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Noise emission data for M109, 155 mm field howitzer

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English summary

This report is part of an effort to improve the ability of the Norwegian Defence Estates Agency to assess noise pollution from firing ranges. Here we analyze results from measurements done near Hjerkinn 21st of September 2006, of the 155 mm field howitzer, M109. M109 is one of the noisiest weapons in the Norwegian defence, and as such represents a limiting factor for activity at firing ranges and training fields.

MILSTØY II is the noise analysis code used by Norwegian Defence Estates Agency to estimate the noise level near military firing ranges and training fields. This code takes as input an emission database, containing the source level relatively close to the weapon. The emission data calculated in this report is presented on a form suitable to be included in the MILSTØY emission database.

Sammendrag

Denne rapporten er del av et arbeid for å forbedre Forsvarsbygg sin evne til å evaluere støynivået rundt skytefelt. Her utføres det en analyse av målinger som ble gjort nær Hjerkinn 21. september 2006, av 155 mm felt haubits, M109. M109 er et av de mest støyende våpnene i Forsvaret, og er dermed en begrensende faktor i forhold til aktiviteten på skytebaner og øvingsfelt.

MILSTØY II er Forsvarsbygg sitt verktøy for å berengne støynivået rundt Forsvarets skytebaner og øvingsfelt. Dette programmet tar som inngangsdata en emmisjonsdatabase, som innholder kildedata relativt nær våpenet. I denne rapporten presenteres det kildedata på en form som er egnet for å inkluderes i MILSTØY sin emmisjonsdatabase.

Contents

1 Background

This report is part of work being conducted at the Norwegian Defence Research Establishment (FFI), to improve the ability of the Norwegian Defence Estates Agency (FB) to estimate noise pollution around military firing ranges. The noise level near firing ranges are subject to strict rules set by the authorities. Failure to comply with these rules will lead to limitations on the training activity.

The work conducted by FFI is part of a joint effort with FB as client. The project group consists of FFI, SINTEF IKT and NGI (Norwegian Geotechnical Institute). For a more comprehensive description of the activity of FFI in this field, we refer to [1, 2, 3, 4, 5, 6, 7, 8, 9, 10].

Currently FB use the linear propagation code MILSTØY II (MS) to calculate the noise propagation in the linear zone (Figure 1.1), where sound pressure is relatively small. MS use an emission database as input, giving source data at the start of the linear zone. There is a need to improve and expand this database. The data in the database are most often results of measurements. A rifle is typically measured 10 m from the muzzle. A large weapon may be measured at 250 m distance. In this report an analysis is presented to arrive at emission data for the M109A3GN, 155 mm field howitzer (Figure 2.1). This is one of the noisiest weapons in the Norwegian defence, and as such represents a limiting factor when planning firing ranges and training fields.

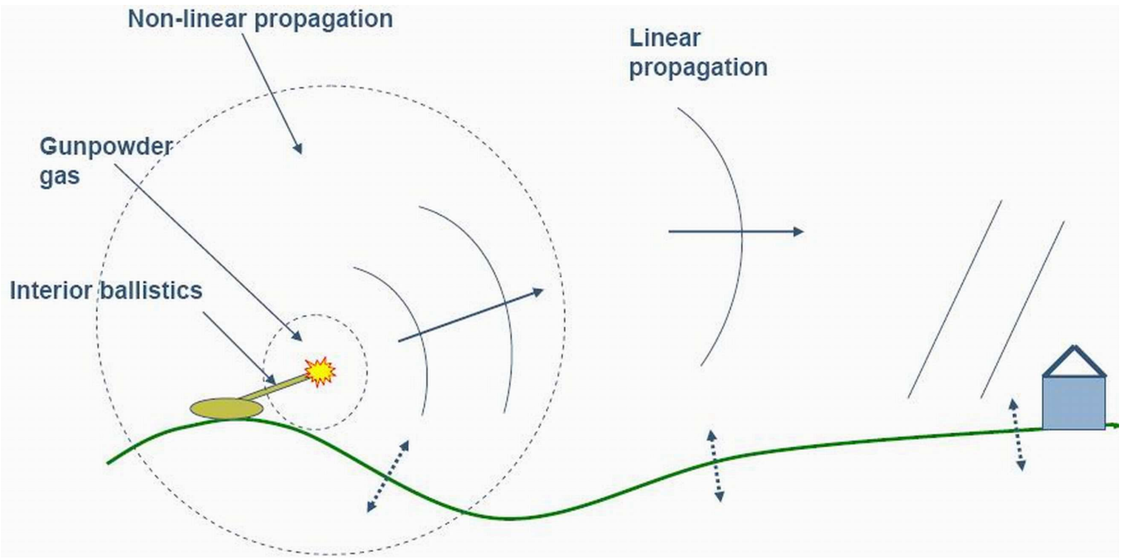


Figure 1.1: The different zones for sound propagation from a weapon.

2 Introduction

This report describes analysis and results of measurements of the M109 conducted at Hjerkinn 21st of September 2006. The details of the measurements are described in [11], and will not be reproduced in this report.

The measurements were made 250 m from the muzzle of the weapon. The M109 was placed at Turrhaugen just north of Dombås, and the target was at Hjerkinn training field, some 20 km north. The measurements were part of a large campaign, where the main purpose was to establish documentation of the properties of cargo ammunition.

Figure 2.1: M109

To produce free field emission data from large weapons close to the ground is not a trivial task. For small weapons several generally accepted methods exist to produce such data [12, 13]. To the author's knowledge, no such consensus has been reached for large weapons.

Noise propagation codes often take free field source data as input. This is motivated by the need to calculate the effect of different types of ground conditions along the propagation path. For a weapon like the M109 it is hard to imagine a setup where it is possible to measure the free field sound pressure. This means that free field source data have to be calculated from the sound pressure measured close to the ground. In this report this is done by first measuring a reference source to estimate the influence of the ground (and weather) for different frequencies. The reference source is 1 kg of TNT, for which we have data describing a free field detonation. Finally the resulting ground correction is added to the measured data for the M109, to produce the free field emission data.

In Section 3 the weapon and ammunition are described. Section 4 summarizes the sensor setup. In Section 5 we describe the calculation of the free field emission data. The results of this analysis are given in Appendix E, F and H.

3 Weapon and ammunition

The measured weapon was a field howitzer of the type M109A3GN (Figure 2.1). The howitzer used in these measurements is called Didrik (named after FFI's Didrik Cappelen). M109 is a 155 mm howitzer that is placed on an armored tracked vehicle.

The muzzle break has NATO number 1025–12–306–5557. It was made in Germany, has two chambers, and weighs 160 kg. The barrel has NATO number 1025–25–136–2638. It is 6045 mm long (39 cal.), maximum chamber pressure is 460 MPa and it weighs approximately 1600 kg. The NATO number of the complete vehicle is 2350–25-136-2496.

The charge was the maximum charge of 5 modules DM72. According to the supplier, each module contains 2.44 kg propelling charge [14, 15]. The measurements analyzed in this report are made with DM662 cargo grenades.

3.1 Calibration with 1 kg TNT

To establish a reference level, 1 kg TNT was detonated. Thursday 21st of September, 1 kg TNT was detonated at 09:38 (shot nr. 3) and at 16:23 (shot nr. 4).

It was not possible to move the M109, so the TNT could not be detonated at the position of the muzzle of the M109. The TNT was detonated about 35 m in front of the weapon, 1.5 m above the ground. The purpose of measuring the sound pressure from 1 kg TNT is to be able to remove the effect of the ground and the meteorology from the measurements for the M109.

4 Setup and measurement data

The setup at the measurement cite is described in detail in [11]. Some errors that have been found in [11] are reported in Appendix G. There were 12 sensors available in the measurements. The positions of these sensors, relative to the muzzle, are given in Table 4.1. In this report we will conduct an analysis based on the measurements at sensors 1–6. Results from sensor 10–12 for TNT are also considered, in order to asses the precision of the reference model for TNT.

In Table 4.1 angles are given between the firing direction and the direction from the muzzle to the sensor. The geometrical data are positions of sources and sensors measured with a differential GPS of accuracy better than 2 cm. We consider two types of angles. The 3D angle is the angle between the firing direction and the line from the muzzle to the sensor. By projecting these two lines on to a horizontal plane, we can calculate the horizontal angle. These two angles differ, because the firing direction is 18.7 degrees above the horizontal plane. We need both angles because the physics of the weapon is a function of the 3D angle, while MILSTØY is oriented towards calculating the noise level in a horizontal plane near the ground. In the plots of time series and in tables, we refer to angles in the horizontal plane. The 3D angle is only applied in Subsection 5.8, where the directional interpolation is explained.

The mesurement site at Turrhaugen is at 960 m above sea level. The data then need to be scaled to sea level, e.g. sensor 1 at 254.47 m from the muzzle has a scaled distance of 244.21 m. In the rest of this report the distances mentioned are the scaled distances. These scaled distances and the horizontal angles can be seen in Table 5.1. The pressure and time references given in this report are scaled to sea level, and thus differ from those given in [11].

The time series of the pressure for M109 is plotted in Appendix B for all 12 sensors (shot nr. 15). The time axis is relative to a flash sensor pointing at the muzzle. The time axis is then relative to when the projectile leaves the muzzle.

The time series of the pressure from detonation of 1 kg TNT is plotted in Appendix C. The flash sensor could not be used for this measurement. In stead the time axis is relative to the time when the blast wave reaches the closest sensor.

Sensor	hor. angle [deg]	3D angle [deg]	hor. dist. [m]	3D dist. [m]	sensor height [m]
1	31.97	37.22	254.47	254.53	-5.65
2	39.51	43.70	250.24	250.31	-6.06
3	69.27	70.90	254.20	254.28	-6.43
4	91.46	91.79	253.84	253.90	-5.62
5	119.28	118.47	258.69	258.94	-11.18
6	149.54	146.69	259.28	259.84	-16.96
7	174.74	163.24	259.72	260.02	-12.38
8	33.69	39.42	129.75	129.89	-6.02
9	31.59	36.17	372.59	372.59	0.27
10	0.92	28.98	18.37	18.67	-3.33
11	59.54	65.37	19.14	19.44	-3.41
12	142.65	139.92	20.34	20.36	-0.80

Table 4.1: Sensor positions relative to the muzzle. Angles are relative to the firing direction. The sensor height is relative to a horizontal plane through the muzzle. The distances are the actual measured distances (and not the scaled).

5 Method for estimation of emission data

It is common that emission databases, that serve as input to linear propagation codes, give noise levels for free field sources. However, the measurements are made very close to the ground. We then need to remove the influence of the ground from the measurements. This is accomplished by calculating the ground correction from measurement of detonation of 1 kg TNT, where we know the free field time series of the pressure. This ground correction is then used to calculate the free field sound exposure level of M109.

Removing the ground influence from these data is by no means a trivial task. For small weapons there exist several reasonably good methods to calculate free field emission data. They often take advantage of the fact that the source and sometimes the receiver are placed relatively high compared to the propagation distance. For the M109 these methods can not be applied. To the authors knowledge there exist no commonly accepted methods to perform this task.

The end result in a MILSTØY calculation for large weapons will typically be a noise map of C-weighted sound exposure level, L_{CE}. Although the procedure below might seem difficult to follow, a few factors are more dominant with regards to this end result. The M109 has the majority of its energy in the frequency range 5 Hz to 80 Hz. In this range the TNT calibration gives us about a 6 dB ground correction. Different choices in the procedure below may give rise to a variation of roughly $\pm$ 2 dB, often less than $\pm$ 1 dB. The main level of the emission data is still dominated by the levels found directly from the measurements, before further analysis.

The directivity of the noise from a weapon is given by the 3D angle relative to the firing direction. MILSTØY takes horizontal angles as input, so emission data have to be given this way for a specific elevation angle of the barrel of the M109. Emission data could be calculated for all elevation angles. Since the noise from M109 is not very directive, this will not have much effect. For other weapons this might not be the case.

Here we describe the steps needed to calculate the emission data (explained further in the Subsections below):

1. Scale measured data to sea level
2. Documentation of free field 1 kg TNT reference detonation
3. Algorithm that reproduces time series of the reference detonation
4. Calculate ground correction from free field 1 kg TNT reference data and 1 kg TNT measured at Hjerkinn
5. Modify ground correction
6. Add ground correction to measured M109 to produce free field M109 spectrum
7. Linearly scale the data to a reference level at 10 m, for use in MILSTØY
8. Curve fit to free field M109 data to find the spectrum at 0, 30, 60, 90, 120, 150 and 180 degrees shooting direction.

5.1 Scaling

The measurements at Hjerkinn were conducted 960 m above sea level. We then scale the results to what they would have been at sea level (Appendix A).

All results in [11] reports the pressure measured at Hjerkinn, without scaling. In this report all measurements are reported scaled to sea level at 15 degrees Celsius. The spectra for M109 presented in this report are based on Table E.2. This table is the scaled version of Table D.1 in [11]. Between these two tables there is a 0.87 dB difference in the sum sound exposure levels, where 0.51 dB accounts for the difference between the conditions at Hjerkin and at sea level. The remaining 0.36 dB accounts for the shorter scaled propagation distance (Table 5.1), and will not have any effect on the calculated emission data. In addition to the changes in the sum level, energy is slightly shifted to higher frequencies because of the scaling of the time axis.

Sensor	hor. angle [deg]	3D dist. scaled [m]
1	31.97	244.21
2	39.51	240.17
3	69.27	243.97
4	91.46	243.62
5	119.28	248.44
6	149.54	249.31
7	174.74	249.48
8	33.69	124.62
9	31.59	357.50
10	0.92	17.91
11	59.54	18.65
12	142.65	19.53

Table 5.1: Sensor positions relative to the muzzle, as referred to in most of this report.

5.2 Reference levels for 1 kg TNT

In a report from Maxwell Laboratories (made for FB), time series of the pressure is plotted for detonation of C4 explosives [16]. The pressure is given for an ideal surface at sea level. Time series of the pressure measured at Hjerkinn show a good correspondence with the plotted values for the sensors at 20 m from the source.

The time series in the Maxwell-report are for C4-data, while the detonations at Hjerkinn were with TNT. The Maxwell-report states that an equivalent weight of 1.32 can be applied. This seems reasonable for our purpose (sound exposure level) as this value lies between the equivalent weight for pressure (1.37) and impulse (1.19) [17].

5.3 Time series for the reference detonation

We need the 1/3-octave spectrum for the reference detonation of TNT. To find this we first apply the FOFT-method to obtain the time series for the pressure [18, 3]. In essence the FOFT-method consists of experimental data for the peak pressure from Baker's book [19], and a model for the time series of the pressure by Reed [20].

The FOFT-method directly calculates the free field reference data for 1 kg TNT. It is these data that are employed to find the effect of the ground and the weather.

In order to increase our confidence in the values calculated with the FOFT-method, we have also used it to calculate the time series of the pressure with the ground present. In order to do this, we employ the "height of burst gain" to find an equivalent energy [17, 21]. In this case the energy of the detonation is calculated to be 2.54 times the energy from a free field detonation. Applying this energy as input for the FOFT-method, we calculate the time series for the pressure above ground (Appendix C).

The time series of the pressure was measured 20 m from the detonation of TNT. In Appendix C these measurements are compared with calculations done with the FOFT-method with ground present, with good agreement. This also means that the FOFT-method is in good agreement with the time series from the Maxwell-report. We now have three methods that have produced similar time series for the pressure above the ground, 20 m from the weapon. This strengthens our confidence in the FOFT-method, and also in the fact that the source indeed was a charge of 1 kg TNT that detonated normally.

Further away from the source (e.g. upper plot in Figure 5.2) the measured pressure does not resemble the free field reference. This is as should be expected, and is the reason we need to find a ground correction.

5.4 Ground correction

We often measure the sound level, L_{meas}, of large weapons between 100 to 500 m from the weapon. There the sound is assumed to be linear. The limit for when a sound is linear is often set to a peak pressure of 1 kPa or 0.1 kPa. In this Report we have applied the limit 1 kPa.

At a given distance from the source, a free field value, $L_{\mathsf{free\ field}}$, and a measured value over the ground is connected by

$$L_{\mathsf{meas}} = L_{\mathsf{free\ field}} + L_{\mathsf{ground}}, \tag{5.1}$$

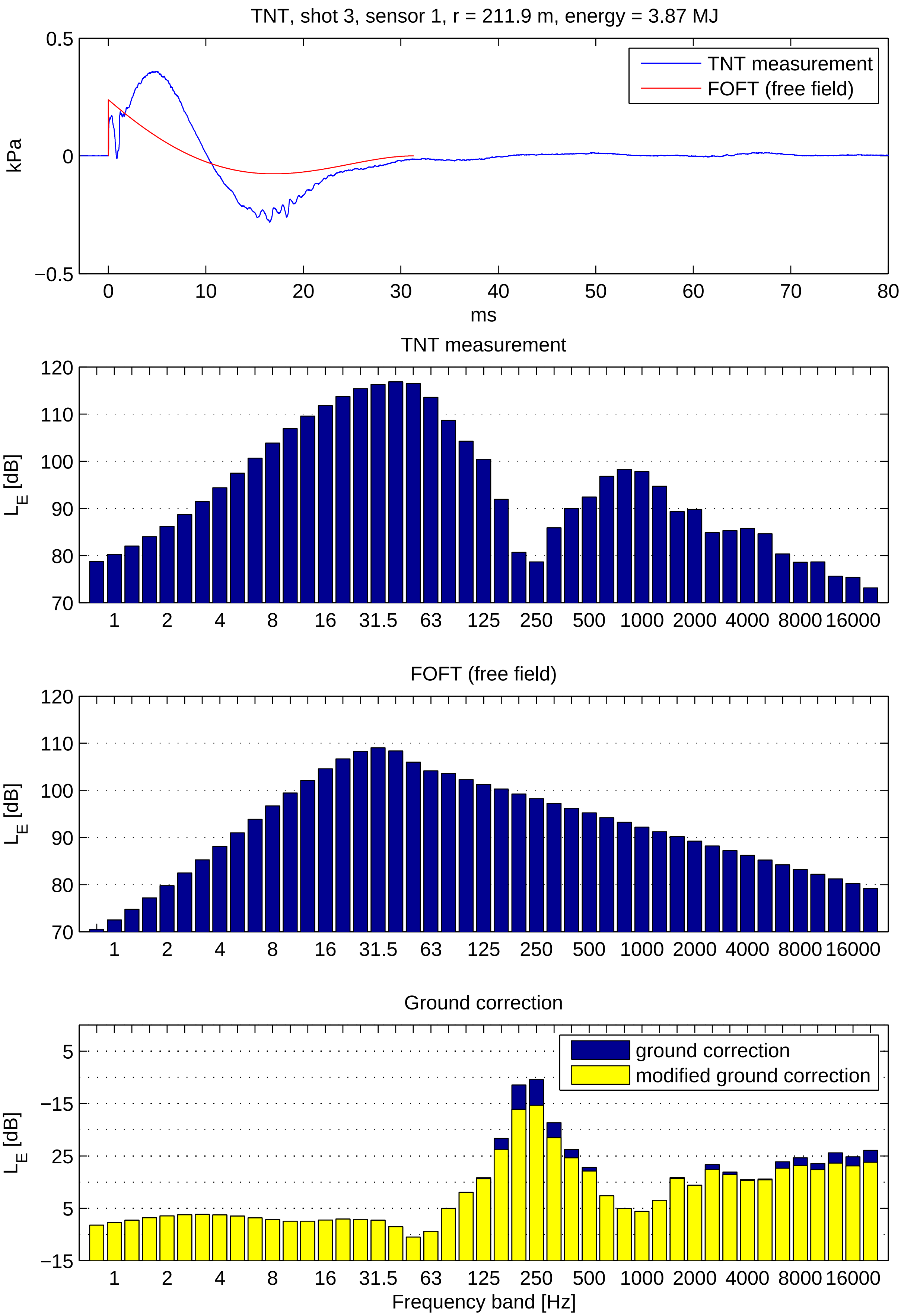


Figure 5.1: Example of generation of ground correction spectrum from calibration detonation of 1 kg TNT.

where L_{ground} is defined by this equation and reflects the influence of the ground and meteorological conditions. Now L_{ground} can be computed from the measured detonation of TNT and the free field calculation. This procedure is plotted in Figure 5.1.

The ground correction term L_{ground} reflects the change in sound level caused by the presence of the ground. This ground correction mainly consists of the linear sound reflected from the ground. In addition this there is a non-linear interaction with the ground near the source. Depending on the height of the source, non-linear interaction typically leads to higher amplitudes and a shift to slightly lower frequencies than in the linear case. Included in the ground correction there also is contributions from the meteorological conditions, e.g. due to a variation in the wind direction.

5.5 Modify ground correction

The ground correction should be identical for 1 kg TNT and the M109, assuming that geometrical and meteorological conditions are the same. The ground correction spectrum calculated from the reference detonation of TNT seems to work fairly well when applied to the measured data from the M109. However, there are three factors that limit the accuracy of the ground correction.

1. We have small fluctuations in the meteorological conditions
2. We were not able to place the TNT detonation at exactly the same location (horizontally) as the muzzle of the M109
3. The TNT was detonated closer to the ground (1.5 m) than the muzzle of the M109

Especially the last two factors may cause the dip in the power spectrum of the TNT to occur at a different frequency than for the M109. This has little influence on the sum levels of the measured spectra. However, we may get a large peak in the corrected spectrum for M109, around 250 Hz. This is because the peak of the correction spectrum (lower plot Figure 5.1) occur at another frequency than the dip in the spectrum for the M109.

The M109 has the main part of its energy in the frequency range from 5 Hz to 80 Hz. This artificial peak around 250 Hz will contribute in a non reasonable way to the sum level for the M109, and should therefore be removed.

There are numerous techniques to remove such phenomena. Finding the one best suited for this application would be too extensive for this report. We made some attempts to correct the difference in geometry by applying standard models for linear sound propagation, e.g. spherical reflection coefficient with impedance model from Delany-Bazley, Attenborough or Darcy-Taraldsen [22, 23]. Perhaps not surprisingly, these models do not explain the measured data sufficiently well, but introduce more errors than the more pragmatic procedure which has been chosen in this work to modify the ground correction spectrum.

To avoid the problem, the ground correction spectrum is modified around the top of the spectrum. The positive values of the ground correction spectrum are multiplied by 0.75, at frequencies below 1000 Hz. This solves the problem of frequency mismatch between the M109 and the TNT, but may result in too small values around 250 Hz. This is however not significant for the sum level of L_{CE}, since the main energy of the M109 is in the frequency range of 5 to 80 Hz.

Above 1000 Hz, a modification was added that reduces the positive ground correction when the measured pressure (for TNT) is very small. This is motivated by the notion that you do not want to add a huge ground correction based on a level that is so small that it has a lower signal quality. Again this is not significant for the sum level of L_{CE}

In the lower plot in Figure 5.1 we see the effect of modifying (yellow) the original ground correction (blue).

In the rest of this report we refer to the modified ground correction as simply the ground correction. The ground correction for all 6 directions are plotted and tabulated in Appendix D.

5.6 Adding ground correction to M109 spectrum

Sensor	hor. angle [deg]	L_E [dB]	L_{CE} [dB]	ground correction L_{CE} [dB]
1	31.97	130.5	125.3	-5.9
2	39.51	129.6	124.7	-5.3
3	69.27	128.3	122.7	-4.7
4	91.46	128.2	122.7	-5.5
5	119.28	127.1	121.9	-4.8
6	149.54	126.4	119.5	-3.1

Table 5.2: Effect of ground correction on sum levels.

In Figure 5.2 we show an example of adding the ground correction spectrum (lower plot Figure 5.1) to the measured spectrum from M109. In this example the correction spectrum is the mean energy of TNT shot 3 and 4. In Table 5.2 we see the effect of the ground correction on L_{CE} for all sensors. The resulting free field spectra at the 6 sensors is plotted and tabulated in Appendix E.

5.7 Linear scaling to 10 m reference level

The linear sound propagation code MILSTØY takes emission data as input at a reference position at 10 m, to calculate the sound back out to the position where the sound level was measured. Obviously the sound propagation is not linear at 10 m from the source. The sound level L_{10_ref} therefore does

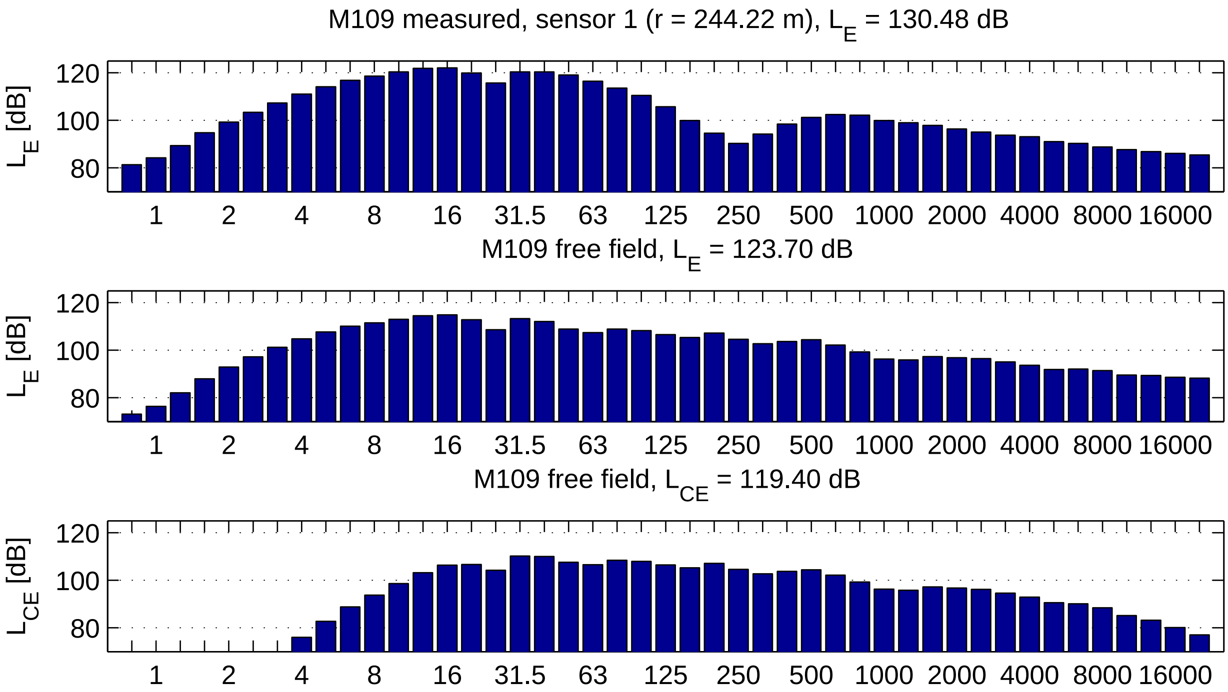


Figure 5.2: Example of adding the ground correction spectrum to M109 data.

not represent the actual sound level, but a linear reference level defined by (5.2). This reference level serves as a definition of the source strength in the emission database in MILSTØY.

$$L_{10\_\text{ref}} = L_{\text{free field}} + 10\log(r/10). \tag{5.2}$$

5.8 Directional interpolation

For the emission database we need the sound level at uniform angles from the firing direction. Therefore we fit the measured data to a function. This function is then used to find the sound level at uniform angles. Here we have chosen to fit the data to a cos-series with 3 degrees of freedom.

$$L_E(\theta) = a_0 + a_1\cos(\theta) + a_2\cos(2\theta). \tag{5.3}$$

The angles used for interpolation is the 3D angles. The curve fit is done with the least squares method [2, 12]. Since we have 6 measurement points we could have chosen to apply a series with 6 degrees of freedom. This would typically give good results for interpolation at angles between two sensors.

In this case however, we have no measurements between 0 and 37 degrees and between 147 and 180 degrees. We then need to extrapolate the values for these angles. At certain frequencies the extrapolation of data from 0 degrees to sensor 1 at 37 degrees is somewhat sensitive to the number of terms in the series.

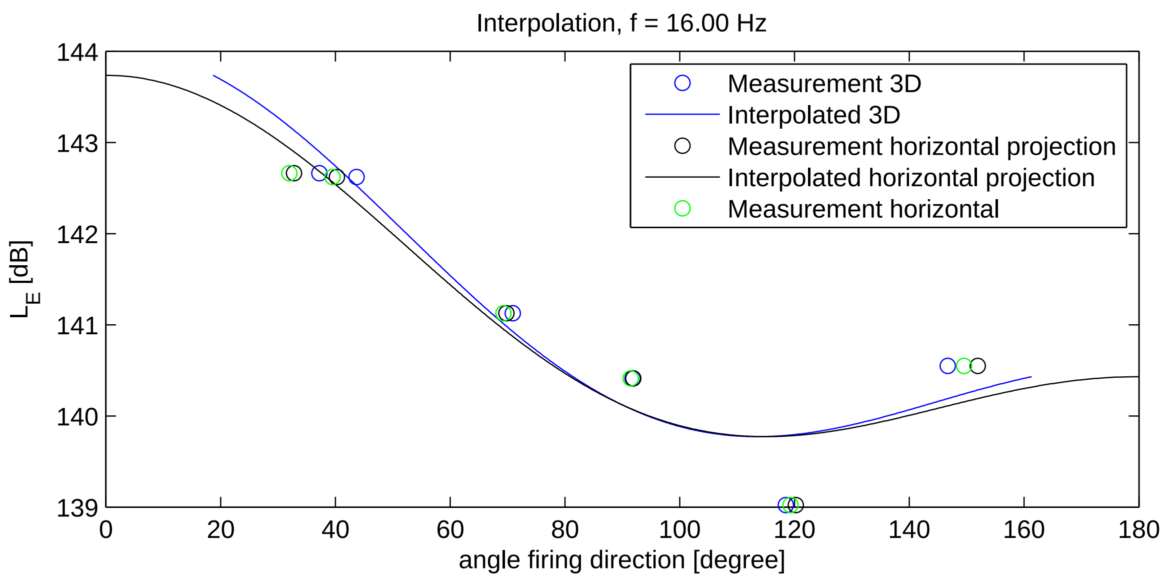


Figure 5.3: Example of angular interpolation at 16 Hz. The blue curve represents the data in 3D angles. The black curve represents the horizontal projection.

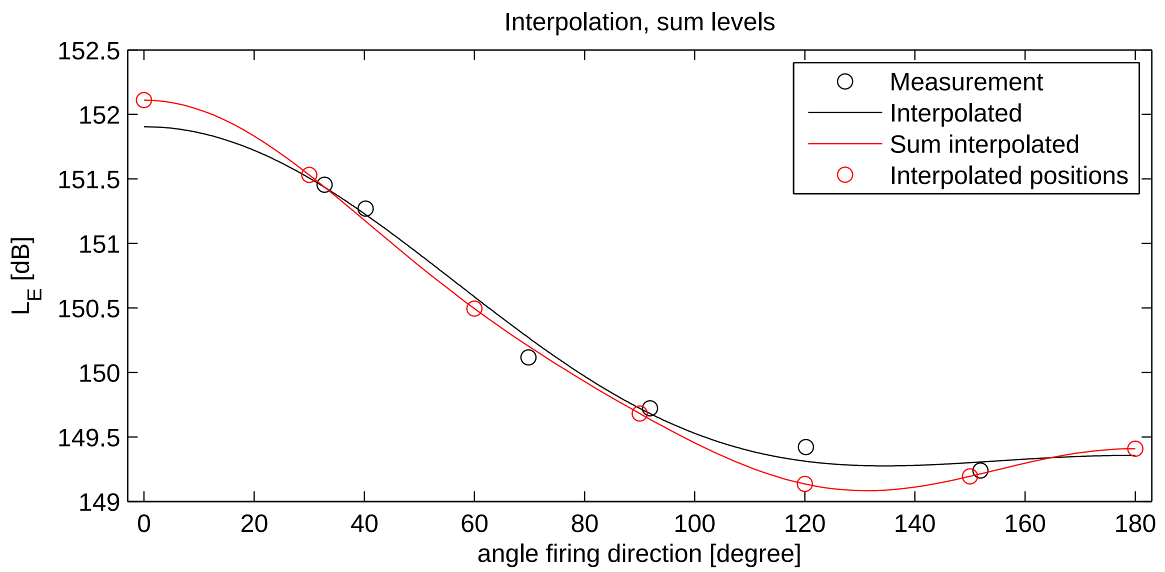


Figure 5.4: Interpolation of sum levels.

We then apply this curve fit to the 6 measurement points for all the 45 frequencies. An example is shown for 16 Hz in Figure 5.3. The blue line is the interpolated curve in 3D angles. The corresponding curve projected down into a horizontal plane through the muzzle is shown in black. The green circles indicate the actual horizontal angles of the sensors, which are different, because the sensors were placed somewhat below the horizontal plane through the muzzle (Table 4.1).

In Figure 5.4 the black line represents the interpolation between the sum levels of the 6 sensors (corresponding to the black curve in Figure 5.3). To arrive at the red curve we have first found an interpolated curve for each of the 45 frequencies (like the 16 Hz black curve in Figure 5.3). We have then taken the energy sum of these 45 curves. The similarity between the curves in Figure 5.4 indicate that the interpolation has worked well at all the 45 frequencies. The red circles indicate the estimated sum levels at the uniform angles used for the input to the emission database. The free field spectrum for M109, at uniform angles, for a reference level at 10 m, is tabulated in Table F.1. This table gives the emission data for M109.

6 Summary

A method has been demonstrated to calculate emission data for large caliber weapons. In Appendix H the emission data for the M109A3GN field howitzer is presented in a form that is suitable for inclusion in the database of the linear propagation code MILSTØY.

A Scaling

Emission data is often given at sea level conditions. We therefore need to scale the data from the conditions at the measurement cite, to sea level conditions. When calculating sound propagation we could also apply this scaling. The propagation medium is here defined by the height above sea level, h, and the air temperature, T.

A.1 Reference conditions (0) at sea level

At sea level the ambient air pressure is taken to be $p_{\text{atm}}^{(0)} = 101.325 \cdot 10^5$ kPa. The reference temperature is 15 degrees Celsius. Then the speed of sound is $c^{(0)} = 340.3$ m/s.

A.2 Standard atmosphere at h m above sea level

In [24] variation of the atmospheric pressure ,$p_{\text{atm}}^{(h)}$, as a function of h is given for a standard atmosphere, together with the sound speed, $c^{(h)}$, as a function of temperature.

Up to 11000 m above sea level the following formula can be used for the standard pressure at the height h

$$p_{\text{atm}}^{(h)} = p_{\text{atm}}^{(0)} \left[\frac{288.15}{288.15 - 0.0065h} \right]^{-5.2559}. \tag{A.1}$$

The sound speed is given by

$$c^{(h)} = c^{(0)} \sqrt{\frac{273.15 + T}{288.15}}. \tag{A.2}$$

Note that $c^{(0)}$ is the speed of sound at 15 degrees Celsius ($h = 0$), not at 0 degrees Celsius.

A.3 Sachs scaling

By Sachs scaling ([19, 17]) we find dimensionless pressure, $\bar{p}$, and time, $\bar{t}$, as a function of only the dimensionless distance , $\bar{t}$.

The Sachs scaling can be interpreted in the following way. Given a measurement of a time series of pressure at a specific distance, we can apply Sachs scaling. We then get a dimensionless time series of pressure at a certain dimensionless distance from the source. For each dimensionless distance there exist a time series. As we move further away from the source the time series broadens, i.e. the energy is shifted to lower frequencies (close to the source). We have knowledge only of the time series at the specific (measured) dimensionless distance. We may now scale the dimensionless time series back to another pressure and temperature condition. We then get a dimensional time series at a new dimensional distance from the source. If we are interested in the pressure at the original distance from the source, some sort of calculation must be performed to transfer the characteristics of the time series to the original distance. This is easily done for the present application, since the measurements are conducted in the linear region.

The input to the scaling are the distance to the source, r, the energy of the explosives, E, the time, t and the pressure, p. These four combines to the dimensionless pressure and time.

$$\begin{aligned} \bar{r} &= \frac{r\, p_{\text{atm}}^{1/3}}{E^{1/3}}, \\ \bar{p} &= \frac{p}{p_{\text{atm}}}, \\ \bar{t} &= \frac{t\, c\, p_{\text{atm}}^{1/3}}{E^{1/3}}. \end{aligned} \tag{A.3}$$

A.4 Scaling of impulse noise in MILSTØY

Source data is generally given at sea level, for a standard ambient pressure and temperature. At present MILSTØY do not contain any correction for height above sea level. For higher h the air pressure is lower, and the sound pressure from a weapon will be smaller. For lower air temperature, the sound speed is lower and the sound pressure from a weapon will be higher. The scaling is more sensitive to change in the ambient air pressure.

This variation can be quantified by scaling. By equating the dimensionless quantities from the two different propagation conditions from (A.2), we get the scaling factors

$$\begin{aligned} r^{(h)} &= \left(\frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}}\right)^{1/3} r^{(0)}, \\ p^{(h)} &= \frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}} p^{(0)}, \\ t^{(h)} &= \left(\frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}}\right)^{1/3} \frac{c^{(0)}}{c^{(h)}} t^{(0)}. \end{aligned} \tag{A.4}$$

Ultimately we want to estimate L_E (sound exposure level [2]) or sound levels that can be found from L_E.

$$L_E = 10 \log \left(\frac{SE}{s\, p_{\text{ref}}^2}\right), \tag{A.5}$$

where the sound exposure is given by

$$SE \equiv \int_0^T p(t)^2\, dt, \tag{A.6}$$

$p_{\text{ref}} = 2 \cdot 10^{-5}$ Pa. Thus, scaling of SE is given by

$$SE^{(h)} = \left(\frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}}\right)^2 \left(\frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}}\right)^{1/3} \frac{c^{(0)}}{c^{(h)}} SE^{(0)}, \qquad r = r^{(h)}, \tag{A.7}$$

since the distance from the source is also scaled. However, we want SE given for the specified height at the original distance $r = r^{(0)}$. We now assume linear sound propagation, i.e. no time scaling and pressure scaling $r^{(h)}/r^{(0)}$. Thus

$$SE^{(h)} = \left(\left(\frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}}\right)^{1/3} \frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}}\right)^2 \left(\frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}}\right)^{1/3} \frac{c^{(0)}}{c^{(h)}} SE^{(0)} = \frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}} \frac{c^{(0)}}{c^{(h)}} SE^{(0)}, \qquad r = r^{(0)}. \quad \text{(A.8)}$$

The difference in L_E is then given by

$$L_E^{(h)} = 10 \log \left(\frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}} \frac{c^{(0)}}{c^{(h)}} \right) + L_E^{(0)}. \quad \text{(A.9)}$$

From (A.1) and (A.2) we then get a simple formula for the scaling of L_E, as a function of h and T, in standard atmosphere:

$$L_E^{(h)} = 10 \log \left(\frac{\left[\frac{288.15}{288.15 - 0.0065h}\right]^{-5.2559}}{\sqrt{\frac{273.15+T}{288.15}}} \right) + L_E^{(0)}. \quad \text{(A.10)}$$

As an example we consider the measurements performed at Hjerkinn (actually closer to Dombås), where $h = 960$ m and $T = 10.5$ degrees Celsius. Then (A.10) gives

$$L_E^{(h)} = -0.50\,\text{dB} + 0.03\,\text{dB} + L_E^{(0)} = -0.47\,\text{dB} + L_E^{(0)}, \quad \text{(A.11)}$$

where we also see the individual contributions of the pressure and the temperature respectively.

At Hjerkinn we also measured the actual atmospheric pressure, $p_{\text{atm}}^{(h)}/p_{\text{atm}}^{(0)} = 0.883$. Then from (A.2) and (A.9) we get

$$L_E^{(h)} = -0.54\,\text{dB} + 0.03\,\text{dB} + L_E^{(0)} = -0.51\,\text{dB} + L_E^{(0)}, \quad \text{(A.12)}$$

A.5 Scaling factors for the measurements at Hjerkinn

At Hjerkinn (shooting from Turrhaugen) 960 m above sea level, the pressure was measured to $p_{\text{atm}}^{(h)} = 0.895 \cdot 10^5$ Pa and the temperature 10.5 degrees Celsius. From (A.2) we get the sound speed $c^{(h)} = 337.6$ m/s. From (A.4) we get

$$\begin{aligned} r^{(0)} &= \left(\frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}}\right)^{1/3} r^{(h)}, \\ p^{(0)} &= \frac{p_{\text{atm}}^{(0)}}{p_{\text{atm}}^{(h)}} p^{(h)}, \\ t^{(0)} &= \left(\frac{p_{\text{atm}}^{(h)}}{p_{\text{atm}}^{(0)}}\right)^{1/3} \frac{c^{(h)}}{c^{(0)}} t^{(h)}. \end{aligned} \quad \text{(A.13)}$$

By inserting the parameters for the condition at the measurement cite we get

$$\begin{aligned} r^{(0)} &= 0.959\, r^{(h)}, \\ p^{(0)} &= 1.132\, p^{(h)}, \\ t^{(0)} &= 0.952\, t^{(h)}, \end{aligned} \tag{A.14}$$

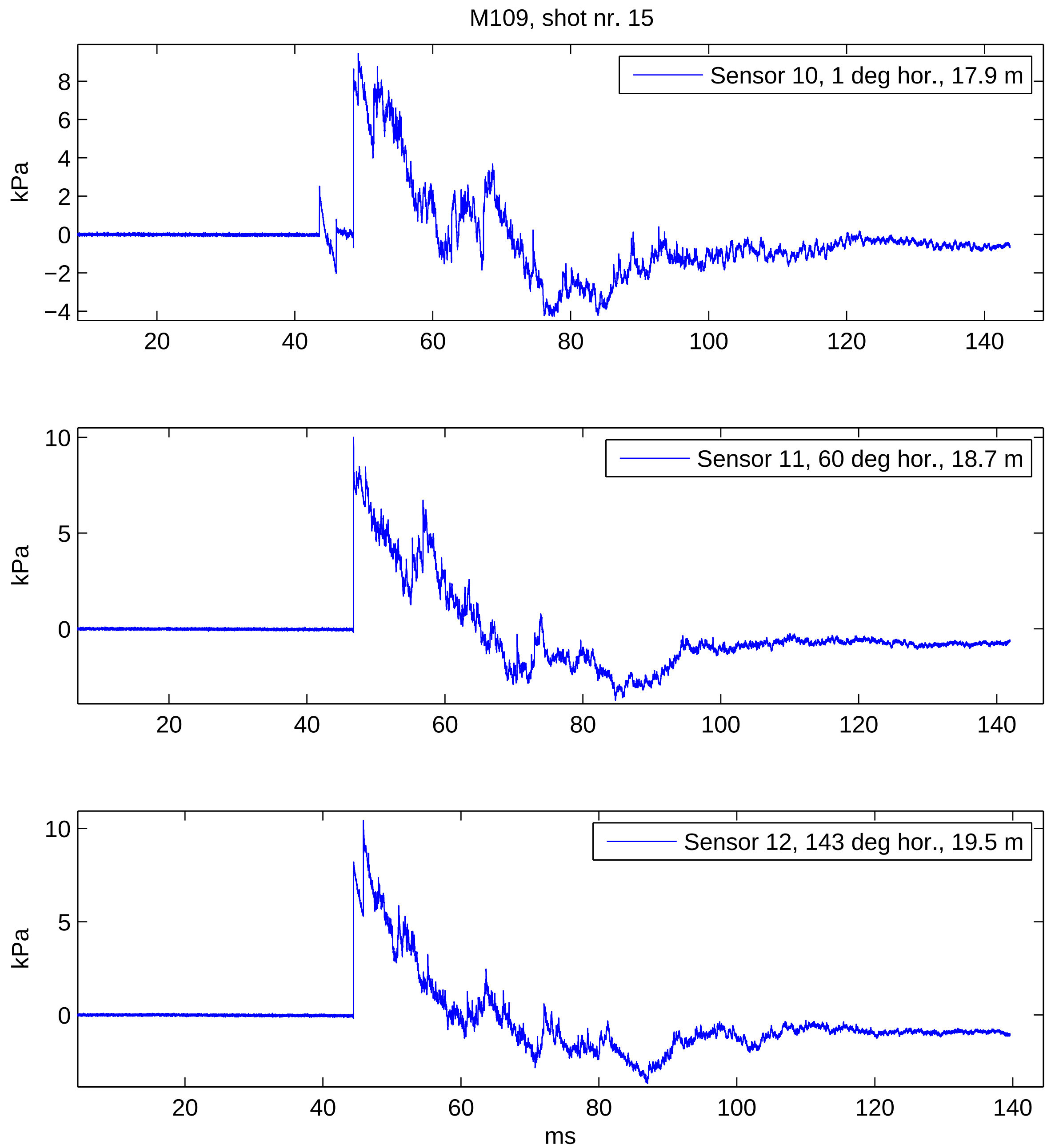
at the distance $r = r^{(0)}$ from the source. By performing the same linear calculation as in A.4 we get

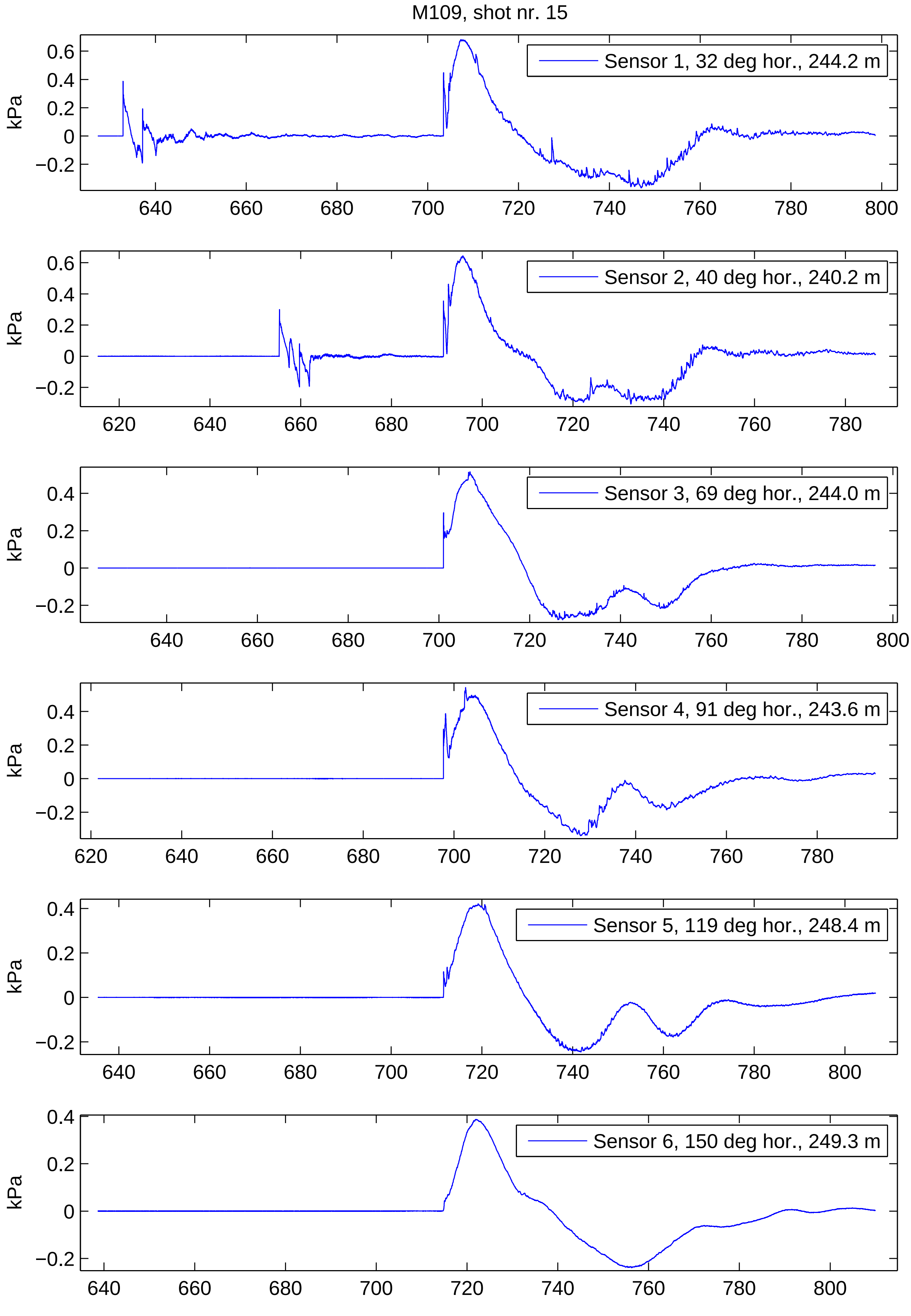
$$\begin{aligned} p^{(0)} &= 1.086\, p^{(h)}, \\ t^{(0)} &= 0.952\, t^{(h)}, \end{aligned} \tag{A.15}$$

at the distance $r = r^{(h)}$ from the source.

B Timeseries M109

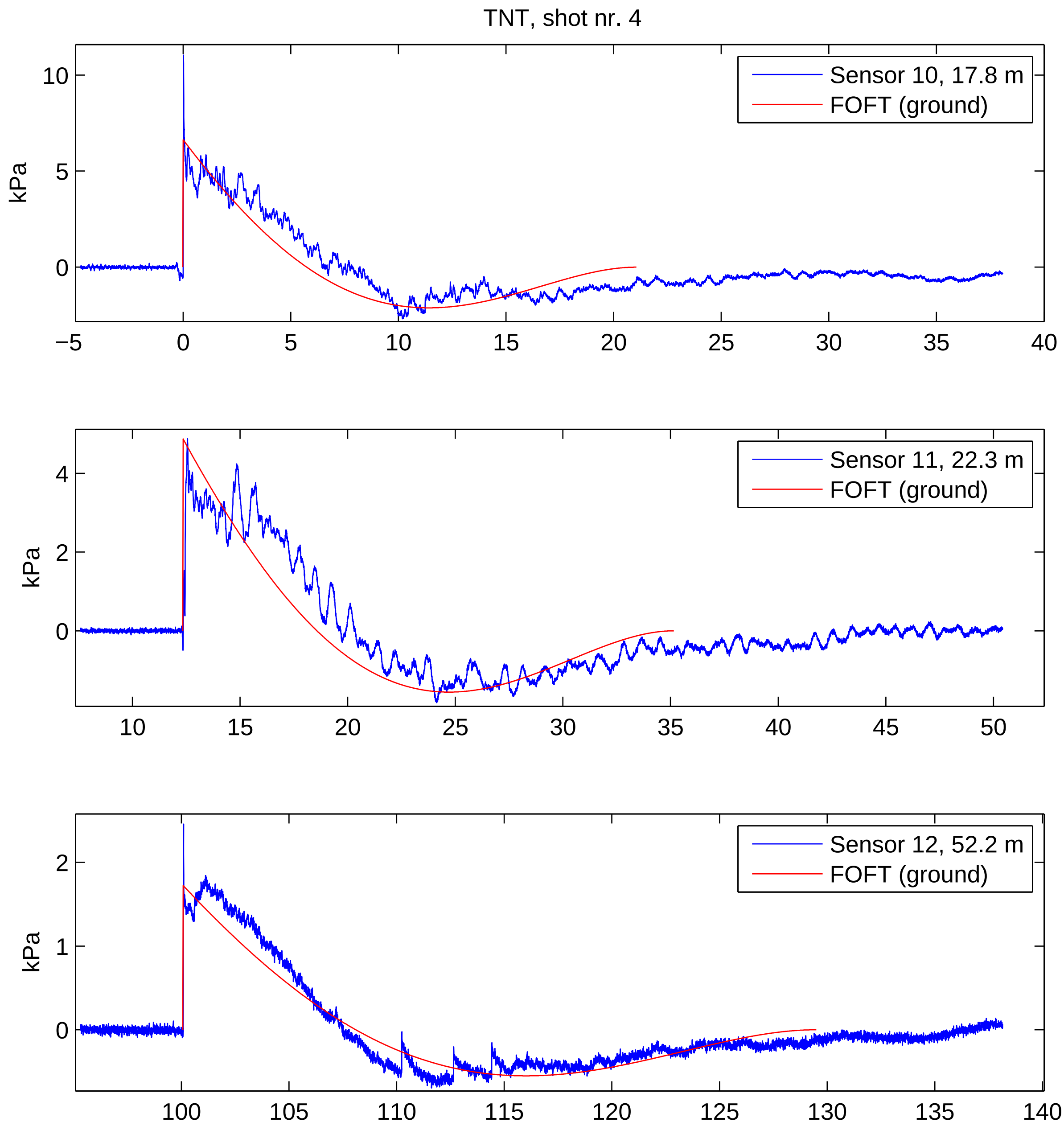
Timeseries for shot 15 for M109. The time is set relative to the flash sensor at the muzzle of the gun, i.e. the point in time when the projectile leaves the muzzle of the gun. All variables are scaled to sea level at 15 degrees Celsius.

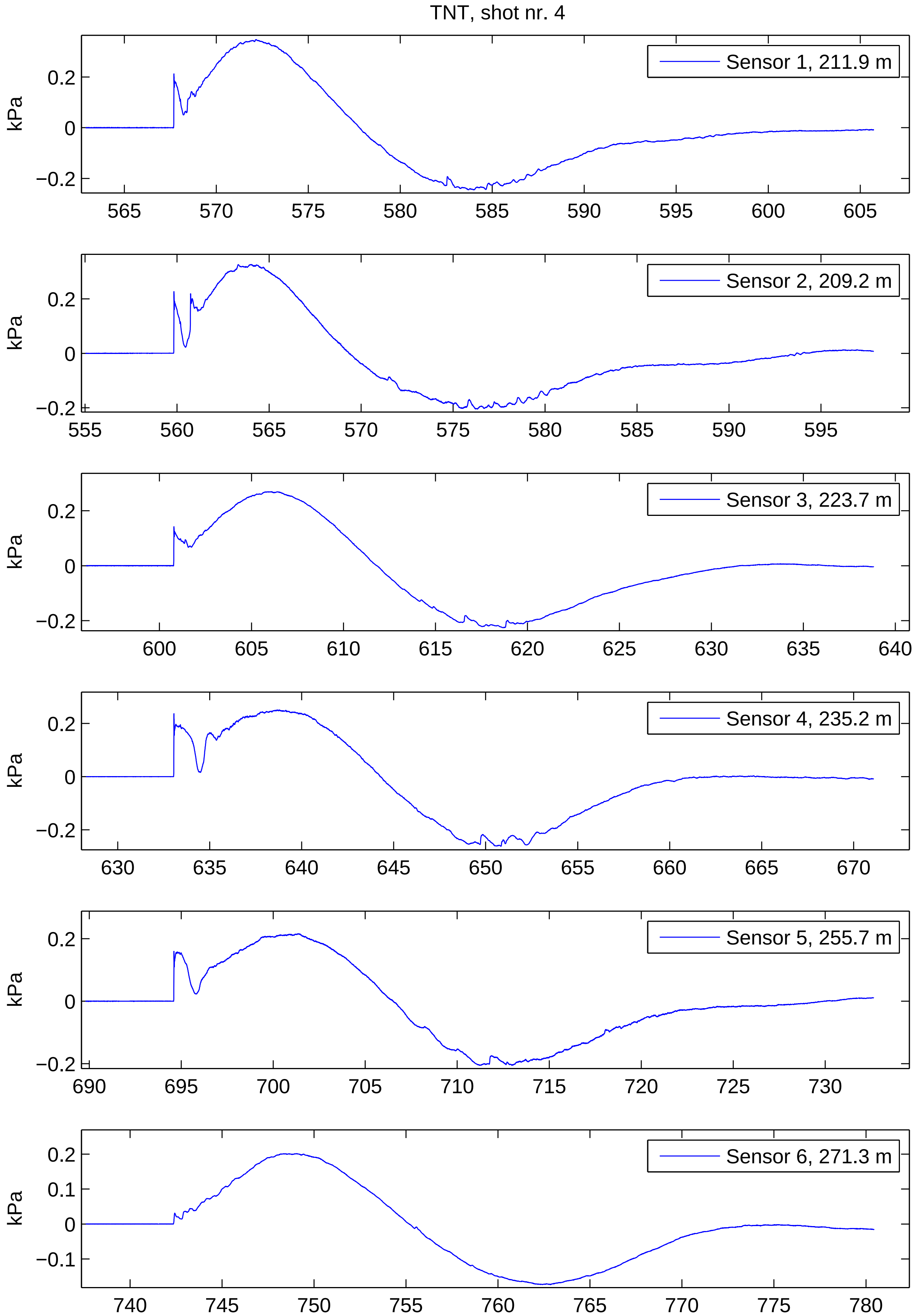



M109, shot nr. 15
Sensor 1, 32 deg hor., 244.2 m
Sensor 2, 40 deg hor., 240.2 m
Sensor 3, 69 deg hor., 244.0 m
Sensor 4, 91 deg hor., 243.6 m
Sensor 5, 119 deg hor., 248.4 m
Sensor 6, 150 deg hor., 249.3 m
kPa

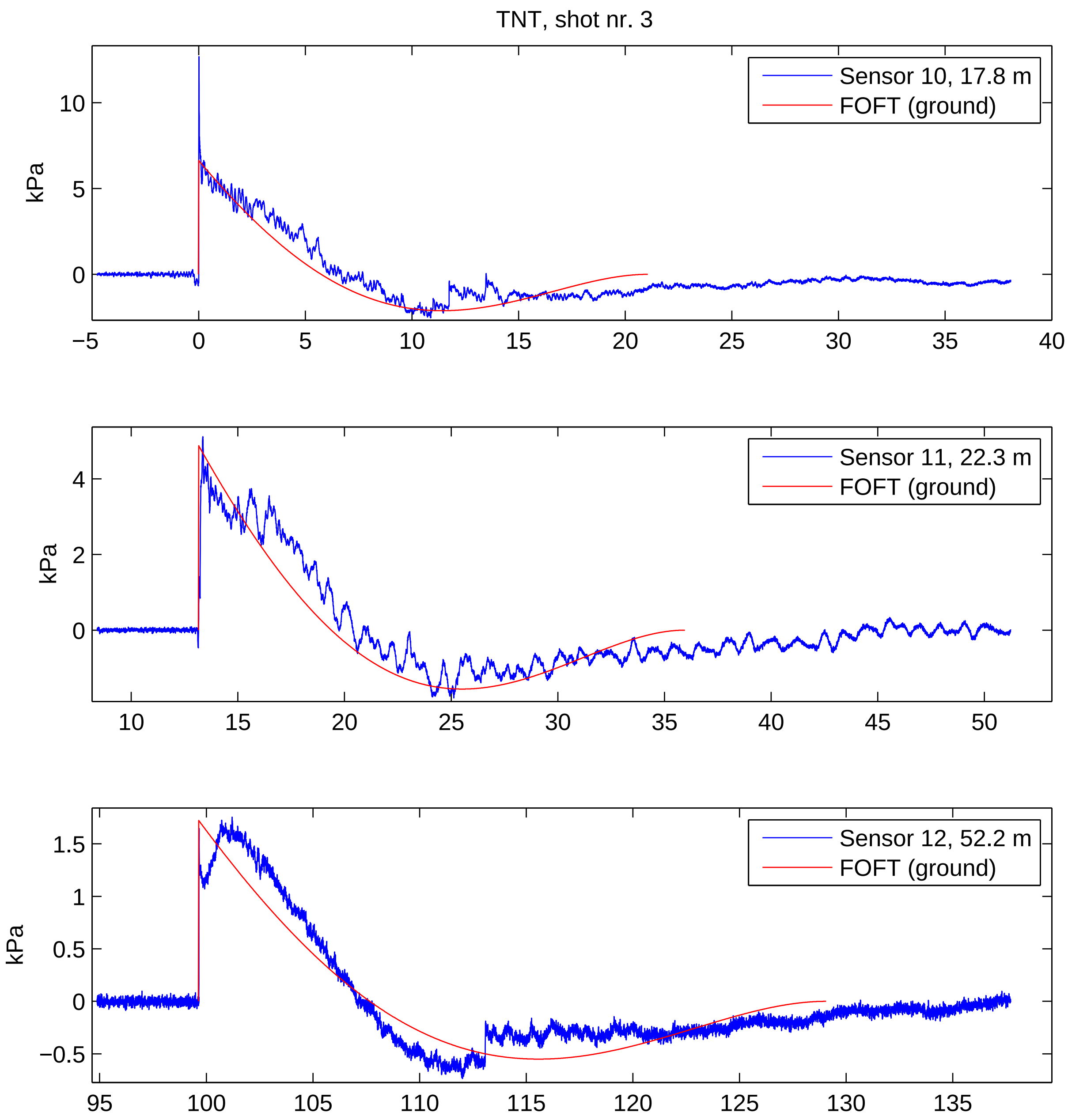
C Timeseries TNT

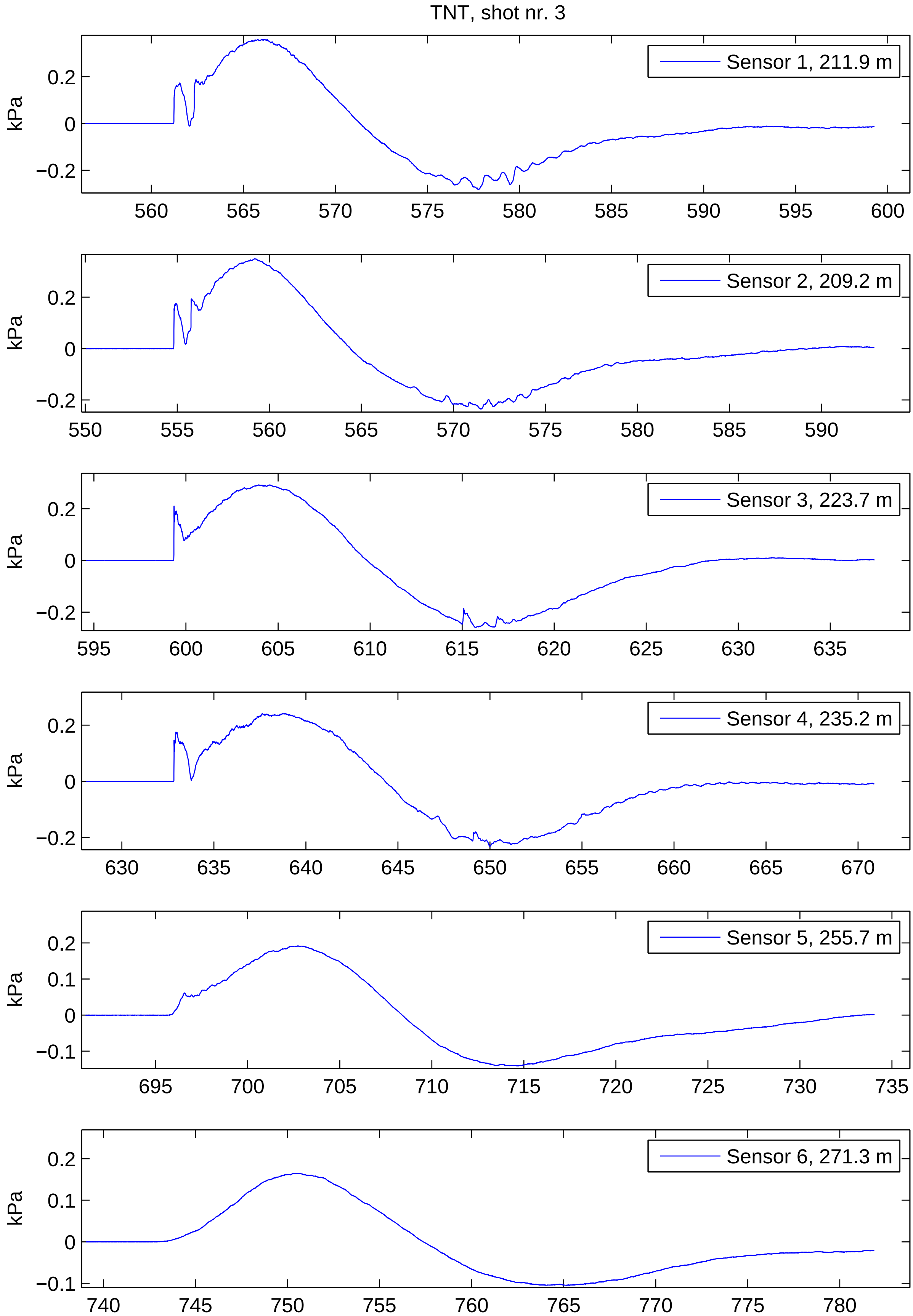
Timeseries for detonation 3 and 4 of 1 kg TNT. The ground correction is found by calculating the mean of the L_E spectra of these two. The time is set relative to the time when the shock front reaches sensor 10. All variables are scaled to sea level at 15 degrees Celsius.



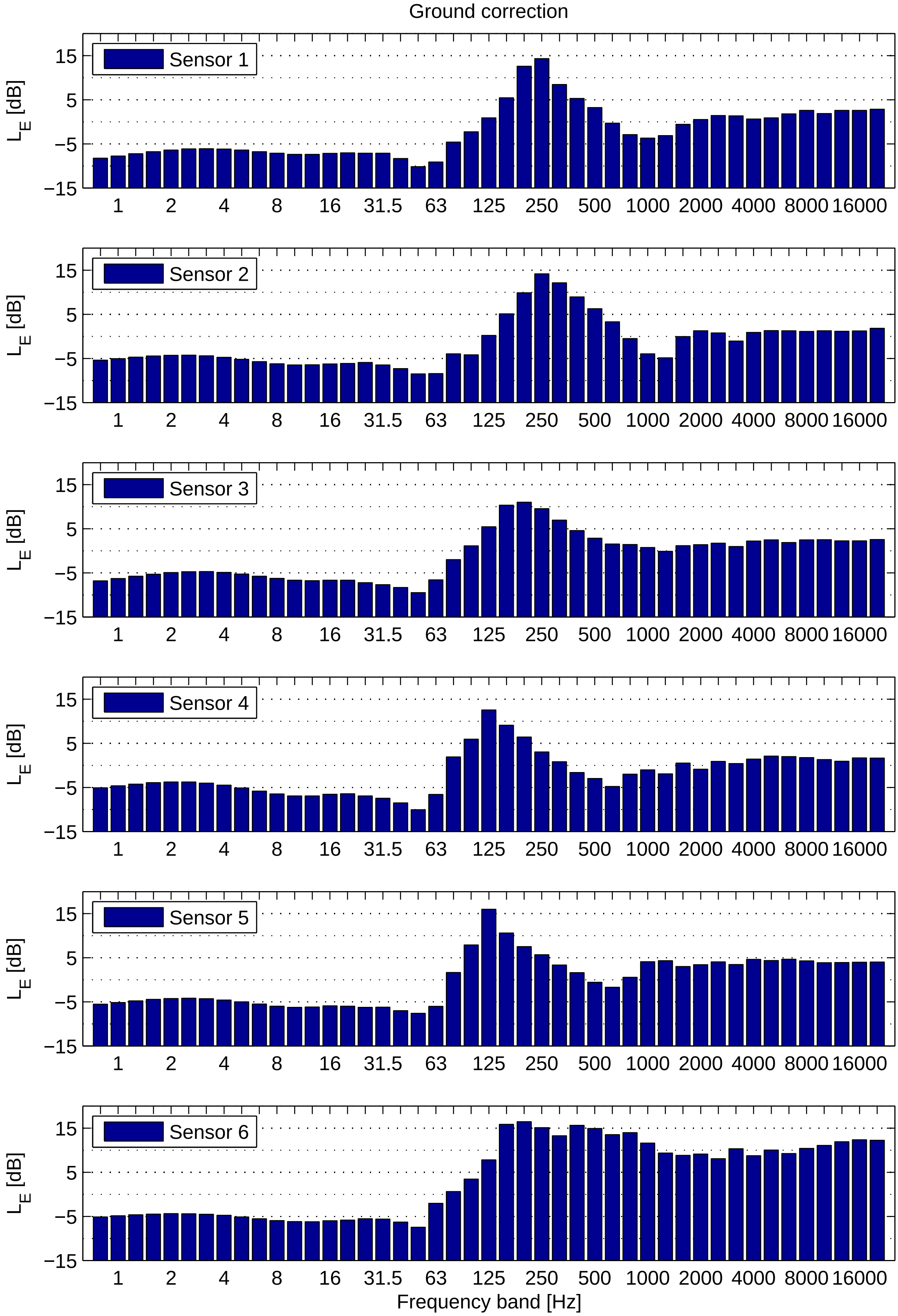


TNT, shot nr. 4
kPa
Sensor 1, 211.9 m
Sensor 2, 209.2 m
Sensor 3, 223.7 m
Sensor 4, 235.2 m
Sensor 5, 255.7 m
Sensor 6, 271.3 m


TNT, shot nr. 3
Sensor 10, 17.8 m
FOFT (ground)
kPa
10
5
0
−5
0
5
10
15
20
25
30
35
40
Sensor 11, 22.3 m
FOFT (ground)
kPa
4
2
0
10
15
20
25
30
35
40
45
50
Sensor 12, 52.2 m
FOFT (ground)
kPa
1.5
1
0.5
0
−0.5
95
100
105
110
115
120
125
130
135


TNT, shot nr. 3
kPa
0.2
0
−0.2
560
565
570
575
580
585
590
595
600
Sensor 1, 211.9 m
kPa
0.2
0
−0.2
550
555
560
565
570
575
580
585
590
Sensor 2, 209.2 m
kPa
0.2
0
−0.2
595
600
605
610
615
620
625
630
635
Sensor 3, 223.7 m
kPa
0.2
0
−0.2
630
635
640
645
650
655
660
665
670
Sensor 4, 235.2 m
kPa
0.2
0.1
0
−0.1
695
700
705
710
715
720
725
730
735
Sensor 5, 255.7 m
kPa
0.2
0.1
0
−0.1
740
745
750
755
760
765
770
775
780
Sensor 6, 271.3 m

D Ground correction



Freq	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6
0.8	-8.3	-5.4	-6.8	-5.1	-5.6	-5.1
1	-7.8	-5.0	-6.3	-4.7	-5.2	-4.9
1.25	-7.2	-4.7	-5.8	-4.3	-4.8	-4.7
1.6	-6.8	-4.4	-5.3	-3.9	-4.4	-4.5
2	-6.4	-4.3	-4.9	-3.8	-4.2	-4.4
2.5	-6.2	-4.3	-4.7	-3.8	-4.2	-4.4
3.15	-6.1	-4.4	-4.7	-4.0	-4.3	-4.5
4	-6.2	-4.8	-4.9	-4.5	-4.6	-4.8
5	-6.4	-5.2	-5.3	-5.1	-5.0	-5.1
6.3	-6.8	-5.7	-5.7	-5.8	-5.5	-5.5
8	-7.1	-6.2	-6.3	-6.5	-6.0	-5.9
10	-7.4	-6.5	-6.7	-6.9	-6.2	-6.2
12.5	-7.4	-6.5	-6.8	-6.9	-6.2	-6.2
16	-7.1	-6.3	-6.7	-6.6	-5.9	-6.0
20	-7.1	-6.1	-6.7	-6.4	-6.0	-5.8
25	-7.1	-5.9	-7.2	-6.9	-6.3	-5.5
31.5	-7.1	-6.5	-7.7	-7.5	-6.2	-5.6
40	-8.3	-7.3	-8.3	-8.5	-7.0	-6.3
50	-10.2	-8.5	-9.5	-10.1	-7.6	-7.5
63	-9.1	-8.4	-6.6	-6.6	-6.0	-2.0
80	-4.6	-3.9	-2.0	1.9	1.7	0.6
100	-2.3	-4.2	1.1	5.9	7.9	3.5
125	0.9	0.2	5.4	12.5	16.0	7.8
160	5.4	5.1	10.4	9.1	10.6	15.8
200	12.6	9.9	11.0	6.4	7.5	16.4
250	14.3	14.2	9.6	3.0	5.7	15.1
315	8.4	12.1	7.0	0.8	3.3	13.2
400	5.3	8.9	4.6	-1.6	1.6	15.6
500	3.2	6.3	2.9	-3.0	-0.6	14.9
630	-0.3	3.3	1.5	-4.8	-1.7	13.5
800	-2.9	-0.5	1.4	-2.0	0.6	14.0
1000	-3.7	-4.0	0.7	-1.0	4.1	11.6
1250	-3.1	-4.9	-0.1	-1.9	4.3	9.3
1600	-0.6	-0.0	1.2	0.5	3.0	8.8
2000	0.5	1.3	1.4	-0.9	3.4	9.1
2500	1.4	0.8	1.7	0.9	4.1	8.1
3150	1.3	-1.1	1.0	0.4	3.4	10.3
4000	0.6	0.9	2.2	1.4	4.6	8.7
5000	0.9	1.3	2.5	2.1	4.4	10.0
6300	1.8	1.3	1.9	2.0	4.7	9.2
8000	2.6	1.1	2.5	1.8	4.3	10.4
10000	1.9	1.3	2.5	1.3	3.9	11.1
12500	2.6	1.1	2.3	0.9	3.9	11.9
16000	2.6	1.2	2.2	1.7	4.0	12.4
20000	2.8	1.8	2.6	1.6	4.0	12.2

Table D.1: Ground correcton in 6 directions (in dB).

E Free field spectrum M109, 245 m from muzzle

The levels have been produced taking the energy mean of the 15 shots. The procedure is described in [2]. This is free field values for M109, resulting from removing the ground effect from the measured levels. Figures E.1–E.6 are graphical interpretations of Table E.1.

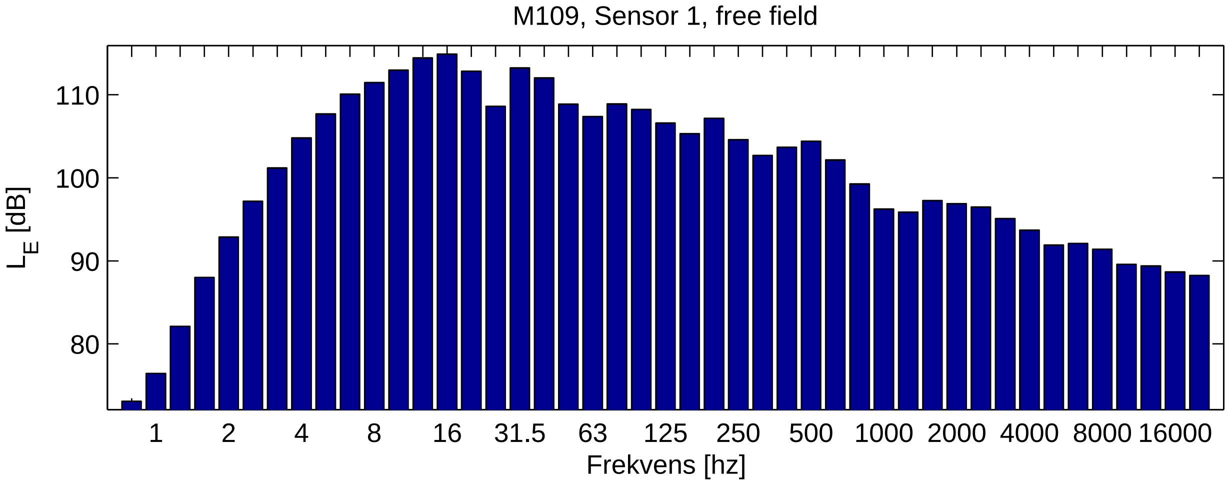


Figure E.1: Free field M109 at sensor 1, 32 degrees (horizontal) from the firing direction, 244 m from the muzzle.

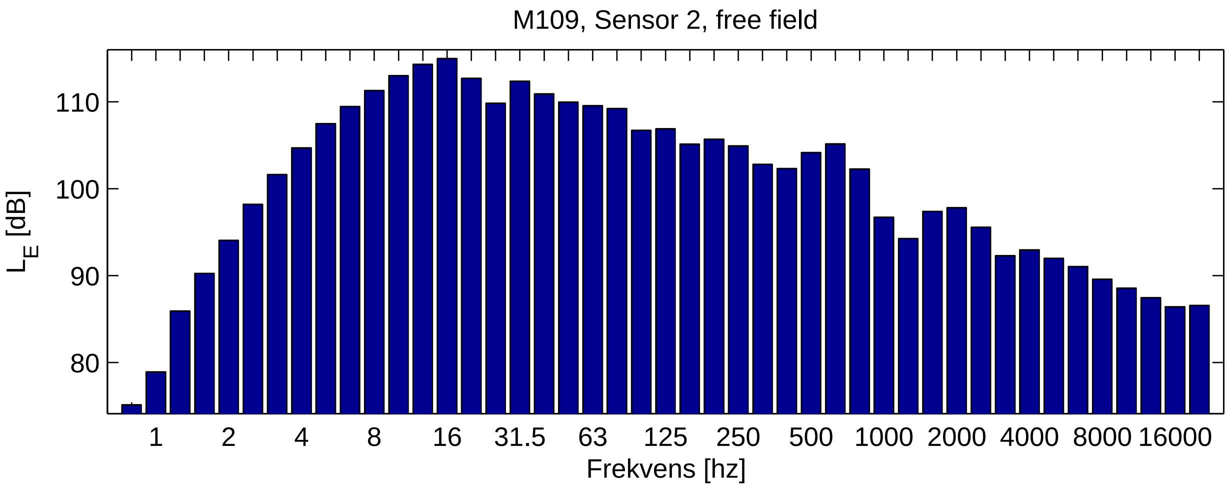


Figure E.2: Free field M109 at sensor 2, 40 degrees (horizontal) from the firing direction, 240 m from the muzzle.

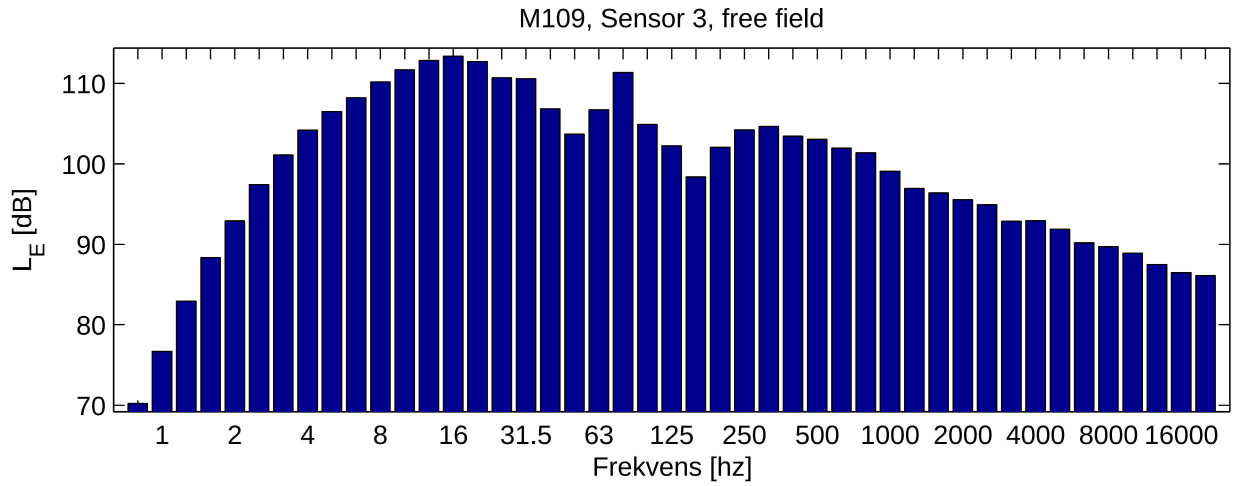


Figure E.3: Free field M109 at sensor 3, 69 degrees (horizontal) from the firing direction, 244 m from the muzzle..

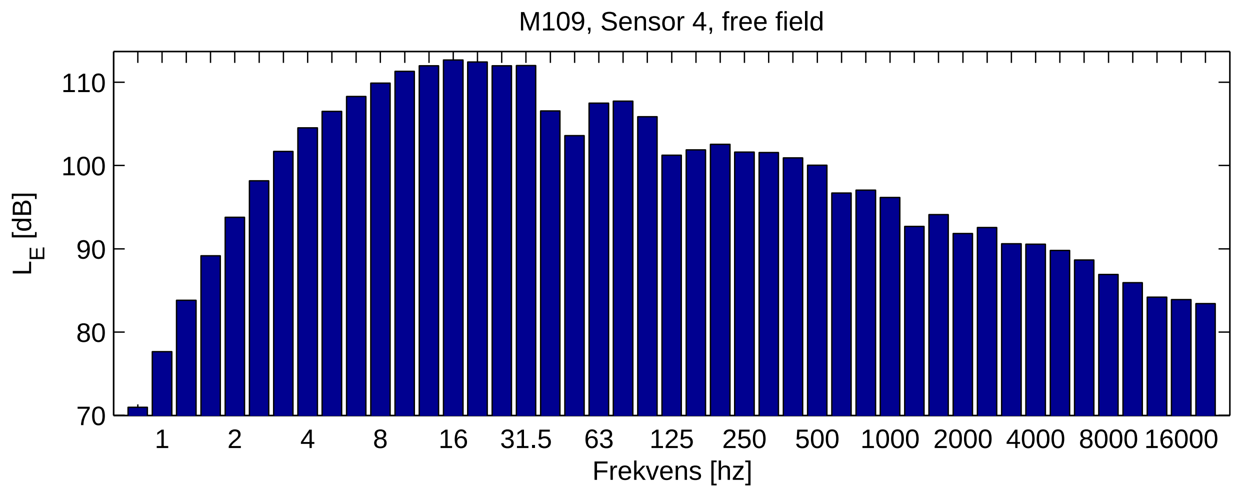


Figure E.4: Free field M109 at sensor 4, 91 degrees (horizontal) from the firing direction, 244 m from the muzzle..

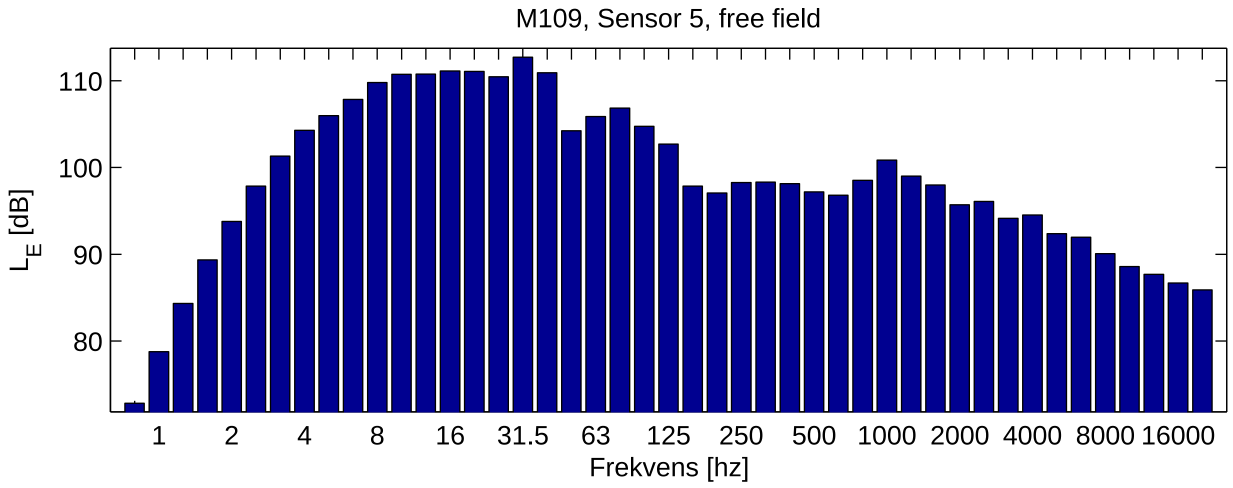


Figure E.5: Free field M109 at sensor 5, 119 degrees (horizontal) from the firing direction, 248 m from the muzzle..

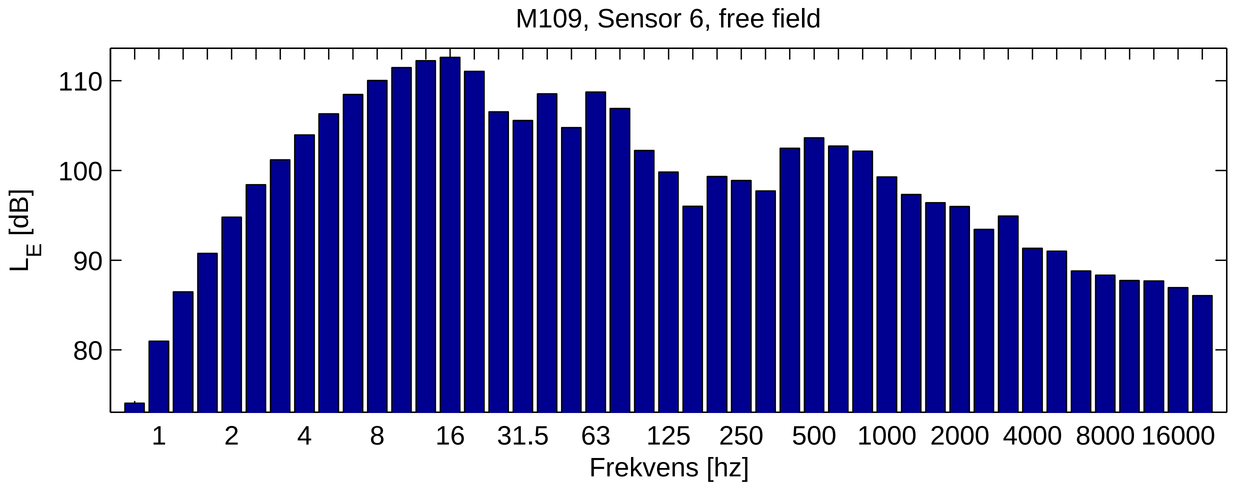


Figure E.6: Free field M109 at sensor 6, 150 degrees (horizontal) from the firing direction, 249 m from the muzzle..

Freq	Sensor 1 32 deg	Sensor 2 40 deg	Sensor 3 69 deg	Sensor 4 91 deg	Sensor 5 119 deg	Sensor 6 150 deg
Sum	123.7	123.7	122.4	122.0	121.5	121.3
0.8	73.1	75.1	70.2	71.0	72.8	74.1
1	76.4	78.9	76.7	77.6	78.8	81.0
1.25	82.1	85.9	82.9	83.8	84.3	86.5
1.6	88.0	90.3	88.3	89.2	89.3	90.8
2	92.9	94.1	92.9	93.8	93.8	94.8
2.5	97.2	98.2	97.4	98.2	97.9	98.4
3.15	101.2	101.6	101.1	101.7	101.3	101.2
4	104.8	104.7	104.2	104.5	104.3	104.0
5	107.7	107.5	106.5	106.5	106.0	106.3
6.3	110.1	109.5	108.2	108.3	107.8	108.5
8	111.5	111.3	110.2	109.9	109.8	110.0
10	113.0	113.0	111.7	111.3	110.7	111.5
12.5	114.5	114.3	112.9	112.0	110.8	112.2
16	114.9	115.0	113.4	112.7	111.1	112.6
20	112.8	112.7	112.7	112.4	111.1	111.1
25	108.6	109.9	110.7	112.0	110.5	106.5
31.5	113.2	112.4	110.6	112.0	112.7	105.6
40	112.0	110.9	106.8	106.6	110.9	108.5
50	108.9	110.0	103.7	103.6	104.2	104.8
63	107.4	109.6	106.7	107.5	105.9	108.7
80	108.9	109.3	111.4	107.7	106.8	106.9
100	108.3	106.7	104.9	105.9	104.8	102.2
125	106.6	106.9	102.2	101.3	102.7	99.8
160	105.3	105.2	98.4	101.9	97.9	96.0
200	107.2	105.7	102.0	102.6	97.1	99.3
250	104.6	104.9	104.2	101.6	98.3	98.9
315	102.7	102.8	104.7	101.5	98.3	97.7
400	103.7	102.3	103.4	100.9	98.1	102.5
500	104.4	104.2	103.1	100.0	97.2	103.6
630	102.2	105.2	102.0	96.7	96.8	102.7
800	99.3	102.3	101.4	97.1	98.5	102.2
1000	96.2	96.7	99.1	96.2	100.8	99.3
1250	95.9	94.3	97.0	92.7	99.0	97.3
1600	97.3	97.4	96.4	94.1	98.0	96.4
2000	96.9	97.8	95.5	91.8	95.7	96.0
2500	96.5	95.6	94.9	92.5	96.1	93.4
3150	95.1	92.3	92.9	90.6	94.1	94.9
4000	93.7	93.0	92.9	90.5	94.5	91.3
5000	91.9	92.0	91.9	89.8	92.4	91.0
6300	92.1	91.1	90.2	88.7	92.0	88.8
8000	91.4	89.6	89.7	86.9	90.1	88.3
10000	89.6	88.6	88.9	85.9	88.6	87.7
12500	89.4	87.5	87.5	84.2	87.7	87.7
16000	88.7	86.4	86.5	83.9	86.7	86.9
20000	88.3	86.6	86.1	83.4	85.9	86.0

Table E.1: Free field M109, approximately scaled distanced 245 m. Angles are in the horizontal plane.

Freq	Sensor 1	Sensor 2	Sensor 3	Sensor 4	Sensor 5	Sensor 6	Sensor 7
	32 deg	40 deg	69 deg	91 deg	119 deg	150 deg	175 deg
Sum	130.5	129.6	128.3	128.2	127.1	126.4	126.8
0.8	81.4	80.5	77.0	76.0	78.4	79.2	90.1
1	84.2	84.0	83.0	82.3	83.9	85.8	90.6
1.25	89.4	90.7	88.7	88.1	89.1	91.1	91.1
1.6	94.8	94.7	93.6	93.1	93.8	95.2	93.3
2	99.3	98.4	97.8	97.6	98.0	99.2	98.0
2.5	103.3	102.5	102.2	102.0	102.1	102.8	101.6
3.15	107.3	106.1	105.8	105.7	105.6	105.7	104.3
4	111.0	109.5	109.1	109.0	108.9	108.7	107.2
5	114.1	112.7	111.8	111.7	111.0	111.4	110.1
6.3	116.9	115.2	114.0	114.1	113.3	114.0	113.0
8	118.6	117.5	116.4	116.4	115.8	116.0	115.3
10	120.4	119.5	118.3	118.2	117.0	117.7	117.2
12.5	121.8	120.8	119.6	118.9	117.0	118.5	118.4
16	122.1	121.3	120.0	119.2	117.0	118.6	119.0
20	119.9	118.9	119.4	118.9	117.0	116.9	117.8
25	115.8	115.8	117.9	118.9	116.7	112.1	112.5
31.5	120.4	118.9	118.3	119.5	118.9	111.2	110.4
40	120.4	118.2	115.1	115.1	117.9	114.8	115.6
50	119.1	118.5	113.2	113.7	111.8	112.2	116.1
63	116.5	118.0	113.3	114.1	111.9	110.8	114.2
80	113.5	113.2	113.4	105.8	105.2	106.3	108.3
100	110.5	110.9	103.8	99.9	96.8	98.8	102.4
125	105.7	106.7	96.8	88.7	86.7	92.0	95.9
160	99.9	100.1	88.0	92.8	87.2	80.2	84.4
200	94.6	95.8	91.0	96.1	89.5	82.9	87.2
250	90.3	90.8	94.7	98.6	92.6	83.8	90.1
315	94.3	90.7	97.7	100.8	95.0	84.5	92.5
400	98.4	93.4	98.8	102.5	96.5	86.9	93.4
500	101.2	97.9	100.2	103.0	97.8	88.7	96.0
630	102.5	101.9	100.4	101.5	98.5	89.2	97.4
800	102.2	102.8	99.9	99.1	98.0	88.2	96.6
1000	99.9	100.7	98.3	97.2	96.7	87.7	94.7
1250	99.0	99.1	97.1	94.6	94.7	88.0	92.7
1600	97.8	97.4	95.2	93.6	95.0	87.6	92.5
2000	96.4	96.6	94.2	92.7	92.3	86.9	91.2
2500	95.1	94.8	93.2	91.7	92.0	85.4	90.2
3150	93.8	93.4	91.9	90.2	90.7	84.6	88.6
4000	93.1	92.1	90.7	89.1	89.9	82.6	87.0
5000	91.1	90.7	89.4	87.7	88.0	81.0	86.8
6300	90.3	89.8	88.3	86.7	87.3	79.6	85.7
8000	88.8	88.5	87.2	85.2	85.8	77.9	85.4
10000	87.7	87.3	86.4	84.6	84.7	76.6	84.8
12500	86.8	86.3	85.2	83.3	83.8	75.8	84.0
16000	86.1	85.2	84.2	82.2	82.7	74.6	82.5
20000	85.4	84.8	83.5	81.8	81.9	73.8	81.6

Table E.2: M109 at approximately 245 m, measured data without ground correction. Angles are in the horizontal plane.

F Free field M109, 10 m ref, uniform angles.

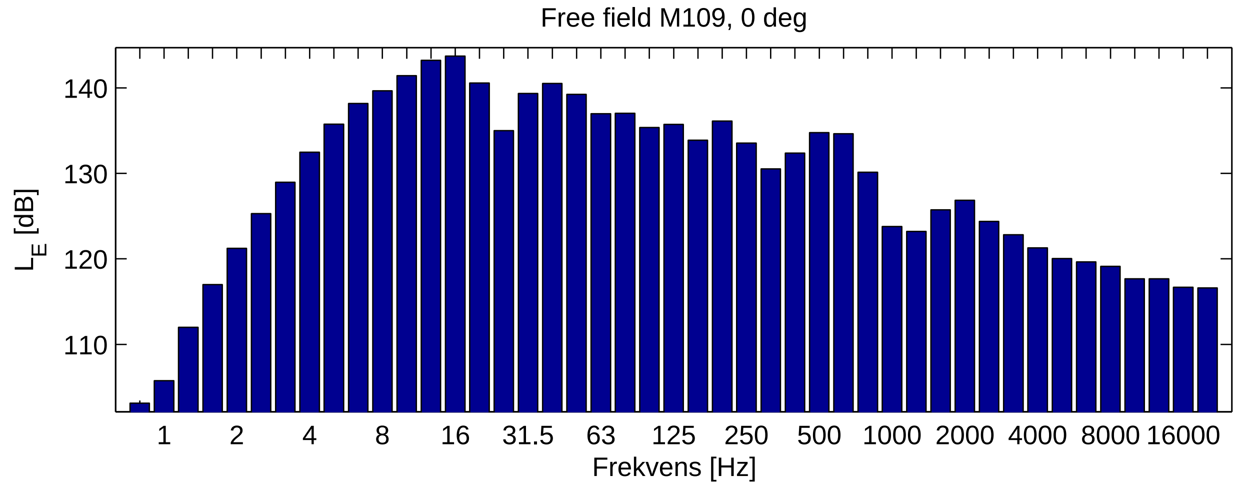


Figure F.1: Free field M109, reference level at 10 m, 0 degrees (horizontal) from the firing direction.

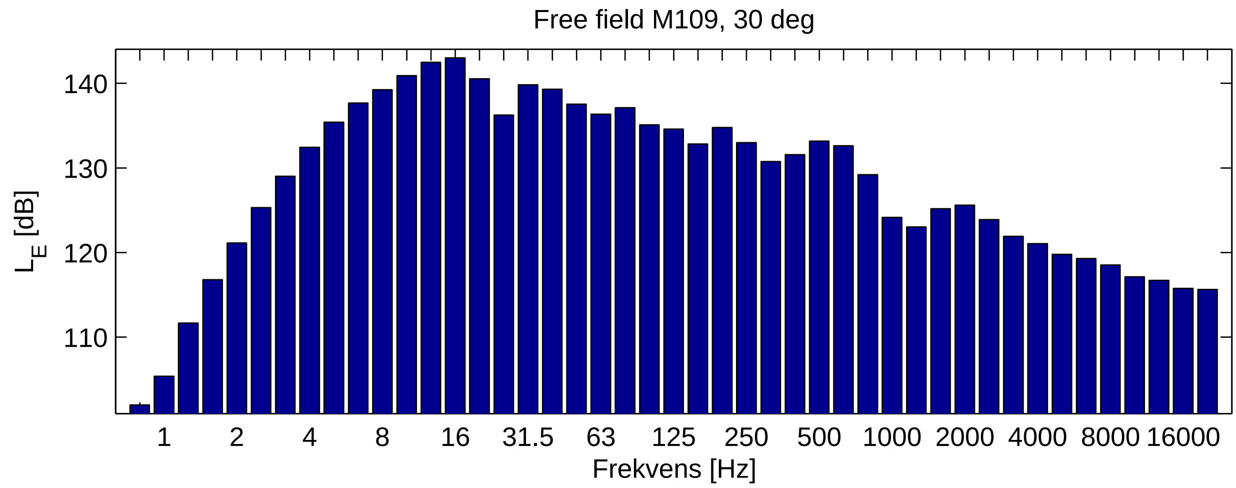


Figure F.2: Free field M109, reference level at 10 m, 30 degrees (horizontal) from the firing direction.

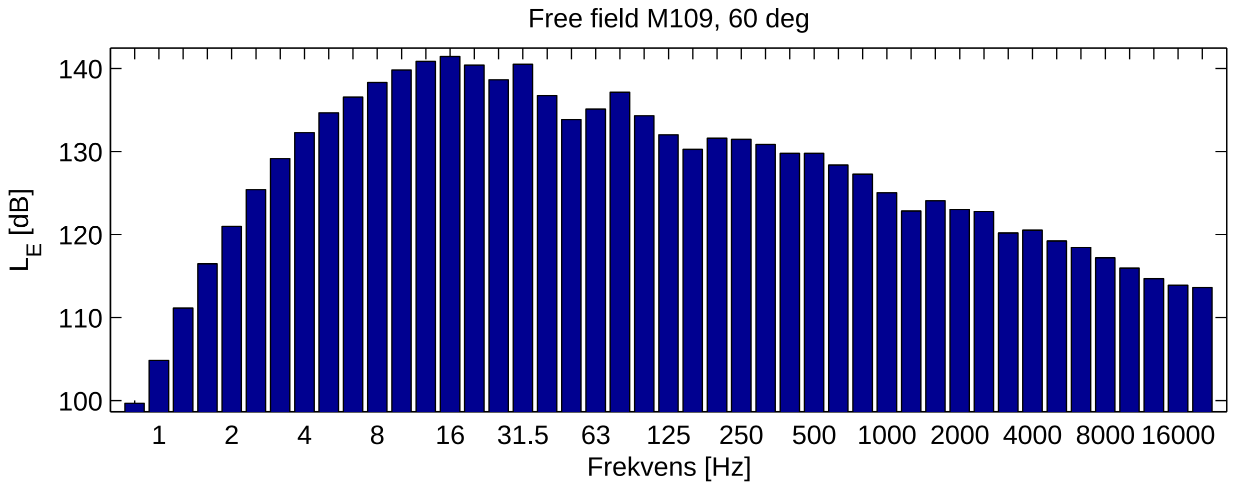


Figure F.3: Free field M109, reference level at 10 m, 60 degrees (horizontal) from the firing direction.

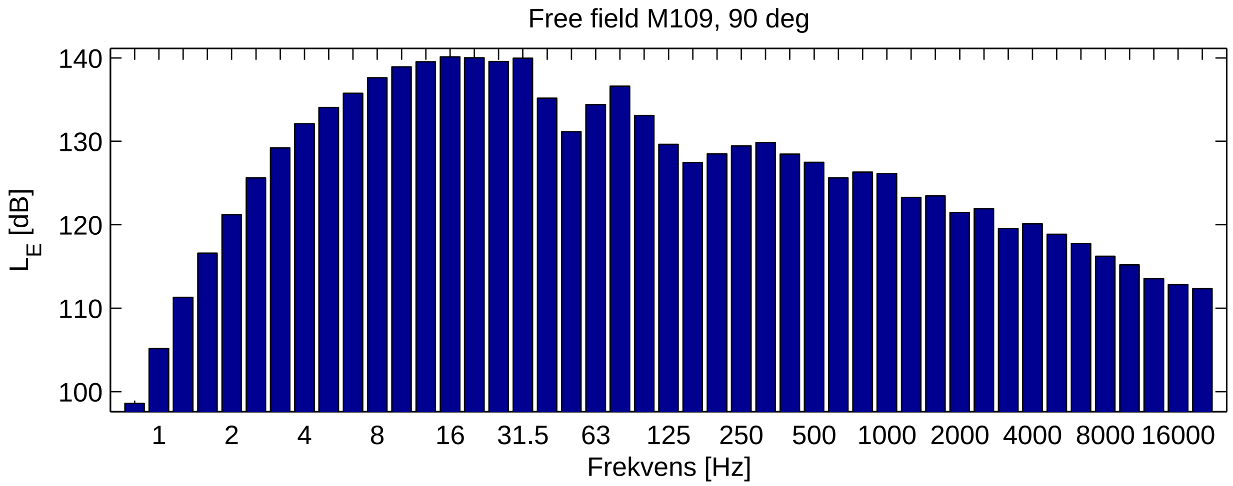


Figure F.4: Free field M109, reference level at 10 m, 90 degrees (horizontal) from the firing direction.

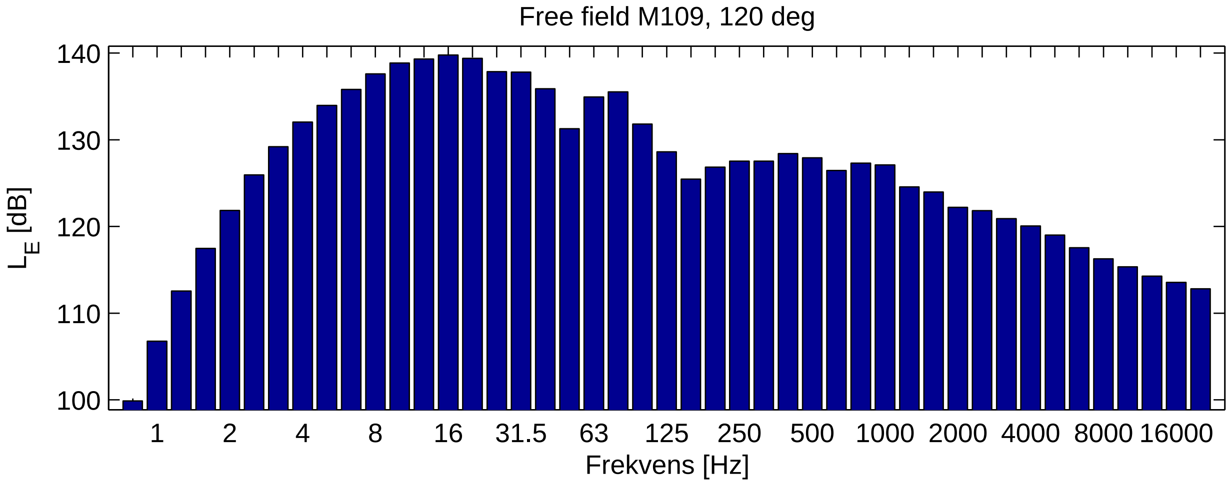


Figure F.5: Free field M109, reference level at 10 m, 120 degrees (horizontal) from the firing direction.

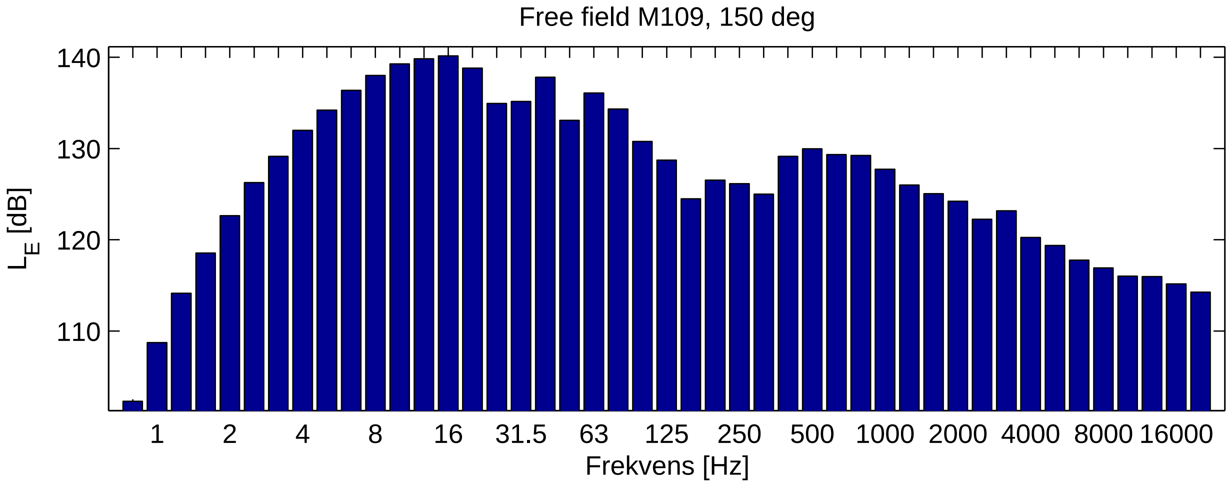


Figure F.6: Free field M109, reference level at 10 m, 150 degrees (horizontal) from the firing direction.

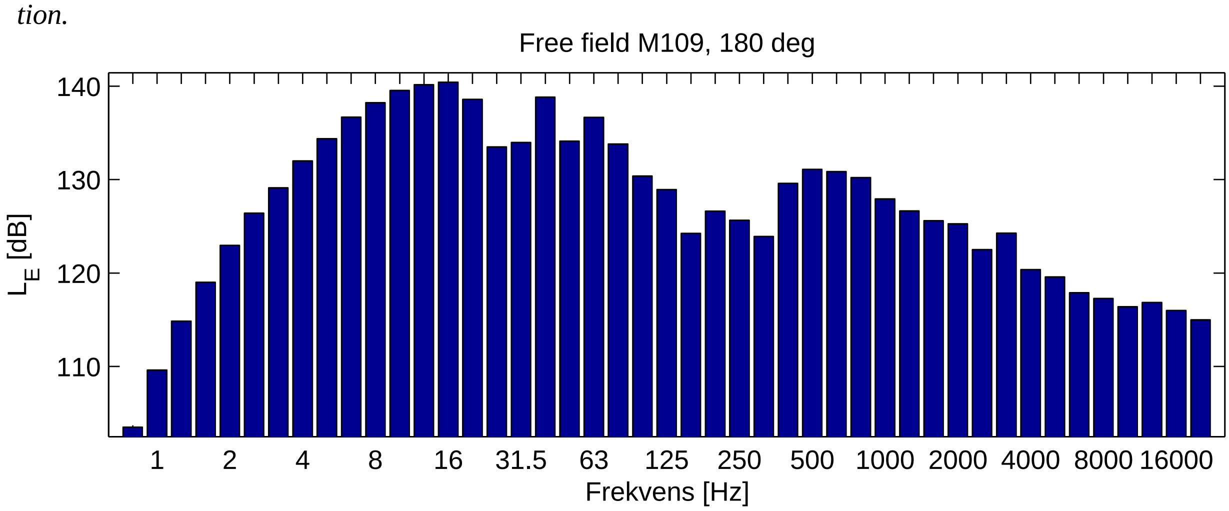


Figure F.7: Free field M109, reference level at 10 m, 180 degrees (horizontal) from the firing direction.

Freq	0 deg	30 deg	60 deg	90 deg	120 deg	150 deg	180 deg
Sum	152.1	151.5	150.5	149.7	149.1	149.2	149.4
0.8	103.1	102.0	99.7	98.6	99.9	102.3	103.5
1	105.7	105.4	104.8	105.2	106.8	108.7	109.6
1.25	112.0	111.7	111.1	111.3	112.6	114.1	114.8
1.6	117.0	116.8	116.5	116.6	117.5	118.5	119.0
2	121.2	121.1	121.0	121.2	121.9	122.6	123.0
2.5	125.3	125.3	125.4	125.6	125.9	126.3	126.4
3.15	129.0	129.0	129.1	129.2	129.2	129.2	129.1
4	132.5	132.4	132.3	132.1	132.0	132.0	132.0
5	135.8	135.4	134.7	134.1	134.0	134.2	134.4
6.3	138.2	137.7	136.6	135.8	135.8	136.4	136.7
8	139.7	139.2	138.3	137.6	137.6	138.0	138.2
10	141.4	140.9	139.8	138.9	138.8	139.3	139.5
12.5	143.2	142.5	140.8	139.5	139.3	139.8	140.2
16	143.7	143.0	141.4	140.1	139.8	140.2	140.4
20	140.6	140.5	140.4	140.0	139.4	138.8	138.6
25	135.0	136.2	138.6	139.6	137.9	134.9	133.5
31.5	139.4	139.8	140.5	140.0	137.8	135.2	134.0
40	140.5	139.3	136.7	135.2	135.9	137.8	138.8
50	139.3	137.5	133.8	131.2	131.3	133.1	134.1
63	137.0	136.4	135.1	134.4	134.9	136.1	136.7
80	137.0	137.1	137.1	136.6	135.5	134.3	133.8
100	135.4	135.1	134.3	133.1	131.8	130.8	130.4
125	135.7	134.6	132.0	129.6	128.6	128.7	128.9
160	133.9	132.8	130.3	127.5	125.5	124.5	124.3
200	136.1	134.8	131.6	128.5	126.8	126.5	126.6
250	133.5	133.0	131.5	129.5	127.5	126.1	125.7
315	130.5	130.7	130.8	129.8	127.5	125.0	123.9
400	132.4	131.6	129.8	128.5	128.4	129.1	129.6
500	134.8	133.2	129.8	127.5	127.9	130.0	131.1
630	134.7	132.6	128.4	125.6	126.5	129.3	130.9
800	130.2	129.2	127.3	126.3	127.3	129.2	130.2
1000	123.8	124.1	125.0	126.1	127.1	127.7	127.9
1250	123.2	123.0	122.8	123.3	124.6	126.0	126.6
1600	125.7	125.2	124.1	123.5	124.0	125.1	125.6
2000	126.9	125.6	123.0	121.5	122.2	124.2	125.3
2500	124.4	123.9	122.8	121.9	121.8	122.3	122.5
3150	122.8	121.9	120.2	119.5	120.9	123.2	124.3
4000	121.3	121.1	120.5	120.1	120.1	120.2	120.4
5000	120.0	119.8	119.2	118.9	119.0	119.4	119.6
6300	119.7	119.3	118.4	117.7	117.6	117.8	117.9
8000	119.1	118.5	117.2	116.2	116.3	116.9	117.3
10000	117.7	117.1	116.0	115.2	115.3	116.0	116.4
12500	117.7	116.7	114.7	113.5	114.3	116.0	116.8
16000	116.7	115.8	113.9	112.8	113.5	115.2	116.0
20000	116.6	115.6	113.6	112.4	112.8	114.3	115.0

Table F.1: Free field 1/3-octave SEL-spectrum for M109, 10 m reference level, uniform angular segments .

G Errors found in FFI-rapport 2007/01450

During the work with this report, some errors were detected in the report containing the raw data, FFI-rapport 2007/01450 [11].

- Page 32, caption for Figure F.1: “shot nr. 3” should be “shot nr. 4”.
- Page 15, Table 4.2: Angle to firing direction is wrong. This angle is calculated from the horizontal angle and the elevations angle the weapon. The wrong angles are also given in the plots and tables in Appendices A–E in [11]. The correct angles are given in Table 4.1 in this report.

H Emisiondata for MILSTØY

Data til MilstoeyII:
Vaapen: M109A3GN (155 mm felthaubits), navn: Didrik.
Elevasjon 18.7 grader.
Ammunisjon: 5 moduler DM72 (maks), DM662.
Maaling: 21 Sept. 2007, Hjerkinn (Turrhaugen).
Versjon kildedata: 1
Dokumentasjon: FFI-rapport 2007/01450 og FFI-rapport 2007/02530.

Det er 45 1/3-oktavbaand fra 0.8 Hz til 20 kHz senterfrekvens.
Senterfrekvensene er (Hz):
0.80 1.00 1.25 1.60 2.00 2.50 3.15 4.00 5.00 6.30 8.00 10.00 12.50 16.00 20.00
25.00 31.50 40.00 50.00 63.00 80.00 100.00 125.00 160.00 200.00 250.00 315.00
400.00 500.00 630.00 800.00 1000.00 1250.00 1600.00 2000.00 2500.00 3150.00
4000.00 5000.00 6300.00 8000.00 10000.00 12500.00 16000.00 20000.00
Det er maalinger i 7 retninger (grader):
0.00 30.00 60.00 90.00 120.00 150.00 180.00

Foelgende skal inn i KILDENIVAA i Milstoey:
SEL L L1s Lfast Limp
1 150.26 150.26 159.26 164.86

Foelgende skal inn i DIREKTIVITET i Milstoey:
1.84 0.69 -1.59 -2.67 -1.40 1.03 2.23 1.03 -1.40 -2.67 -1.59 0.69 1.84
-1.03 -1.39 -1.93 -1.59 0.01 1.97 2.86 1.97 0.01 -1.59 -1.93 -1.39 -1.03
-0.57 -0.90 -1.43 -1.24 -0.01 1.57 2.28 1.57 -0.01 -1.24 -1.43 -0.90 -0.57
-0.42 -0.63 -0.95 -0.78 0.07 1.14 1.62 1.14 0.07 -0.78 -0.95 -0.63 -0.42
-0.47 -0.58 -0.72 -0.51 0.15 0.92 1.27 0.92 0.15 -0.51 -0.72 -0.58 -0.47
-0.46 -0.44 -0.36 -0.14 0.20 0.52 0.66 0.52 0.20 -0.14 -0.36 -0.44 -0.46
-0.16 -0.11 0.00 0.08 0.08 0.03 -0.00 0.03 0.08 0.08 0.00 -0.11 -0.16
0.30 0.24 0.09 -0.06 -0.16 -0.19 -0.20 -0.19 -0.16 -0.06 0.09 0.24 0.30
1.15 0.81 0.05 -0.55 -0.64 -0.39 -0.23 -0.39 -0.64 -0.55 0.05 0.81 1.15
1.52 0.99 -0.12 -0.92 -0.87 -0.30 0.02 -0.30 -0.87 -0.92 -0.12 0.99 1.52
1.33 0.90 -0.03 -0.73 -0.75 -0.34 -0.10 -0.34 -0.75 -0.73 -0.03 0.90 1.33
1.64 1.12 -0.01 -0.87 -0.95 -0.52 -0.26 -0.52 -0.95 -0.87 -0.01 1.12 1.64
2.39 1.65 0.01 -1.29 -1.52 -1.00 -0.67 -1.00 -1.52 -1.29 0.01 1.65 2.39
2.41 1.69 0.11 -1.21 -1.55 -1.17 -0.90 -1.17 -1.55 -1.21 0.11 1.69 2.41
0.73 0.70 0.55 0.16 -0.45 -1.03 -1.27 -1.03 -0.45 0.16 0.55 0.70 0.73
-2.32 -1.09 1.28 2.23 0.53 -2.40 -3.82 -2.40 0.53 2.23 1.28 -1.09 -2.32
0.56 1.02 1.68 1.16 -1.01 -3.65 -4.84 -3.65 -1.01 1.16 1.68 1.02 0.56

2.76 1.52 -1.04 -2.59 -1.89 0.05 1.06 0.05 -1.89 -2.59 -1.04 1.52 2.76
4.42 2.70 -1.01 -3.67 -3.57 -1.75 -0.71 -1.75 -3.57 -3.67 -1.01 2.70 4.42
1.28 0.66 -0.61 -1.29 -0.77 0.38 0.97 0.38 -0.77 -1.29 -0.61 0.66 1.28
0.86 0.94 0.95 0.44 -0.67 -1.86 -2.37 -1.86 -0.67 0.44 0.95 0.94 0.86
2.03 1.75 0.96 -0.23 -1.54 -2.57 -2.96 -2.57 -1.54 -0.23 0.96 1.75 2.03
3.91 2.78 0.19 -2.19 -3.21 -3.10 -2.88 -3.10 -3.21 -2.19 0.19 2.78 3.91
4.23 3.19 0.62 -2.18 -4.19 -5.15 -5.39 -5.15 -4.19 -2.18 0.62 3.19 4.23
4.68 3.33 0.15 -2.94 -4.59 -4.90 -4.81 -4.90 -4.59 -2.94 0.15 3.33 4.68
3.15 2.59 1.08 -0.93 -2.87 -4.24 -4.74 -4.24 -2.87 -0.93 1.08 2.59 3.15
1.38 1.59 1.69 0.69 -1.62 -4.15 -5.25 -4.15 -1.62 0.69 1.69 1.59 1.38
2.43 1.62 -0.15 -1.47 -1.54 -0.79 -0.35 -0.79 -1.54 -1.47 -0.15 1.62 2.43
3.91 2.29 -1.11 -3.40 -2.96 -0.90 0.22 -0.90 -2.96 -3.40 -1.11 2.29 3.91
4.48 2.45 -1.81 -4.55 -3.72 -0.85 0.67 -0.85 -3.72 -4.55 -1.81 2.45 4.48
1.69 0.73 -1.19 -2.14 -1.16 0.78 1.75 0.78 -1.16 -2.14 -1.19 0.73 1.69
-2.44 -2.10 -1.21 -0.10 0.86 1.48 1.69 1.48 0.86 -0.10 -1.21 -2.10 -2.44
-1.12 -1.30 -1.49 -1.04 0.23 1.68 2.32 1.68 0.23 -1.04 -1.49 -1.30 -1.12
1.10 0.54 -0.58 -1.17 -0.65 0.42 0.96 0.42 -0.65 -1.17 -0.58 0.54 1.10
2.75 1.49 -1.09 -2.64 -1.89 0.12 1.16 0.12 -1.89 -2.64 -1.09 1.49 2.75
1.61 1.10 0.00 -0.85 -0.94 -0.52 -0.27 -0.52 -0.94 -0.85 0.00 1.10 1.61
1.01 0.10 -1.63 -2.26 -0.90 1.37 2.46 1.37 -0.90 -2.26 -1.63 0.10 1.01
0.80 0.56 0.04 -0.37 -0.43 -0.25 -0.14 -0.25 -0.43 -0.37 0.04 0.56 0.80
0.68 0.41 -0.14 -0.49 -0.36 0.03 0.23 0.03 -0.36 -0.49 -0.14 0.41 0.68
1.34 0.96 0.12 -0.59 -0.76 -0.56 -0.42 -0.56 -0.76 -0.59 0.12 0.96 1.34
1.80 1.19 -0.14 -1.09 -1.07 -0.42 -0.06 -0.42 -1.07 -1.09 -0.14 1.19 1.80
1.48 0.93 -0.22 -0.99 -0.85 -0.16 0.21 -0.16 -0.85 -0.99 -0.22 0.93 1.48
2.07 1.08 -0.93 -2.07 -1.35 0.36 1.23 0.36 -1.35 -2.07 -0.93 1.08 2.07
1.91 0.99 -0.89 -1.93 -1.23 0.39 1.22 0.39 -1.23 -1.93 -0.89 0.99 1.91
2.31 1.34 -0.68 -1.93 -1.47 -0.04 0.71 -0.04 -1.47 -1.93 -0.68 1.34 2.31

Foelgende skal inn i SPEKTER i Milstoey:
-49.00 -43.50 -37.70 -32.86 -28.55 -24.51 -21.14 -18.07 -15.65 -13.59 -11.91
-10.46 -9.42 -8.93 -10.41 -12.93 -11.45 -12.49 -15.42 -14.55 -14.08 -16.92
-18.44 -20.61 -18.82 -19.87 -21.10 -20.32 -19.38 -20.08 -21.80 -24.02 -25.93
-25.62 -26.15 -27.49 -28.45 -29.77 -30.90 -31.94 -32.93 -34.08 -34.65 -35.49
-35.97

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