - | $10^{-5}$ |
| | 915.0 | -20 | $43.1 \times 10^{-4}$ W/m$^2$ | - | $10^{-4}$ |
| Mould machines | 57.4 | -46 | 0.01 V/m | $10^{-4}$ | - |
| | 72.8 | -10 | 0.741 V/m | $10^{-2}$ | - |
| | 82.6 | -34 | 0.05 V/m | $10^{-4}$ | - |
| | 168.9 | -34 | 0.054 V/m | $10^{-4}$ | - |
| | 254.0 | -46 | $6.2 \times 10^{-7}$ W/m$^2$ | - | $10^{-8}$ |
| | 335.5 | -62 | $3.0 \times 10^{-8}$ W/m$^2$ | - | $10^{-9}$ |
| | 344.0 | -50 | $3.0 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |
| | 404.6 | -60 | $4.0 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |
| | 431.7 | -48 | $5.9 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |
| | 480.7 | -64 | $2.0 \times 10^{-8}$ W/m$^2$ | - | $10^{-9}$ |
| | 514.6 | -42 | $2.9 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |
| | 545.4 | -60 | $5.0 \times 10^{-8}$ W/m$^2$ | - | $10^{-9}$ |
| | 526.8 | -34 | $19.2 \times 10^{-6}$ W/m$^2$ | - | $10^{-6}$ |
| | 604.5 | -36 | $13.6 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |
| | 617.0 | -58 | $9.0 \times 10^{-8}$ W/m$^2$ | - | $10^{-9}$ |
| | 612.4 | -12 | $3.5 \times 10^{-3}$ W/m$^2$ | - | $10^{-4}$ |
| | 689.1 | -72 | $4.0 \times 10^{-9}$ W/m$^2$ | - | $10^{-10}$ |
| | 693.5 | -48 | $9.6 \times 10^{-7}$ W/m$^2$ | - | $10^{-8}$ |
| | 708.9 | -40 | $6.2 \times 10^{-6}$ W/m$^2$ | - | $10^{-7}$ |

TABLE 1 Measured Exposure Indices at RF Range of the ATE and Moulding Equipment.

From the above tabulated results, the maximum measured electric field intensity was 0.741 V/m and emitted by the moulding machine. The main contribution in the $\vec{E}_{ind}$ and $\vec{P}_{ind}$ indices come mainly from the fundamental frequency indicating that for both the ATE and moulding machine, the harmonics contribution in the RFR is extremely low. Comparing between the moulding instrument and ATE, the radiation level of the former is 100 times higher than the later. It was also noted, at a distance 1 to 2 meters from the tested equipment, the RF field decreased by a factor varying from 3.0 to 4.5. For both the ATE and moulding machines, the exposure indices are generally very low. The normalized values are at least two decades below the limit defined by the ANSI. However, it was also found that those indices are $10^4$ and $10^6$ higher than the radiation originating from natural sources and from the mobile phone transmitter respectively. Since, exposure to the $\vec{E}$ field especially at RF range leads to the builds-up of a potentially hazardous body currents, the excessive exposure, eventhough of lower intensity cannot completely be neglected (Jokela et al. 1994)

## CONCLUSION

All measured RFR are consistently well below the ANSI guideline for controlled environment. Due to the lack an inconclusive evidence on biological effects of the RFR, it is not possible to definitely evaluate actual health risks on the basis of the results presented. However, the experiences and data obtained from this study could be used in developing guidelines for protection against RFR.

## REFERENCES

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## ACKNOWLEDGEMENT

The author acknowledges the research grant (# 131/0230/0370) provided by the Universiti Sains Malaysia, Penang that has resulted in this article.