

# Electromagnetic interference from personal dust monitors and other electronic devices with proximity detection systems

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**Abstract** ■ In April 2016, the U.S. Mine Safety and Health Administration (MSHA) began requiring the use of continuous personal dust monitors to monitor and measure respirable mine dust exposures to underground coal miners. Mines are currently using the PDM3700 personal dust monitor to comply with this regulation. After the PDM3700's implementation, mine operators discovered that it interfered with proximity detection systems, thus exposing miners to potential striking and pinning hazards from continuous mining machines. Besides the PDM3700, other electronic devices were also previously reported to interfere with proximity detection systems. MSHA sought the aid of the U.S. National Institute for Occupational Safety and Health (NIOSH) and mining industry stakeholders to determine how the PDM3700 and some other electronic devices and proximity detection systems interact with each other. Accordingly, NIOSH investigated existing standards, developed test protocols, designed experiments and conducted laboratory evaluations. Some interferences were observed to be caused by electromagnetic interference from some electronic devices, including the PDM3700. Results showed that there was no significant interference when the PDM3700, as well as other electronic devices, and the miner-wearable component of the proximity detection system were separated by distances of 15 cm (6 in.) or greater. In the present study, it was found that the PDM3700 and the personal alarm device needed to be at least 15 cm (6 in.) apart in order for them to be used simultaneously and reduce potential interference.

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## Introduction

Underground coal miners are exposed on a daily basis to a variety of hazards, such as coal dust exposures, high noise levels, roof and rib falls, potential for fires and explosions, and operating and working with heavy machinery. One of the hazardous jobs

is that of operating or working near a continuous mining machine. According to U.S. Mine Safety and Health Administration (MSHA) statistics, 44 miners had been fatally struck or pinned by a continuous mining machine since 1984. In an effort to prevent future striking and pinning fatalities from occurring,

proximity detection systems have been developed and are required on all operating continuous mining machines in underground coal mines, with the exception of full-face continuous mining machines, by 2018 (MSHA, 2015a).

Proximity detection systems are designed to sound an alarm to warn miners and stop machine motion in order to protect miners from being struck, pinned or crushed by continuous mining machines (Jobes, Carr and DuCarme, 2012). Currently, MSHA-approved proximity detection systems, installed on continuous mining machines, are based on the principle of magnetic flux density, or B-field (Li, Carr and Jobes, 2012; Li, Jobes and Carr, 2011). The system generates a magnetic field around a continuous mining machine

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and determines the relative distance a miner is from the continuous mining machine based on detected magnetic flux density. A proximity detection system includes multiple magnetic field generators, mounted at different places around the continuous mining machine, and personal alarm devices or miner-wearable component, worn by the miners to detect the magnetic flux density. When a miner wearing a personal alarm device gets closer to the machine, the device detects a stronger magnetic field from the generators, and it detects a weaker magnetic field when the miner moves away from the machine. The magnetic field generators installed on continuous mining machines typically produce modulated magnetic wave signals at frequencies between 10 and 120 kHz. The magnetic fields are measured by three small magnetic coil antennas mounted on orthogonal axes inside the personal alarm device worn by the miner. According to Faraday's Law, the changing magnetic field induces a voltage in each coil antenna, and the voltage values are wirelessly transmitted from the personal alarm device back to a controller on the continuous mining machine, typically at a frequency between 400 MHz and 2.5 GHz. These values are then used to determine the distance between the miner and the generators of the machine. Typically, this information is used to determine when a miner wearing a personal alarm device is in a warning zone or stop zone, which would trigger different alarms and actions such as slowing the machine down or stopping it.

When integrating electronic devices like proximity detection systems into an environment, the electromagnetic compatibility of the devices and the electromagnetic interference should be considered (Sevgi, 2009; Shechter, 2015). Electromagnetic interference is an unintentional electromagnetic interaction between two electronic devices or systems in which one of the devices experiences a degradation in its performance and functionality. This relates to an electronic device's inherent ability to emit levels of electromagnetic energy that may potentially interfere with the proper operation of another device in its vicinity. Electromagnetic compatibility can be defined as the ability to control electromagnetic interference so that two systems in close proximity to each other are able to operate as designed without any degradation in performance quality. The effects of electromagnetic compatibility and electromagnetic interference have, historically, been implicated in numerous incidents in which control systems failed, causing ships to run off course, aircraft to crash, and medical devices such as pacemakers and defibrillators to malfunction (Sterling, 2007; Paul, 2006; Hubing and Orlandi, 2005). These cases highlight the critical need to consider electromagnetic compatibility and electromagnetic interference in the design and integration of electronic devices into any given environment. Considerations to mitigate this phenomenon are critical in industries such as the military and medical fields, where faulty operation of equipment may result in costly repairs and even loss of life.

Over the years, several standards have been developed to achieve compatibility between different electronic devices and to prevent the degradation of performance quality of these devices (International Electrotechnical Commission, 1997; U.S. Department of Defense, 1999; Tuite, 2010). Several administrative and engineering controls have also been incorporated to overcome these challenges and can include

filtering of radio frequencies, shielding of electronic components, and recommendations for separation distances of devices to reduce the likelihood of electromagnetic interference (Katrai and Arcus, 1998; Liu and Guo, 2002; Colaneri and Schacklette, 1992). With the promulgation of regulations mandating the use of electronic devices and sensors, the challenges of electromagnetic compatibility and, by extension, electromagnetic interference are being brought to the forefront.

One case of electromagnetic interference transpired soon after continuous personal dust monitors were required to be used to determine respirable dust exposure in underground coal mines (MSHA, 2016). The PDM3700 personal dust monitor (Thermo Fisher Scientific, Waltham, MA) is the instrument used by coal mines to comply with this regulation. The PDM3700 is a device worn by a miner that continuously monitors and displays the amount of respirable coal mine dust in the vicinity of the miner (Page et al., 2008). It has an internal motor that drives a pump to continuously draw in air from the miner's breathing zone through a tube. The air is drawn through with a cyclone that only permits respirable size particles to collect on the filter, and the mass of the particles is determined by a tapered oscillating microbalance (TEOM). The results — the amount of dust in the vicinity of the miner — are displayed on a small screen. After its implementation in underground coal mines, MSHA confirmed reports that the PDM3700 was at times causing interference with the proximity detection system (MSHA, 2016).

Electromagnetic energy can be transferred between the source and victim devices by conduction or radiation or both. An example of conducted interference is a source producing electromagnetic noise on its power cable, with the noise then appearing in the electrical supply and the victim's power cable, causing degradation in the victim's performance. An example of radiation interference is radio frequency (RF) energy intentionally or unintentionally emitted by a source, which is intercepted by circuitry within a victim device, such as a proximity personal alarm device, causing degradation in the victim's performance. In the case of the PDM3700 and the personal alarm device, neither device has a power cord or other electrically conducting appendage attached. Hence, there is no need to consider conduction-type interference.

The PDM3700 is battery-operated and has a variety of electronic circuits to turn the battery-supplied DC voltage into an AC voltage in various frequencies. These circuits can generate RF noise covering the frequencies in an extended range, including the operating frequency of the proximity detection system. This RF noise could start to influence the function of the proximity detection system when the signal-to-noise ratio, or the ratio of the desired signal to the background noise, is low. In other words, the signal detected by the personal alarm device from the proximity detection system is not sufficient enough to overcome the signal generated by the personal dust monitor. Whether the personal dust monitor interferes with the proximity detection system depends upon the strength of the signal from the proximity detection system and the magnitude of the noise, in the same frequency bandwidth, from the personal dust monitor. As the personal dust monitor gets closer to the personal alarm device, the noise strength increases, and as the person-

al alarm device gets further from the generators, the signal from the proximity detection system weakens. At a certain distance from the proximity detection system generators, and a certain distance between the personal alarm device and personal dust monitor, the amplitude of the proximity detection system signal is not sufficient to overcome the RF noise. As a result, the proximity detection system controller will determine a wrong location of the miner based on the erroneous signal received from the personal alarm device.

Testing procedures for electromagnetic interference or electromagnetic compatibility independently evaluate the source and the victim device. The source device is evaluated for its emissions. Emissions can be either intentional, such as through a broadcasting handheld radio or cellphone, or unintentional, as in the case of the PDM3700 voltage controller radiating RF energy. The victim is evaluated for its susceptibility or immunity to performance degradation from RF energy. For example, in our case, radiated emissions testing is necessary on the PDM3700, and radiated susceptibility testing is necessary on the personal alarm device. In the present study, emissions from the PDM3700, and other electronic devices commonly used in underground coal mines, as well as the susceptibility of the proximity detection system were quantified in NIOSH's Pittsburgh laboratory using the MIL-STD-461E military standard.

## Methods

To quantify when the interaction between the PDM3700 and proximity detection system results in an interference, the susceptibility of the proximity detection system needs to be determined, and then the emissions from the PDM3700 at different distances from the proximity detection system need to be evaluated. Because other electronic devices have been demonstrated to cause some interference to proximity detection systems, they also need to be evaluated to calculate compatibility between the proximity detection system and other electronic devices used in underground coal mines (MSHA, 2015b).

**Measuring radiation susceptibility of the proximity detection system.** The strength of the magnetic field produced by generators installed around the continuous mining machine depends on the distance from the machine. The further away the personal alarm device is located, the more vulnerable the proximity detection system is to electromagnetic interference because of a low signal-to-noise ratio. The susceptibility of the proximity detection system was therefore evaluated at the edge of the warning zone, or the farthest point from the machine where the proximity detection system detects the presence of the personal alarm device, indicating a miner is located in the warning zone. At this point, the miner may be approaching a hazardous condition, and the proximity detection system will apply a safety function such as activating an alarm and/or reducing machine speed.

NIOSH worked with proximity detection system manufacturer Strata (Atlanta, GA) to acquire a customized system, with software modifications described by Bissert, Carr and DuCarme (2016), to enable laboratory testing. The proximity detection system includes four generators with a ferrite core wrapped around with insulated wire, which produces a magnetic field. The magnetic field strength is pro-

portional to the current running through the coil. Miners working on the section have a personal alarm device, which is a transceiver that measures the field strength emitted by the generators and transmits a data packet containing the field strength reading over a RF link to the proximity detection system controller mounted on the machine. The magnetic field generator's pulses contain identification information so that the personal alarm device can determine which generator's field strength it is reading. This type of system utilizes the principle of magnetic flux density: the closer the personal alarm device is to the field generators, the higher the field strength reading. Thus, a miner's presence can be determined once he gets too close to the machine, because the miner's personal alarm device will measure a magnetic flux density beyond a certain threshold. These thresholds are used on a per-generator basis to "shape" the fields for both warning and stop zones around a machine.

The proximity system used in this study also had a sophisticated mathematical model of the shape and size of electromagnetic fields, as previously developed by NIOSH researchers (Bissert et al., 2016). At the core of this model is an equation for the shapes of three-dimensional magnetic "shells" formed around magnetic field generators. Shells close to the generator have a more irregular shape because as the distance between the generator and the personal alarm device is increased, shells become larger and more uniform in shape. This nonlinear variation in size and shape is well described by this model. For any measured field strength, an associated shell exists that can be approximated using this model. This means that if a personal alarm device detects a given field strength, the associated shell can be determined by the proximity detection system, indicating that the personal alarm device must be located somewhere on that shell.

This does not, however, give an exact position. In order to continuously track the position of personal alarm devices, the position of the personal alarm device is found using multiple magnetic field generators on the continuous mining machine. The magnetic field strength for each of the generators is measured by the personal alarm device, and a magnetic shell is determined for each generator based on the magnetic field model. The position of the personal alarm device is given by the intersection of two or more magnetic shells.

Although this concept for calculating miners' positions is fairly simple, calculating the intersection of the magnetic shells is not a trivial task. Shell shapes are irregular and vary nonlinearly with distance, making it difficult to find a direct mathematical solution for the intersection. Therefore, NIOSH researchers have developed a new search method using a series of geometric approximations to calculate shell intersections (Carr, Jobes and Li, 2010). The system uses this method to continuously track the position of multiple miners around the mining machine with a high degree of accuracy. The achievable accuracy of the position triangulation is limited by the stability and repeatability of magnetic readings. A given magnetic field strength reading should be associated with a distinct shell around the machine.

There is some variability in the magnetic field influenced by several operational and environmental variables. As a result, the magnetic field reading from a personal alarm device generally shows a certain level of variation even when it is stationary. This normal variation in the electromagnetic

proximity system causes the same reading to be observed over a range of distances at any given point on that shell. NIOSH researchers quantified the system accuracy in the laboratory by taking thousands of shell measurements while varying these conditions, with variability of up to 30.5 cm (12 in.) observed. At a certain threshold, the electromagnetic interference of an electronic device can cause the personal alarm device not to detect the magnetic signal from the generator, resulting in the magnetic field strength detected by the system staying constant or frozen. In this case, the miner can move without being detected by the proximity detection system. This phenomenon occurs when signals from two generators are constant or frozen.

The apparatus for military standard MIL-STD-461E RS101 (Fig. 1a) (U.S. Department of Defense, 1999) was set up at the edge of the “warning zone” of the Strata proximity detection system at the Pittsburgh Mining Research Division’s proximity detection laboratory. The susceptibility was then quantified using military standard RS101. In this setup, an Agilent 33220A signal generator (Agilent Technologies, Santa Clara, CA) was used to feed a signal to a type 9230-1 radiating loop antenna, which generated a magnetic field to attack a personal alarm device, and a Tektronix RSA5103A signal analyzer (Tektronix Inc., Beaverton, OR) was used to measure the voltage from the current probe BCP-510. As the signal level from the signal generator increases, the antenna current increases, and so does the voltage from the current probe. The current increase also results in strengthening of the magnetic field generated by the antenna. The change of magnetic flux density with antenna current change could be quantitatively determined from the output voltage of the current probe. The threshold for electromagnetic interfer-

ence is identified when the magnetic flux density reaches a point at which the generated field is significantly interfering with the personal alarm device.

In this study, when the field caused two generator readings from the personal alarm device to freeze, the magnetic flux density reading was defined as the threshold of electromagnetic interference. In this procedure, the personal alarm device was set 5 cm (2 in.) from the antenna and then the strength of the 10 kHz signal directed toward the personal alarm device was increased. The test was repeated, and the field was strengthened at different frequencies to determine the electromagnetic interference threshold at those frequencies. Up to 37 frequencies were selected from 10 to 146 kHz at steps of 0.5 to 46 kHz. A small frequency step was taken for those of the selected frequencies close to 73.5 kHz, while a large step was taken for those far from 73.5 kHz. This procedure was repeated for several different positions around the continuous mining machine as well as four different orientations of the PDM3700.

**Measuring electromagnetic interference from electronic devices.** The emissions from electronic devices were quantified using the military standard MIL-STD-461E RE101, as shown in Fig. 1b (U.S. Department of Defense, 1999). RE101 requires the electronic device to be 7 cm (2.8 in.) away from the antenna.

In this test, an HP 11966k magnetic field coil antenna (Agilent Technologies, Santa Clara, CA) was used to receive the RF noise generated by the personal dust monitor, and a Tektronix RSA5103A signal analyzer was used to store the RF noise signals and perform the noise spectrum analysis. The HP 11966k antenna is specified for a frequency span between 20 and 50 kHz but was used to measure between 10 and 120 kHz. Therefore, the antenna was calibrated to determine its capability to measure beyond 50 kHz.

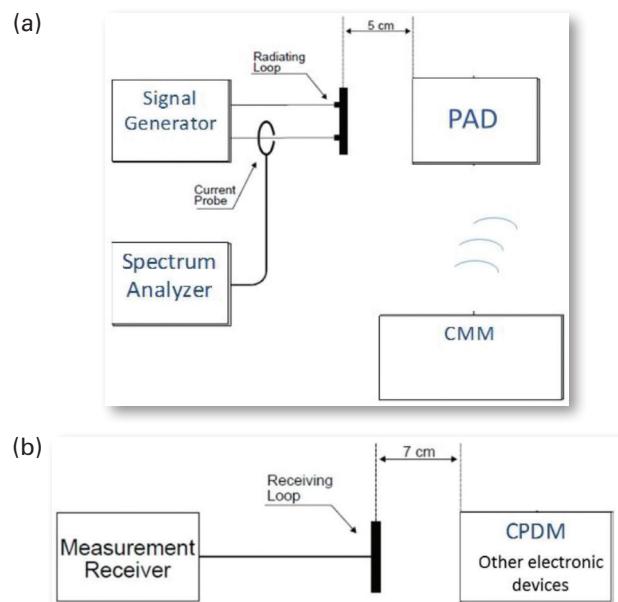
Using the apparatus shown in Fig. 2, we obtained the receiving characteristics of the HP 11966k. In the apparatus, a signal generated by the Agilent 33220A signal generator was fed to the A.H. SAS-564 transmitting antenna (A.H. Systems Inc., Chatsworth, CA), which produced a steady magnetic field. A voltage was induced on the HP 11966k positioned at a fixed distance of 12 in. (30 cm) from the A.H. SAS-564 at one frequency at a time, and measured by the Tektronix RSA-5103A signal analyzer. The measurements, covering frequencies from 10 to 100 kHz, permitted us to make a comparison of the receiving characteristics of the A.H. SAS-564 between bands of from 10 to 50 kHz and from 50 to 100 kHz.

As seen in Fig. 3, the measurements show that the frequency response of the antenna from 50 to 100 kHz can be seen as a linear extension of that from 10 kHz to 50 kHz. The antenna has much smaller variations on frequency response from 50 to 100 kHz than from 10 to 50 kHz. The antenna, therefore, has a better linear response over frequencies from 50 to 100 kHz than from 10 to 50 kHz. Therefore, the results are more accurate between 50 and 100 kHz than 10 to 50 kHz. This should have minimal influence on the results or conclusion for this study as the strong noise generated by the personal dust monitor was between 50 and 100 kHz, which is within the linear range of the antenna.

The emissions from the PDM3700 were measured for

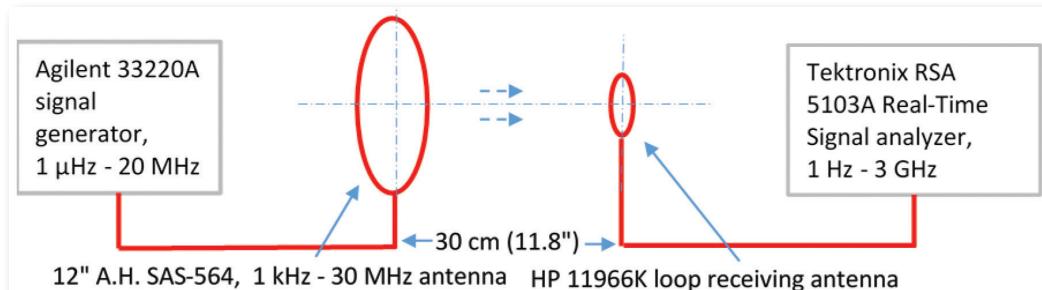
## Figure 1

**Figure 1: Apparatus for military standards (a) RS101 and (b) RE101 (CPDM = continuous personal dust monitor, PAD = personal alarm device, CMM = continuous mining machine).**



## Figure 2

Schematic of apparatus used to calibrate the HP 11966k loop antenna.

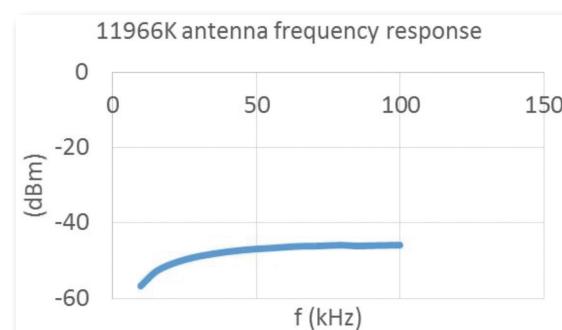


different orientations, as shown in Fig. 4. In order to determine the electromagnetic interference at different separation distances between the personal alarm device and electronic device, the same test used in military standard RE101 was performed at different distances between the electronic device and the antenna. In addition to two PDM3700s, other electronic devices that are common in underground coal mines were also tested at various orientations. These instruments included an Industrial Scientific MX4 multigas analyzer, an Industrial Scientific MX6 multigas analyzer (Industrial Scientific Corp., Pittsburgh, PA), a Bosch GLM 80 laser distance finder (Bosch GmbH, Gerlingen, Germany), a Hilti PD 40 laser distance finder (Hilti Corp., Schaan, Liechtenstein) and a Zefon Escort ELF Pump (Zefon International, Ocala, FL). The laser finders were tested with and without the distance ranging feature actuated.

**Separation distances.** The next step was to determine the necessary separation distances to avoid interference between the two systems. The personal alarm device was inserted into a belt worn by a mannequin. The mannequin was moved to within the warning zone of the proximity detection system in the laboratory at the location that demonstrated the worst case of susceptibility based upon the RS101 results. The responses of the four generators were recorded. The number

## Figure 3

Frequency response of the antenna from 50 to 100 kHz.



of times the system froze was also recorded. This test was designed to provide a baseline of the number of times the proximity detection system would freeze without the influence of the PDM3700. A PDM3700 was then added to the belt (Fig. 5) at a distance of 15 cm (6 in.) from the personal alarm device. The experiment was repeated with separation distances of 7.6, 13, 20 and 28 cm (3, 5, 8 and 11 in.).

## Figure 4

Positions of the PDM3700 tested: Cyclone = where the dust would enter the instrument through a cyclone (size selector), TEOM = where the mass would be measured using the tapered element oscillating microbalance, Body = part that would be against the body if worn on a belt, and Front = opposite side of the body.



## Results and discussion

Results showed that the PDM3700 interfered with the function of the proximity detection system at three out of the four orientations tested when 7 cm (2.8 in.) away from the personal alarm device. Figure 6 shows the emissions measured from the PDM3700 when it was 7 cm (2.8 in.) from the antenna when using military standard RE101, with the susceptibility curve showing the lowest values out of the several orientations tested with RS101. The level of electromagnetic interference from the PDM3700 in this measurement would be what is exposed to the personal alarm device when the devices are 7 cm (2.8 in.) from each other. This electromagnetic interference at the front, body and cyclone

positions was above the susceptibility curve at a range of frequencies — hence the PDM3700 could interfere with the proximity detection system. The emissions were below the susceptibility curve when the TEOM side was close to the personal alarm device, showing that when the PDM3700 TEOM side is toward the personal alarm device, the electromagnetic interference may not influence the proximity detection system.

This test was also repeated using a different PDM3700 to confirm accuracy of results. These levels of electromagnetic interference were not just the result of the characteristics of one instrument, as the electromagnetic interference was consistent for the two different instruments (Fig. 7). The PDM3700's influence on the proximity detection system was confirmed when it was placed within 7 cm (2.8 in.) of the personal alarm device while the proximity detection system was operated. In these circumstances, during testing at the NIOSH Pittsburgh laboratory, it was observed that the PDM3700 would cause the signal from the generators of the proximity detection system to freeze. The position of the miner indicated by the proximity detection system would then be stationary no matter where the miner was actually located, allowing the miner to approach the continuous mining machine without being detected.

These results do not mean that the PDM3700 is emitting high electromagnetic interference, for the emission levels from the PDM3700 were shown (Fig. 6) in our test to be below the U.S. Navy electromagnetic interference standards — electromagnetic interference levels that all electronic equipment must be below to be used in the U.S. Navy and ensure compatibility with other systems (U.S. Department of Defense, 1999) — except for a few peaks in the cyclone position that were just barely at or above the level. However, even though they were below the Navy standard, the emissions were above the susceptibility of the proximity detection system, meaning that at 7 cm (2.8 in.) apart the PDM3700 and proximity detection system cannot be operated simultaneously. Further, the susceptibility curve of the proximity de-

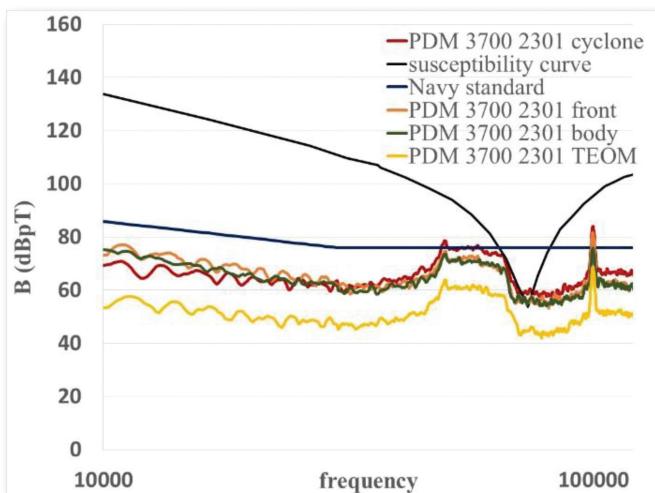
**Figure 5**

**The PDM3700 and the personal alarm device of the proximity detection system (PDS) inserted into a belt on a mannequin to quantify the effects of the PDM3700 on the PDS.**



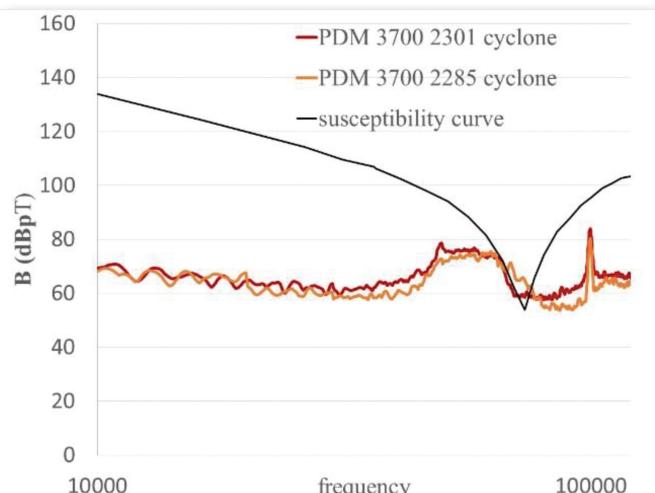
**Figure 6**

**Graph showing that the electromagnetic interference from the PDM3700 was above the susceptibility curve for the PDS at the cyclone, front and body positions.**



**Figure 7**

**Two different PDM3700s showing similar emissions.**



tection system demonstrated what levels of electromagnetic interference are necessary to influence the proximity detection system from other electronic devices commonly used in underground coal mines as well.

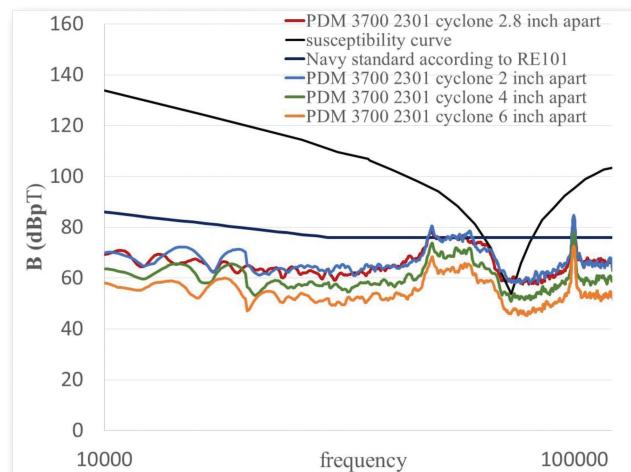
One way to mitigate the influence of electromagnetic interference is to separate the personal alarm device from the PDM3700. For this purpose, electromagnetic interference measurements were collected with the PDM3700 at different distances from the antenna. As seen in Fig. 8 (where the PDM3700 position was the worst case for emissions of electromagnetic interference levels), when the PDM3700 is 15 cm (6 in.) from the antenna, the electromagnetic interference is below the susceptibility of the proximity detection system. Therefore, a 15 cm (6 in.) separation distance between the PDM3700 and personal alarm device should result in no significant interference, meaning that the two devices tested in this laboratory can operate simultaneously if kept at least 15 cm (6 in.) apart.

After the PDM3700, other electronic devices commonly used in underground coal mines were also tested (Table 1). As with the PDM3700, the emissions were compared to the proximity detection system susceptibility curve to determine if the device would influence the proximity detection system. In addition, each device was tested at different distances from the antenna. The Zeflon ELF pump and the Bosch GLM 80 laser distance finder did not provide levels of electromagnetic interference that would potentially cause an observable interference until they were 5 cm (2 in.) from a personal alarm device. The gas analyzers tested did not provide observable interference even when 5 cm (2 in.) from a personal alarm device. Similar to the PDM3700, the Hilti PD 40 laser distance finder did emit electromagnetic interference levels that could influence the performance of the system when less than 15 cm (6 in.) from the personal alarm device. Unlike the PDM3700, this interference would only be intermittent, as it only occurred when the ranging feature was actuated. The electromagnetic interference from none of the instruments tested was above the susceptibility curve when 15 cm (6 in.) from the antenna. In other words, no noticeable influence on the proximity detection system was observed with any of the electronic devices tested when 15 cm (6 in.) from the antenna. The electronic devices do not represent all of the instruments used in underground coal mines, but this paper provides information on some common ones.

The separation distance or electromagnetic compatibility distance of at least 25 cm (9.8 in.) from the PDM3700 is based upon the electromagnetic interference levels and susceptibility measurements. Next, this mitigation strategy needed to be validated with the proximity detection system. As the PDM3700 provides the worst electromagnetic interference of the devices tested and is most likely to be close to the personal alarm device, this device was used to validate the RE101 and RS101 results. The PDM3700 and personal alarm device were placed at different distances from each other and the influence of the PDM3700 on the proximity detection system was quantified. The values of the generators were recorded first with just the personal alarm device and no PDM3700, to act as baseline, and then with the PDM3700 present at different distances from the personal alarm device. This experiment was performed at the position around the continuous mining machine that would be

## Figure 8

**Electromagnetic interference of the PDM3700 at the cyclone position (worst case) at different distances from the antenna. No significant electromagnetic interference was observed when the distance between the PDM3700 and antenna was 15 cm (6 in.).**



## Table 1

**Distance between the personal alarm device and electronic device when the electromagnetic interference would affect the proximity detection system.**

Device	Distance
PDM3700	< 15 cm (6 in.)
IS multigas analyzer MX4	< 5 cm (2 in.)
IS multigas analyzer MX6	< 5 cm (2 in.)
Bosch GLM 80 laser distance finder	≤ 5 cm (2 in.)
Hilti PD 40 laser distance finder	< 15 cm (6 in.)
Zefon Escort ELF pump	≤ 5 cm (2 in.)

the most susceptible to electromagnetic interference based upon RS101 testing.

As seen in Fig. 9, when the personal alarm device and PDM3700 were less than 15 cm (6 in.) apart, the proximity detection system was influenced, as indicated by several instances of the readout being frozen. However, when the personal alarm device and PDM3700 were at least 15 cm (6 in.) from each other, the number of times the proximity detection system was frozen was close to baseline. A 15-cm (6-in.) electromagnetic compatibility separation distance between the personal alarm device and PDM3700 resulted in little to no influence on the proximity detection system, while a separation distance less than 15 cm (6 in.) resulted in some influence on the performance of the proximity detection system.

# Technical Papers

## Conclusion

When close enough to the personal alarm device of a proximity detection system, some electronic devices used in underground coal mines can result in interference of the system. The main device of concern in this study is the PDM3700, for this device is most likely to be used consistently near the personal alarm device and produces constant electromagnetic interference to the PDM3700, as opposed to intermittent electromagnetic interference as with a distance range finder. At least 15 cm (6 in.) of electromagnetic compatibility separation distance between the PDM3700 and personal alarm device was observed to reduce the electromagnetic interference to levels that have no significant interference on the proximity detection system for the systems tested. This conclusion was first drawn after performing RE101 tests, and then validated by evaluating the effects of the PDM3700 on the proximity detection system at different distances between the personal alarm device and PDM3700. This separation distance is consistent with proximity detection system manufacturer recommendations (Strata, 2016; Matrix, 2016).

This electromagnetic compatibility separation distance was determined with just one type of proximity detection system and in the laboratory. Therefore, further testing with other types of proximity detection system as well as field data would be beneficial. Beneficial future work could also investigate other electromagnetic interference mitigation strategies besides separation distance, such as shielding of electromagnetic interference sources and investigating methods to detect these types of interferences and compensate for them. Currently, manufacturers of proximity detection systems and electronic devices are involved in further testing, including a personal alarm device that identifies the presence of an interference, shielding around

electromagnetic interference sources, and shielded pouches for electronic devices. ■

## Disclaimer

Mention of a company name or product does not constitute an endorsement by NIOSH. The findings and conclusions in this report are those of the authors and do not necessarily represent the views of NIOSH.

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**Figure 9**

**Graph showing that when the distance between the PDM3700 and personal alarm device (PAD) was less than 15 cm (6 in.), the proximity detection system (PDS) would malfunction periodically, but the PDM3700 had little to no influence on the PDS when the distances were 15 cm (6 in.) or greater.**

