Homo-condensation of Acetophenones toward Imidazothinones

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Supporting information

1. Materials and instrumentation

All reagents and starting materials were obtained commercially from Sigma-Aldrich, Acros and Merck, and were used as received without any further purification unless otherwise noted. Gas chromatographic (GC) analyses were performed using a Shimadzu GC 2010-Plus equipped with a flame ionization detector (FID) and an SPB-5 column (length = 30 m, inner diameter = 0.25 mm, and film thickness = 0.25 μm). GC-MS analyses were analyzed on a Shimadzu GCMS-QP2010Ultra with a ZB-5MS column (length = 30 m, inner diameter = 0.25 mm, and film thickness = 0.25 μm). The ^{1}H NMR and ^{13}C NMR were recorded on Bruker AV 500 spectrometers using residual solvent peak as a reference. HR-MS spectra were recorded by an Agilent HPLC 1200 Series coupled to Bruker micrOTOF-QII. IR spectra were obtained using a Perkin Elmer Spectrum 100 FT-IR spectrometer.

2. Studies of reaction conditions

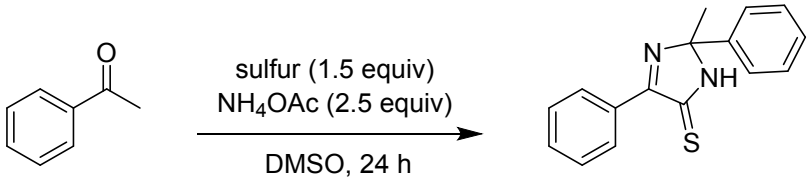
2.1. General procedure

To a dried thick-walled 8 mL glass pressure tube equipped with a magnetic stir bar was charged with acetophenone **1a** (0.1 mmol), elemental sulfur, ammonium acetate, diphenyl ether (0.1 mmol)

as internal standard and DMSO solvent. The mixture was then stirred at 60 °C. After the reaction finished as monitored by TLC, the reaction mixture was cooled down to room temperature, then diluted with water (2 mL) and ethyl acetate (2 mL). Aliquots from the reaction mixture were withdrawn and washed with water (2 ml). The organic components were then extracted into ethyl acetate (2 ml x 2). Combined organic layers were dried over anhydrous Na_2SO_4, filtered, and analyzed by GC with reference to diphenyl ether.

2.2 Optimization studies

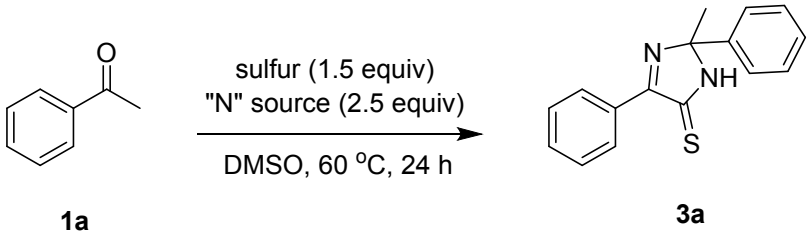
2.2.1. Effect of temperature



1a **3a**

Entry	temperature	yield of **3a**, %
1	r.t	3
2	50 °C	31
3	**60 °C**	**84**
4	70 °C	71
5	80 °C	20

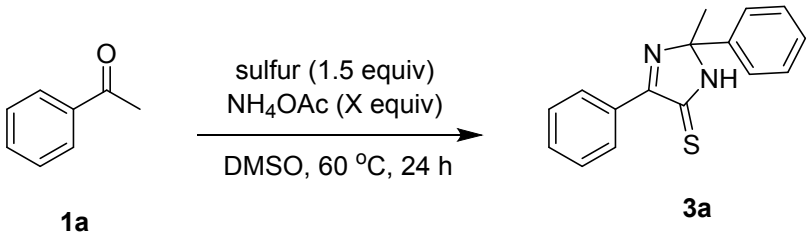
2.2.2. Effect of nitrogen source



1a **3a**

Entry	nitrogen source	yield of **3a**, %
1	NH_4OAc	84
2	NH_3 (28% aqueous solution)	n.d
3	Urea	n.d
4	NH_4HCO_3	n.d

2.2.3. Effect of NH_4OAc amount

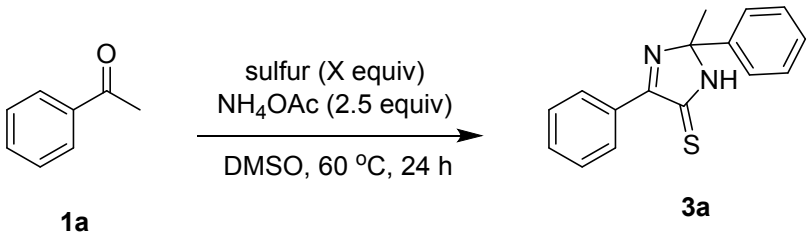


1a **3a**

Entry	value of X	yield of **2a**, %
1	1	5

2	2	58
3	**2.5**	**84**
4	3	81
5	3.5	87
6	4	85

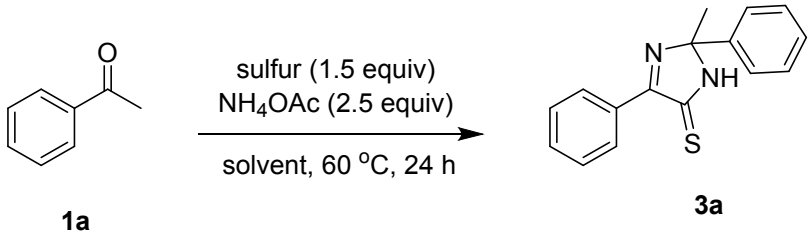
2.2.4. Effect of sulfur amount



1a **3a**

Entry	sulfur amount (equivalent)	yield of **3a**, %
1	1	34
2	1.25	78
3	**1.5**	**84**
4	1.75	80
5	2	48

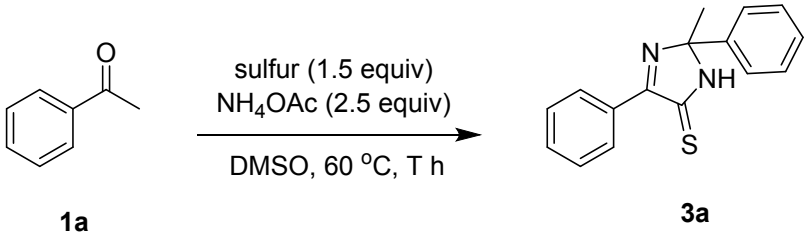
2.2.5. Effect of solvent



1a **3a**

Entry	solvent	yield of **3a**, %
1	1,4-dioxane	n.d
2	chlorobenzene	n.d
3	**DMSO**	**84**
4	DMF	n.d
5	dimethyl carbonate	n.d
6	ethylene glycol	n.d
7	no solvent	n.d

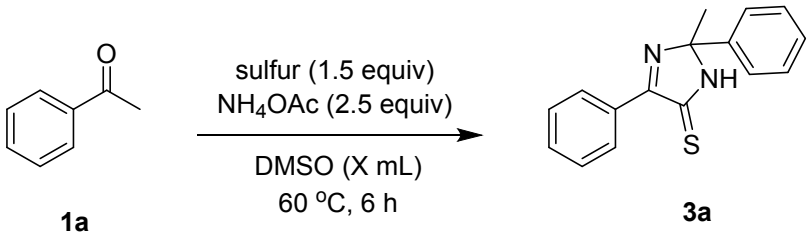
2.2.6. Effect of reaction time



1a **3a**

Entry	Reaction time (h)	yield of **3a**, %
1	2	38
2	4	73
3	**6**	**84**
4	8	84
5	24	84

2.2.7. Effect of DMSO amount



1a **3a**

Entry	X (mL)	yield of **3a**, %
1	0	trace
2	0.5	57
3	**1**	**84**
4	2	78

5	3	80

2.3. Gram-scale experiment

To a 25-mL round bottomed flask equipped with a magnetic stir bar and a reflux condenser with acetophenone **1a** (2.0 mmol, 240 mg), elemental sulfur (3.0 mmol, 96 mg), ammonium acetate (5.0 mmol, 385 mg), and DMSO (10 ml) in a 25-mL round bottomed flask. The mixture was then stirred at 60 ℃ for 24 h in a sand bath. Upon completion, the crude mixture was slowly cooled to room temperature, then added water (50 mL) and ethyl acetate (50 mL). The organic components were then washed with water (20 ml) and extracted into ethyl acetate (3×10 mL). Combined organic layers were dried over anhydrous Na_2SO_4, filtered, and concentrated under vacuum. The crude mixture was then purified using column chromatography on silica gel using ethyl acetate/hexane 1:5 eluent to afford **3a** (202 mg, 76%) as a light-yellow oil which slowly solidified under air.

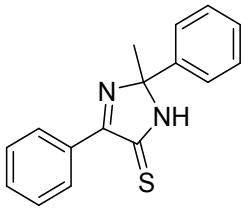
3. Synthesis of imidazothiones

3.1. General procedure

To a dried thick-walled 8 mL glass pressure tube equipped with a magnetic stir bar was charged with an acetophenone (0.2 mmol), elemental sulfur (0.3 mmol, 9.6 mg), ammonium acetate (0.5 mmol, 38.5 mg), and DMSO (1.0 ml) solvent. The mixture was then stirred at 60 °C. After the reaction finished as monitored by TLC, the reaction mixture was cooled down to room temperature, then diluted with ethyl acetate (5 mL) and water (5 mL). The organic components were then extracted into ethyl acetate (5 ml x 3), then dried over anhydrous Na_2SO_4, filtered and concentrated under vacuum. The crude product was purified using hexanes/ethyl acetate eluent to afford the desired imidazothione.

3.2. Characterization data of unknown products

2-Methyl-2,5-diphenyl-2,3-dihydro-4*H*-imidazole-4-thione (3a)



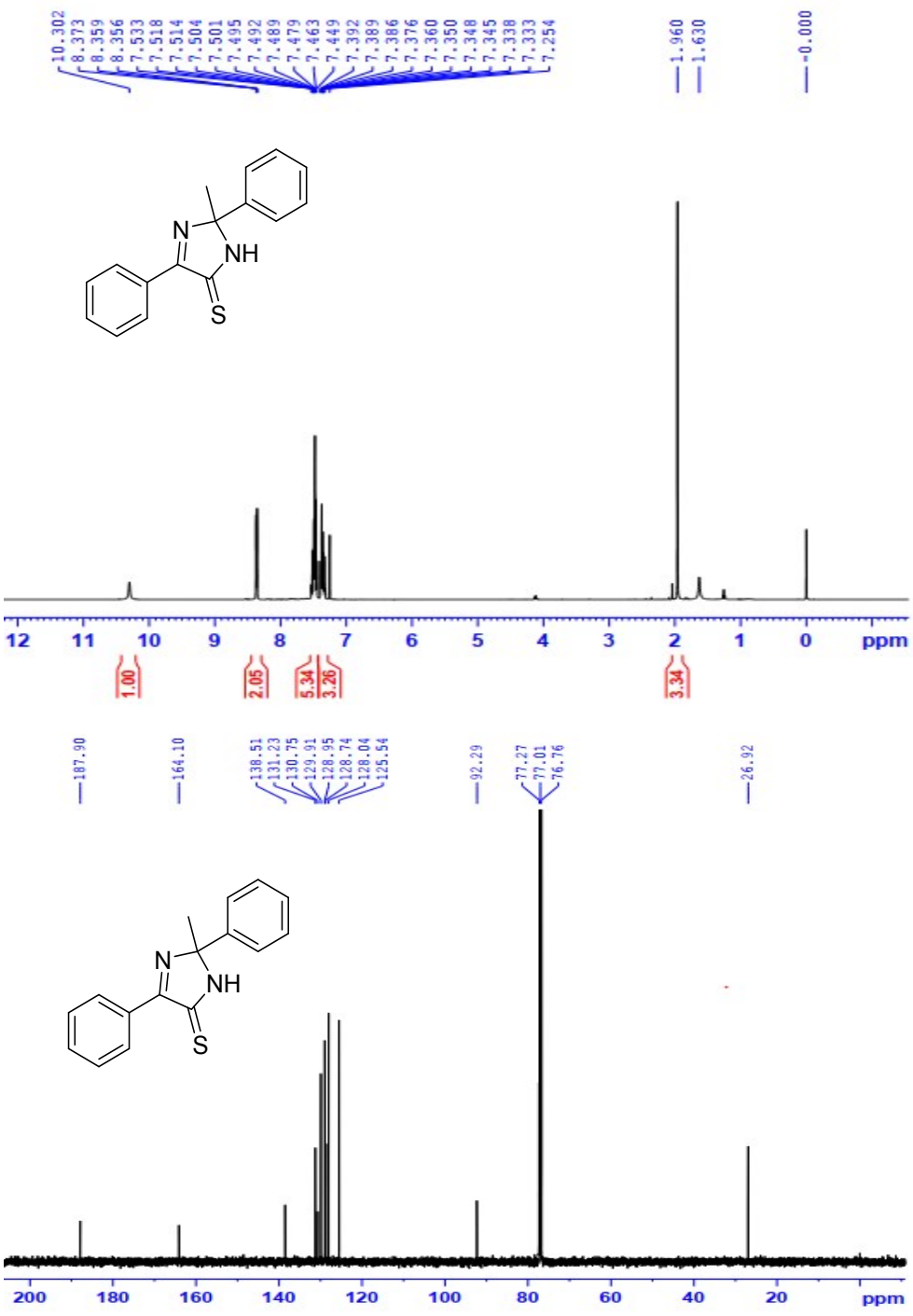
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.40): light yellow oil which slowly solidified, 80% yield (21.2 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.30 (s, 1H), 8.39 – 8.34 (m, 2H), 7.54 – 7.43 (m, 5H), 7.42 – 7.30 (m, 3H), 1.96 (s, 3H).

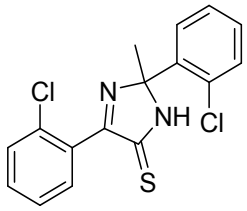
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.9, 164.1, 138.5, 131.2, 130.7, 129.9, 128.9, 128.7, 128.0, 125.5, 92.3, 26.9.

FT-IR (neat, cm^{-1}) υ 1650, 1230.

HRMS calcd for $C_{16}H_{15}N_2S$: $[M + H]^+$ 267.0950, found: 267.0941.


10.302
8.373
8.359
8.356
7.533
7.518
7.514
7.504
7.501
7.495
7.492
7.489
7.479
7.463
7.449
7.392
7.389
7.386
7.376
7.360
7.350
7.348
7.345
7.338
7.333
7.254
1.960
1.630
0.000
N
NH
S
12 11 10 9 8 7 6 5 4 3 2 1 0 ppm
1.00
2.05
5.34
3.26
3.34
187.90
164.10
138.51
131.23
130.75
129.91
128.95
128.74
128.04
125.54
92.29
77.27
77.01
76.76
26.92
N
NH
S
200 180 160 140 120 100 80 60 40 20 ppm

2,5-Bis(2-chlorophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3b)



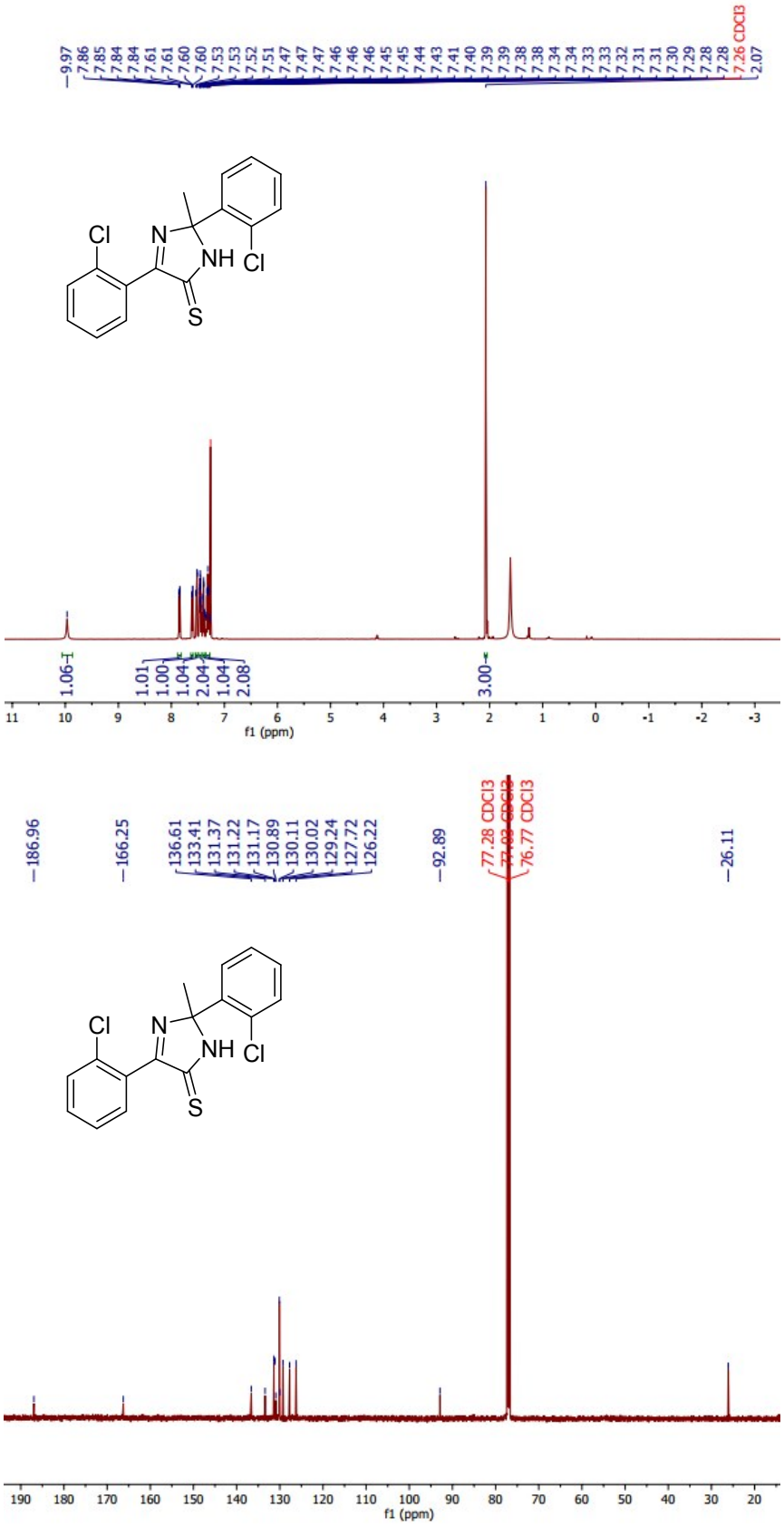
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.37): light yellow oil, 45% yield (15.2 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 9.97 (s, 1H), 7.85 (dd, *J* = 7.5, 2.1 Hz, 1H), 7.60 (dd, *J* = 7.6, 1.8 Hz, 1H), 7.52 (dd, *J* = 8.0, 1.3 Hz, 1H), 7.49 – 7.43 (m, 2H), 7.39 (td, *J* = 7.5, 1.3 Hz, 1H), 7.35 – 7.28 (m, 2H), 2.07 (s, 3H).

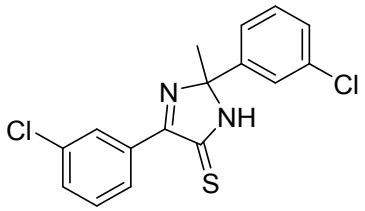
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 186.9, 166.2, 136.6, 133.4, 131.4, 131.22, 131.17, 130.9, 130.1, 130.0, 129.2, 127.7, 126.2, 92.9, 26.1. One carbon signal could not be located.

FT-IR (neat, cm^{-1}) υ 1642, 1250, 828, 825.

HRMS calcd for $C_{16}H_{13}{}^{35}Cl_2N_2S$: $[M + H]^+$ 335.0171, found: 335.0173.


9.97
7.86
7.85
7.84
7.84
7.61
7.61
7.60
7.60
7.53
7.53
7.52
7.51
7.47
7.47
7.47
7.46
7.46
7.46
7.45
7.45
7.44
7.43
7.41
7.40
7.39
7.39
7.38
7.38
7.34
7.34
7.33
7.33
7.32
7.31
7.31
7.30
7.29
7.28
7.28
7.26 CDCl3
2.07
Cl
N
NH
Cl
S
1.06
1.01
1.00
1.04
2.04
1.04
2.08
3.00
f1 (ppm)
186.96
166.25
136.61
133.41
131.37
131.22
131.17
130.89
130.11
130.02
129.24
127.72
126.22
92.89
77.28 CDCl3
77.03 CDCl3
76.77 CDCl3
26.11
f1 (ppm)

2,5-Bis(3-chlorophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3c)



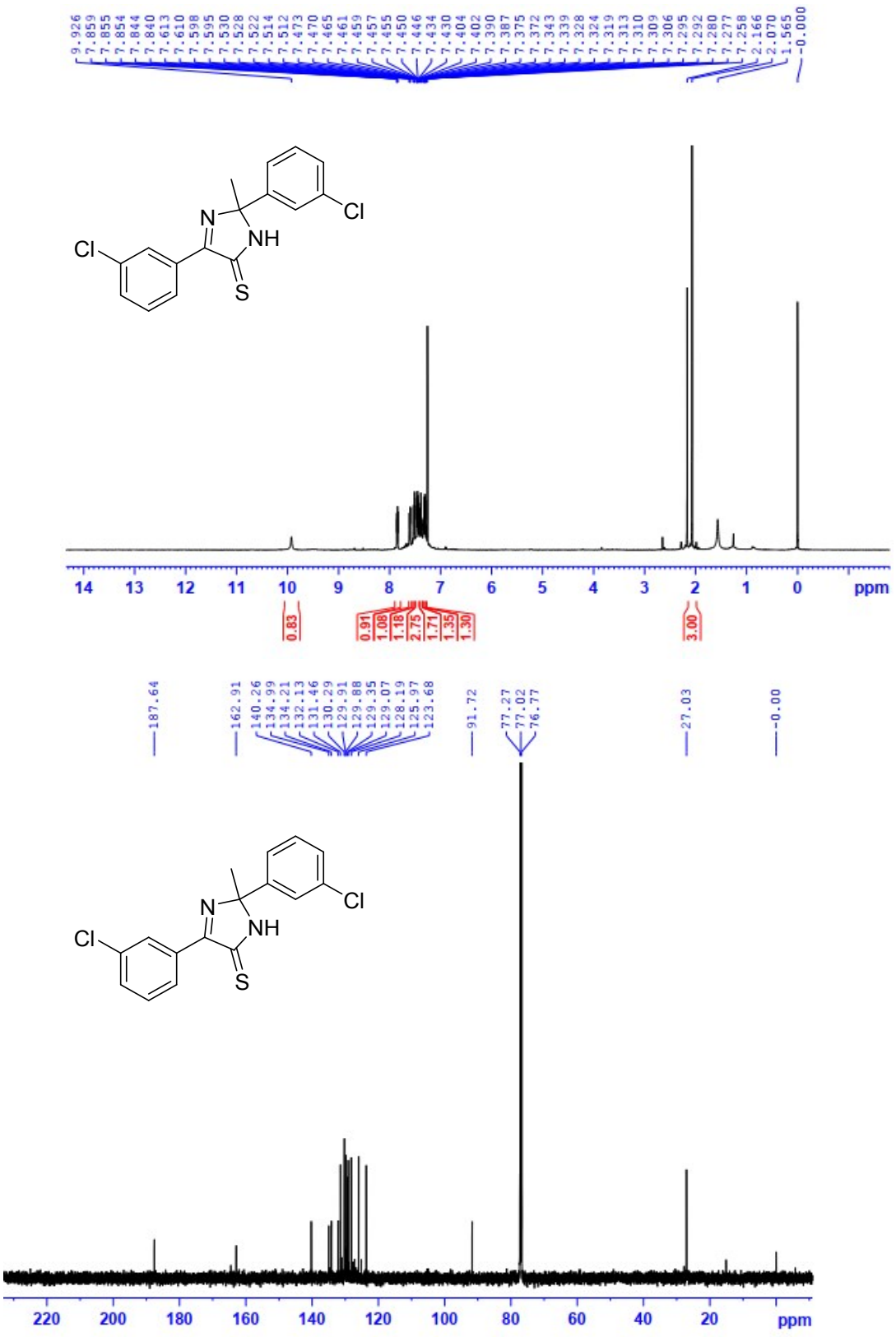
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.48): light yellow oil, 69% yield (23.3 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.06 (s, 1H), 8.42 – 8.32 (m, 2H), 7.55 – 7.46 (m, 3H), 7.36 – 7.26 (m, 3H), 1.95 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.6, 162.9, 140.3, 135.0, 134.2, 132.1, 131.5, 130.3, 129.9, 129.3, 129.1, 128.2, 126.0, 123.7, 91.7, 27.0.

FT-IR (neat, cm^{-1}) υ 1638, 1241, 819, 812.

HRMS calcd for $C_{16}H_{13}{}^{35}Cl_2N_2S$: $[M + H]^+$ 335.0171, found: 335.0174.


9.926
7.859
7.855
7.854
7.844
7.840
7.613
7.610
7.598
7.595
7.530
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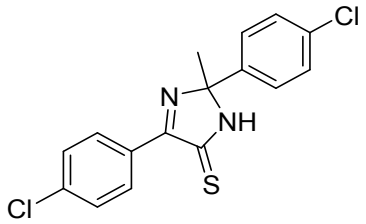
7.522
7.514
7.512
7.473
7.470
7.465
7.461
7.459
7.457
7.455
7.450
7.446
7.434
7.430
7.404
7.402
7.390
7.387
7.375
7.372
7.343
7.339
7.328
7.324
7.319
7.313
7.310
7.309
7.306
7.295
7.292
7.280
7.277
7.258
2.166
2.070
1.565
0.000
N
NH
S
Cl
Cl
14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 ppm
0.83
0.91
1.08
1.18
2.75
1.71
1.35
1.30
3.00
187.64
162.91
140.26
134.99
134.21
132.13
131.46
130.29
129.91
129.88
129.35
129.07
128.19
125.97
123.68
91.72
77.27
77.02
76.77
27.03
0.00
220 200 180 160 140 120 100 80 60 40 20 ppm

2,5-Bis(4-chlorophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3d)



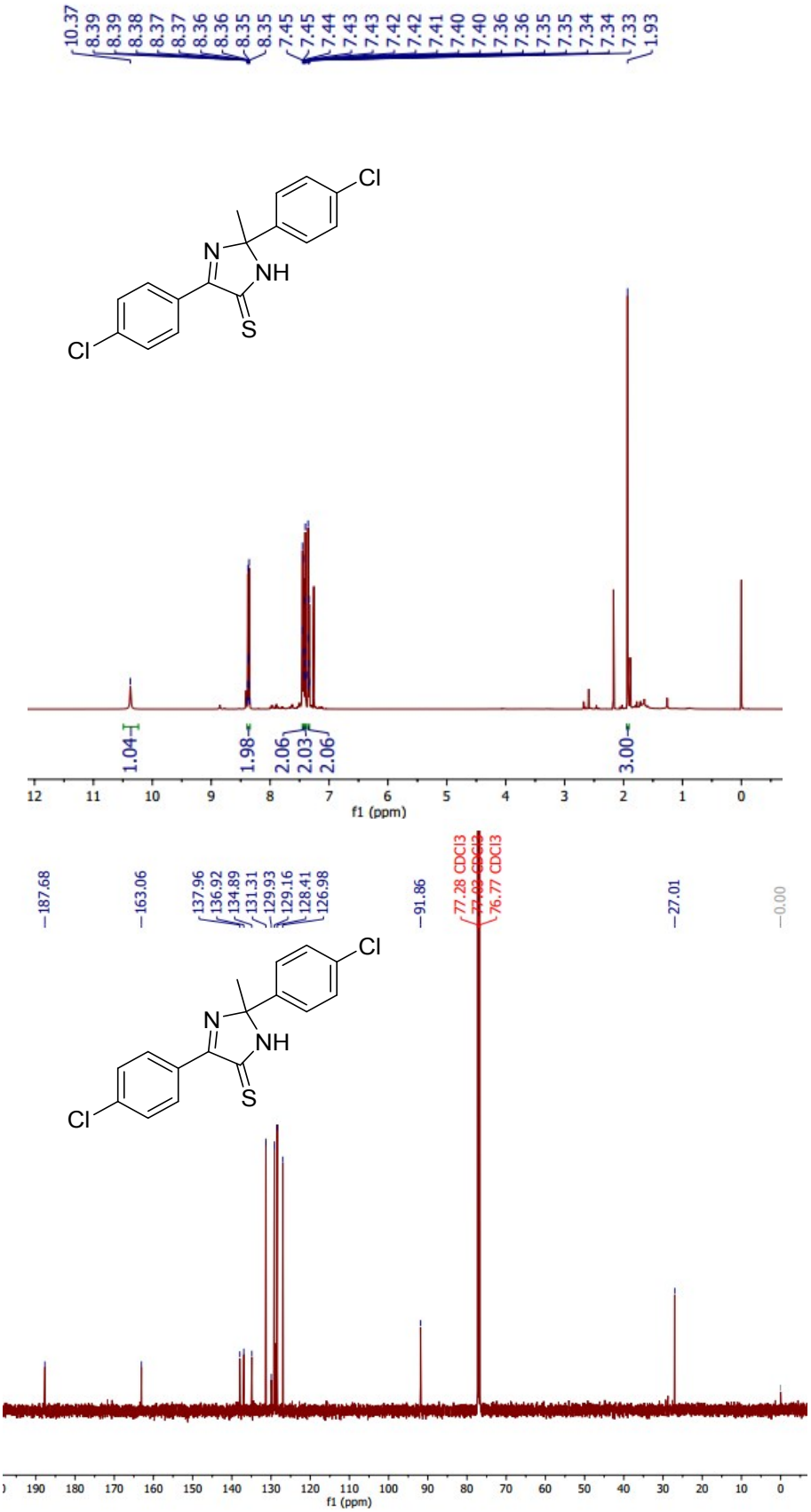
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.46): light yellow oil which slowly solidified, 80% yield (27.0 mg).

^{1}H-NMR (500 MHz, $CDCl_3$, ppm) δ 10.37 (s, 1H), 8.39 – 8.33 (m, 2H), 7.44 (d, *J* = 8.6 Hz, 2H), 7.41 (d, *J* = 8.7 Hz, 2H), 7.35 (d, *J* = 8.7 Hz, 2H), 1.93 (s, 3H).

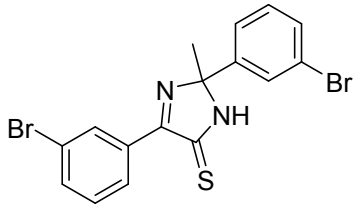
^{13}C-NMR (125 MHz, $CDCl_3$, ppm) δ 187.7, 163.1, 138.0, 136.9, 134.9, 131.3, 129.9, 129.2, 128.4, 127.0, 91.9, 27.0.

FT-IR (neat, cm^{-1}) υ 1640, 1208, 830, 822.

HRMS calcd for $C_{16}H_{13}{}^{35}Cl_2N_2S$: $[M + H]^+$ 335.0176, found: 335.0179.


10.37
8.39
8.39
8.38
8.37
8.37
8.36
8.36
8.35
8.35
7.45
7.44
7.43
7.43
7.42
7.42
7.41
7.40
7.40
7.36
7.36
7.35
7.35
7.34
7.34
7.33
1.93
Cl
N
NH
S
Cl
1.04
1.98
2.06
2.03
2.06
3.00
f1 (ppm)
187.68
163.06
137.96
136.92
134.89
131.31
129.93
129.16
128.41
126.98
91.86
77.28 CDCl3
76.77 CDCl3
27.01
0.00
Cl
N
NH
S
Cl
f1 (ppm)

2,5-Bis(3-bromophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3e)



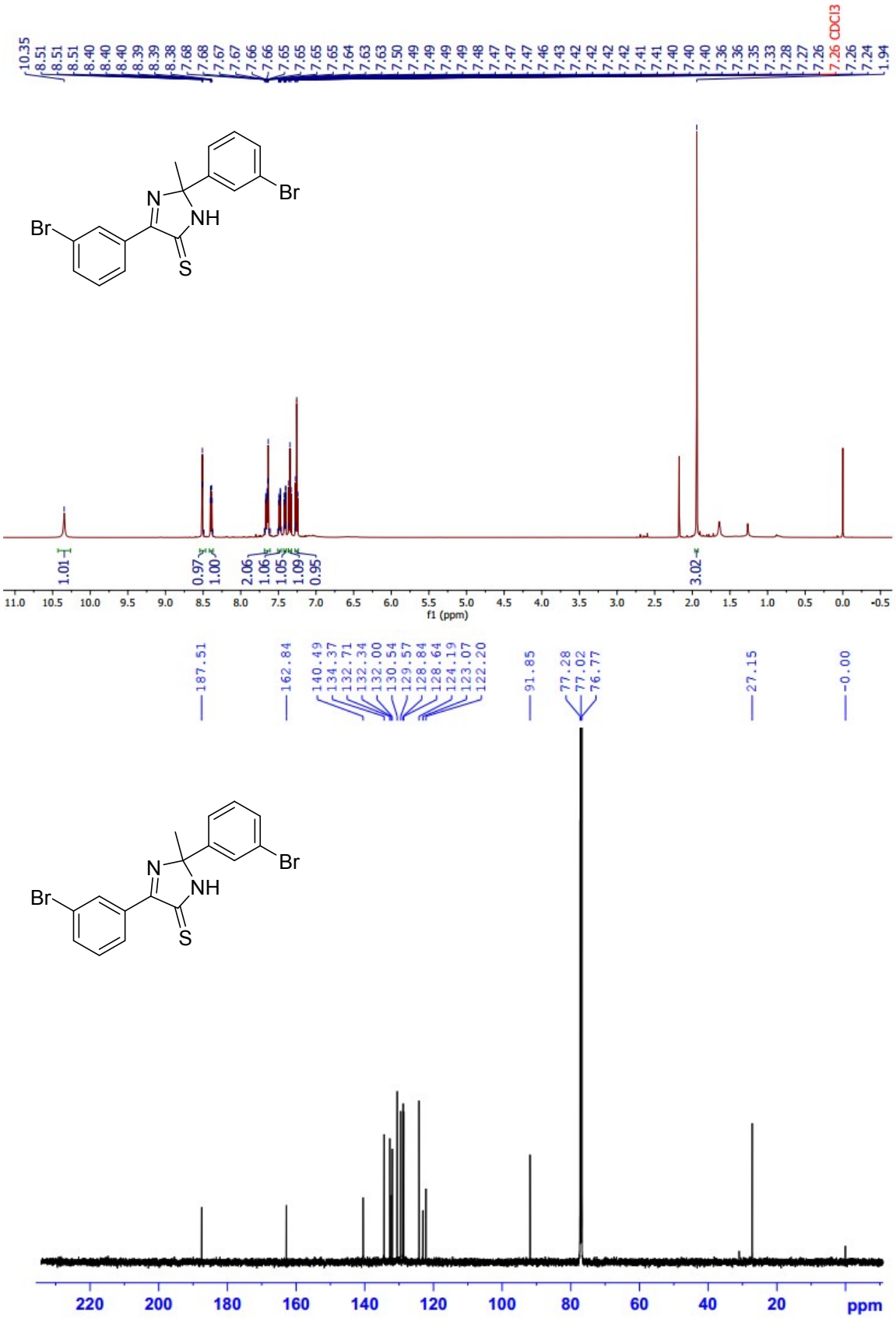
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.20): light orange liquid, 80% yield (33.9 mg).

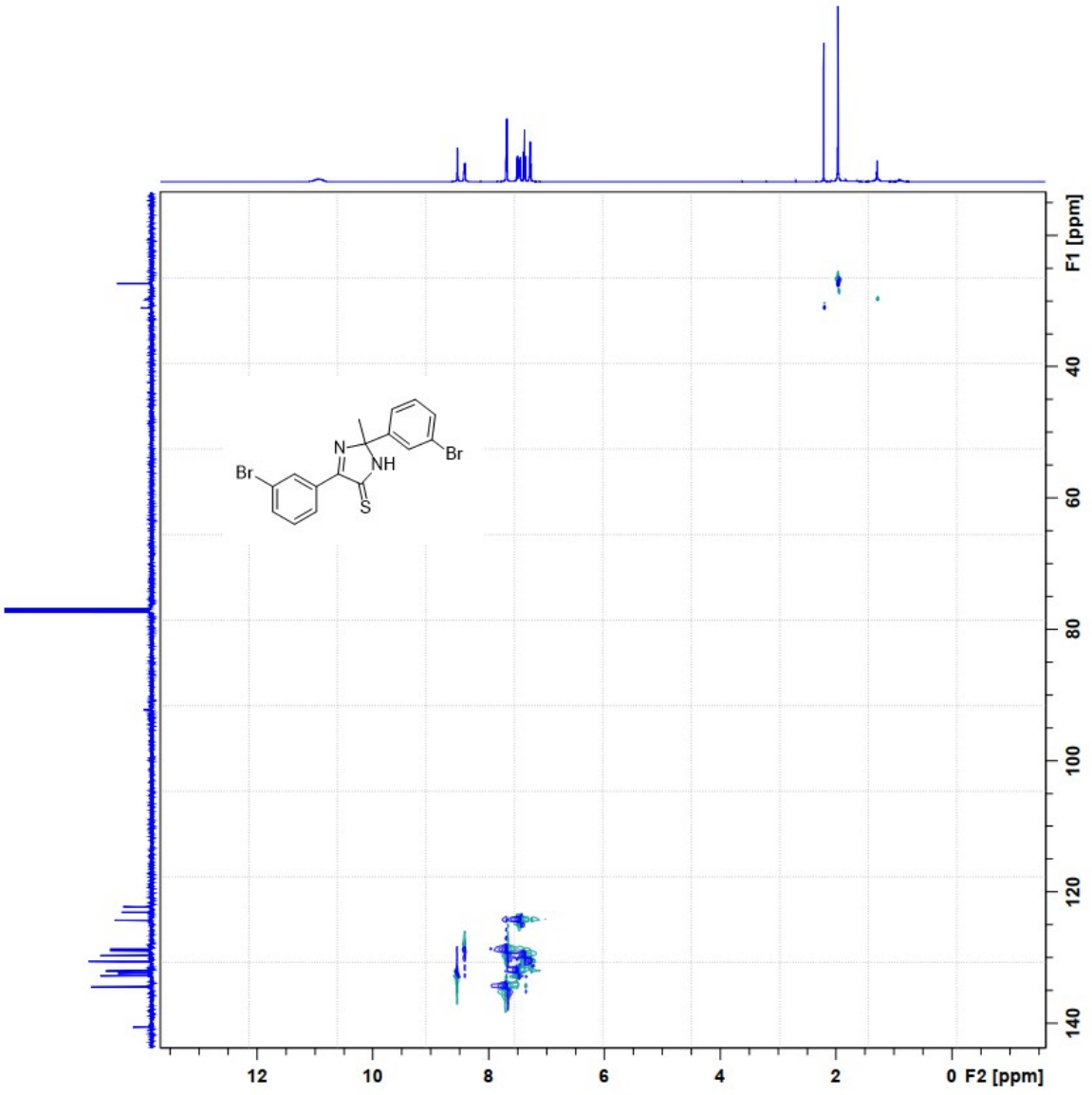
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.35 (s, 1H), 8.51 (t, *J* = 1.9 Hz, 1H), 8.39 (dt, *J* = 7.8, 1.4 Hz, 1H), 7.68 – 7.61 (m, 2H), 7.48 (ddd, *J* = 8.0, 2.0, 1.0 Hz, 1H), 7.41 (ddd, *J* = 7.8, 1.9, 1.0 Hz, 1H), 7.35 (t, *J* = 7.9 Hz, 1H), 7.28 – 7.23 (m, 1H), 1.94 (s, 3H).

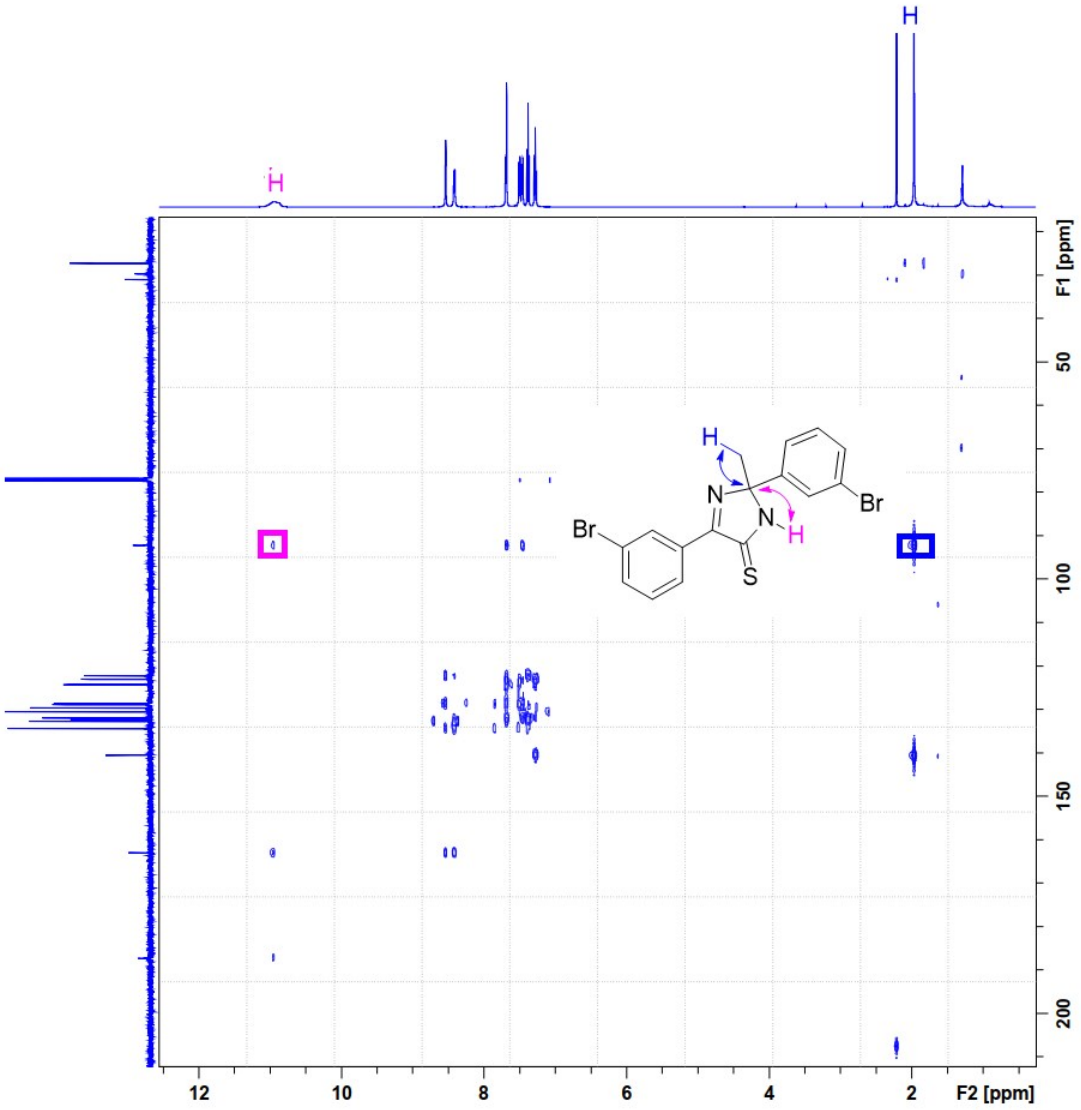
^{13}C NMR (125 MHz, $CDCl_3$, ppm) 187.5, 162.8, 140.5, 134.4, 132.7, 132.3, 132.0, 130.5, 129.6, 128.8, 128.6, 124.2, 123.1, 122.2, 91.8, 27.1.

FT-IR (neat, cm^{-1}) υ 1638, 1252, 838, 815.

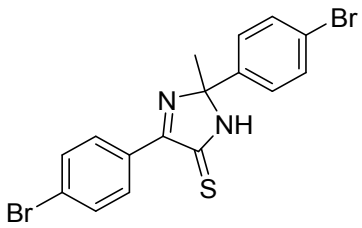
HRMS calcd for $C_{16}H_{13}{}^{79}Br_2N_2S$: $[M + H]^+$ 424.9140, found: 424.9133.


Br
N
NH
S
Br
f1 (ppm)
ppm


Br
N
NH
Br
S
F1 [ppm]
40
60
80
100
120
140
12
10
8
6
4
2
0 F2 [ppm]



2,5-Bis(4-bromophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3f)



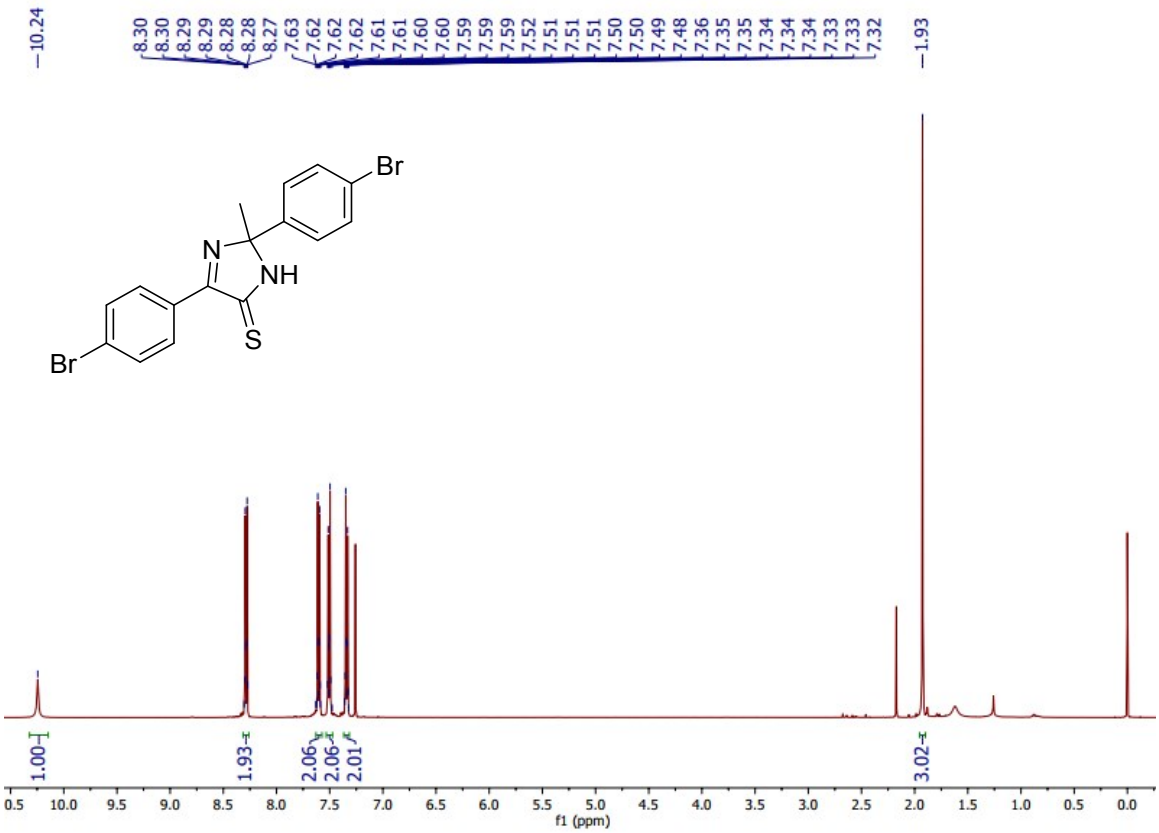
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.58): light yellow oil which slowly solidified, 75% yield (31.9 mg).

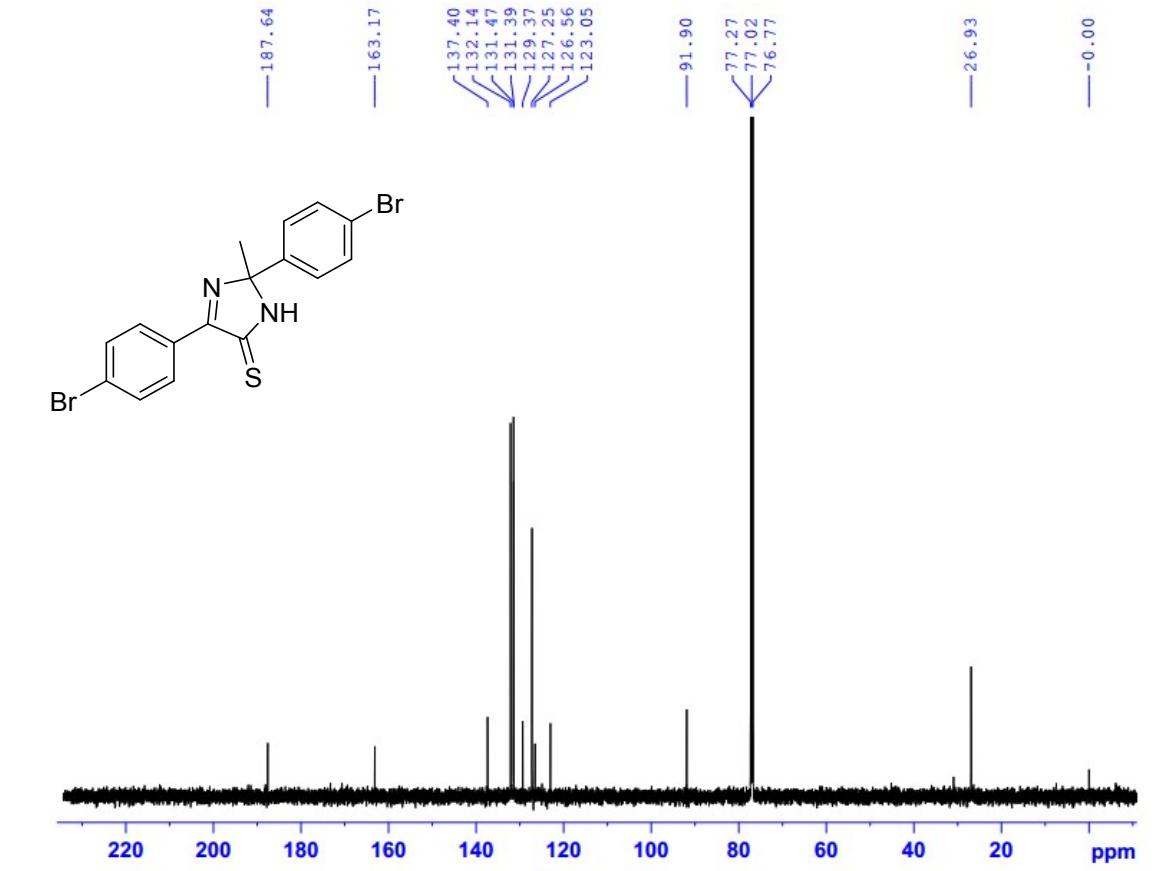
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.24 (s, 1H), 8.34 – 8.22 (m, 2H), 7.63 – 7.58 (m, 2H), 7.53 – 7.48 (m, 2H), 7.37 – 7.25 (m, 2H), 2.05 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) 187.6, 163.2, 137.4, 132.1, 131.5, 131.4, 129.4, 127.3, 126.6, 123.0, 91.9, 26.9.

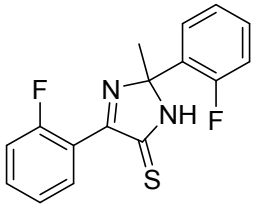
FT-IR (neat, cm^{-1}) υ 1648, 1248, 818, 810.

HRMS calcd for $C_{16}H_{13}{}^{79}Br_2N_2S$: $[M + H]^+$ 424.9140, found: 424.9141.


10.24
8.30
8.30
8.29
8.29
8.28
8.28
8.27
7.63
7.62
7.62
7.62
7.61
7.61
7.60
7.60
7.59
7.59
7.59
7.52
7.51
7.51
7.51
7.50
7.50
7.49
7.48
7.36
7.35
7.35
7.34
7.34
7.34
7.33
7.33
7.32
1.93
Br
N
NH
S
Br
1.00
1.93
2.06
2.06
2.01
3.02
f1 (ppm)


187.64
163.17
137.40
132.14
131.47
131.39
129.37
127.25
126.56
123.05
91.90
77.27
77.02
76.77
26.93
0.00
Br
N
NH
S
Br
220
200
180
160
140
120
100
80
60
40
20
ppm

2,5-Bis(2-fluorophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3g)



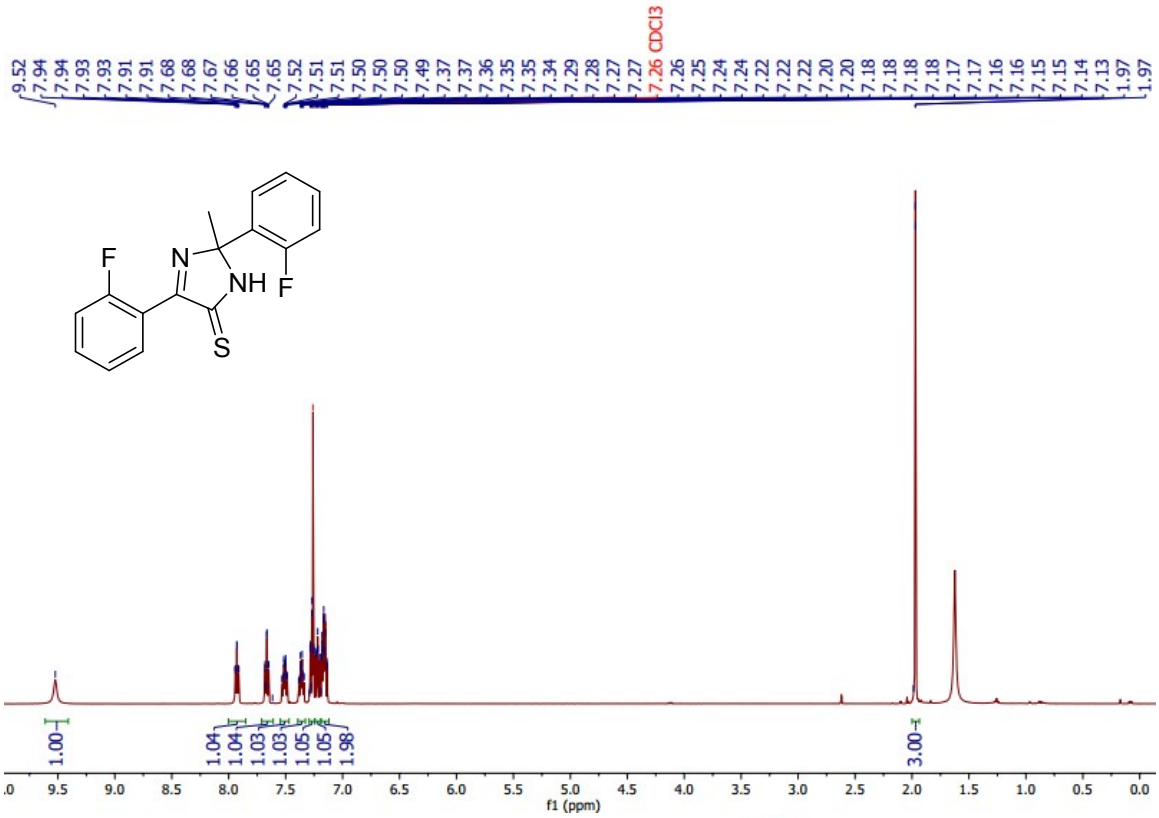
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.18): light yellow oil, 58% yield (17.5 mg).

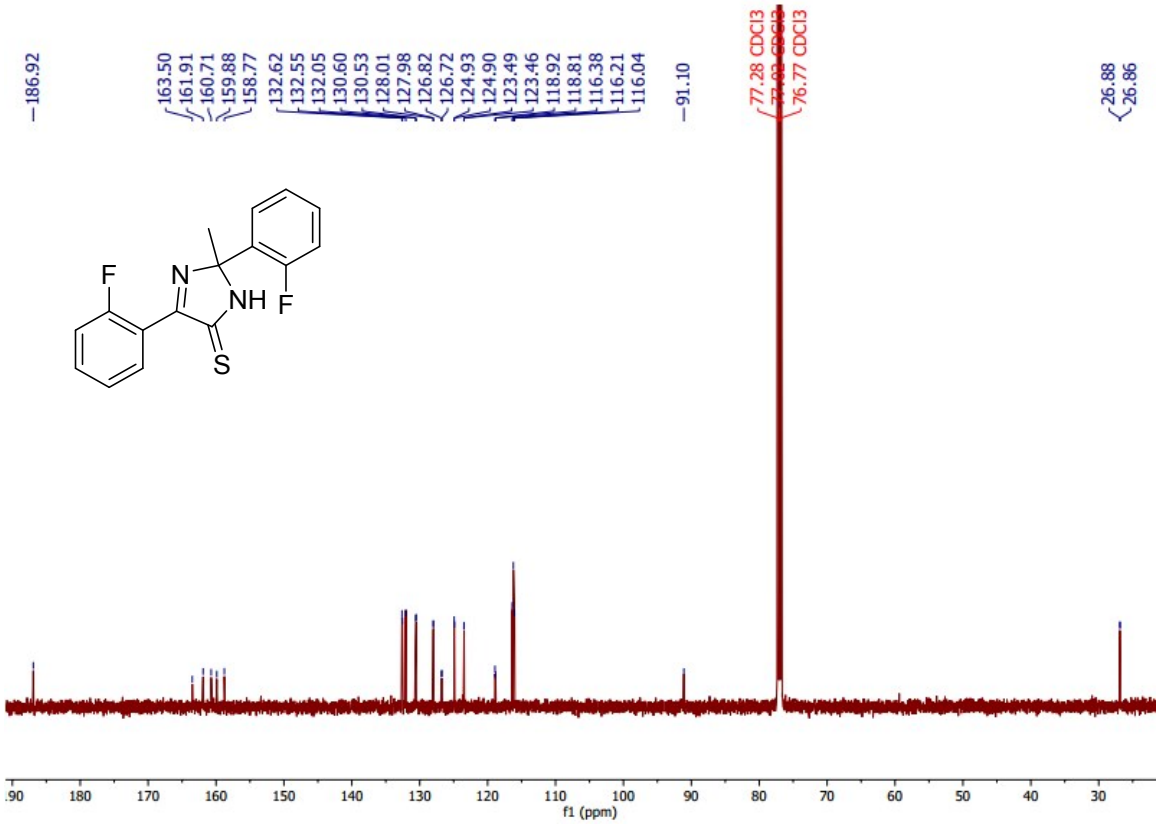
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 9.52 (s, 1H), 7.93 (td, *J* = 7.4, 1.8 Hz, 1H), 7.67 (td, *J* = 7.9, 1.9 Hz, 1H), 7.55 – 7.47 (m, 1H), 7.36 (tdd, *J* = 7.6, 5.4, 1.8 Hz, 1H), 7.27 (td, *J* = 7.6, 1.1 Hz, 1H), 7.22 (ddd, *J* = 9.7, 8.3, 1.1 Hz, 1H), 7.19 – 7.12 (m, 2H), 2.00 – 1.94 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm, possible peaks are listed due to overlapping of two different fluoroarenes) δ 186.9, 163.5, 161.9, 160.7, 159.9, 158.8, 132.6, 132.5, 132.0, 130.6, 130.5, 128.01, 127.98, 126.8, 126.7, 124.93, 124.90, 123.49, 123.46, 118.9, 118.8, 116.4, 116.2, 116.0, 91.1, 26.9.

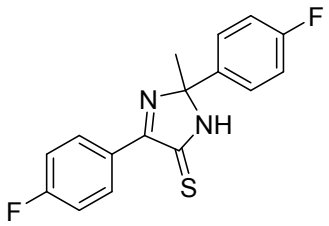
FT-IR (neat, cm^{-1}) υ 1642, 1238, 825, 820.

HRMS calcd for $C_{16}H_{13}F_2N_2S$: $[M + H]^+$, 303.0762, found: 303.0765.


F
N
NH
F
S
f1 (ppm)


F
N
NH
F
S
f1 (ppm)

2,5-Bis(4-fluorophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3h)



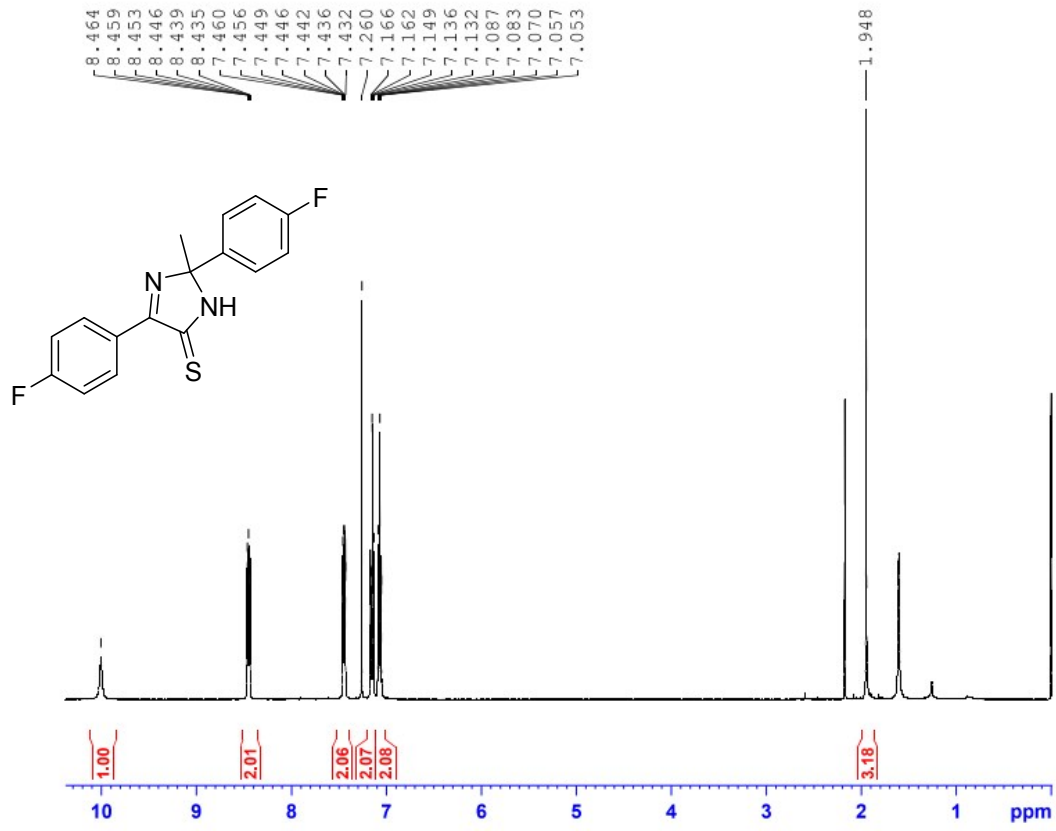
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 µm, ethyl acetate/cyclohexane = 1:6 (v./v.), TLC silica gel 60 F254, R_f = 0.50): white foam, 57% yield (17.2 mg).

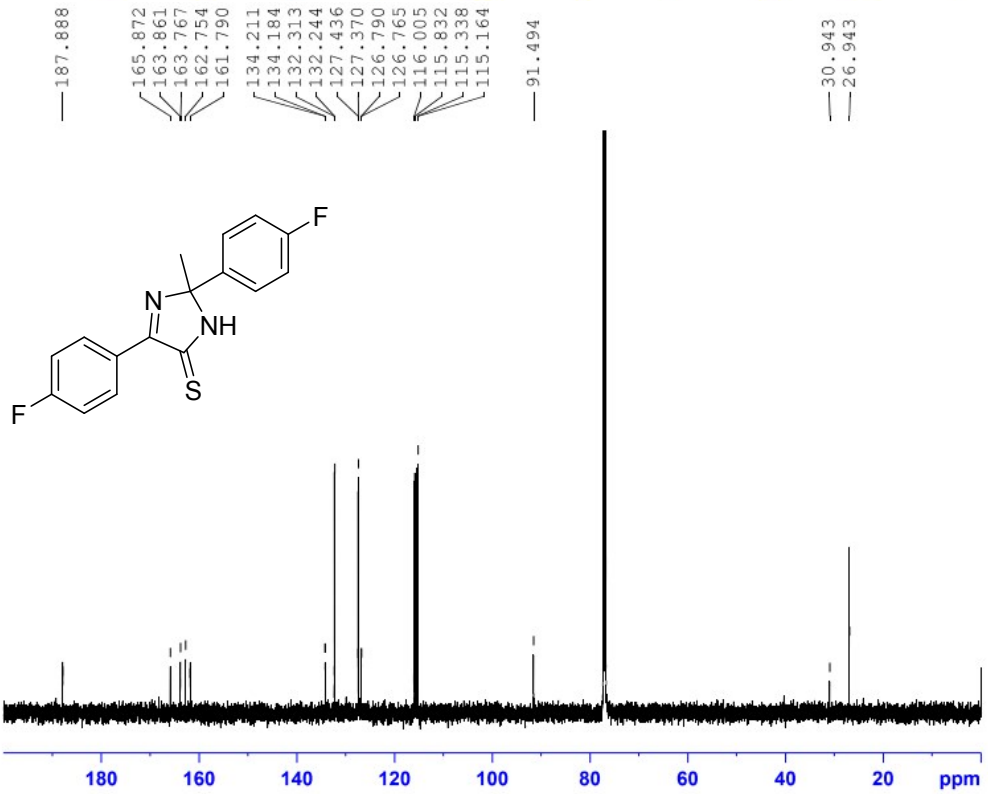
^{1}H-NMR (500 MHz, $CDCl_3$, ppm) δ 10.01 (s, 1H), 8.54 – 8.39 (m, 2H), 7.55 – 7.37 (m, 2H), 7.28 – 7.12 (m, 2H), 7.11 – 6.95 (m, 2H), 1.95 (s, 3H).

^{13}C-NMR (125 MHz, $CDCl_3$, ppm, possible peaks are listed due to overlapping of two different fluoroarenes) δ 187.9, 165.9, 163.9, 163.8, 162.8, 161.8, 134.2, 132.2, 127.4, 126.8, 115.8, 115.2, 91.5, 26.9.

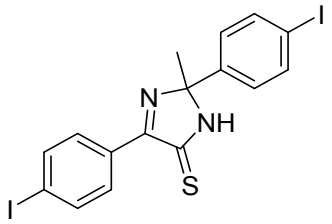
FT-IR (neat, cm^{-1}) υ 1654, 1275, 816, 805.

HRMS calcd for $C_{16}H_{13}F_2N_2S$: $[M + H]^+$ 303.0762, found: 303.0762.


8.464
8.459
8.453
8.446
8.439
8.435
7.460
7.456
7.449
7.446
7.442
7.436
7.432
7.260
7.166
7.162
7.149
7.136
7.132
7.087
7.083
7.070
7.057
7.053
1.948
F
N
NH
S
F
1.00
2.01
2.06
2.07
2.08
3.18
10
9
8
7
6
5
4
3
2
1
ppm


187.888
165.872
163.861
163.767
162.754
161.790
134.211
134.184
132.313
132.244
127.436
127.370
126.790
126.765
116.005
115.832
115.338
115.164
91.494
30.943
26.943
F
N
NH
S
F
180
160
140
120
100
80
60
40
20
ppm

2,5-Bis(4-iodophenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3i)



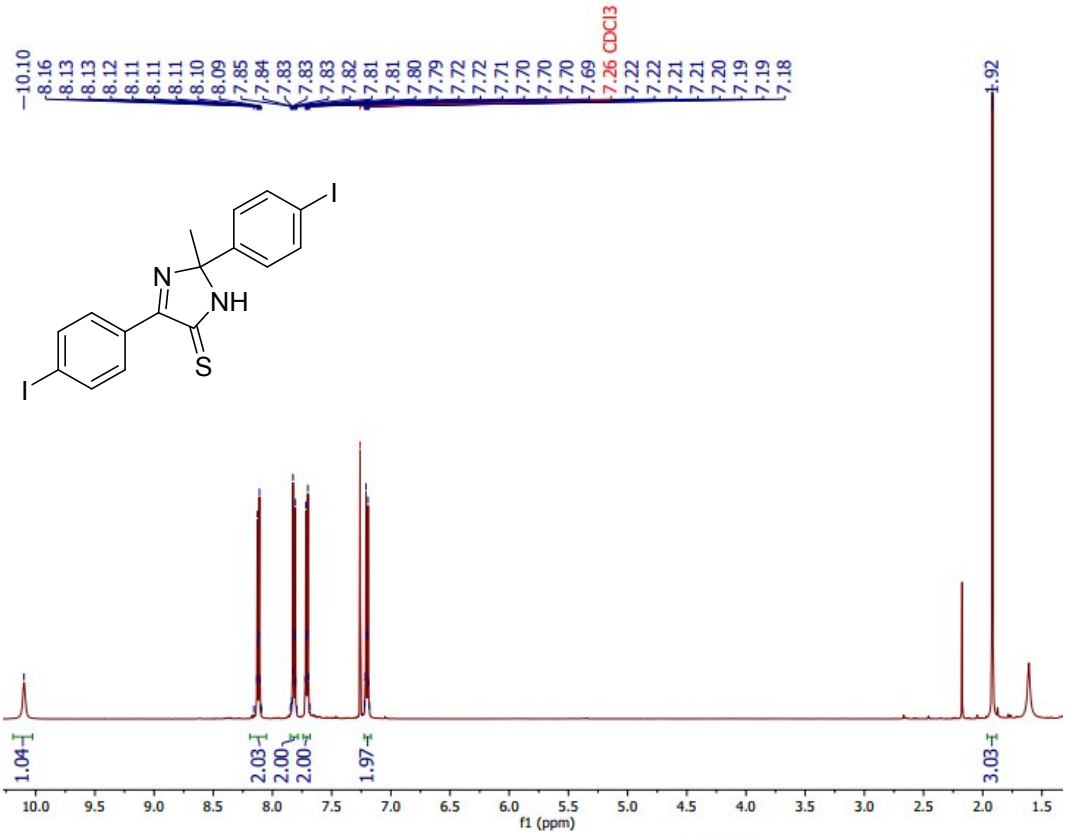
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:8 (v./v.), TLC silica gel 60 F254, R_f = 0.20): light yellow oil which slowly solidified, 50% yield (26.0 mg).

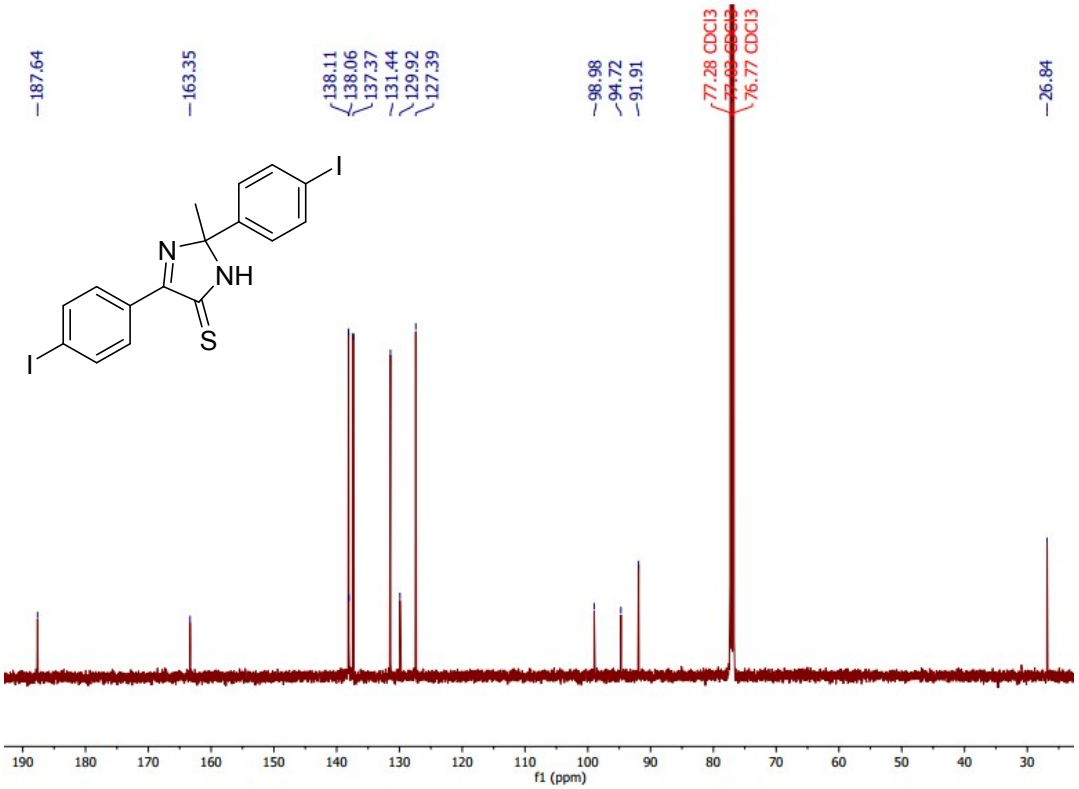
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.10 (s, 1H), 8.12 (d, *J* = 8.5 Hz, 2H), 7.82 (d, *J* = 8.5 Hz, 2H), 7.71 (d, *J* = 8.5 Hz, 2H), 7.30 – 7.15 (m, 2H), 1.92 (s, 3H)

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.6, 163.3, 138.11, 138.06, 137.4, 131.4, 129.9, 127.4, 99.0, 94.7, 91.9, 26.8.

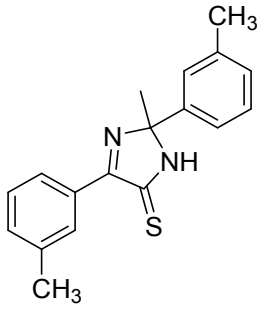
FT-IR (neat, cm^{-1}) υ 1632, 1265, 822, 815.

HRMS calcd for $C_{16}H_{13}I_2N_2S$: $[M + H]^+$ 518.8883, found: 518.8854.


10.10
8.16
8.13
8.13
8.12
8.11
8.11
8.11
8.10
8.09
7.85
7.84
7.83
7.83
7.83
7.82
7.81
7.81
7.80
7.79
7.72
7.72
7.71
7.70
7.70
7.70
7.69
7.26 CDCl3
7.22
7.22
7.21
7.21
7.20
7.19
7.19
7.18
1.92
I
N
NH
S
I
1.04
2.03
2.00
2.00
1.97
3.03
10.0 9.5 9.0 8.5 8.0 7.5 7.0 6.5 6.0 5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5
f1 (ppm)


187.64
163.35
138.11
138.06
137.37
131.44
129.92
127.39
98.98
94.72
91.91
77.28 CDCl3
76.77 CDCl3
26.84
I
N
NH
S
I
190 180 170 160 150 140 130 120 110 100 90 80 70 60 50 40 30
f1 (ppm)

2,5-Bis(3-methylphenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3j)



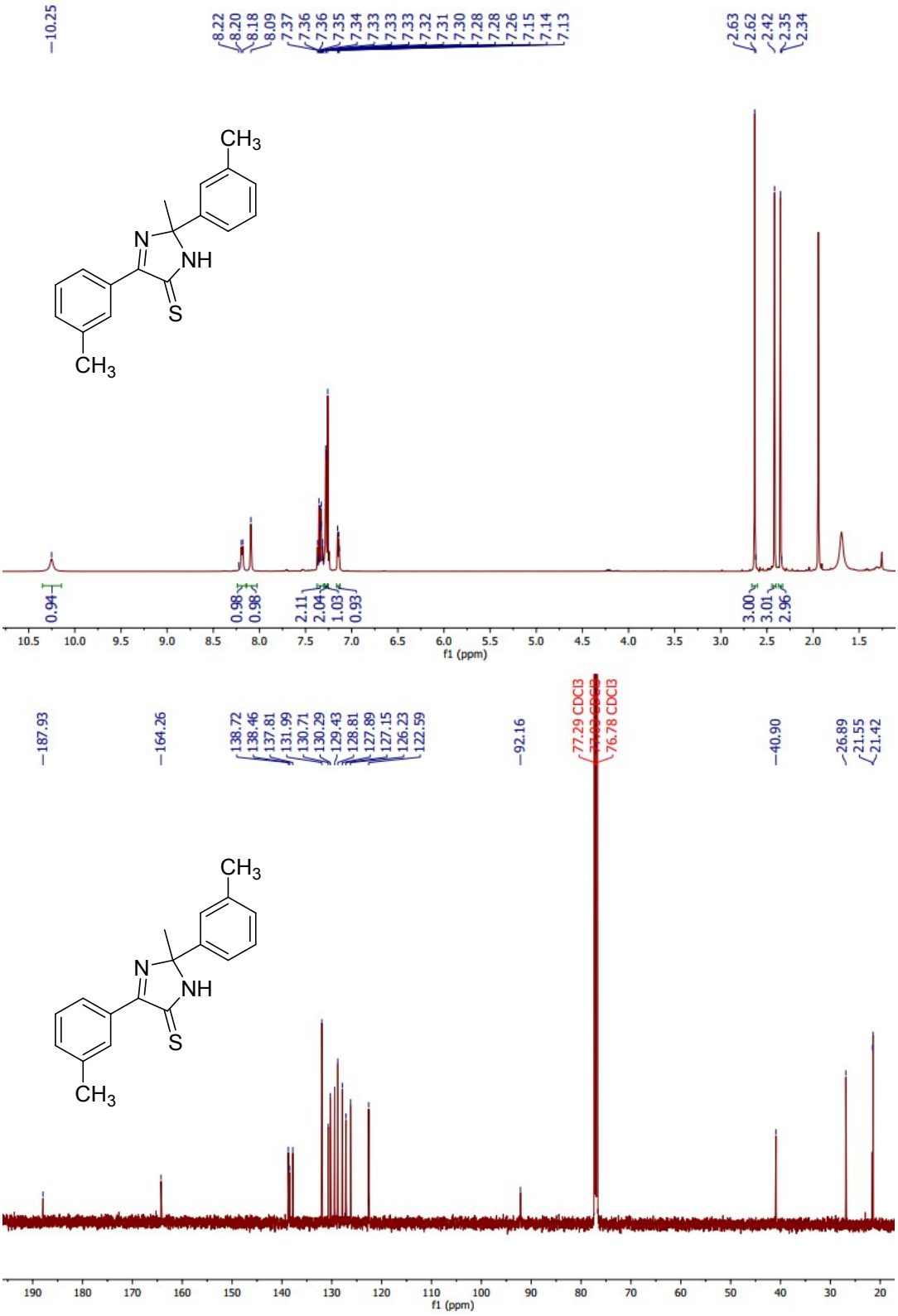
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:10 (v./v.), TLC silica gel 60 F254, R_f = 0.14): light yellow oil, 79% yield (23.2 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.25 (s, 1H), 8.19 (d, *J* = 7.4 Hz, 1H), 8.09 (s, 1H), 7.38 – 7.31 (m, 2H), 7.28 (d, *J* = 2.4 Hz, 2H), 7.26 (s, 1H), 7.15 (d, *J* = 6.9 Hz, 1H), 2.63 (s, 3H), 2.42 (s, 3H), 2.35 (s, 3H).

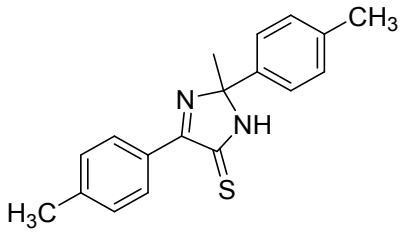
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.9, 164.3, 138.7, 138.5, 137.8, 132.0, 130.7, 130.3, 129.4, 128.8, 127.9, 127.1, 126.2, 122.6, 92.16, 40.9, 26.9, 21.5.

FT-IR (neat, cm^{-1}) υ 1651, 1257.

HRMS calcd for $C_{18}H_{19}N_2S$: $[M + H]^+$ 295.1263, found: 295.1268.


10.25
8.22
8.20
8.18
8.09
7.37
7.36
7.36
7.35
7.34
7.33
7.33
7.33
7.32
7.31
7.30
7.28
7.28
7.26
7.15
7.14
7.13
2.63
2.62
2.42
2.35
2.34
CH3
N
NH
S
CH3
0.94
0.98
0.98
2.11
2.04
1.03
0.93
3.00
3.01
2.96
f1 (ppm)
187.93
164.26
138.72
138.46
137.81
131.99
130.71
130.29
129.43
128.81
127.89
127.15
126.23
122.59
92.16
77.29 CDCl3
76.78 CDCl3
40.90
26.89
21.55
21.42
CH3
N
NH
S
CH3
f1 (ppm)

2,5-Bis(4-methylphenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3k)



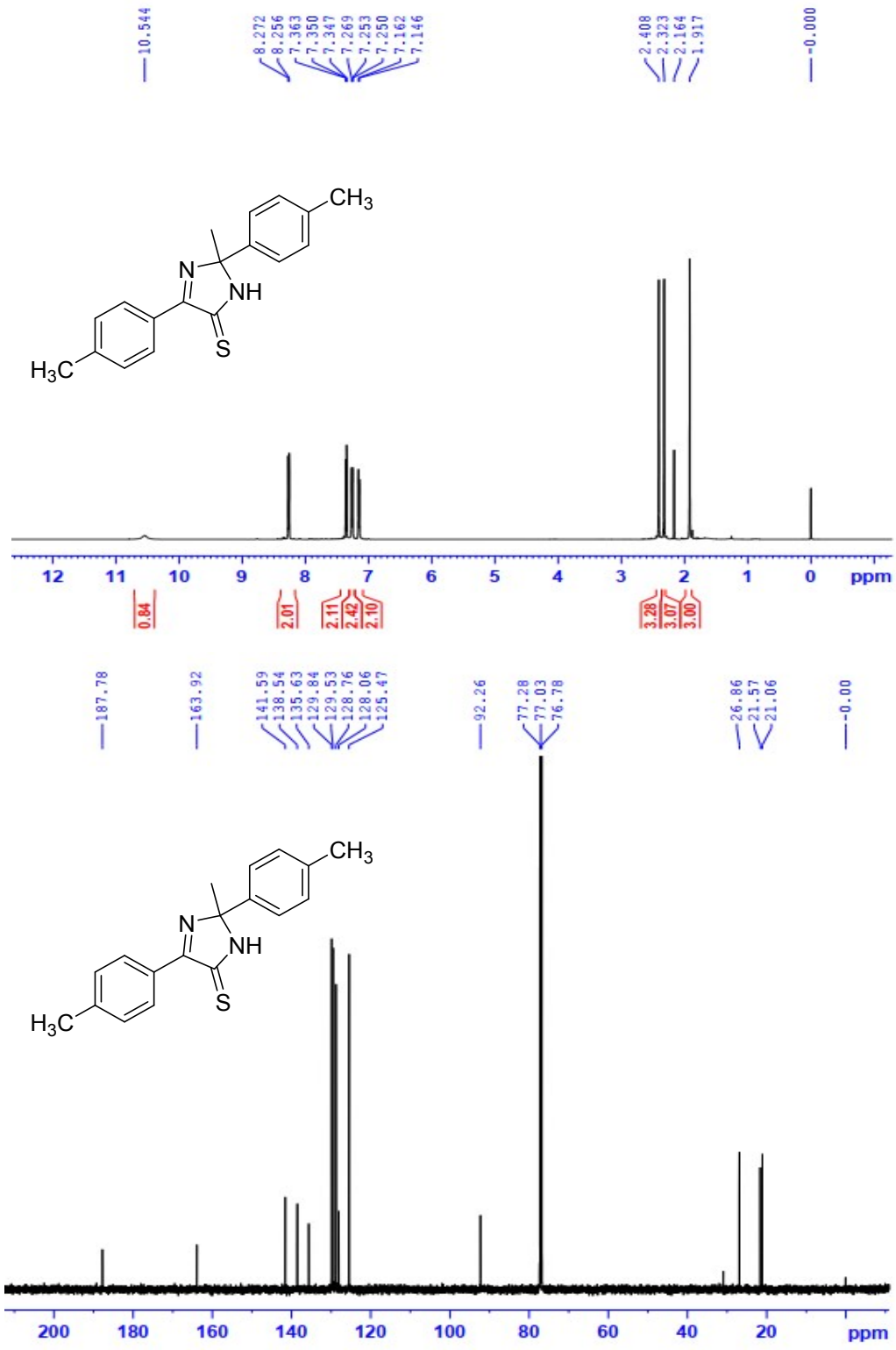
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.44): light yellow oil, 83% yield (24.6 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.54 (s, 1H), 8.26 (d, *J* = 8.2 Hz, 2H), 7.36 (d, *J* = 8.3 Hz, 2H), 7.29 – 7.23 (m, 2H), 7.15 (d, *J* = 8.0 Hz, 2H), 2.41 (s, 3H), 2.32 (s, 3H), 1.92 (s, 3H).

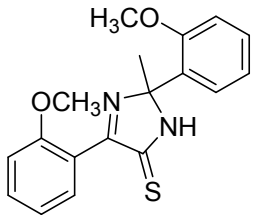
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.8, 163.9, 141.6, 138.5, 135.6, 129.8, 129.5, 128.8, 128.1, 125.5, 92.3, 26.9, 21.6, 21.1.

FT-IR (neat, cm^{-1}) υ 1652, 1248.

HRMS calcd for $C_{18}H_{19}N_2S$: $[M + H]^+$ 295.1263, found: 295.1255.


10.544
8.272
8.256
7.363
7.350
7.347
7.269
7.253
7.250
7.162
7.146
2.408
2.323
2.164
1.917
0.000
CH3
N
NH
S
H3C
12
11
10
9
8
7
6
5
4
3
2
1
0
ppm
0.84
2.01
2.11
2.42
2.10
3.28
3.07
3.00
187.78
163.92
141.59
138.54
135.63
129.84
129.53
128.76
128.06
125.47
92.26
77.28
77.03
76.78
26.86
21.57
21.06
0.00
CH3
N
NH
S
H3C
200
180
160
140
120
100
80
60
40
20
ppm

2,5-Bis(2-methoxyphenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3l)



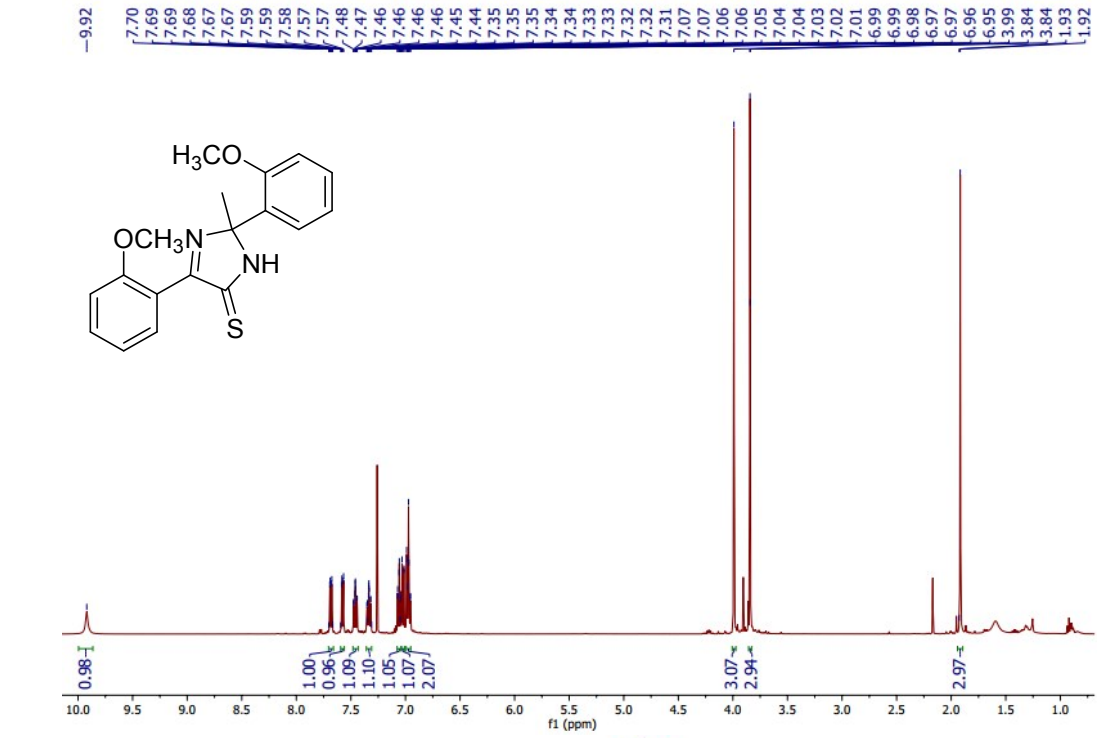
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:4 (v./v.), TLC silica gel 60 F254, R_f = 0.25): light yellow foam, 70% yield (22.8 mg).

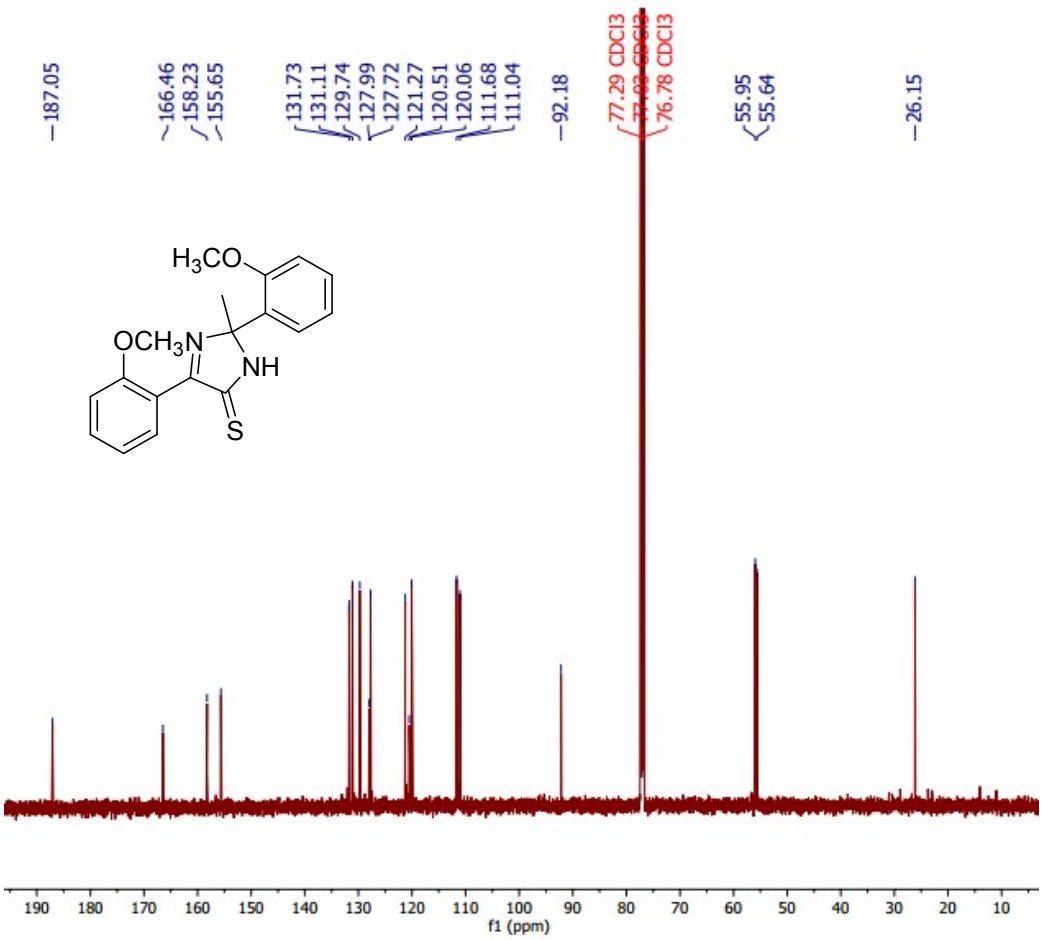
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 9.92 (s, 1H), 7.68 (dd, *J* = 7.6, 1.8 Hz, 1H), 7.58 (dd, *J* = 7.5, 1.8 Hz, 1H), 7.46 (ddd, *J* = 8.4, 7.4, 1.7 Hz, 1H), 7.38 – 7.30 (m, 1H), 7.10 – 6.91 (m, 4H), 3.99 (s, 3H), 3.84 (s, 3H), 1.92 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.0, 166.5, 158.2, 155.6, 131.7, 131.1, 129.7, 128.0, 127.7, 121.3, 120.5, 120.1, 111.7, 111.0, 92.2, 55.9, 55.6, 26.1.

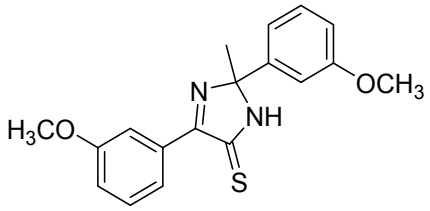
FT-IR (neat, cm^{-1}) υ 1644, 1311, 1305, 1251.

HRMS calcd for $C_{18}H_{19}N_2O_2S$: $[M + H]^+$ 327.1162, found: 327.1161.


9.92
7.70
7.69
7.69
7.68
7.67
7.67
7.59
7.59
7.58
7.57
7.57
7.48
7.47
7.46
7.46
7.46
7.46
7.45
7.44
7.35
7.35
7.35
7.34
7.34
7.33
7.33
7.32
7.32
7.31
7.07
7.07
7.06
7.06
7.05
7.04
7.04
7.03
7.02
7.01
6.99
6.99
6.98
6.97
6.97
6.96
6.95
3.99
3.84
3.84
1.93
1.92
H3CO
OCH3
N
NH
S
0.98
1.00
0.96
1.09
1.10
1.05
1.07
2.07
3.07
2.94
2.97
f1 (ppm)


187.05
166.46
158.23
155.65
131.73
131.11
129.74
127.99
127.72
121.27
120.51
120.06
111.68
111.04
92.18
77.29 CDCl3
77.03 CDCl3
76.78 CDCl3
55.95
55.64
26.15
H3CO
OCH3
N
NH
S
f1 (ppm)

2,5-Bis(3-methoxyphenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3m)



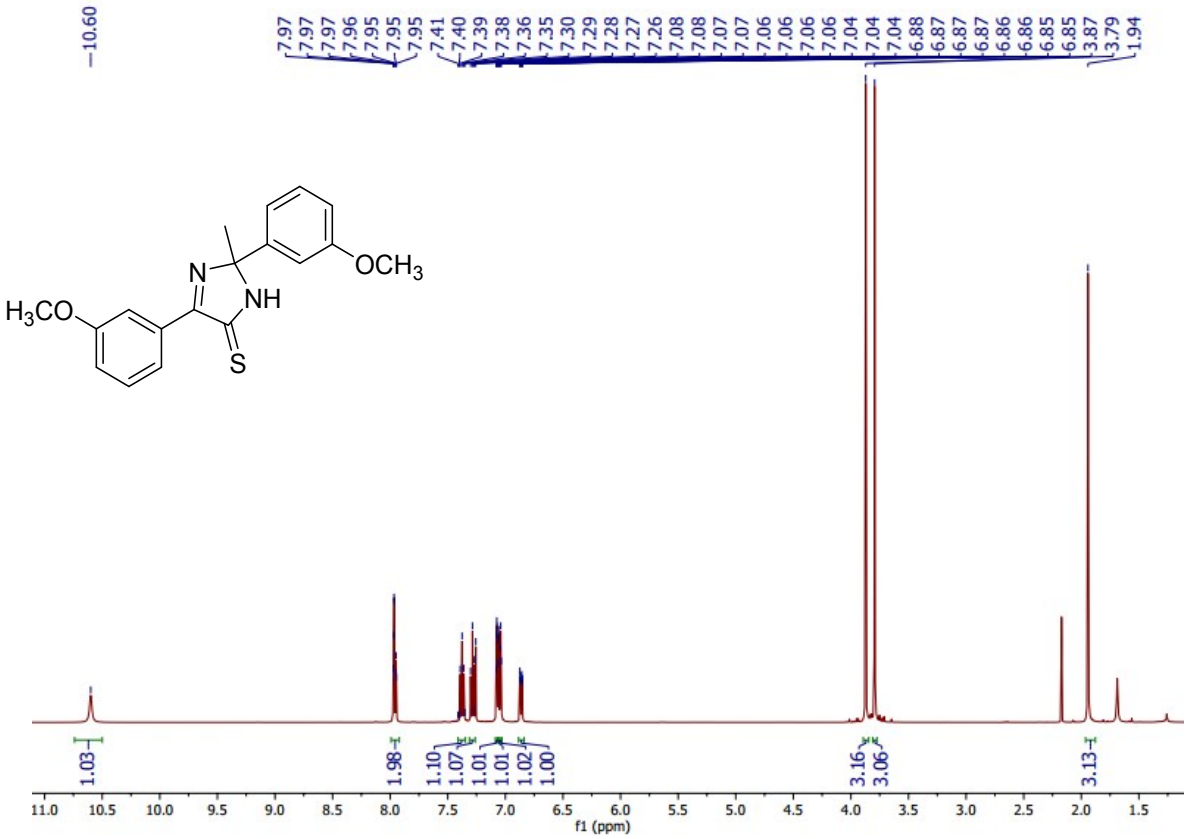
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.40): light yellow oil, 86% yield (28.0 mg).

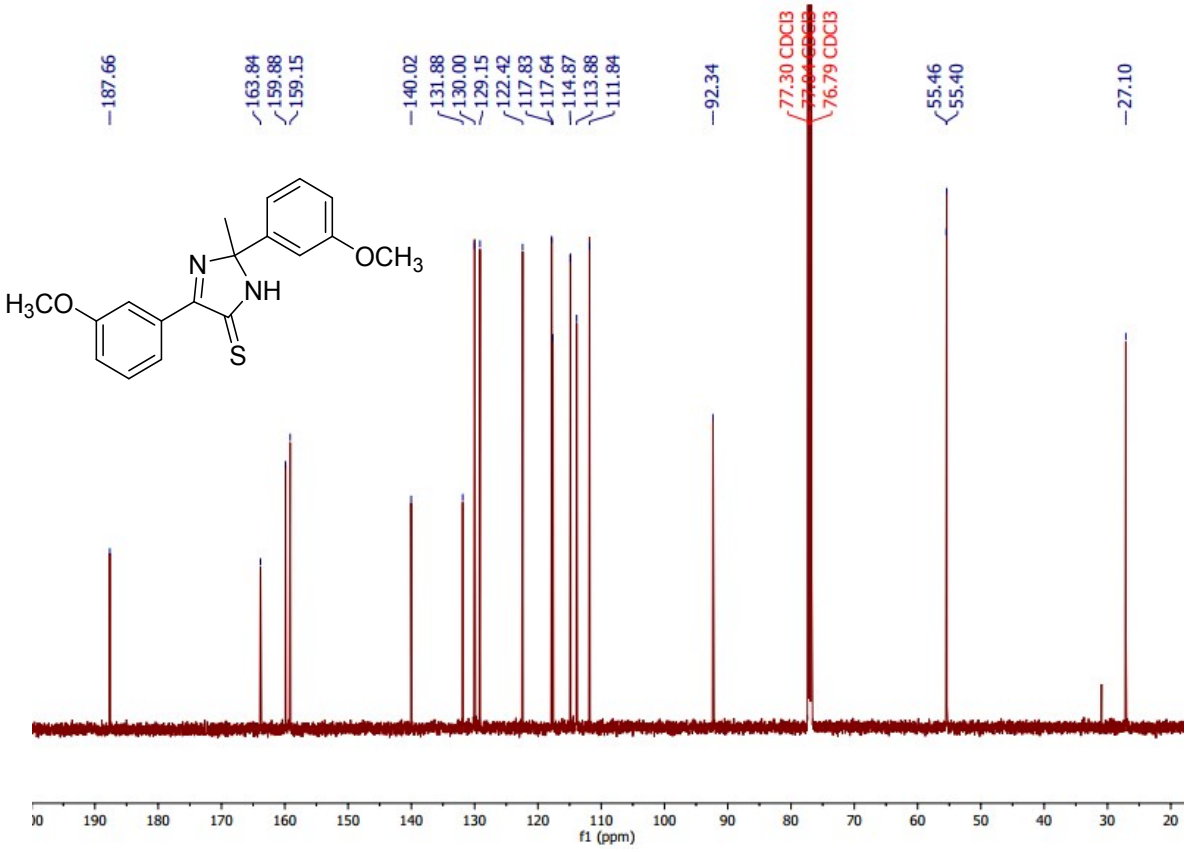
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.60 (s, 1H), 7.99 – 7.92 (m, 2H), 7.38 (t, *J* = 7.9 Hz, 1H), 7.29 (t, *J* = 8.0 Hz, 1H), 7.09 – 7.07 (m, 1H), 7.07 – 7.05 (m, 1H), 7.04 (t, *J* = 2.2 Hz, 1H), 6.86 (ddd, *J* = 8.2, 2.6, 0.9 Hz, 1H), 3.87 (s, 3H), 3.79 (s, 3H), 1.94 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.7, 163.8, 159.9, 159.1, 140.0, 131.9, 130.0, 129.1, 122.4, 117.8, 117.6, 114.9, 113.9, 111.8, 92.3, 55.5, 55.4, 27.1.

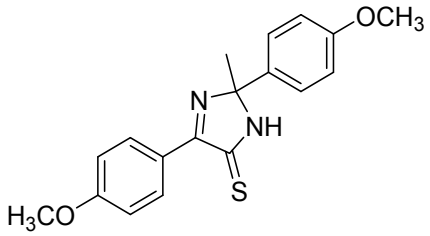
FT-IR (neat, cm^{-1}) υ 1648, 1292, 1278, 1247.

HRMS calcd for $C_{18}H_{19}N_2S$: $[M + H]^+$ 327.1162, found: 327.1159.


10.60
7.97
7.97
7.97
7.96
7.95
7.95
7.95
7.41
7.40
7.39
7.38
7.36
7.35
7.30
7.29
7.28
7.27
7.26
7.08
7.08
7.07
7.07
7.06
7.06
7.06
7.06
7.04
7.04
7.04
6.88
6.87
6.87
6.87
6.86
6.86
6.85
6.85
3.87
3.79
1.94
OCH3
H3CO
N
NH
S
1.03
1.98
1.10
1.07
1.01
1.01
1.02
1.00
3.16
3.06
3.13
f1 (ppm)


187.66
163.84
159.88
159.15
140.02
131.88
130.00
129.15
122.42
117.83
117.64
114.87
113.88
111.84
92.34
77.30 CDCl3
76.79 CDCl3
55.46
55.40
27.10
OCH3
H3CO
N
NH
S
f1 (ppm)

2,5-Bis(3-methoxyphenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3n)



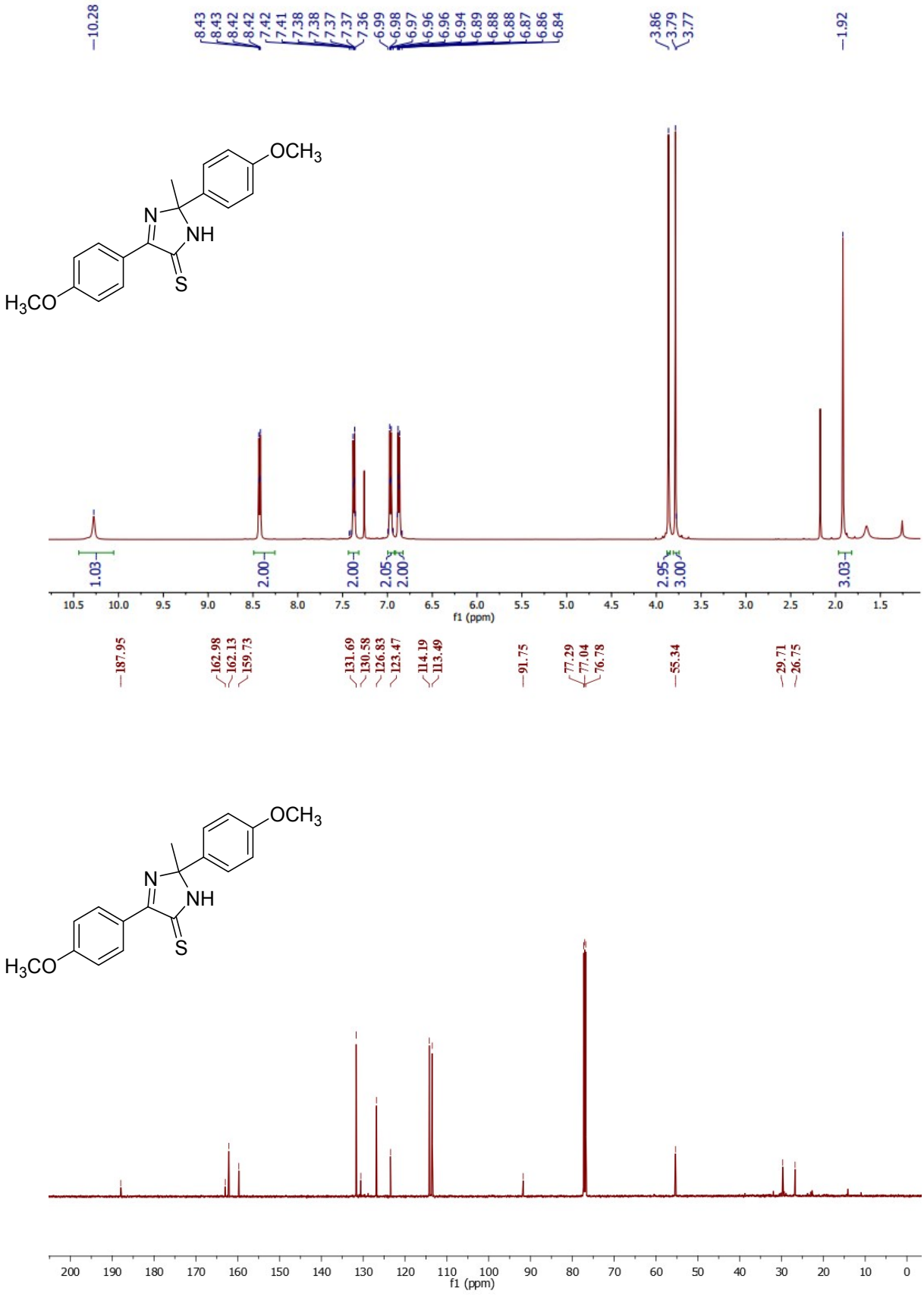
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.26): light yellow oil, 82% yield (26.7 mg).

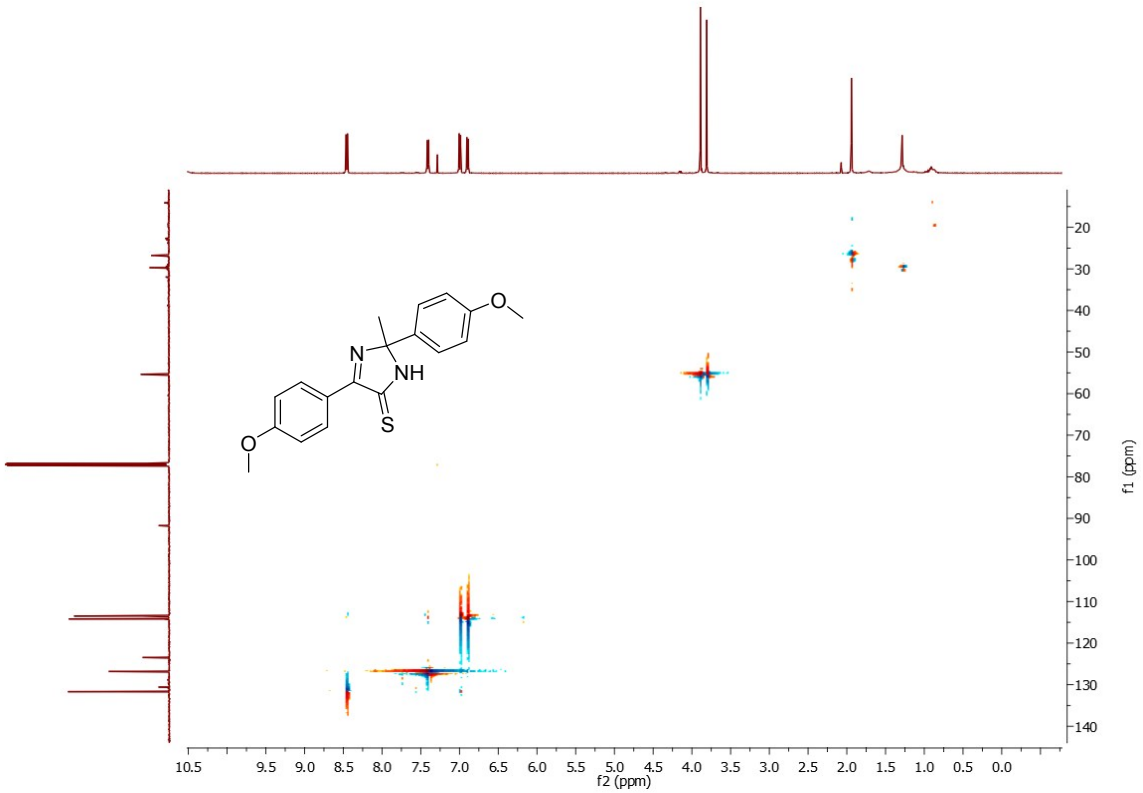
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.28 (s, 1H), 8.49 – 8.26 (m, 2H), 7.43 – 7.32 (m, 2H), 7.00 – 6.92 (m, 2H), 6.91 – 6.83 (m, 2H), 3.86 (s, 3H), 3.79 (s, 3H), 1.92 (s, 3H).

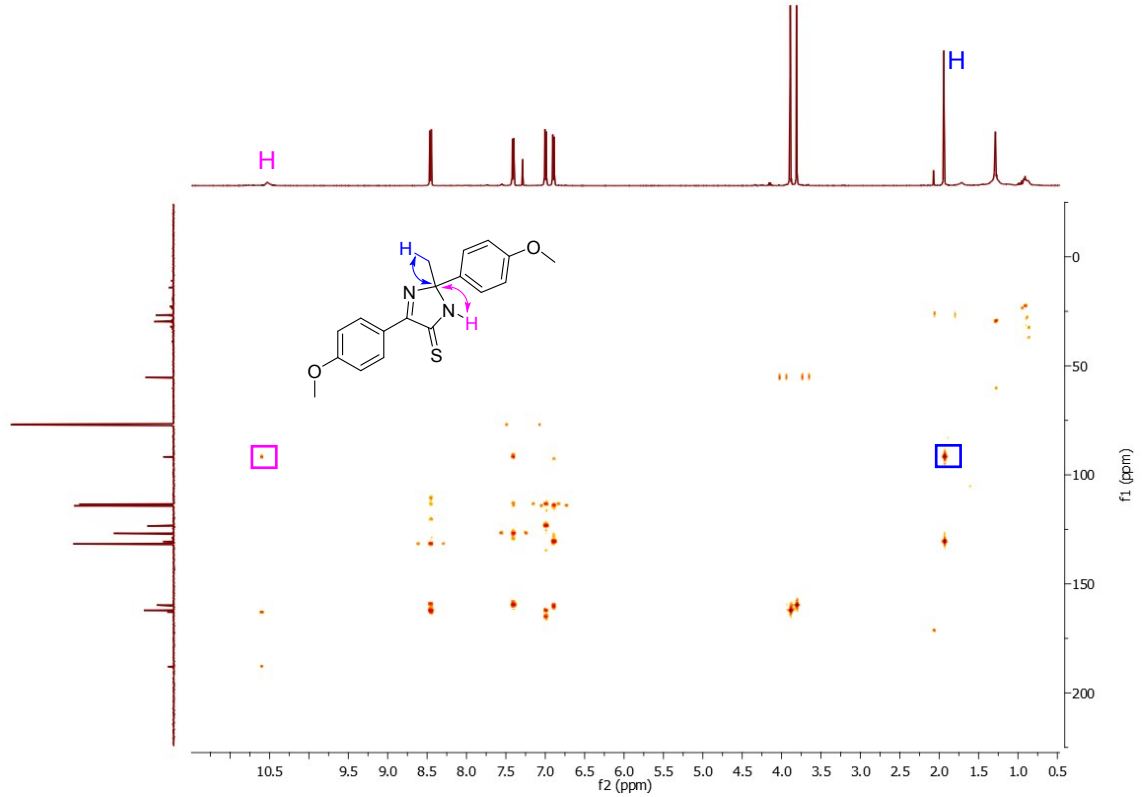
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 188.0, 163.0, 162.1, 159.7, 131.7, 130.6, 126.8, 123.5, 114.2, 113.5, 91.7, 55.3, 29.7, 26.7.

FT-IR (neat, cm^{-1}) υ 1645, 1310, 1297, 1285.

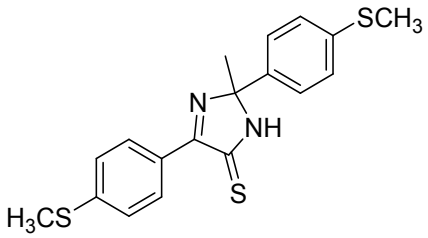
HRMS calcd for $C_{18}H_{19}N_2S$: $[M + H]^+$ 327.1162, found: 327.1160.


10.28
8.43
8.43
8.42
8.42
7.42
7.41
7.38
7.38
7.37
7.37
7.37
7.36
6.99
6.98
6.97
6.96
6.96
6.94
6.89
6.88
6.88
6.87
6.86
6.84
3.86
3.79
3.77
1.92
OCH3
N
NH
S
H3CO
1.03
2.00
2.00
2.05
2.00
2.95
3.00
3.03
f1 (ppm)
187.95
162.98
162.13
159.73
131.69
130.58
126.83
123.47
114.19
113.49
91.75
77.29
77.04
76.78
55.34
29.71
26.75
f1 (ppm)


N
NH
S
O
O
f1 (ppm)
f2 (ppm)


H
H
H
N
N
H
S
O
O
f1 (ppm)
f2 (ppm)

2,5-Bis(4-(methylthio)-phenyl)-2-methyl-2,3-dihydro-4*H*-imidazole-4-thione (3o)



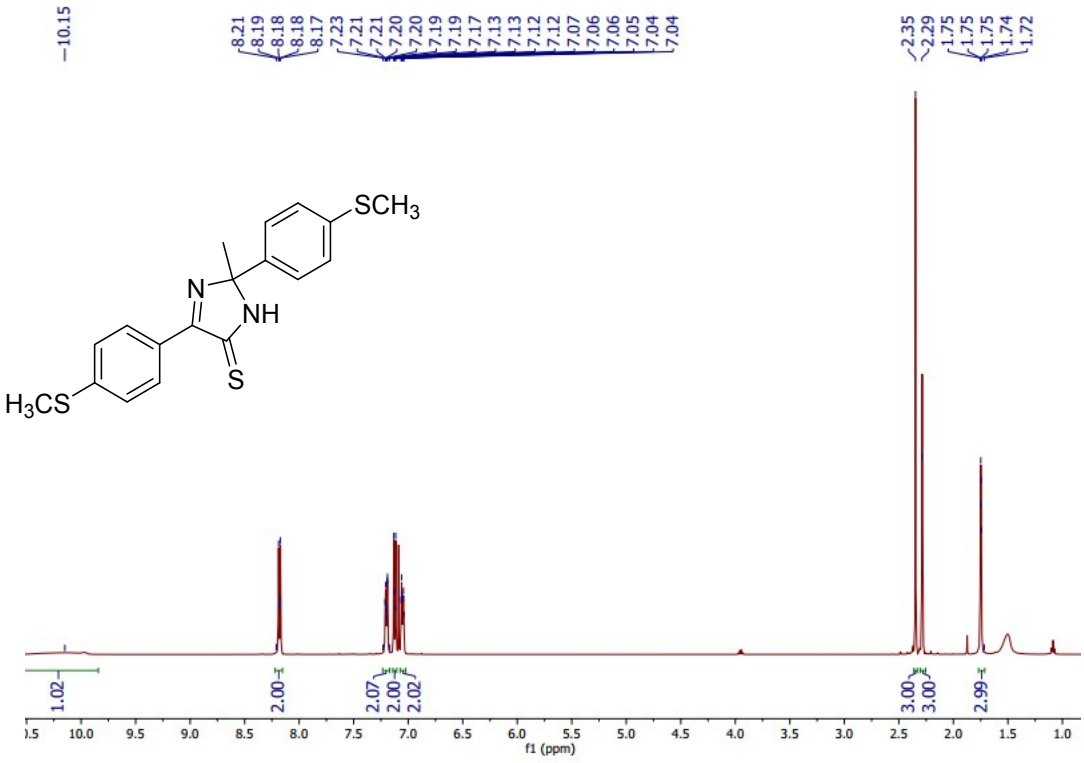
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:10 (v./v.), TLC silica gel 60 F254, R_f = 0.29): yellow liquid, 74% yield (26.5 mg).

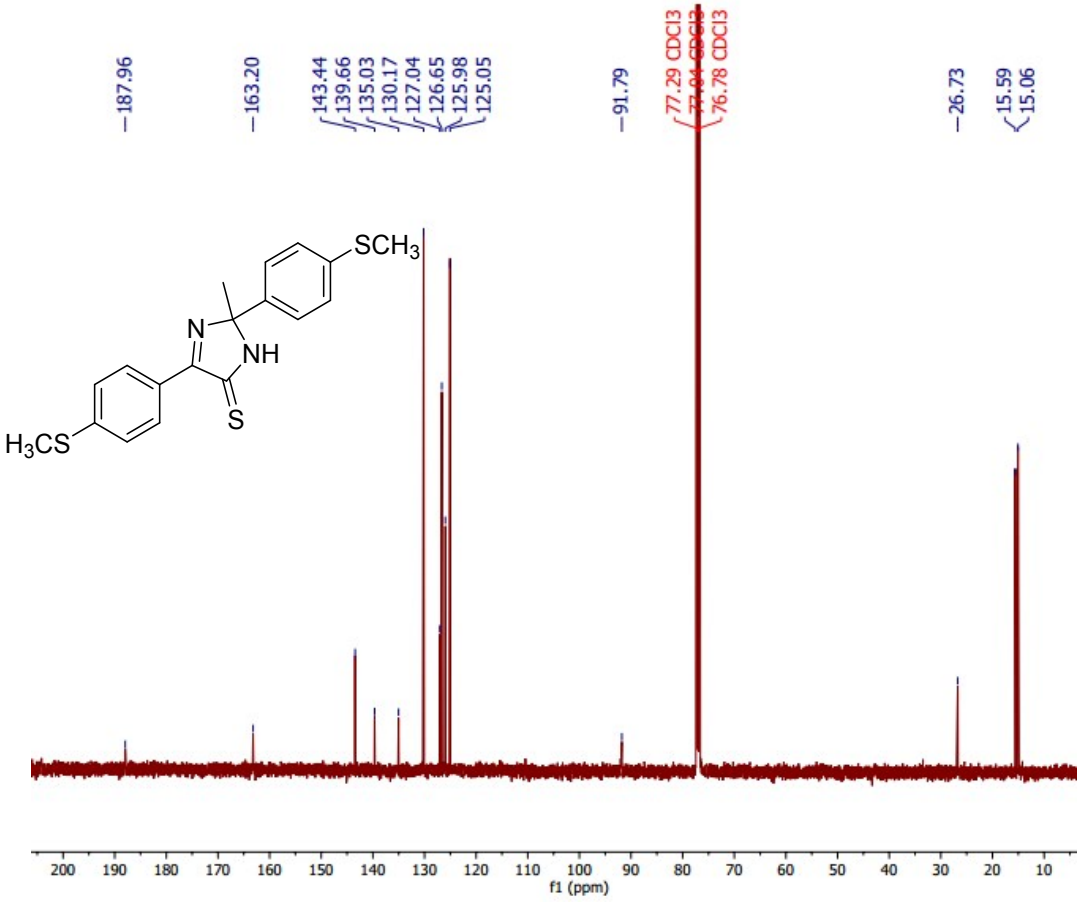
^{1}H-NMR (500 MHz, $CDCl_3$, ppm) δ 10.15 (s, 1H), 8.22 – 8.15 (m, 2H), 7.23 – 7.17 (m, 2H), 7.14 – 7.10 (m, 2H), 7.05 (dt, *J* = 8.7, 2.1 Hz, 2H), 2.35 (s, 3H), 2.29 (s, 3H), 1.75 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 188.0, 163.2, 143.4, 139.7, 135.0, 130.2, 127.0, 126.6, 126.0, 125.0, 91.8, 26.7, 15.6, 15.1.

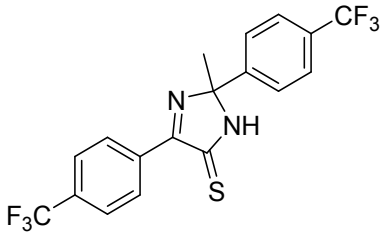
FT-IR (neat, cm^{-1}) υ 1656, 1252, 662.

HRMS calcd for $C_{18}H_{19}N_2S_3$: $[M + H]^+$ 359.0705, found: 359.0698.


10.15
8.21
8.19
8.18
8.18
8.17
7.23
7.21
7.21
7.20
7.20
7.19
7.19
7.17
7.13
7.13
7.12
7.12
7.07
7.06
7.06
7.05
7.04
7.04
2.35
2.29
1.75
1.75
1.75
1.74
1.72
SCH3
N
NH
S
H3CS
1.02
2.00
2.07
2.00
2.02
3.00
3.00
2.99
f1 (ppm)


187.96
163.20
143.44
139.66
135.03
130.17
127.04
126.65
125.98
125.05
91.79
77.29 CDCl3
77.04 CDCl3
76.78 CDCl3
26.73
15.59
15.06
SCH3
N
NH
S
H3CS
f1 (ppm)

2-Methyl-2,5-bis(3-(trifluoromethyl)phenyl)-2,3-dihydro-4*H*-imidazole-4-thione (3p)



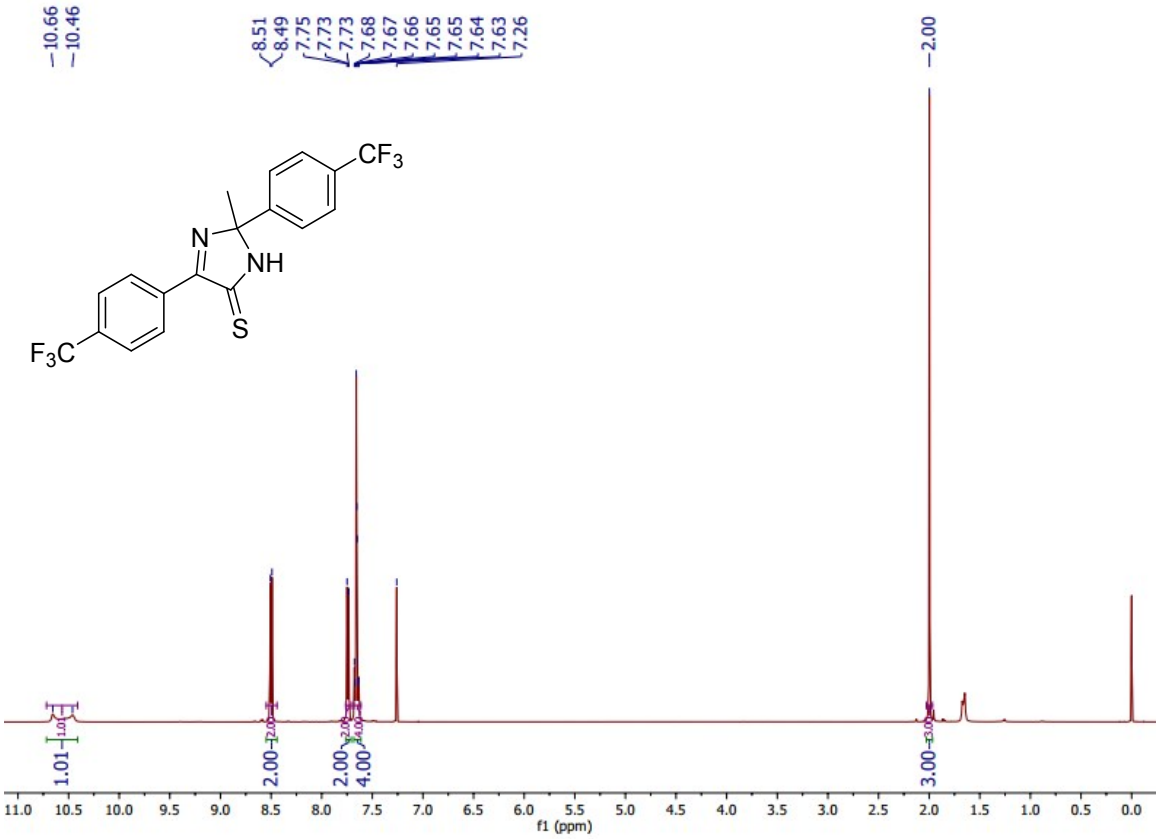
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.43): light yellow oil, 79% yield (31.8 mg).

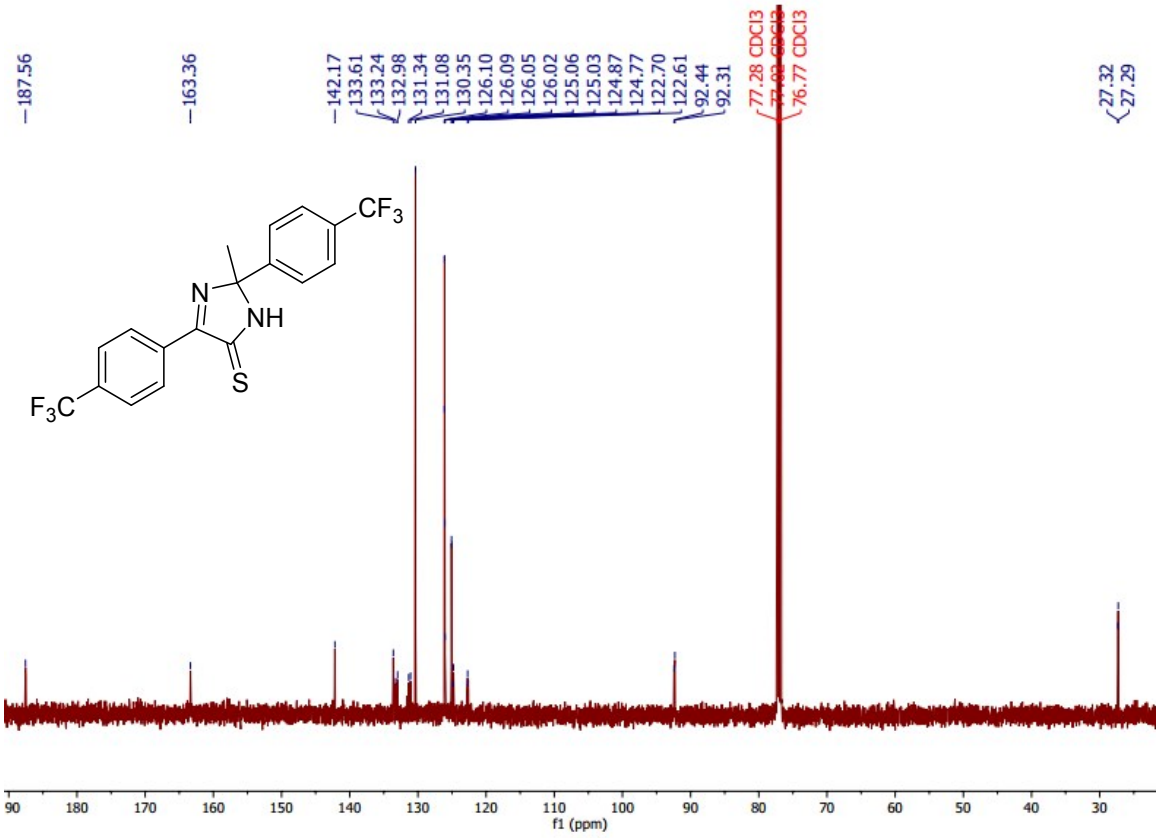
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.56 (d, *J* = 97.4 Hz, 1H), 8.50 (d, *J* = 8.1 Hz, 2H), 7.76 – 7.71 (m, 2H), 7.68 – 7.61 (m, 4H), 2.00 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.6, 163.4, 142.2, 133.6, 133.1 (q, *J* = 32.5 Hz), 131.2 (q, *J* = 33.1 Hz), 130.3, 126.1 (q, *J* = 2.8 Hz), 125.0 (q, *J* = 3.6 Hz), 123.8 (q, *J* = 272.7 Hz), 123.7 (q, *J* = 272.2 Hz), 92.4, 27.3.

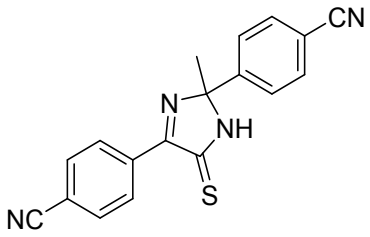
FT-IR (neat, cm^{-1}) υ 1650, 1247.

HRMS calcd for $C_{18}H_{13}N_2F_6S$: $[M + H]^+$ 403.0698, found: 403.0704.


10.66
10.46
8.51
8.49
7.75
7.73
7.73
7.68
7.67
7.66
7.65
7.65
7.64
7.63
7.26
2.00
CF3
N
NH
S
F3C
1.01
2.00
2.00
4.00
3.00
f1 (ppm)


187.56
163.36
142.17
133.61
133.24
132.98
131.34
131.08
130.35
126.10
126.09
126.05
126.02
125.06
125.03
124.87
124.77
122.70
122.61
92.44
92.31
77.28 CDCl3
77.03 CDCl3
76.77 CDCl3
27.32
27.29
CF3
N
NH
S
F3C
f1 (ppm)

4,4'-(2-Methyl-5-thioxo-2,5-dihydro-1*H*-imidazole-2,4-diyl)dibenzonitrile (3q)



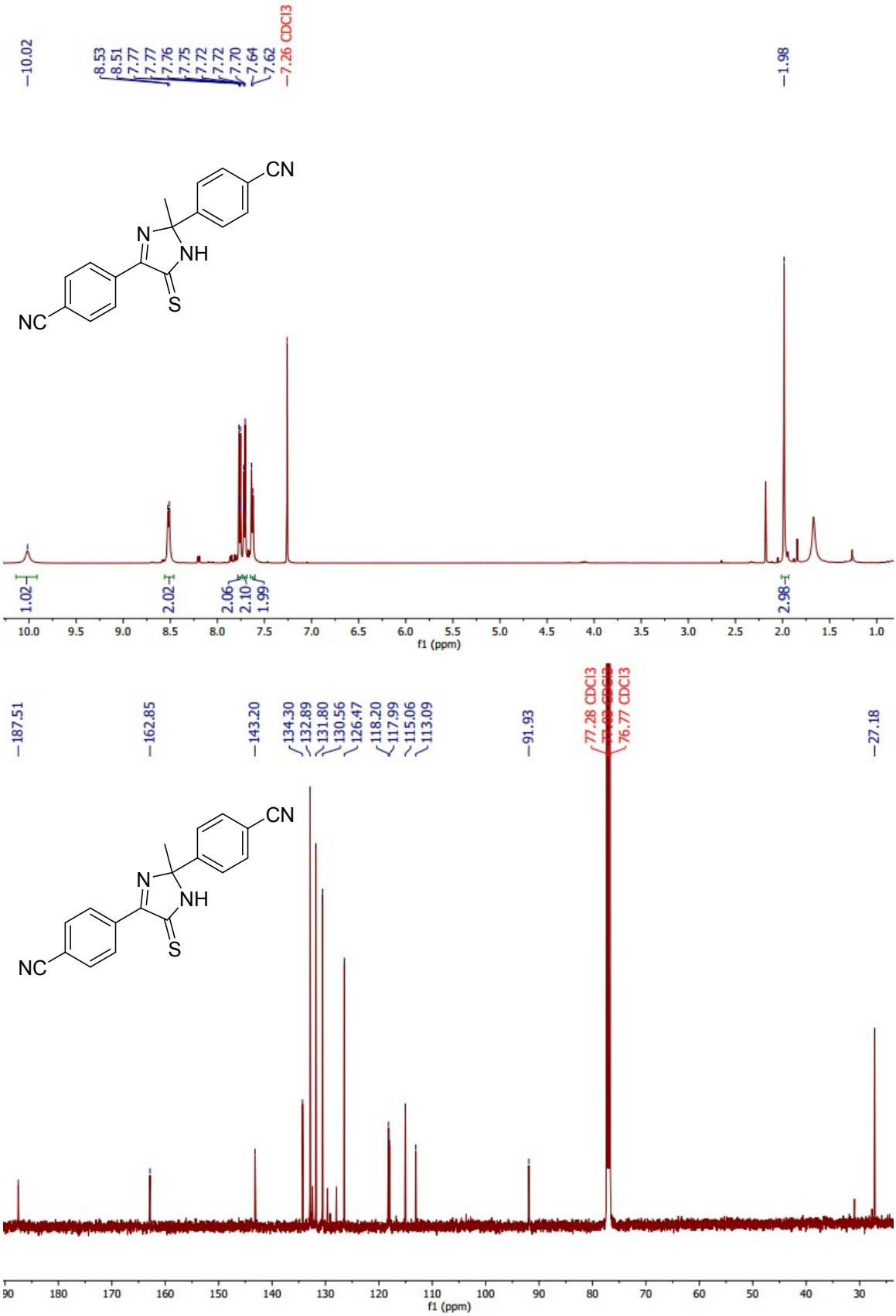
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.17): light yellow oil which slowly solidified, 78% yield (24.6 mg).

^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.02 (s, 1H), 8.52 (d, *J* = 8.0 Hz, 2H), 7.78 – 7.74 (m, 2H), 7.71 (d, *J* = 8.3 Hz, 2H), 7.63 (d, *J* = 8.1 Hz, 2H), 1.98 (s, 3H).

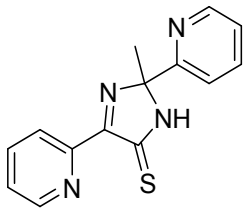
^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 187.5, 162.8, 143.2, 134.3, 132.9, 131.8, 130.6, 126.5, 118.2, 118.0, 115.1, 113.1, 91.9, 27.2.

FT-IR (neat, cm^{-1}) υ 2238, 1645, 1252.

HRMS calcd for $C_{18}H_{13}N_4S$: $[M + H]^+$, 317.0855, found: 317.0850.


10.02
8.53
8.51
7.77
7.77
7.76
7.75
7.72
7.72
7.70
7.64
7.62
7.26 CDCl3
1.98
CN
N
NH
S
NC
1.02
2.02
2.06
2.10
1.99
2.98
f1 (ppm)
187.51
162.85
143.20
134.30
132.89
131.80
130.56
126.47
118.20
117.99
115.06
113.09
91.93
77.28 CDCl3
76.77 CDCl3
27.18
f1 (ppm)

2-Methyl-2,5-di(pyridin-2-yl)-2,3-dihydro-4*H*-imidazole-4-thione (3r)



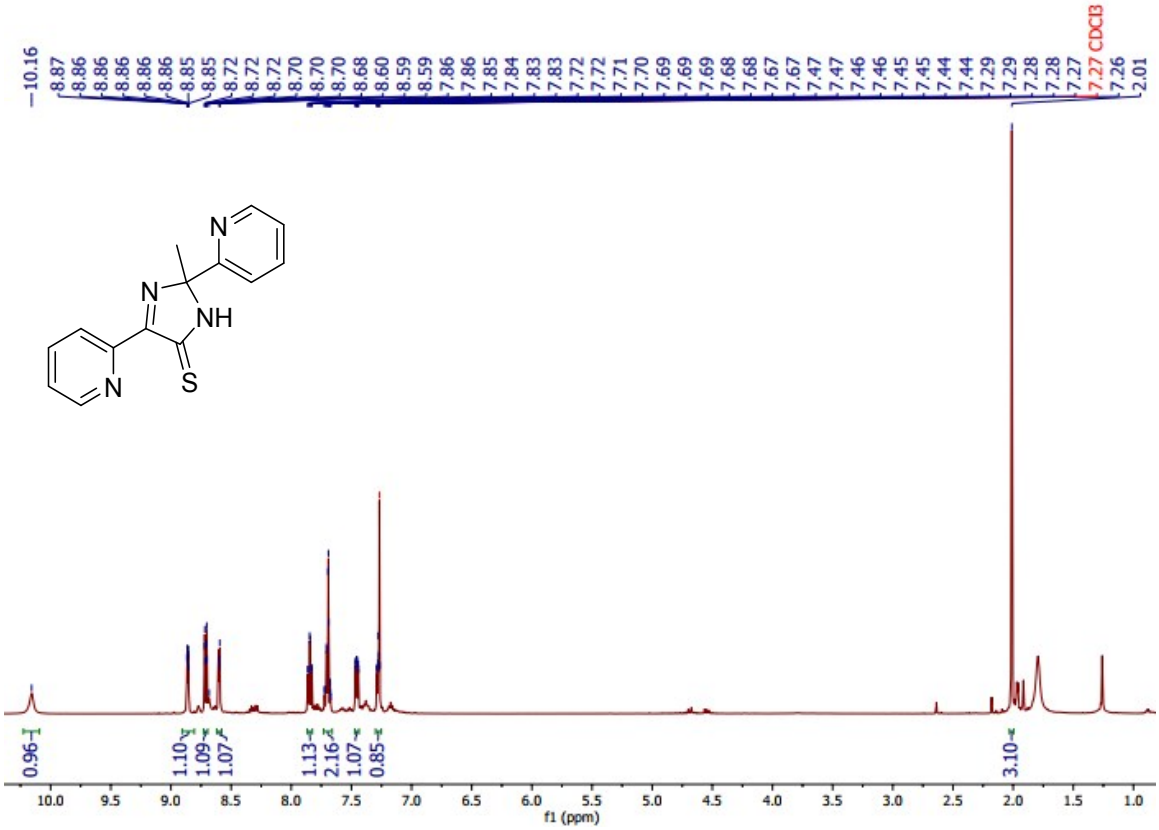
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f = 0.14): light yellow oil, 74% yield (19.8 mg).

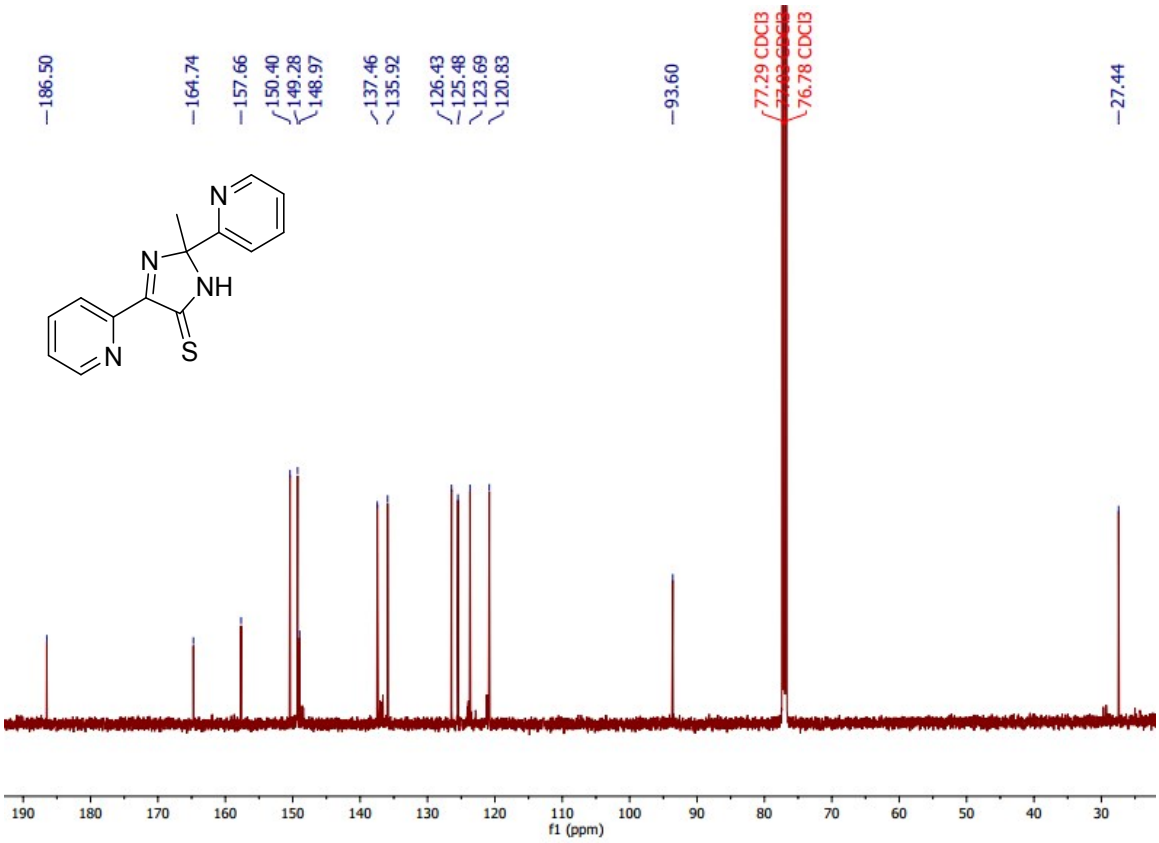
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 10.16 (s, 1H), 8.86 (ddd, *J* = 4.8, 1.8, 0.9 Hz, 1H), 8.71 (dt, *J* = 7.9, 1.1 Hz, 1H), 8.59 (t, *J* = 1.4 Hz, 1H), 7.85 (td, *J* = 7.8, 1.8 Hz, 1H), 7.73 – 7.66 (m, 2H), 7.45 (ddd, *J* = 7.7, 4.8, 1.2 Hz, 1H), 7.30 – 7.25 (m, 1H), 2.01 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 186.5, 164.7, 157.7, 150.4, 149.3, 149.0, 137.5, 135.9, 126.4, 125.5, 123.7, 120.8, 93.6, 27.4.

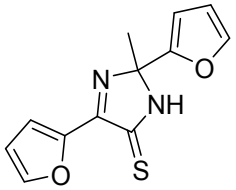
FT-IR (neat, cm^{-1}) υ 1642, 1251.

HRMS calcd for $C_{14}H_{13}N_4S$: $[M + H]^+$ 269.0855, found: 269.0861.


10.16
8.87
8.86
8.86
8.86
8.86
8.86
8.85
8.85
8.72
8.72
8.72
8.70
8.70
8.70
8.70
8.68
8.60
8.59
8.59
7.86
7.86
7.85
7.84
7.83
7.83
7.72
7.72
7.71
7.70
7.69
7.69
7.69
7.68
7.68
7.67
7.67
7.47
7.47
7.46
7.46
7.45
7.45
7.44
7.44
7.29
7.29
7.28
7.28
7.27
7.27 CDCl3
7.26
2.01
N
N
NH
N
S
0.96
1.10
1.09
1.07
1.13
2.16
1.07
0.85
3.10
10.0
9.5
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
f1 (ppm)


186.50
164.74
157.66
150.40
149.28
148.97
137.46
135.92
126.43
125.48
123.69
120.83
93.60
77.29 CDCl3
76.78 CDCl3
27.44
N
N
NH
N
S
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
f1 (ppm)

2-Methyl-2,5-di(pyridin-2-yl)-2,3-dihydro-4*H*-imidazole-4-thione (3s)



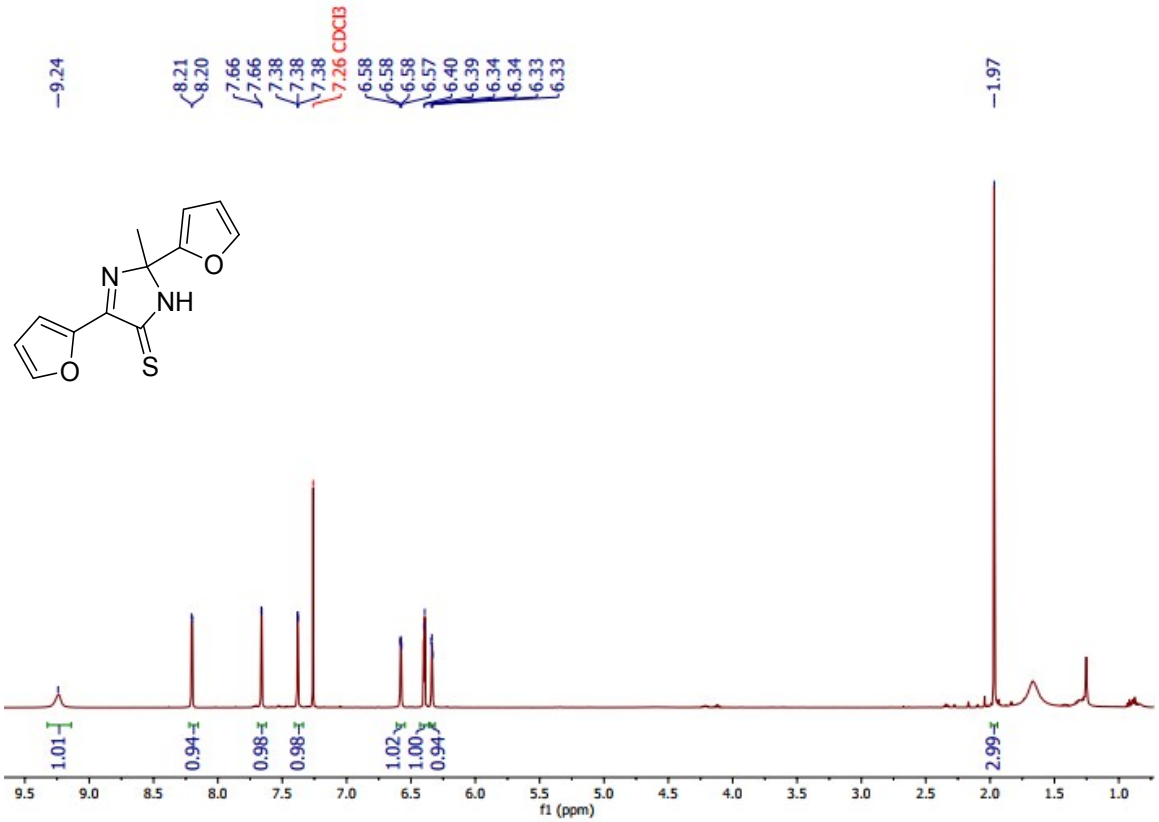
Prepared as shown in the general procedure and purified on silica gel (230-400 mesh or 37-63 μm, ethyl acetate/cyclohexane = 1:5 (v./v.), TLC silica gel 60 F254, R_f =0.14): light yellow oil which slowly solidified, 60% yield (14.8 mg).

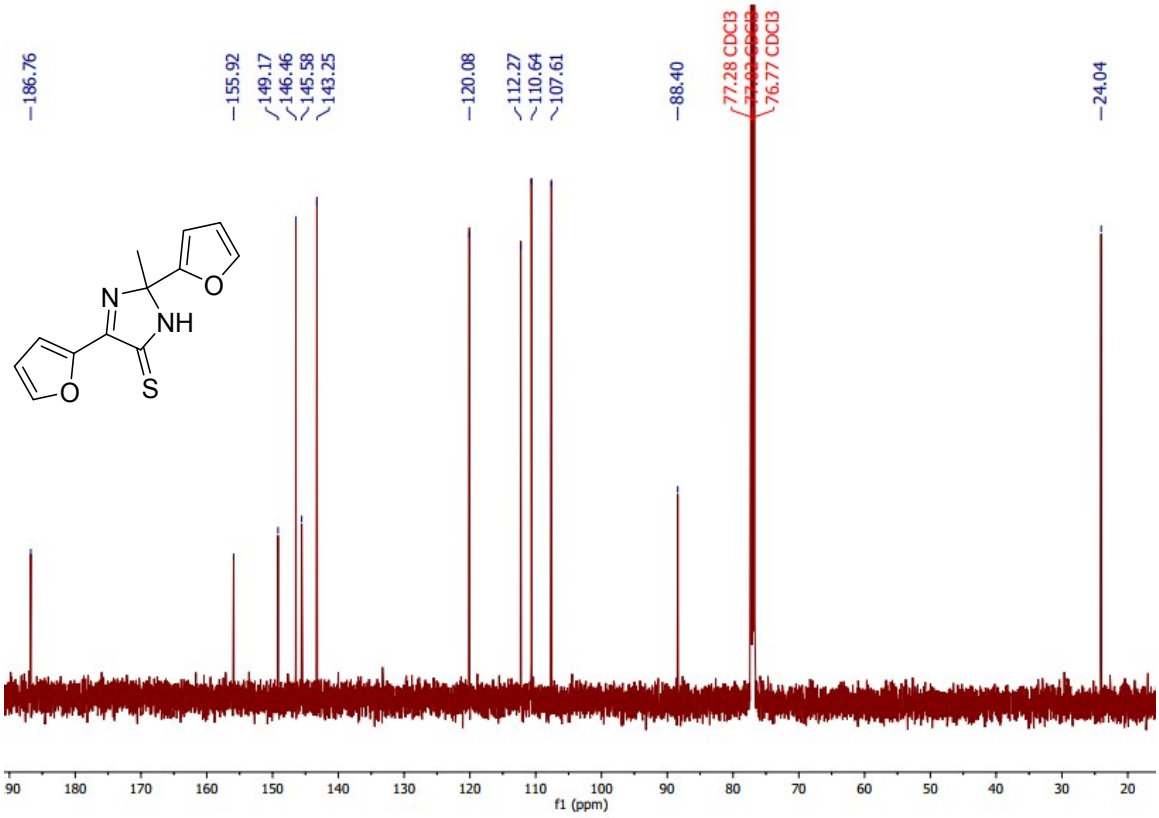
^{1}H NMR (500 MHz, $CDCl_3$, ppm) δ 9.24 (s, 1H), 8.20 (d, *J* = 3.5 Hz, 1H), 7.66 (d, *J* = 1.7 Hz, 1H), 7.40 – 7.34 (m, 1H), 6.58 (dd, *J* = 3.6, 1.7 Hz, 1H), 6.40 (d, *J* = 3.3 Hz, 1H), 6.34 (dd, *J* = 3.4, 1.8 Hz, 1H), 1.97 (s, 3H).

^{13}C NMR (125 MHz, $CDCl_3$, ppm) δ 186.8, 155.9, 149.2, 146.5, 145.6, 143.2, 120.1, 112.3, 110.6, 107.6, 88.4, 24.0.

FT-IR (neat, cm^{-1}) υ 1653, 1530, 1249.

HRMS calcd for $C_{12}H_{11}N_2OS$: $[M + H]^+$ 247.0536, found: 247.0541.


9.24
8.21
8.20
7.66
7.66
7.38
7.38
7.38
7.26 CDCl3
6.58
6.58
6.58
6.57
6.40
6.39
6.34
6.34
6.33
6.33
1.97
N
NH
O
O
S
1.01
0.94
0.98
0.98
1.02
1.00
0.94
2.99
f1 (ppm)


186.76
155.92
149.17
146.46
145.58
143.25
120.08
112.27
110.64
107.61
88.40
77.28 CDCl3
76.77 CDCl3
24.04
N
NH
O
O
S
f1 (ppm)

4. Plausible mechanism