

Supporting Information

Ruthenium(0) Catalyzed Endiyne- α -Ketol [4+2] Cycloaddition: Convergent Assembly of Type II Polyketide Substructures via C-C Bond Forming Transfer Hydrogenation

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General Information

All reactions were run under an atmosphere of argon. Anhydrous solvents were distilled using solvent stills, and solvents were transferred by oven-dried syringe. Sealed tubes (13×100 mm²) were purchased from Fisher Scientific (catalog number 14-959-35C) and were dried in an oven overnight and cooled under a stream of argon prior to use. Ru₃(CO)₁₂ was recrystallized from cyclohexane prior to use. All ligands were used without purification. All other commercially available starting materials were used without purification. α -Hydroxyketones **2e** and **2h** were prepared according to known literature procedures.^{1,2,3} Analytical thin-layer chromatography (TLC) was carried out using 0.25 mm commercial silica gel plates (Silicycle Siliaplate, F-254). Visualization was accomplished with UV light followed by dipping in a ceric ammonium molybdate solution and heating. Purification of reaction products was carried out by flash column chromatography using Silicycle silica gel (40-63 μ m), according to the method described by Still.⁴ Stereochemistry of products **3d**, **5d**, *t*-Bu-**5d** and **10** were determined by single crystal X-ray structure analysis.

Spectroscopy, Spectrometry, and Data Collection

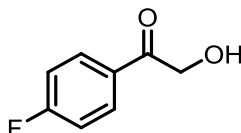
Infrared spectra were recorded on a Thermo Nicolet 380 spectrometer. High-resolution mass spectra (HRMS) were obtained on a Karatos MS9 and are reported as *m/z* (relative intensity). Accurate masses are reported for the molecular ion (M+H, M or M-H) or a suitable fragment ion. Melting points were obtained on a Stuart SMP3 apparatus and are uncorrected. ¹H NMR spectra and NOESY experiments were recorded on a Varian Gemini (400 MHz) spectrometer at ambient temperature unless otherwise noted. Chemical shifts are reported in delta (δ) units, parts per million (ppm), relative to the center of the singlet at 7.26 ppm for deuteriochloroform. Data are reported as: multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, sext = sextet, m = multiplet), integration and coupling constant(s) in Hz. ¹³C NMR spectra were recorded on a Varian Gemini (100 MHz) spectrometer and were routinely run with broadband decoupling. Chemical shifts are reported in ppm, with the residual solvent resonance employed as the internal standard (CDCl₃ at 77.0 ppm). ¹⁹F NMR spectra were recorded on a Varian Gemini 400 (376 MHz) spectrometer.

References:

1. Yoshikawa, N.; Suzuki, T.; Shibasaki, M. *J. Org. Chem.* **2002**, *67*, 2556.
2. Sharma, R.; Lee, J.; Wang, S.; Milne, G. W.A.; Lewin, N. E.; Blumberg, P. M.; Marquez, V. E. *J. Med. Chem.* **1996**, *39*, 19.
3. Bálint, J.; Egri, G.; Kolbert, A.; Dianóczy, C.; Fogassy, E.; Novák, L.; Poppe, L. *Tetrahedron:Asymmetry* **1999**, *10*, 4017.
4. Still, W.C.; Kahn, M.; Mitra, A. *J. Org. Chem.* **1978**, *43*, 2923.

Detailed Procedures and Spectral Data for α -Hydroxyketones (2b-2g, 2i):

1-(4-Fluorophenyl)-2-hydroxyethan-1-one (2b)



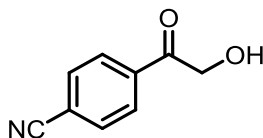
Detailed Procedures

A microwave vial equipped with a stir bar was charged with 2-bromo-4'-fluoroacetophenone (617 mg, 2.8 mmol, 100 mol%), deionized water (21 mL), sealed with a rubber septum and purged with argon. The rubber septum was replaced with a Teflon cap and heated to 120 °C in a microwave reactor with stirring for 25 min. The resulting mixture was extracted with EtOAc (2 x 50 mL). The combined organic layer was washed with a saturated solution of sodium thiosulfate (2 x 10 mL), brine (2 x 10 mL), water (2 x 10 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (10% EtOAc/hexane→70% EtOAc/hexane). The title compound **2b** was obtained as a white solid (309 mg) in 72% yield. Spectral data for **2b** was consistent with that reported in literature.⁵

References:

5. McLaughlin, M.; Belyk, K. M.; Qian, G.; Reamer, R. A.; Chen, C.-y. *J. Org. Chem.* **2012**, 77, 5144.

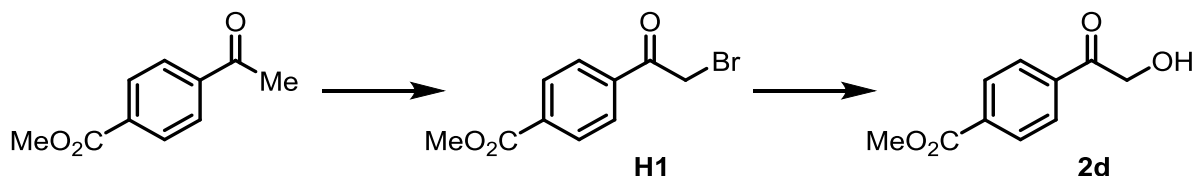
4-(2-Hydroxyacetyl)benzonitrile (**2c**)



Detailed Procedures

A microwave vial equipped with a stir bar was charged 2-bromo-4'-cyanoacetophenone (224 mg, 1.0 mmol, 100 mol%), deionized water (21 mL), sealed with a rubber septum and purged with argon. The rubber septum was replaced with a Teflon cap and heated to 120 °C in a microwave reactor with stirring for 25 min. The resulting mixture was extracted with EtOAc (2 x 50 mL). The combined organic layer was washed with a saturated solution of sodium thiosulfate (2 x 10 mL), brine (2 x 10 mL), water (2 x 10 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (20% EtOAc/hexane→80% EtOAc/hexane). The title compound **2c** was obtained as a white solid (95 mg) in 59% yield. Spectral data for **2c** was consistent with that reported in literature.⁵

Methyl 4-(2-hydroxyacetyl)benzoate (**2d**)



Detailed Procedures

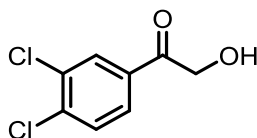
Compound **H1** was made according to known literature procedure.⁶

A microwave vial equipped with a stir bar was charged with **H1** (514 mg, 2.0 mmol, 100 mol%), deionized water (21 mL), sealed with a rubber septum and purged with argon. The rubber septum was replaced with a Teflon cap and heated to 120 °C in a microwave reactor with stirring for 25 min. The resulting mixture was extracted with EtOAc (2 x 50 mL). The combined organic layer was washed with a saturated solution of sodium thiosulfate (2 x 10 mL), brine (2 x 10 mL), water (2 x 10 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (5% EtOAc/hexane→50% EtOAc/hexane). The title compound **2d** was obtained as a white solid (204 mg) in 53% yield. Spectral data for **2d** was consistent with that reported in literature.⁷

References:

6. Hou, Z.; Nakanishi, I.; Kinoshita, T.; Takei, Y.; Yasue, M.; Misu, R.; Suzuki, Y.; Nakamura, S.; Kure, T.; Ohno, H.; Murata, K.; Kitaura, K.; Hirasawa, A.; Tsujimoto, G.; Oishi, S.; Fujii, N. *J. Med. Chem.* **2012**, 55, 2899.
7. Kuhl, N.; Glorius, F. *Chem. Commun.* **2011**, 47, 573.

Methyl 4-(2-hydroxyacetyl)benzoate (2f)



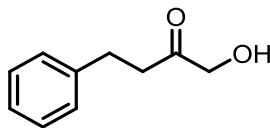
Detailed Procedures

A 250 mL round bottom flask equipped with a stir bar was charged with bis(trifluoroacetoxy) iodobenzene (13.4 g, 31 mmol) and purged with argon. A solution of 3,5-dichloroacetophenone (2.94 g, 15.5 mmol), trifluoroacetic acid (4.8 mL) in acetonitrile/water (90 mL, 9:1) was injected. The solution was heated to 85 ° C for 3 hours. The solution was cooled to 25 °C and concentrated *in vacuo*. The residue was extracted with dichloromethane (250 mL), washed with saturated aqueous sodium bicarbonate (2 x 200 mL), brine (1 x 200 mL), dried (MgSO₄), filtered and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (20% EtOAc/hexane→30% EtOAc/hexane). The title compound **2f** was obtained as a white flaky solid (825 mg) in 26% yield. Spectral data for **2f** was consistent with that reported in literature.⁸

References:

8. Rosowsky, A.; Fu, H.; Queener, S. F. *J. Heterocyclic Chem.* **2001**, 38, 1197.

1-Hydroxy-4-phenylbutan-2-one (2g)



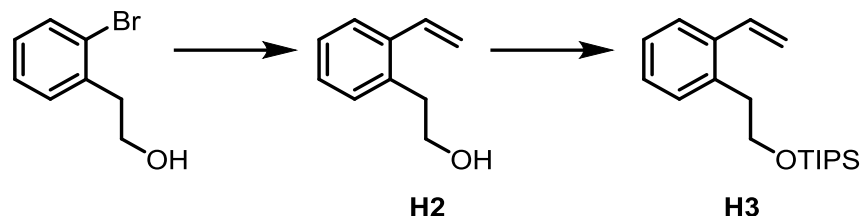
Detailed Procedures

To an argon-flushed 250 mL round bottom flask equipped with a stir bar was injected 4-phenyl-1-butene (1.05 mL, 7.0 mmol, 100 mol%), acetone (56 mL), deionized water (13 mL) and glacial acetic acid (2.7 mL). To this was added a solution of KMnO_4 (1.77 g, 11.2 mmol, 160 mol%) in acetone (22 mL) and deionized water (7 mL). The mixture was stirred at 25 °C for 2 hours. Saturated aq. NaHCO_3 (75 mL) was poured into the reaction mixture and extracted with CH_2Cl_2 (3 x 100 mL). The combined organic layer was washed with brine (2 x 50 mL), dried (Na_2SO_4), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (5% EtOAc/hexane→40% EtOAc/hexane). The title compound **2g** was obtained as a white solid (640 mg) in 56% yield. Spectral data for **2c** was consistent with that reported in literature.⁹

References:

9. Tsujigami, T.; Sugai, T.; Ohta, H. *Tetrahedron:Asymmetry* **2001**, 12, 2543.

Triisopropyl(2-vinylphenethoxy)silane (**H3**)



Detailed Procedures

Compound **H2** was made according to known literature procedure.¹⁰

To an argon-flushed 50 mL round bottom flask equipped with a stir bar was added imidazole (1.36 g, 20.0 mmol, 250 mol%) and **H2** (1.19 g, 8.0 mmol, 100 mol%). Dry DMF (15 mL) was injected into the flask followed by TIPSCl (2.23 mL, 10.4 mmol, 130 mol%). The mixture was stirred at 25 °C for 16 hours. Saturated aq. NH₄Cl (25 mL) was poured into the reaction mixture and extracted with Et₂O (3 x 40 mL). The combined organic layer was washed with brine (2 x 25 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (5% CH₂Cl₂/hexane→20% CH₂Cl₂/hexane). The title compound **H3** was obtained as a colorless oil in quantitative yield.

¹H NMR (400 MHz, CDCl₃) δ 7.59-7.53 (m, 1H), 7.29-7.24 (m, 3H), 7.13 (dd, *J* = 17.4, 10.9 Hz, 1H), 5.71 (dd, *J* = 17.4, 1.5 Hz, 1H), 5.37 (dd, *J* = 10.9, 1.5 Hz, 1H), 3.91 (t, *J* = 7.4 Hz, 2H), 3.04 (t, *J* = 7.4 Hz, 2H), 1.16-1.08 (m, 21H).

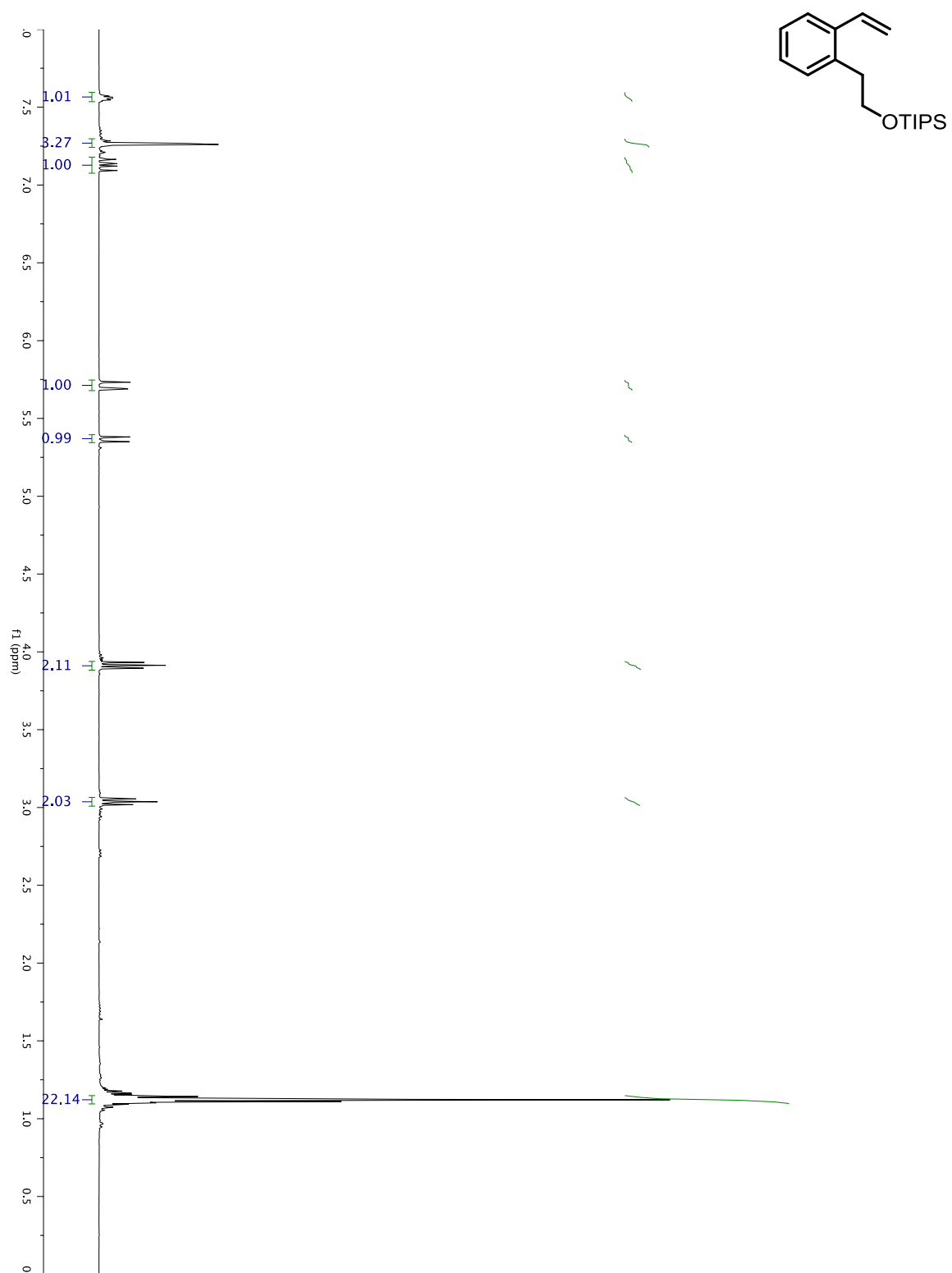
¹³C NMR (100 MHz, CDCl₃) δ 137.0, 136.3, 134.7, 130.5, 127.6, 126.6, 125.6, 115.5, 64.1, 37.0, 18.0, 12.0.

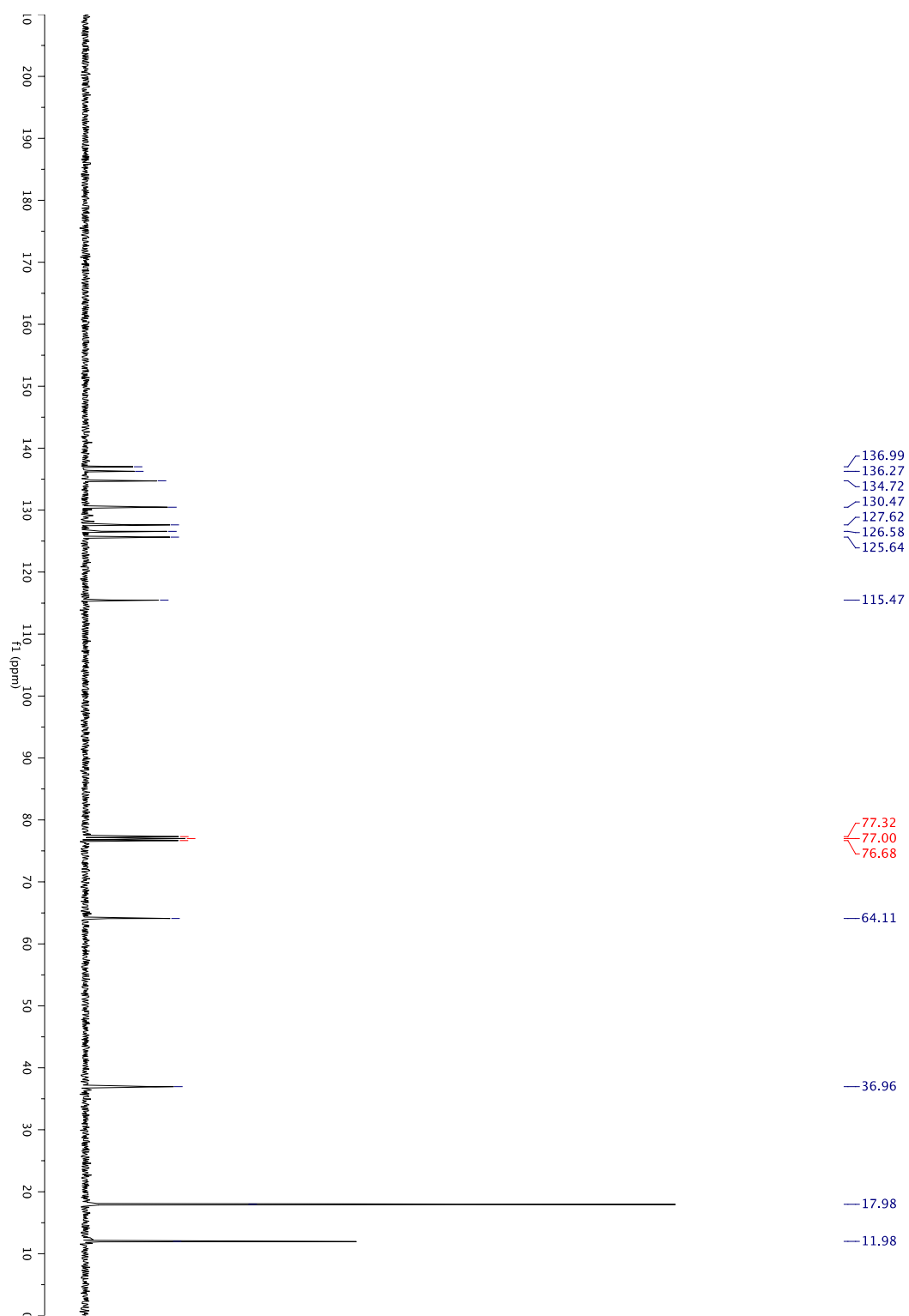
LRMS (CI) Calcd. for C₁₉H₃₂OSi [M]⁺: 305, Found: 305.

FTIR (neat): 2942, 2891, 2865, 1462, 1096, 988, 881, 770, 750, 679 cm⁻¹.

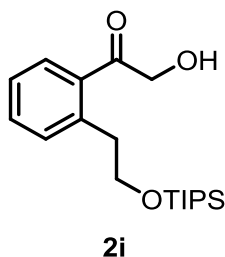
References:

10. Marsault, E.; Hoveyda, H. R.; Peterson, M. L.; Saint-Louis, C.; Landry, A.; Vézina, M.; Ouellet, L.; Wang, Z.; Ramaseshan, M.; Beaubien, S.; Benakli, K.; Beauchemin, S.; Déziel, R.; Peeters, T.; Fraser, G. L. *J. Med. Chem.* **2006**, 49, 7190.





2-Hydroxy-1-(2-(2-((triisopropylsilyl)oxy)ethyl)phenyl)ethan-1-one (2i)



Detailed Procedures

To an argon-flushed 250 mL round bottom flask equipped with a stir bar was added **H3** (2.13 g, 7.0 mmol, 100 mol%), acetone (50 mL), H₂O (13 mL), and acetic acid (2.7 mL). To this was added a solution of KMnO₄ (1.77 g, 11.2 mmol, 160 mol%) in acetone (28 mL) and H₂O (7 mL). The resulting mixture was stirred at 25 °C for 2 hours, and then filtered through a short-pad of celite using CH₂Cl₂ (150 mL) as eluent. The filtrate was concentrated *in vacuo*. Saturated aq. NaHCO₃ (100 mL) was poured into the residue and extracted with CH₂Cl₂ (3 x 75 mL). The combined organic layer was washed with brine (50 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (5% EtOAc/hexane→20% EtOAc/hexane). The title compound **2i** was obtained as a colorless oil (913 mg) in 39% yield.

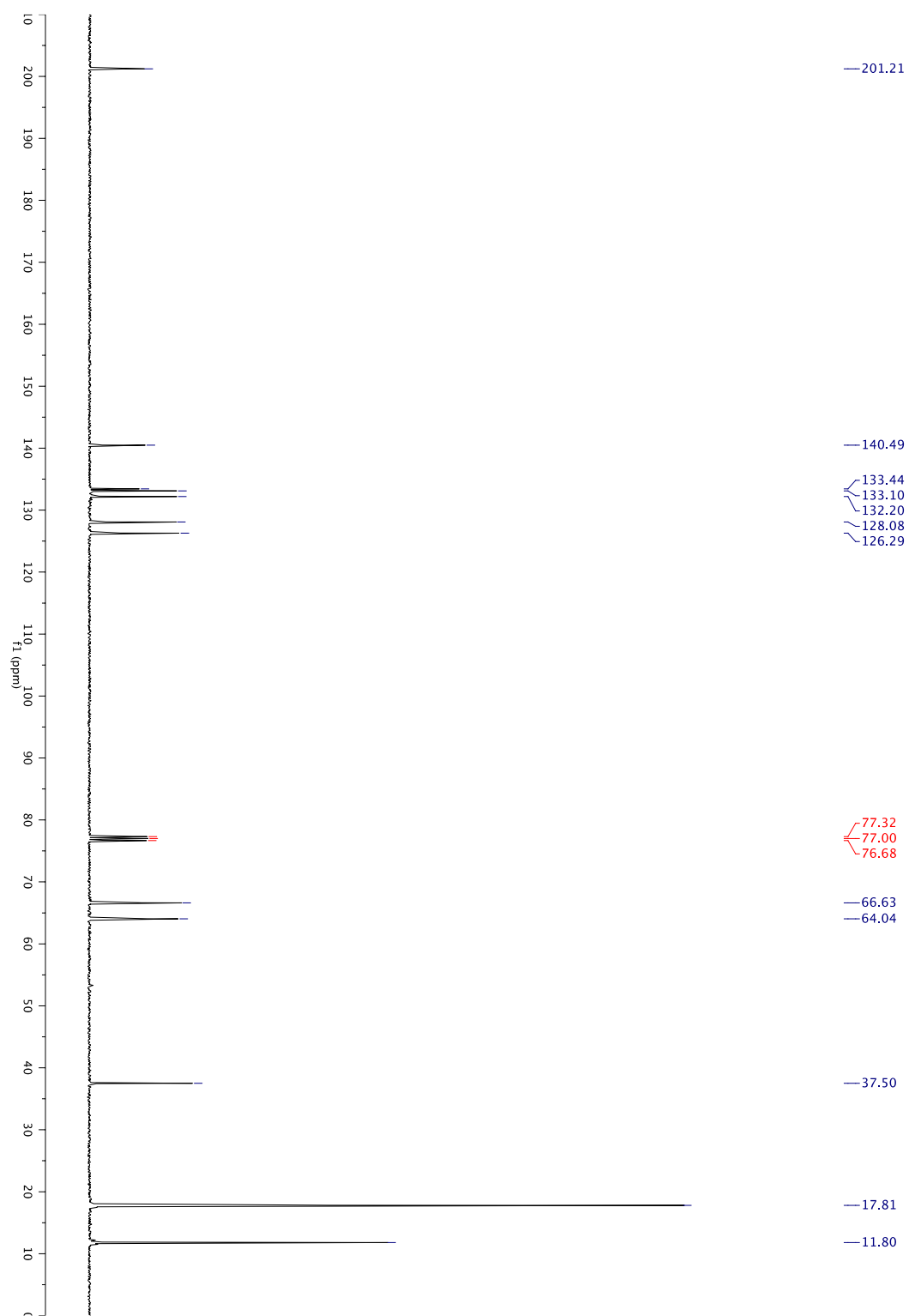
¹H NMR (400 MHz, CDCl₃) δ 7.58 (dd, *J* = 7.8, 1.3 Hz, 1H), 7.46 (td, *J* = 7.5, 1.4 Hz, 1H), 7.41 (dd, *J* = 7.7, 1.5 Hz, 1H), 7.31 (td, *J* = 7.5, 1.5 Hz, 1H), 4.74 (d, *J* = 4.7 Hz, 2H), 3.92 (t, *J* = 6.5 Hz, 2H), 3.58 (t, *J* = 4.7 Hz, 1H), 3.15 (t, *J* = 6.5 Hz, 2H), 1.04-0.96 (m, 21H).

¹³C NMR (100 MHz, CDCl₃) δ 201.2, 140.5, 133.4, 133.1, 132.2, 128.1, 126.3, 66.6, 64.0, 37.5, 17.8, 11.8.

LRMS (CI) Calcd. for C₁₉H₃₂O₃Si [M]⁺: 337, Found: 337.

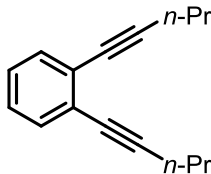
FTIR (neat): 2941, 2865, 1686, 1463, 1091, 971, 882, 754, 736, 680 cm⁻¹.





Detailed Procedures and Spectral Data for Diynes (1a-1e):

1,2-Di(pent-1-yn-1-yl)benzene (1a)



Detailed Procedures

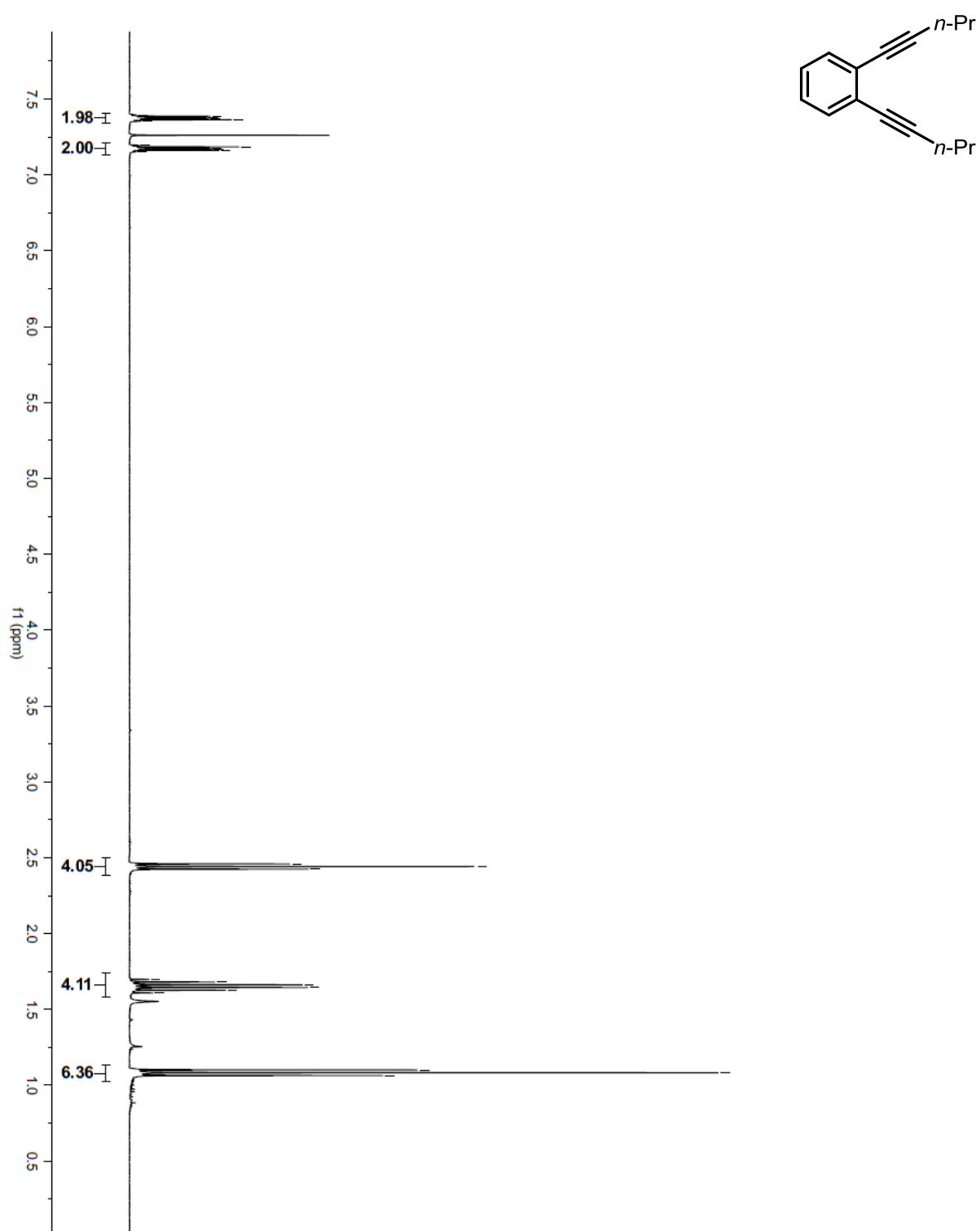
A microwave vial equipped with a stir bar was charged with palladium tetrakis(triphenylphosphine) (116 mg, 0.10 mmol, 5 mol%), copper(I) iodide (76 mg, 0.40 mmol, 20 mol%), tetrabutylammonium iodide (1.85 g, 5.0 mmol, 250 mol%), sealed with a rubber septum and purged with argon. To this mixture was injected a solution of 1,2-dibromobenzene (472 mg, 2.0 mmol, 100 mol%) in dimethylformamide/diethylamine (10 mL, 1:1), followed by 1-pentyne (409 mg, 6.0 mmol, 300 mol%). The solution was degassed by bubbling with argon for 5 min. The rubber septum was quickly replaced with a Teflon cap and heated to 120 °C in a microwave reactor with stirring for 20 min. The resulting dark yellow solution was poured into diethyl ether (150 mL), washed with 1 M HCl (2 x 100 mL), brine (100 mL) and dried over anhydrous magnesium sulfate. The extract was filtered and concentrated *in vacuo*. The residue was adsorbed onto silica gel and purified by column chromatography on silica gel (5% CH₂Cl₂/hexane). The title compound **1a** was obtained as a yellow oil (286 mg) in 75% yield.

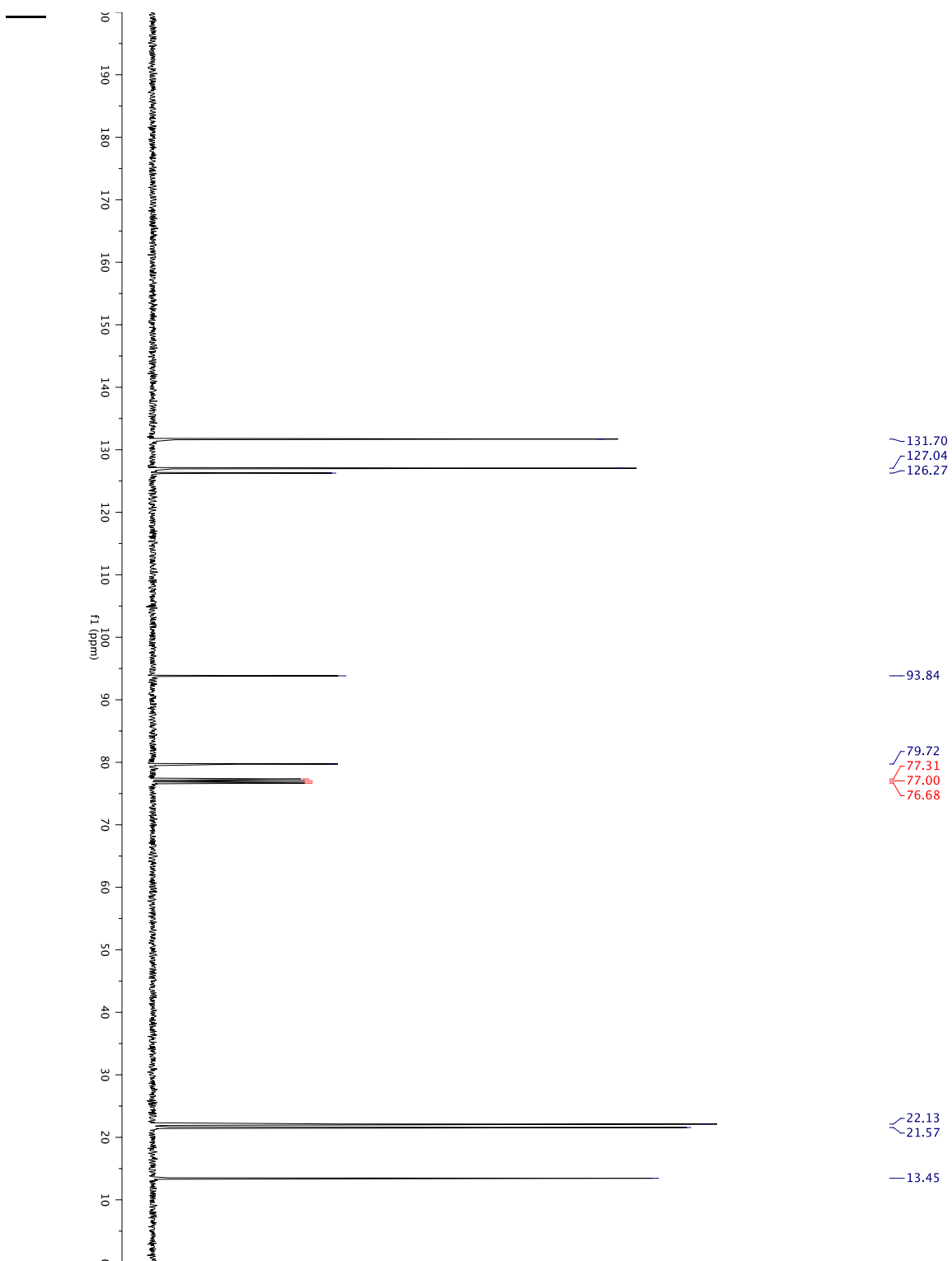
¹H NMR (400 MHz, CDCl₃) δ 7.37 (dd, J = 5.7, 3.4 Hz, 2H), 7.20-7.14 (m, 2H), 2.44 (t, J = 7.0 Hz, 4H), 1.65 (sext, J = 7.2 Hz, 4H), 1.08 (t, J = 7.4 Hz, 6H).

¹³C NMR (100 MHz, CDCl₃) δ 131.7, 127.0, 126.3, 93.8, 79.7, 22.1, 21.6, 13.5.

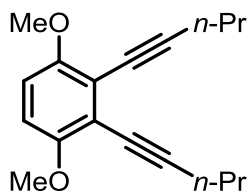
LRMS (CI) Calcd. for C₁₆H₁₈ [M]⁺: 211.1, Found: 211.0.

FTIR (neat): 2962, 2933, 2871, 2229, 1480, 1379, 1338, 1035, 947, 755 cm⁻¹.





1,4-Dimethoxy-2,3-di(pent-1-yn-1-yl)benzene (**1b**)



Detailed Procedures

A microwave vial equipped with a stir bar was charged with 2,3-dibromo-1,4-dimethoxy benzene (296 mg, 1.0 mmol, 100 mol%), palladium tetrakis(triphenylphosphine) (116 mg, 0.10 mmol, 10 mol%), copper(I) iodide (76 mg, 0.40 mmol, 40 mol%), tetrabutyl ammonium iodide (1.12 g, 3.0 mmol, 300 mol%), sealed with a rubber septum and purged with argon. The vial was injected with a solution of 1-pentyne (273 mg, 4.0 mmol, 400 mol%) in dimethylformamide/diethylamine (5 mL, 1:1). The septum was replaced quickly with a teflon cap and heated to 120 °C with stirring in a microwave for 2 hours. The mixture was cooled and poured into diethyl ether (100 mL), washed with 1 M HCl (3 x 50 mL), brine (50 mL) and dried over anhydrous magnesium sulfate. The organic extract was filtered and concentrated *in vacuo*. The residue was adsorbed on to silica gel and purified by column chromatography on silica gel (5% CH₂Cl₂/hexane→20% CH₂Cl₂/hexane). The title compound **1b** was obtained as an orange solid (171 mg) in 63% yield.

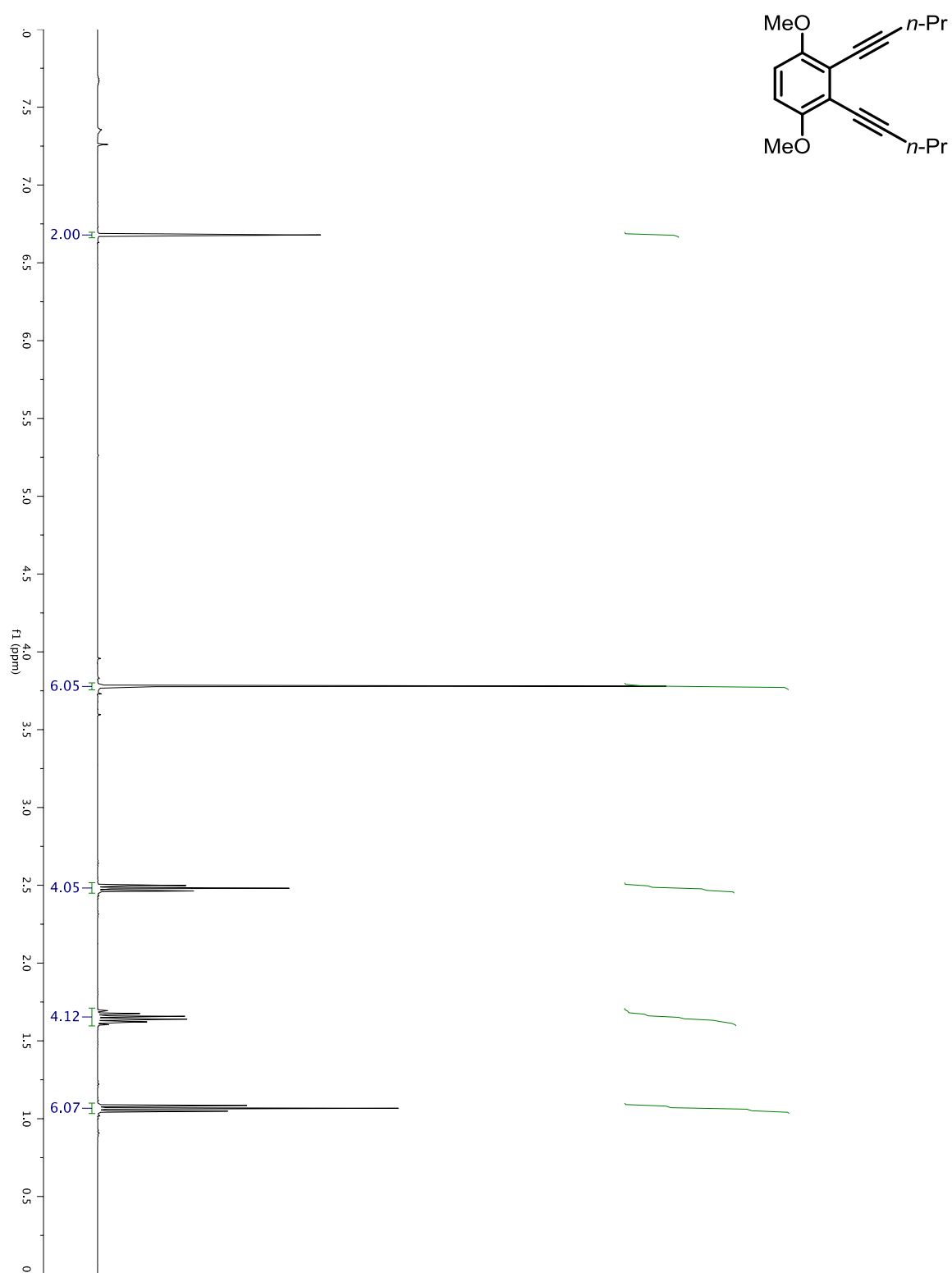
¹H NMR (400 MHz, CDCl₃) δ 6.68 (s, 2H), 3.78 (s, 6H), 2.48 (t, *J* = 7.0 Hz, 4H), 1.65 (sext, *J* = 7.2 Hz, 4H), 1.07 (t, *J* = 7.4 Hz, 6H).

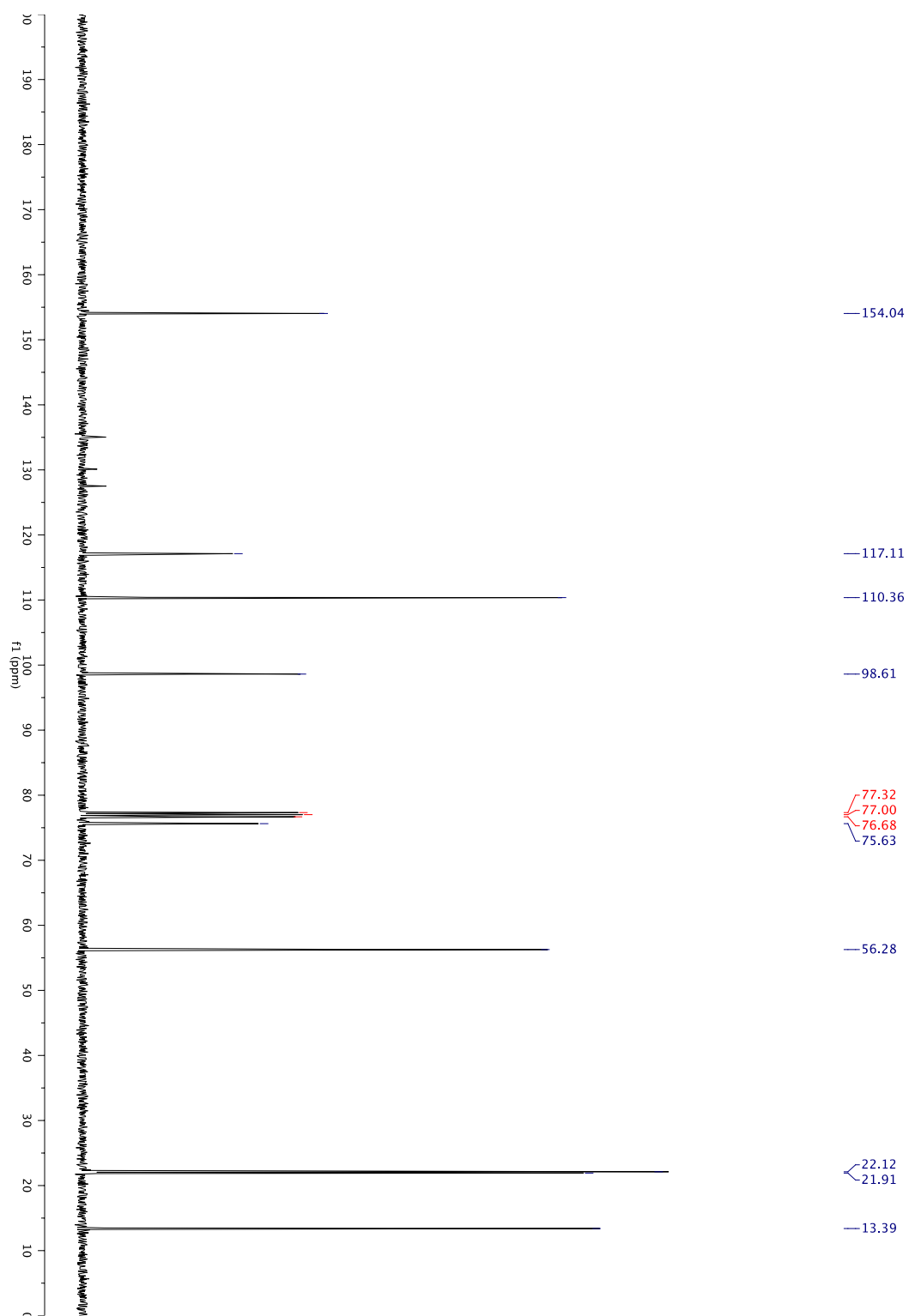
¹³C NMR (100 MHz, CDCl₃) δ 154.0, 117.1, 110.4, 98.6, 75.6, 56.3, 22.1, 21.9, 13.4.

LRMS (ESI) Calcd. for C₁₈H₂₃O₂ [M+H]⁺: 271.2, Found: 271.0.

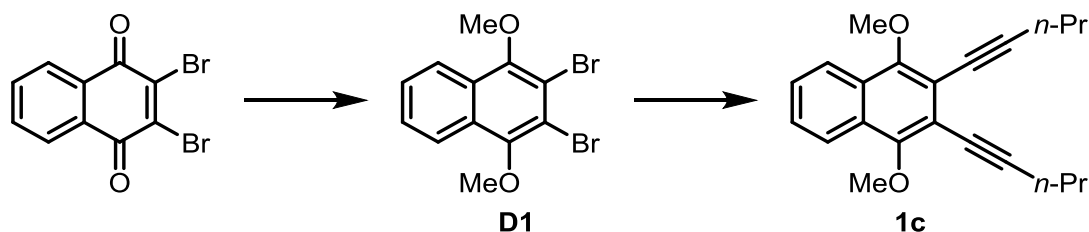
FTIR (neat): 2955, 2223, 1475, 1436, 1265, 1244, 1084, 1000, 789, 750 cm⁻¹.

MP: 65-67 °C.





1,4-Dimethoxy-2,3-di(pent-1-yn-1-yl)benzene (**1c**)



Detailed Procedures

2,3-Dibromo-1,4-naphthoquinone (3.63 g, 11.5 mmol, 100 mol%) was dissolved in diethyl ether (290 mL) and CH_2Cl_2 (290 mL) and transferred to a separatory funnel. To this was added a solution of $\text{Na}_2\text{S}_2\text{O}_4$ (30.1 g, 173 mmol, 1500 mol%) in water (575 mL) and the mixture was shaken vigorously for 15 minutes. The organic layer was washed with brine (400 mL), dried (Na_2SO_4), filtered, and concentrated *in vacuo*. A stir bar and 4Å Molecular sieves (500 mg) were added to the crude mixture and the flask was purged with argon. Dry and distilled CH_2Cl_2 (250 mL) was injected into the flask and cooled to 0 °C. Trimethyloxonium tetrafluoroborate (3.55 g, 24.15 mmol, 210 mol%) and Proton-sponge (5.2 g, 24.15 mmol, 210 mol%) were added and the mixture was stirred at 0 °C for 30 min. and then at 25 °C for 1 hour. Water (75 mL) was poured into the mixture and extracted with CH_2Cl_2 (3 x 100 mL). The combined organic layer was washed with 1M HCl (2 x 100 mL), brine (150 mL), water (150 mL), dried (Na_2SO_4), filtered, and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→30% CH_2Cl_2 /hexane). The title compound **D1** was obtained as a white solid (3.08 g) in 78% yield. Spectral data for **D1** was consistent with that reported in literature.¹¹

A microwave vial equipped with a stir bar was charged with palladium tetrakis(triphenylphosphine) (337 mg, 0.292 mmol, 10 mol%), copper(I) iodide (222 mg, 1.17 mmol, 40 mol%), tetrabutylammonium iodide (3.24 g, 8.76 mmol, 300 mol%) and **D1** (1.00 g, 2.92 mmol, 100 mol%). A solution of 1-pentyne (796 mg, 11.7 mmol, 400 mol%) in dimethylformamide/diethylamine (20 mL, 1:1) was added and the mixture was degassed with bubbling argon for 5 minutes. The vial was sealed with a Teflon cap and heated to 120 °C with stirring in a microwave for 1 hour. The resulting dark red mixture was poured into methylene chloride (150 mL), washed with 1 N HCl (3 x 100 mL), brine (100 mL) and dried over anhydrous Na_2SO_4 . The organic extract was filtered and concentrated *in vacuo*. The residue was adsorbed onto silica gel and purified by column chromatography on silica gel (2.5% EtOAc/hexane). The title compound **1c** was obtained as a dark red flowing oil (635 mg) in 68% yield.

¹H NMR (400 MHz, CDCl_3) δ 8.07 (dd, J = 6.4, 3.3 Hz, 2H), 7.50 (dd, J = 6.4, 3.3 Hz, 2H), 4.05 (s, 6H), 2.56 (t, J = 7.0 Hz, 4H), 1.72 (sext, J = 8.0 Hz, 4H), 1.13 (t, J = 7.4 Hz, 6H).

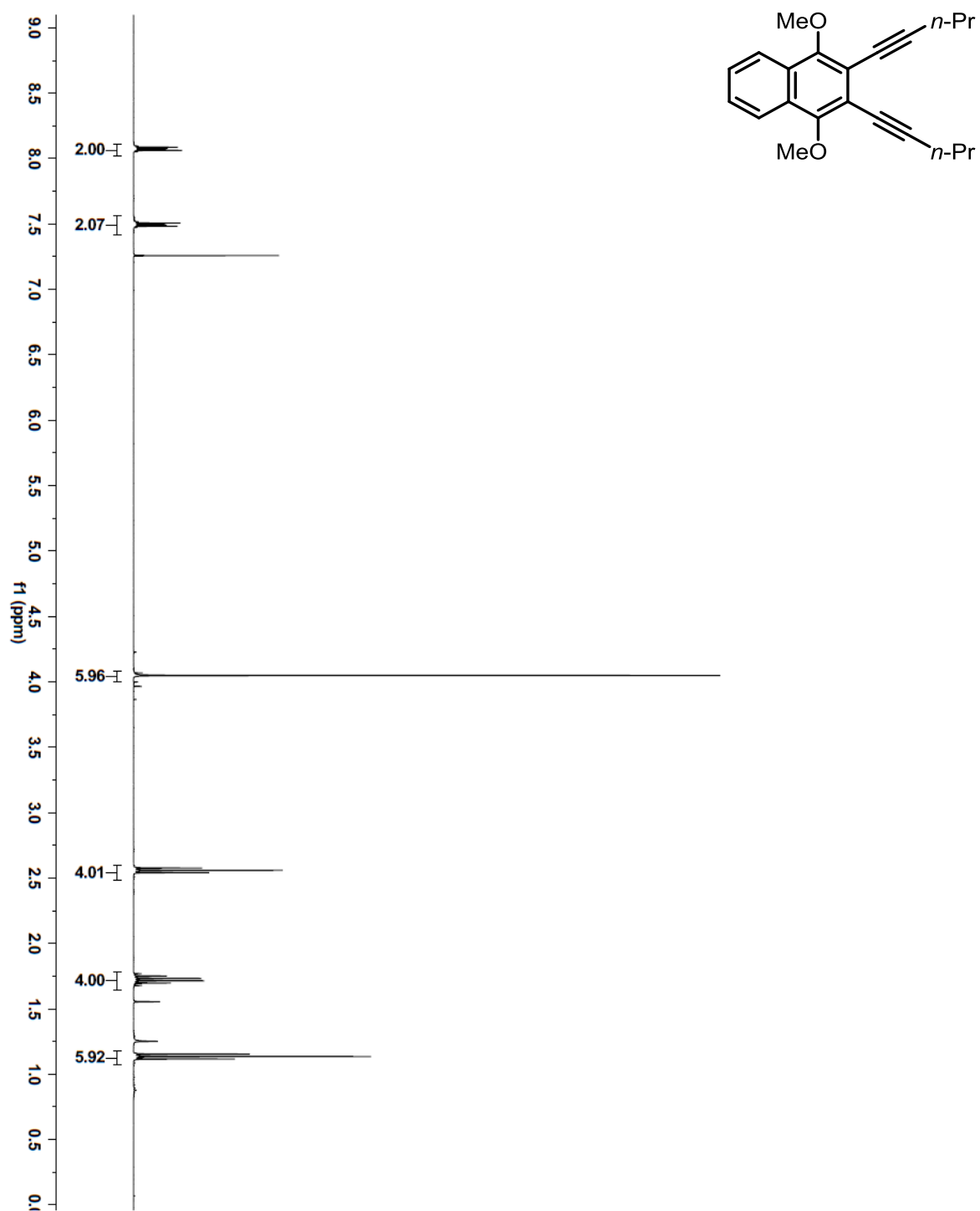
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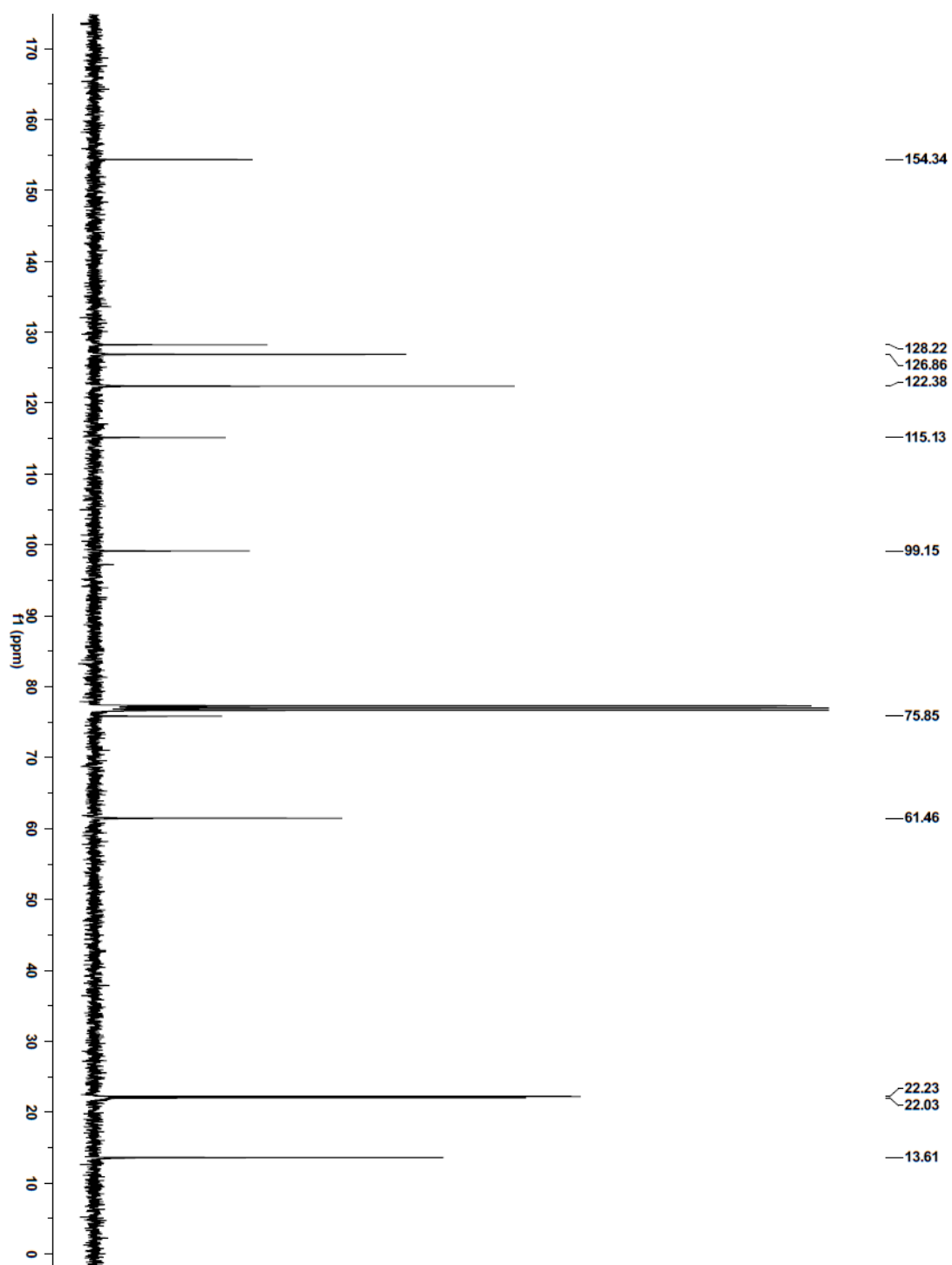
11. Evans, P. A.; Brandt, T. A. *J. Org. Chem.* **1997**, 62, 5321.

¹³C NMR (100 MHz, CDCl₃) δ 154.3, 128.2, 126.9, 122.4, 115.1, 99.2, 75.8, 61.5, 22.2, 22.0, 13.6.

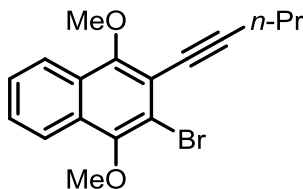
LRMS (CI) Calcd. for C₂₂H₂₄O₂ [M]⁺: 320, Found: 320.

FTIR (neat): 2961, 2931, 2227, 1575, 1454, 1354, 1077 cm⁻¹.





2-Bromo-1,4-dimethoxy-3-(pent-1-yn-1-yl)naphthalene (D2)



Detailed Procedures

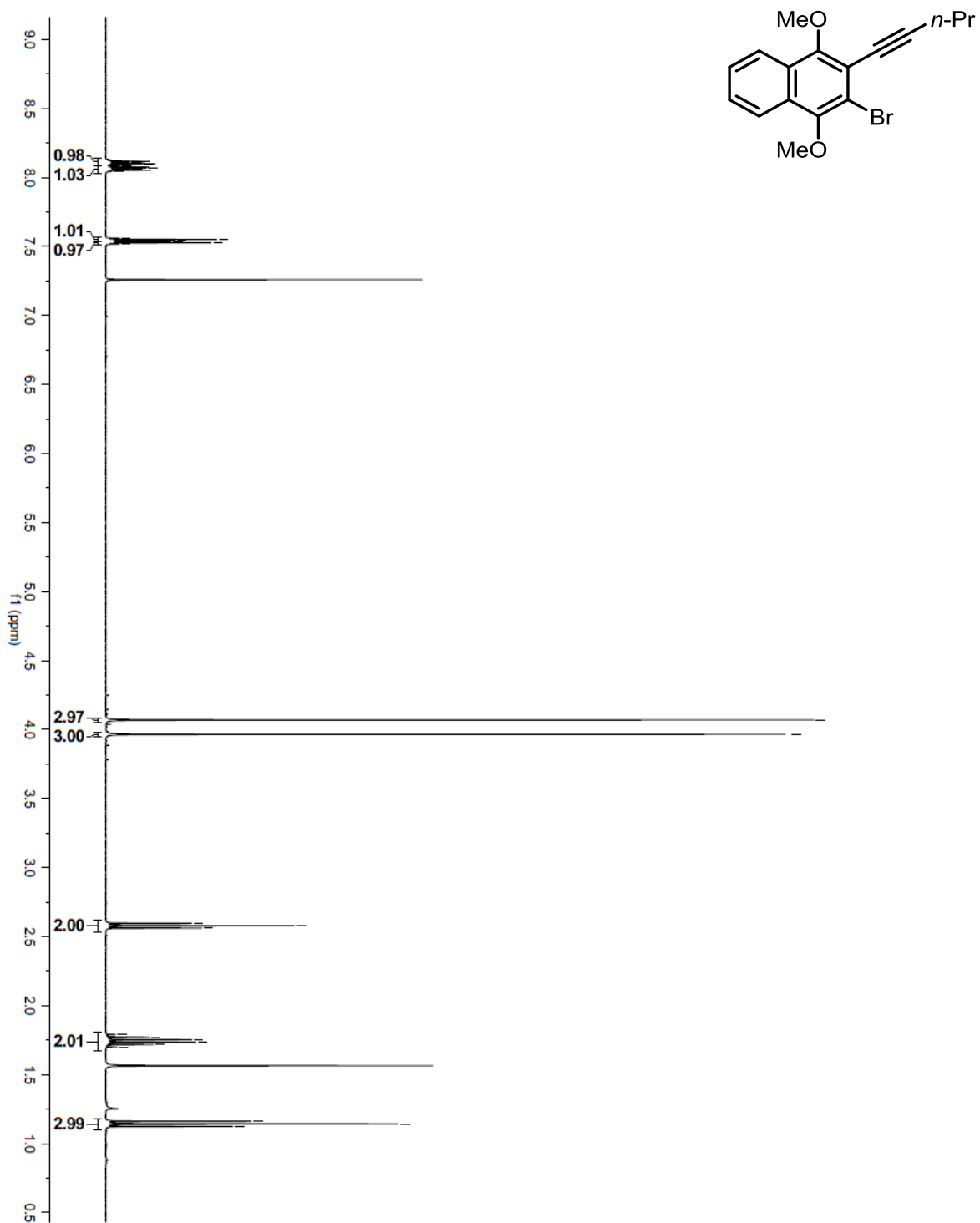
A 25 mL round bottom flask equipped with a stir bar was charged with Pd(PPh₃)₂Cl₂ (210.6 mg, 0.30 mmol, 30 mol%), copper(I) iodide (38.1 mg, 0.20 mmol, 20 mol%), 2,3-dibromo-1,4-dimethoxynaphthalene (343 mg, 1.0 mmol, 100 mol%), sealed with a septum and purged with argon. A solution of 1-pentyne (163.5 mg, 2.4 mmol, 240 mol%) in triethylamine (5 mL) was injected. The mixture was heated to 60 °C with stirring for 14 hours. The black mixture was extracted with diethyl ether (50 mL), washed with 1 N HCl, (3 x 50 mL), brine (50 mL) and dried over anhydrous magnesium sulfate. The organic extract was filtered and concentrated in *vacuo*. The residue was adsorbed onto silica gel and purified by column chromatography on silica gel (10% CH₂Cl₂/hexane). The title compound **D2** was obtained as a yellow oil (220 mg) in 66% yield.

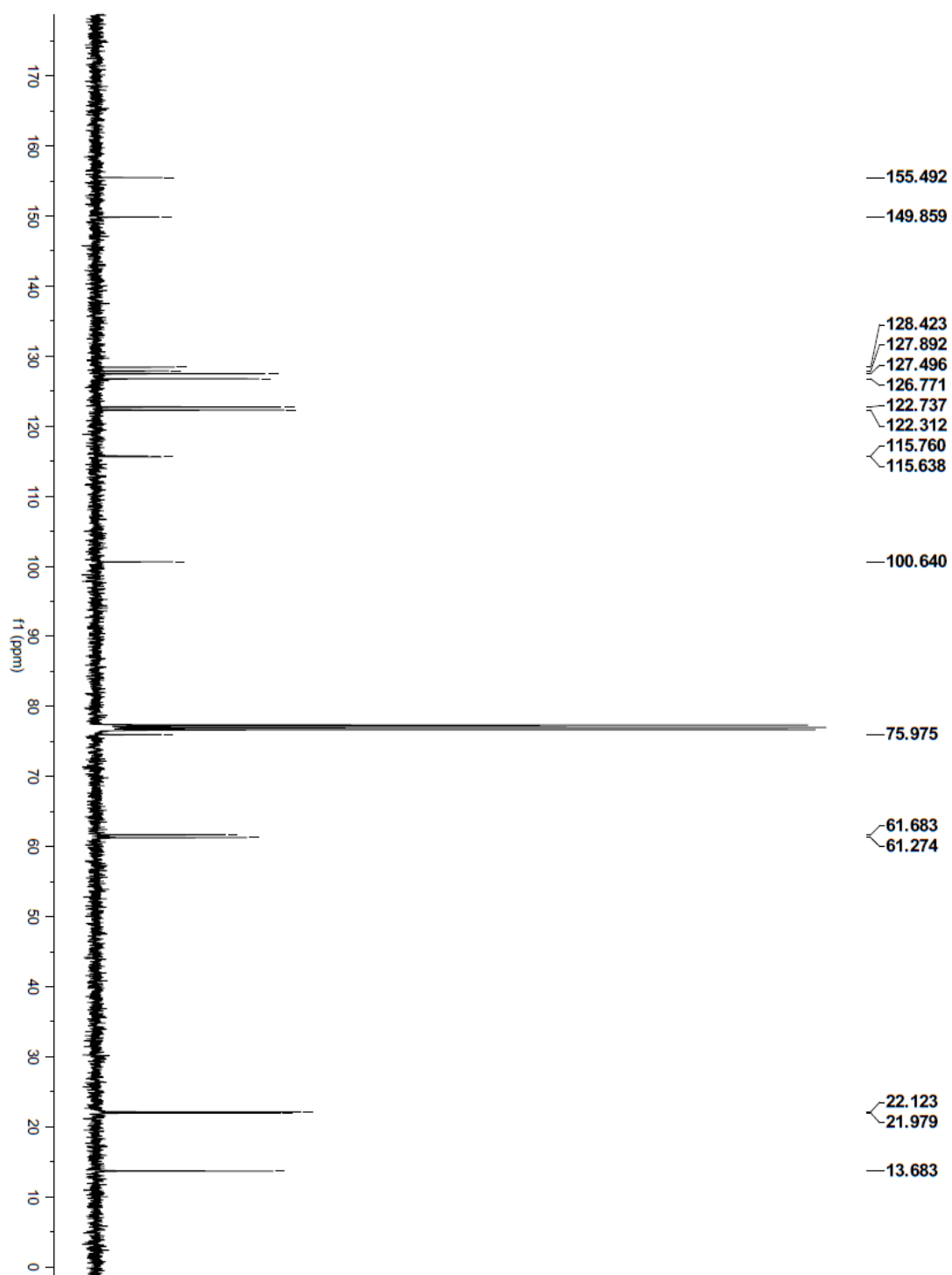
¹H NMR (400 MHz, CDCl₃) δ 8.09-8.14 (m, 2H), 8.03-8.09 (m, 2H), 7.54-7.57 (m, 1H), 7.51-7.54 (m, 1H), 4.07 (s, 3H), 3.97 (s, 3H), 2.58 (t, *J* = 6.8 Hz, 2H), 1.74 (sext, *J* = 7.2 Hz, 2H), 1.14 (t, *J* = 7.2 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 155.5, 149.9, 128.4, 127.9, 127.5, 126.8, 122.7, 122.3, 115.8, 115.6, 100.6, 76.0, 61.7, 61.3, 22.1, 22.0, 13.7.

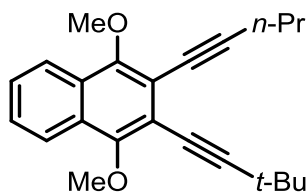
LRMS (CI) Calcd. for C₁₇H₁₈BrO₂ [M+H]⁺: 334, Found: 334.

FTIR (neat): 2961, 2931, 2227, 1575, 1559, 1454, 1352 cm⁻¹.





2-(3,3-Dimethylbut-1-yn-1-yl)-1,4-dimethoxy-3-(pent-1-yn-1-yl)naphthalene (1d)



Detailed Procedures

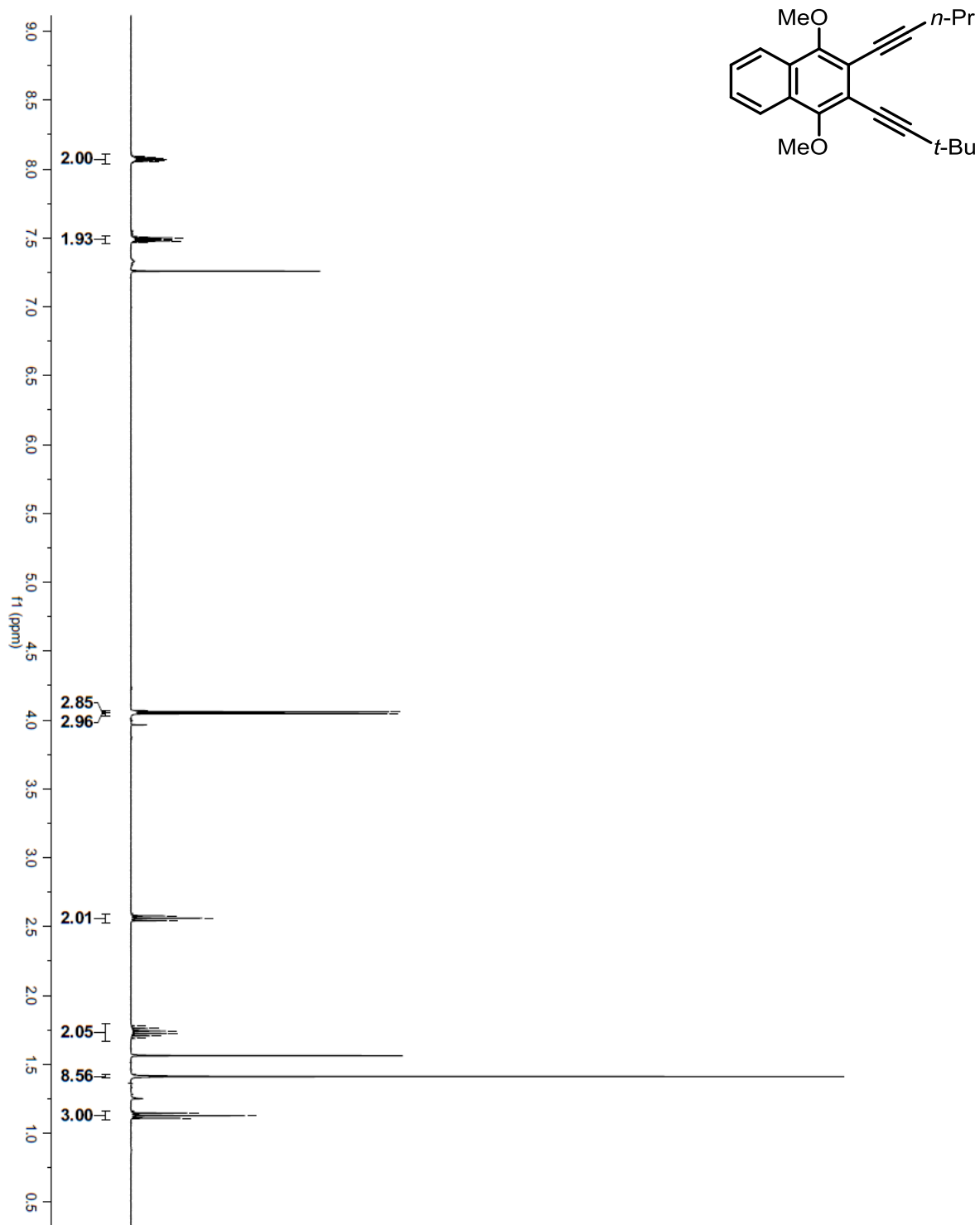
A 10 mL microwave vial equipped with a stir bar was charged with palladium tetrakis(triphenylphosphine) (76.3 mg, 0.066 mmol, 10 mol%), copper(I) iodide (50.3 mg, 0.264 mmol, 40 mol%), tetrabutylammonium iodide (366 mg, 1.0 mmol, 150 mol%), sealed with a rubber septum and purged with argon. The vial was injected with a solution of **D2** (220 mg, 0.660 mmol, 100 mol%) in dimethylformamide/diethylamine (3.3 mL, 1:1) then *t*-butylacetylene (135.5 mg, 1.65 mmol, 250 mol%). The septum was replaced quickly with a Teflon lined cap and heated to 120 °C in a microwave reactor for 1 hour. The mixture was extracted with diethyl ether (50 mL), washed with 1 M HCl (3 x 50 mL), brine (50 mL) and dried over anhydrous magnesium sulfate. The organic extract was filtered and concentrated *in vacuo*. The residue was adsorbed onto silica gel and purified by column chromatography on silica gel (2.5% EtOAc/hexane). The title compound **1d** was obtained as a yellow oil (163.1 mg) in 74% yield.

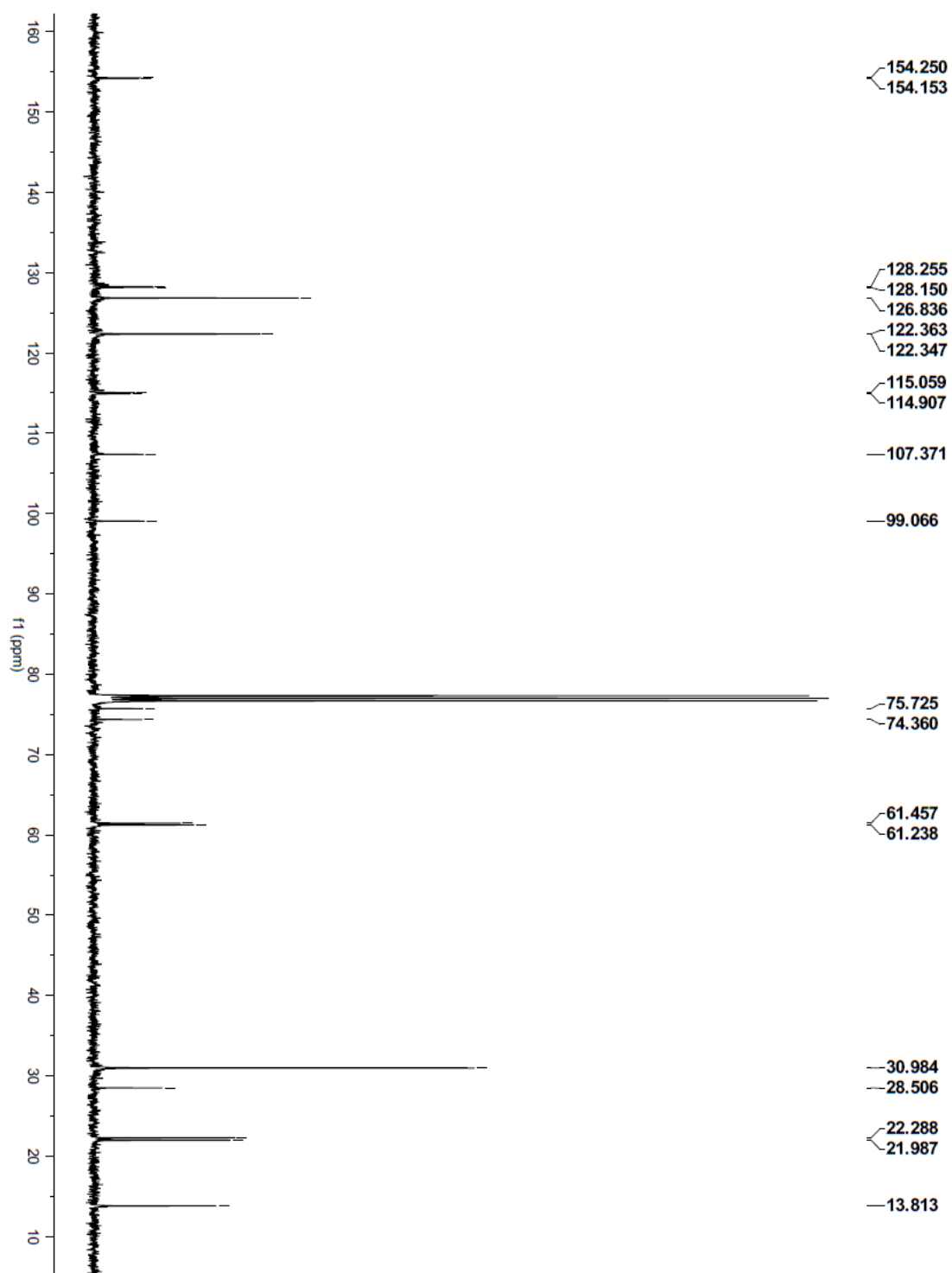
¹H NMR (400 MHz, CDCl₃) δ 8.04-8.11 (m, 2H), 7.46-7.52 (m, 2H), 4.06 (s, 3H), 4.05 (s, 3H), 2.56 (t, *J* = 7.2 Hz, 2H), 1.73 (sext, *J* = 7.2 Hz, 2H), 1.41 (s, 9H), 1.13 (t, *J* = 7.2 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 154.3, 154.2, 128.3, 128.2, 126.8, 122.36, 122.35, 115.1, 114.9, 107.4, 99.1, 75.7, 74.4, 61.5, 61.2, 31.0, 28.5, 22.3, 22.0, 13.8.

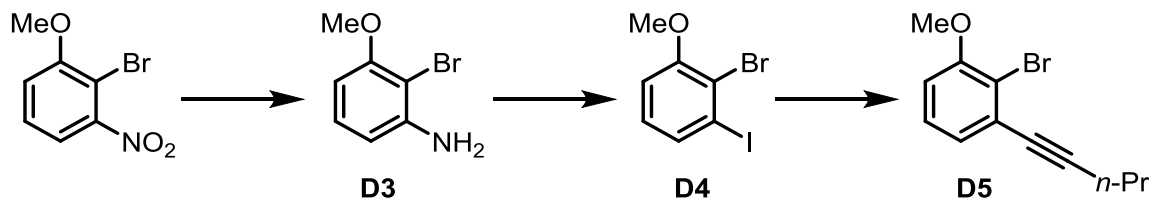
LRMS (ESI) Calcd. for C₂₃H₂₇O₂ [M+H]⁺: 335.2, Found: 335.2.

FTIR (neat): 2965, 2930, 2228, 1576, 1454, 1354, 1072 cm⁻¹.





2-Bromo-1-methoxy-3-(pent-1-yn-1-yl)benzene (**D5**)



Detailed Procedures

Compound **D3** was made according to known literature procedure.¹²

Compound **D4** was made according to known literature procedure.¹³

A 50 mL round bottom flask equipped with a stir bar was charged with $\text{Pd(PPh}_3)_2\text{Cl}_2$ (112.3 mg, 0.16 mmol, 4 mol%), copper(I) iodide (15.2 mg, 0.08 mmol, 2 mol%), and **D4** (1.25 g, 4.00 mmol, 100 mol%), sealed with a septum and purged with argon. A solution of 1-pentyne (0.43 mL, 4.40 mmol, 110 mol%) in dry triethylamine (20 mL) was injected. The mixture was heated to 50 °C with stirring for 16 hours. The black mixture was extracted with diethyl ether (50 mL), washed with 1 N HCl, (3 x 50 mL), brine (50 mL) and dried over anhydrous magnesium sulfate. The organic extract was filtered and concentrated in *vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→10% CH_2Cl_2 /hexane). The title compound **D5** was obtained as a yellow oil (738 mg) in 73% yield.

¹H NMR (400 MHz, CDCl_3) δ 7.16 (dd, J = 8.2, 7.7 Hz, 1H), 7.05 (dd, J = 7.7, 1.4 Hz, 1H), 6.79 (dd, J = 8.2, 1.4 Hz, 1H), 3.87 (s, 3H), 2.44 (t, J = 7.0 Hz, 2H), 1.66 (sext, J = 7.2 Hz, 2H), 1.08 (t, J = 7.4 Hz, 3H).

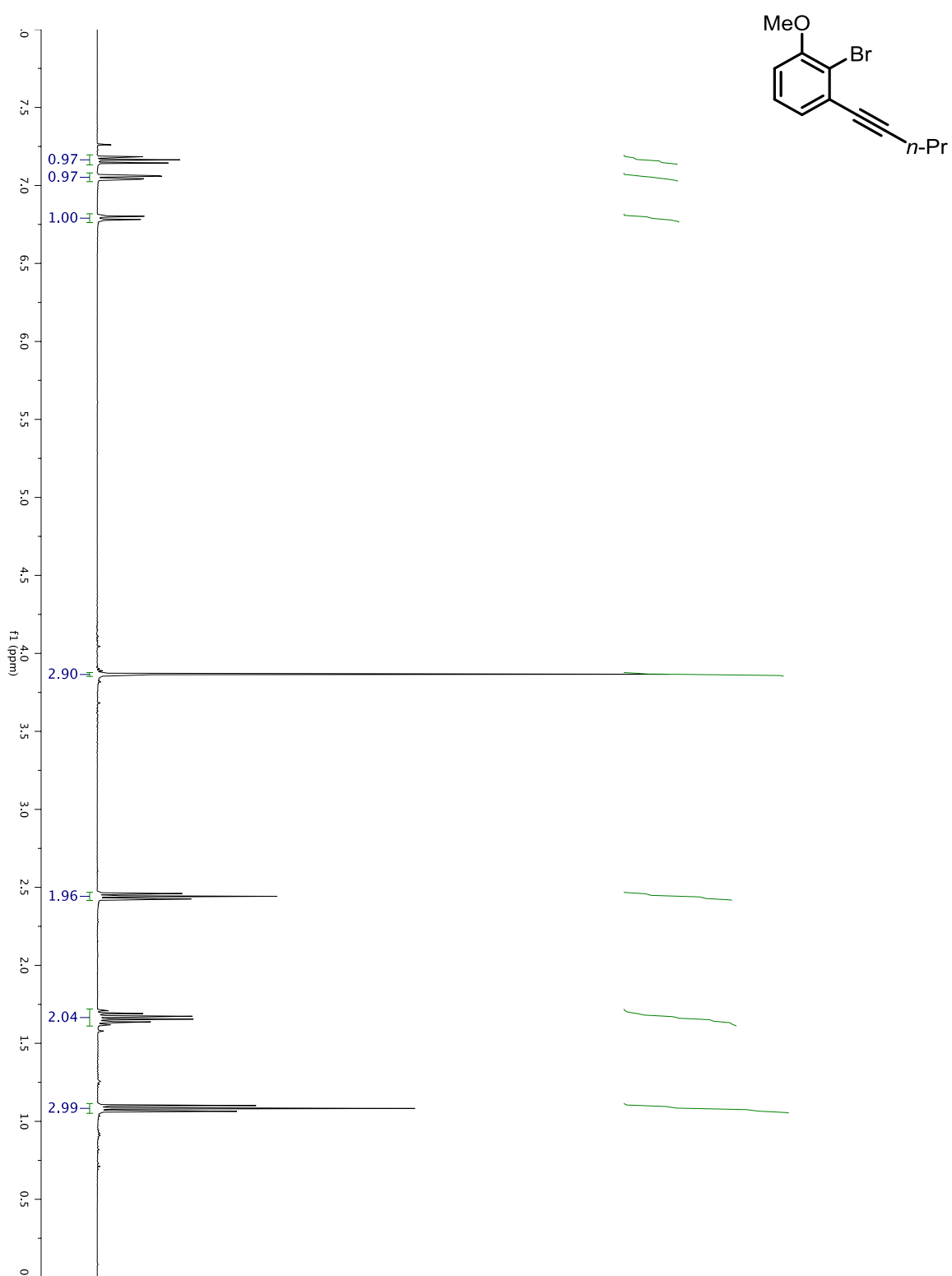
¹³C NMR (100 MHz, CDCl_3) δ 156.1, 127.5, 127.5, 125.3, 114.9, 110.8, 95.4, 79.5, 56.3, 22.0, 21.5, 13.5.

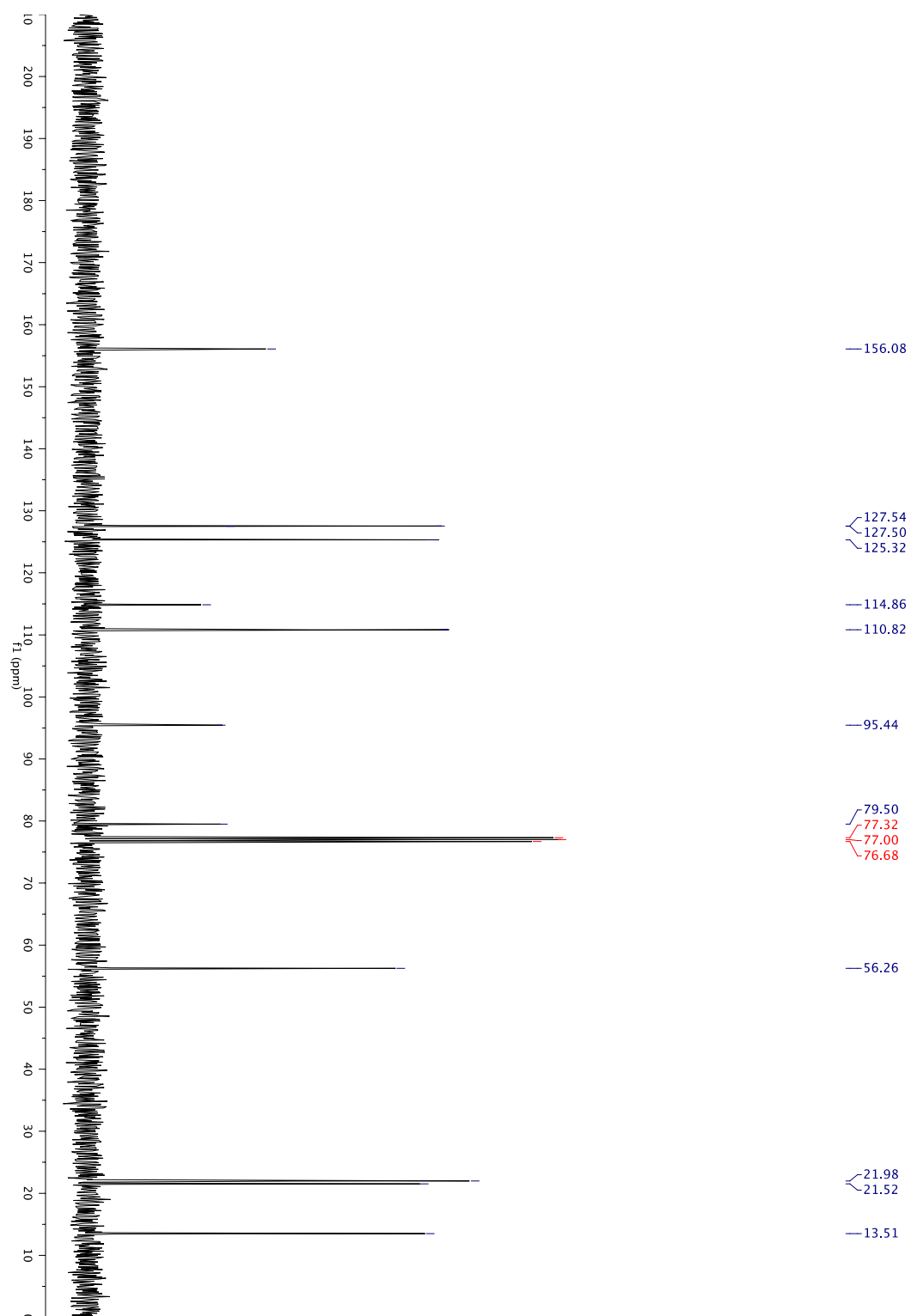
LRMS (CI) Calcd. for $\text{C}_{12}\text{H}_{13}\text{BrO}$ $[\text{M}]^+$: 253, Found: 253.

FTIR (neat): 2962, 2934, 2226, 1561, 1465, 1422, 1267, 1089, 1034, 776 cm^{-1} .

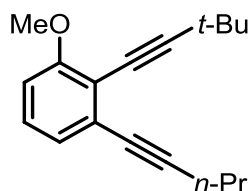
References:

12. Krolski, M.; Renaldo, A. F.; Rudisill, D. E.; Stille, J. K. *J. Org. Chem.* **1988**, *53*, 1170.
13. Ooi, T.; Takahashi, M.; Yamada, M.; Tayama, E.; Omoto, K.; Maruoka, K. *J. Am. Chem. Soc.* **2004**, *126*, 1150.





2-(3,3-Dimethylbut-1-yn-1-yl)-1-methoxy-3-(pent-1-yn-1-yl)benzene (**1e**)



Detailed Procedures

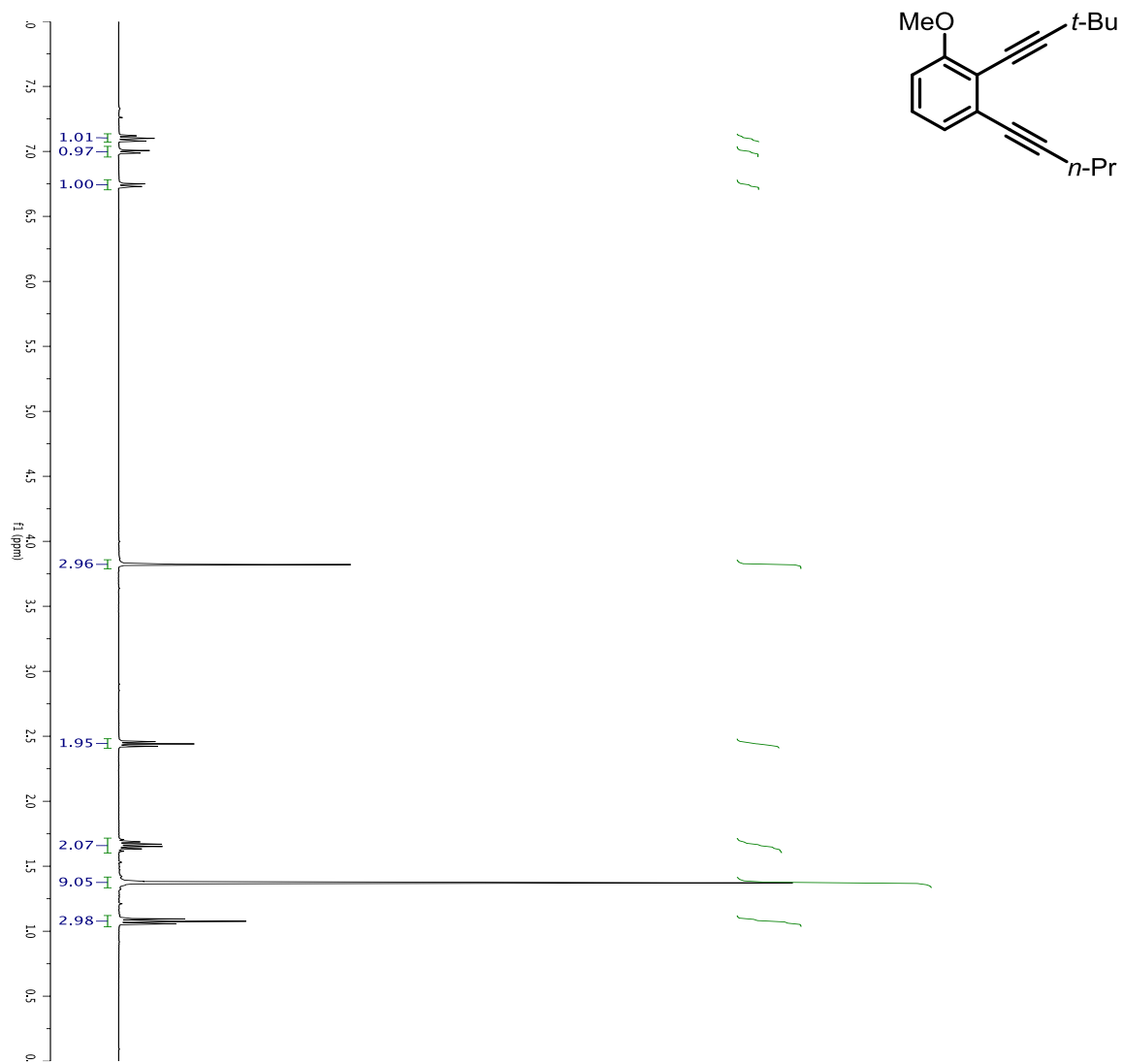
A 35 mL microwave vial equipped with a stir bar was charged with palladium tetrakis(triphenylphosphine) (250.8 mg, 0.217 mmol, 10 mol%), copper(I) iodide (165.3 mg, 0.870 mmol, 40 mol%), tetrabutylammonium iodide (1.20 g, 3.26 mmol, 150 mol%), sealed with a rubber septum and purged with argon. The vial was injected with a solution of **D5** (550 mg, 2.17 mmol, 100 mol%) in dimethylformamide/diethylamine (10 mL, 1:1) then *t*-butylacetylene (0.8 mL, 6.51 mmol, 300 mol%). The septum was replaced quickly with a Teflon lined cap and heated to 120 °C in a microwave reactor for 1 hour. The mixture was extracted with CH₂Cl₂ (75 mL), washed with 1 M HCl (2 x 50 mL), brine (50 mL) and dried over anhydrous magnesium sulfate. The organic extract was filtered and concentrated *in vacuo*. The residue was adsorbed onto silica gel and purified by column chromatography on silica gel (5% CH₂Cl₂/hexane→20% CH₂Cl₂/hexane). The title compound **1e** was obtained as a yellow oil (446.7 mg) in 81% yield.

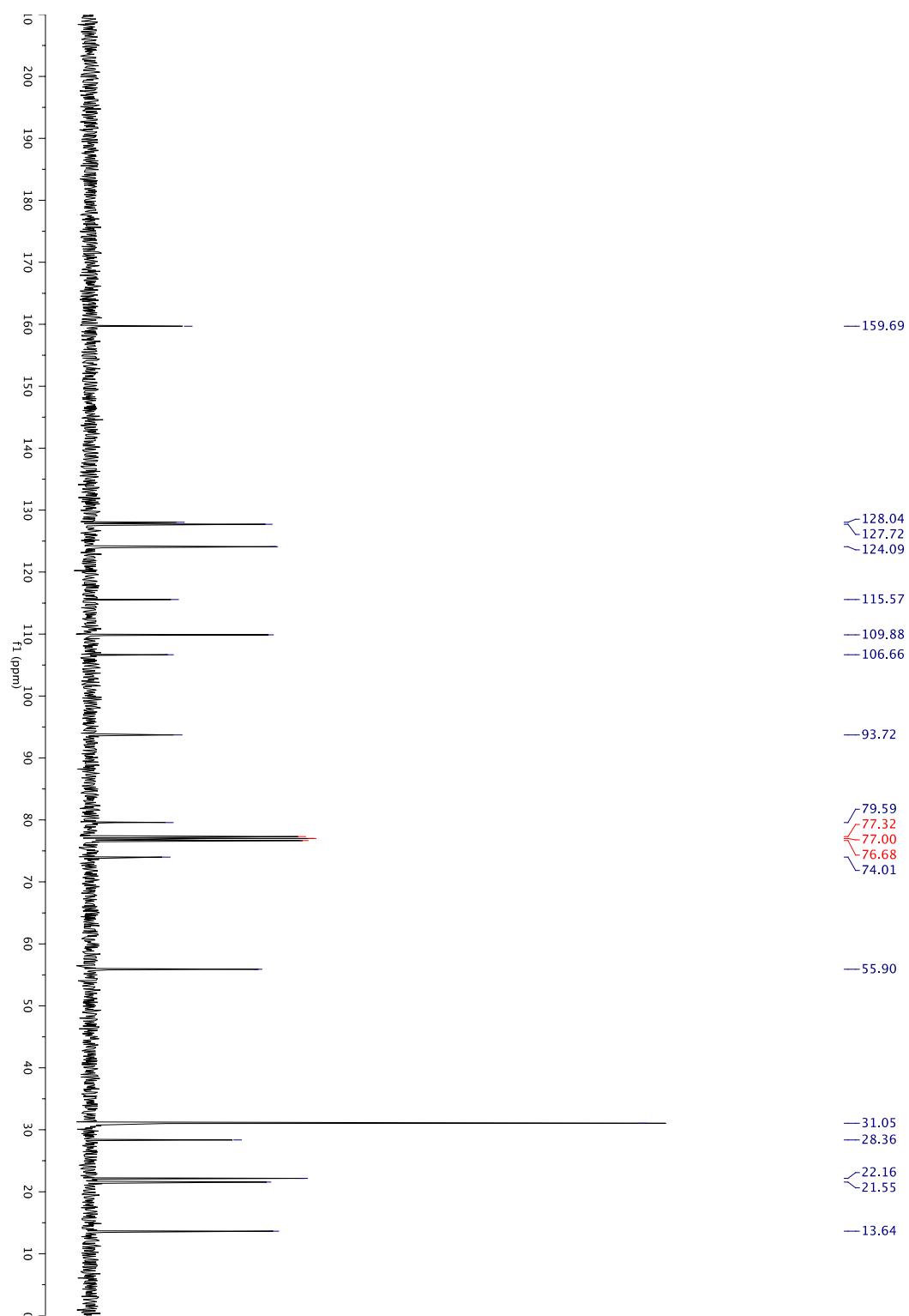
¹H NMR (400 MHz, CDCl₃) δ 7.10 (t, *J* = 8.0 Hz, 1H), 7.00 (dd, *J* = 7.8, 1.1 Hz, 1H), 6.74 (dd, *J* = 8.3, 1.1 Hz, 1H), 3.82 (s, 3H), 2.44 (t, *J* = 7.0 Hz, 2H), 1.66 (sext, *J* = 7.2 Hz, 2H), 1.37 (s, 9H), 1.08 (t, *J* = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 159.7, 128.0, 127.7, 124.1, 115.6, 109.9, 106.7, 93.7, 79.6, 74.0, 55.9, 31.1, 28.4, 22.2, 21.6, 13.6.

LRMS (CI) Calcd. for C₁₈H₂₂O [M]⁺: 254, Found: 254.

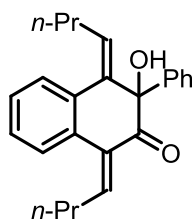
FTIR (neat): 2966, 2934, 2225, 1562, 1466, 1254, 1102, 1045, 786, 733 cm⁻¹.





Detailed Procedures and Spectral Data for Endiyne- α -Ketol [4+2] Cycloadducts (3a-3h, 4a-4g, 4i, 5a-5h, *t*-Bu-5d, *des*-MeO-4d):

(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-3-phenyl-3,4-dihydronaphthalen-2(1*H*)-one (3a)



Detailed Procedures

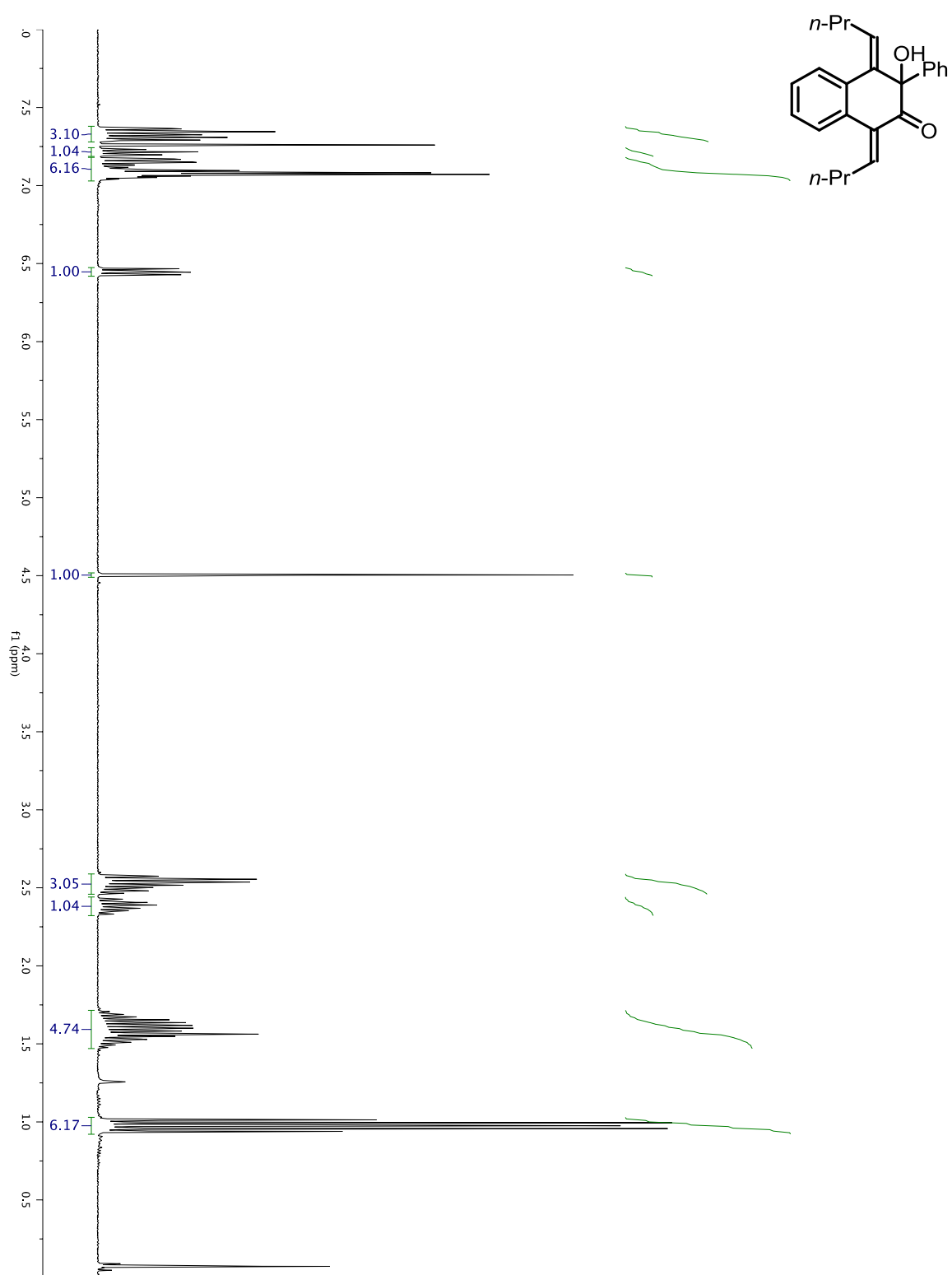
An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and 2-hydroxyacetophenone **2a** (40.8 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 60 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→60% CH_2Cl_2 /hexane). The title compound **3a** was obtained as a pale yellow oil (66.1 mg) in 64% yield.

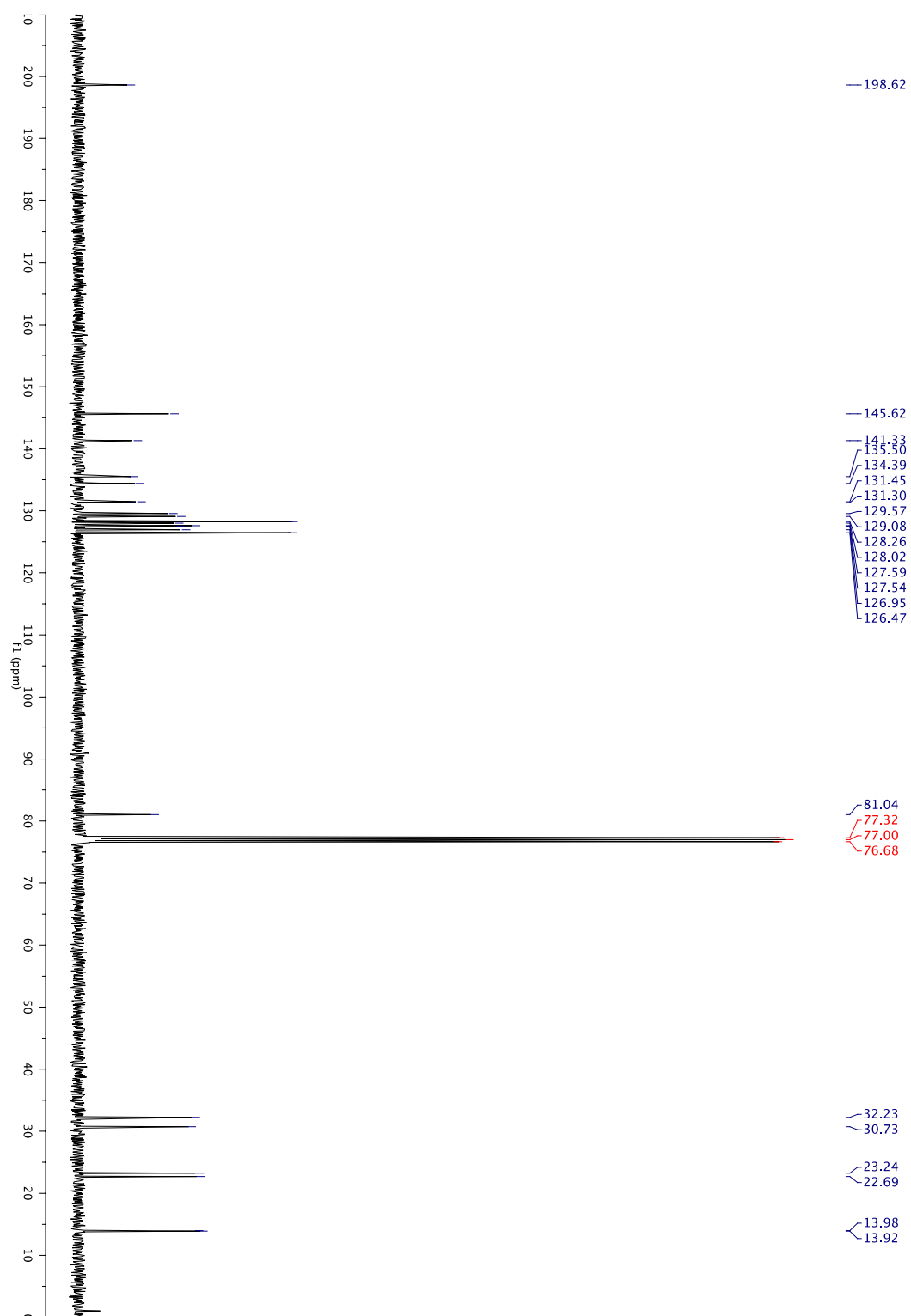
^1H NMR (400 MHz, CDCl_3) δ 7.38-7.28 (m, 3H), 7.21 (td, J = 7.5, 1.4 Hz, 1H), 7.18-7.03 (m, 6H), 6.45 (dd, J = 8.7, 6.6 Hz, 1H), 4.50 (s, 1H), 2.59-2.45 (m, 3H), 2.44-2.32 (m, 1H), 1.72-1.46 (m, 4H), 0.99 (t, J = 7.4 Hz, 3H), 0.96 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 198.6, 145.6, 141.3, 135.5, 134.4, 131.4, 131.3, 129.6, 129.1, 128.3, 128.0, 127.6, 127.5, 127.0, 126.5, 81.0, 32.2, 30.7, 23.2, 22.7, 14.0, 14.0.

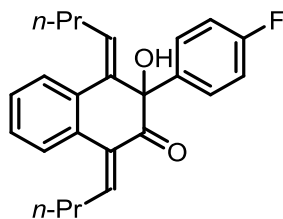
LRMS (ESI) Calcd. for $\text{C}_{24}\text{H}_{26}\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 369.2, Found: 369.2.

FTIR (neat): 3462, 2958, 2929, 1691, 1601, 1448, 1229, 1104, 964, 761 cm^{-1} .





(1E,4E)-1,4-Dibutylidene-3-(4-fluorophenyl)-3-hydroxy-3,4-dihydronaphthalen-2(1H)-one (3b)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2b** (46.2 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 60 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane \rightarrow 70% CH_2Cl_2 /hexane). The title compound **3b** was obtained as a pale yellow oil (75.0 mg) in 68% yield.

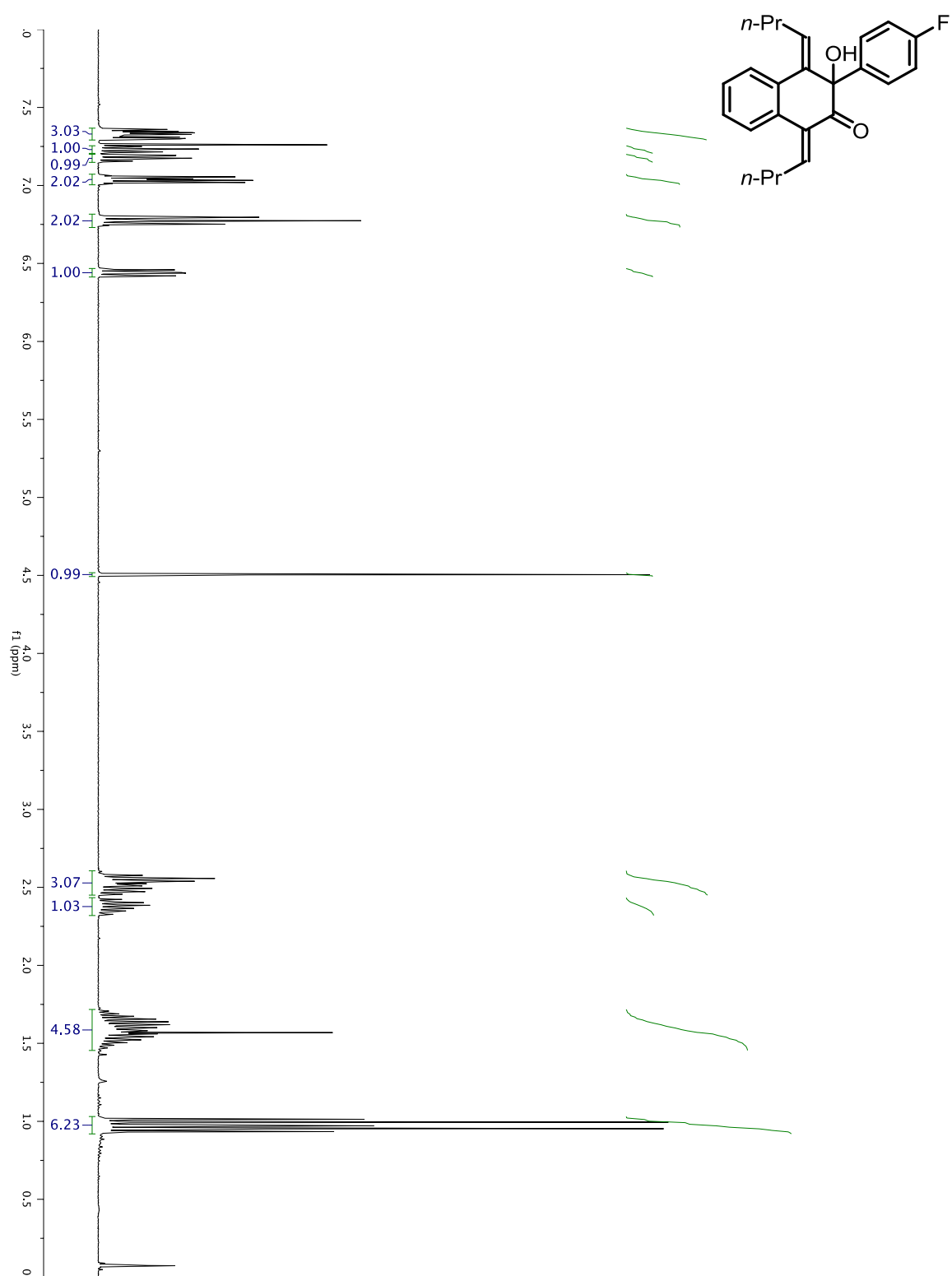
^1H NMR (400 MHz, CDCl_3) δ 7.37-7.29 (m, 3H), 7.23 (td, $J = 7.5, 1.5$ Hz, 1H), 7.17 (td, $J = 7.5, 1.5$ Hz, 1H), 7.07-7.00 (m, 2H), 6.81-6.74 (m, 2H), 6.44 (dd, $J = 8.7, 6.6$ Hz, 1H), 4.50 (s, 1H), 2.59-2.45 (m, 3H), 2.43-2.32 (m, 1H), 1.72-1.46 (m, 4H), 0.99 (t, $J = 7.4$ Hz, 3H), 0.95 (t, $J = 7.4$ Hz, 3H).

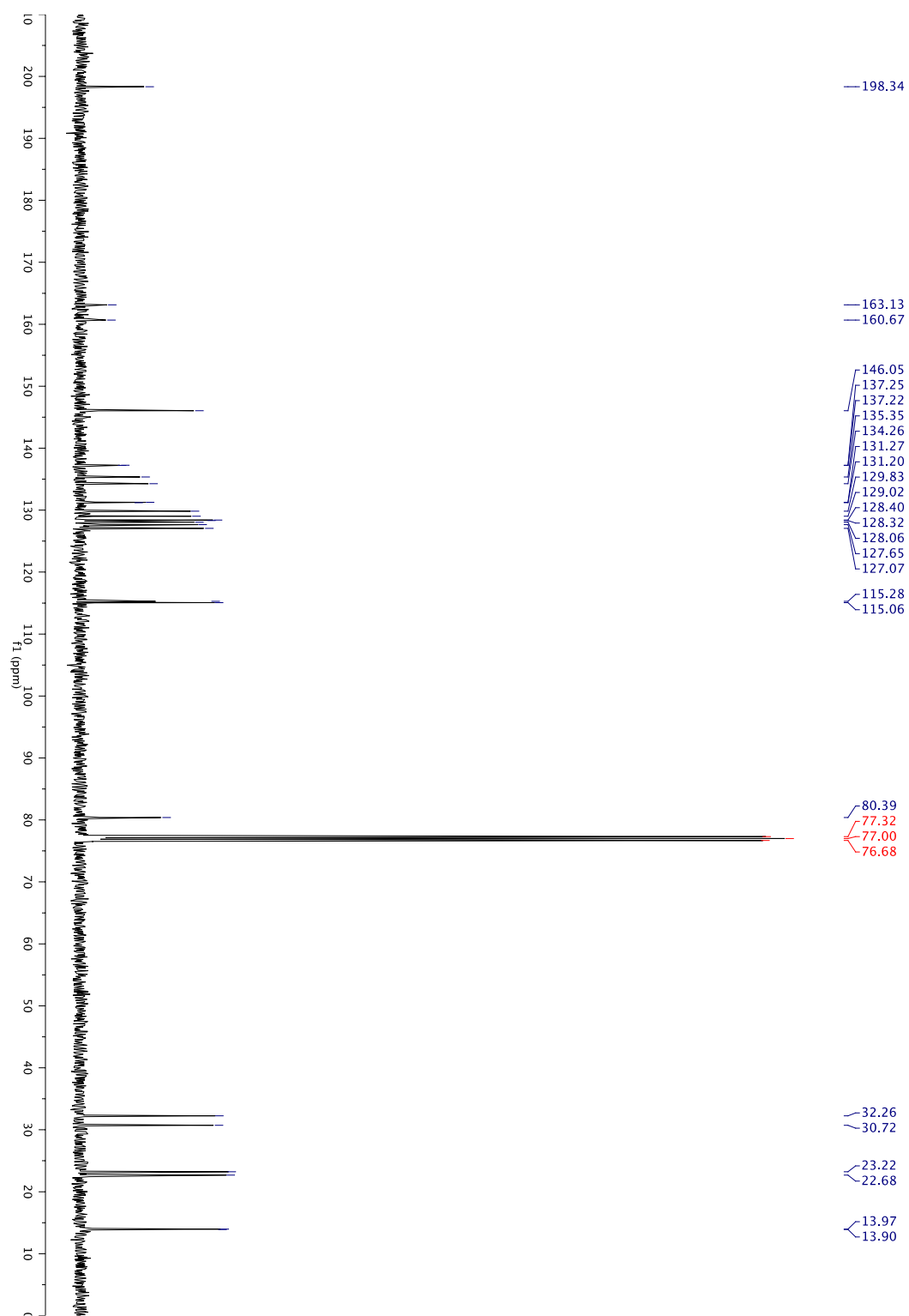
^{13}C NMR (100 MHz, CDCl_3) δ 198.3, 161.9 (d, $J = 246.6$ Hz, 1C), 146.1, 137.2 (d, $J = 3.3$ Hz, 1C), 135.4, 134.3, 131.3, 131.2, 129.8, 129.0, 128.4 (d, $J = 8.3$ Hz, 2C), 128.1, 127.7, 127.1, 115.2 (d, $J = 21.6$ Hz, 2C), 80.4, 32.3, 30.7, 23.2, 22.7, 14.0, 13.9.

^{19}F NMR (376 MHz, CDCl_3) δ -114.3.

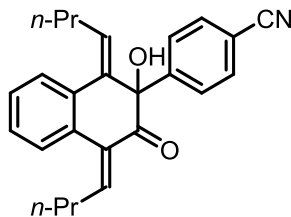
LRMS (ESI) Calcd. for $\text{C}_{24}\text{H}_{25}\text{FO}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 387.2, Found: 387.2.

FTIR (neat): 3467, 2959, 2931, 1693, 1600, 1506, 1227, 1159, 897, 763 cm^{-1} .





4-((1*E*,4*E*)-1,4-Dibutylidene-2-hydroxy-3-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)benzonitrile (3c**)**



Detailed Procedures

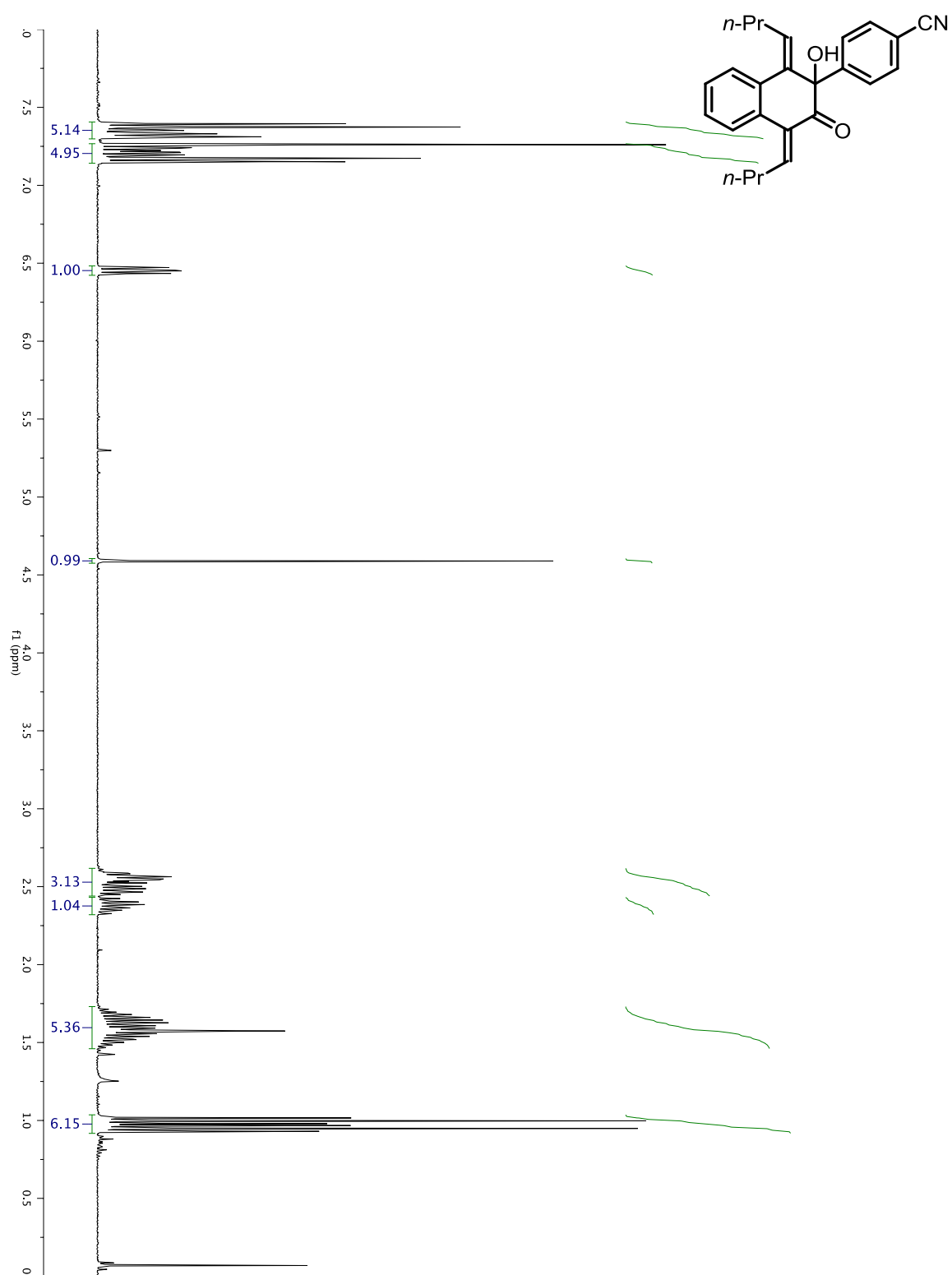
An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2c** (48.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 70 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH_2Cl_2 /hexane \rightarrow 70% CH_2Cl_2 /hexane). The title compound **3c** was obtained as a pale yellow oil (73.8 mg) in 66% yield.

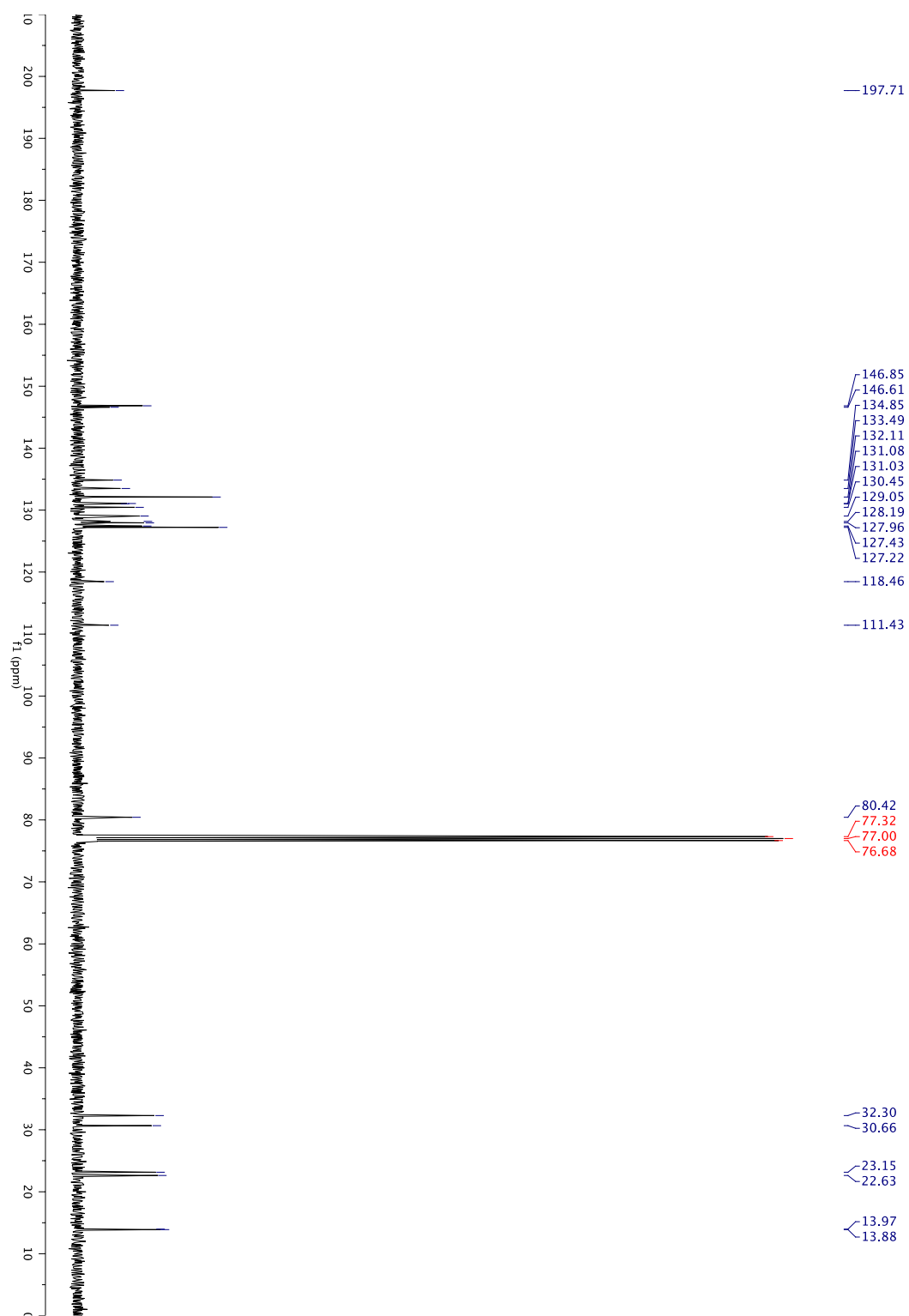
^1H NMR (400 MHz, CDCl_3) δ 7.41-7.29 (m, 5H), 7.27-7.14 (m, 4H), 6.45 (dd, $J = 8.8, 6.5$ Hz, 1H), 4.59 (s, 1H), 2.60-2.44 (m, 3H), 2.43-2.32 (m, 1H), 1.73-1.45 (m, 4H), 1.00 (t, $J = 7.4$ Hz, 3H), 0.95 (t, $J = 7.4$ Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 197.7, 146.9, 146.6, 134.9, 133.5, 132.1, 131.1, 131.0, 130.5, 129.1, 128.2, 128.0, 127.4, 127.2, 118.5, 111.4, 80.4, 32.3, 30.7, 23.2, 22.6, 14.0, 13.9.

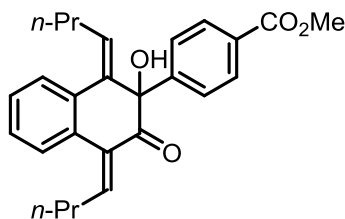
LRMS (ESI) Calcd. for $\text{C}_{25}\text{H}_{25}\text{NO}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 394.2, Found: 394.2.

FTIR (neat): 2960, 2931, 2229, 1711, 1605, 1360, 1220, 1092, 843, 763 cm^{-1} .





Methyl 4-((1E,4E)-1,4-dibutylidene-2-hydroxy-3-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)benzoate (3d)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2d** (58.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH_2Cl_2 /hexane \rightarrow 100% CH_2Cl_2 /hexane). The title compound **3d** was obtained as an off-white solid (90.8 mg) in 75% yield. The material was recrystallized from EtOAc and hexane *via* vapor diffusion to afford colorless crystals suitable for single crystal x-ray diffraction spectroscopy.

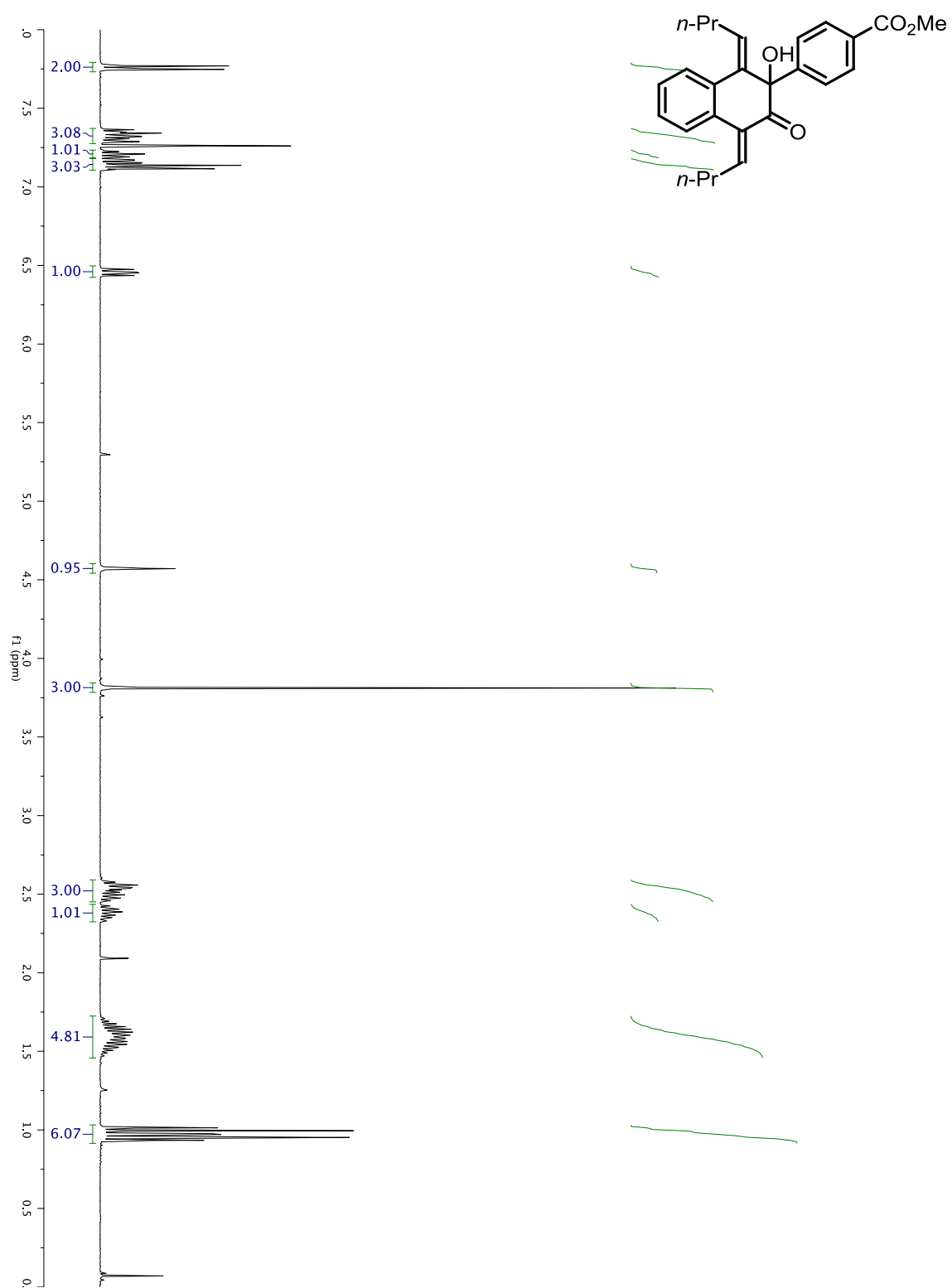
^1H NMR (400 MHz, CDCl_3) δ 7.79-7.73 (m, 2H), 7.38-7.27 (m, 3H), 7.21 (td, $J = 7.5, 1.5$ Hz, 1H), 7.18-7.10 (m, 3H), 6.46 (dd, $J = 8.8, 6.6$ Hz, 1H), 4.57 (s, 1H), 3.81 (s, 3H), 2.60-2.45 (m, 3H), 2.44-2.32 (m, 1H), 1.72-1.46 (m, 4H), 0.99 (t, $J = 7.4$ Hz, 3H), 0.95 (t, $J = 7.4$ Hz, 3H).

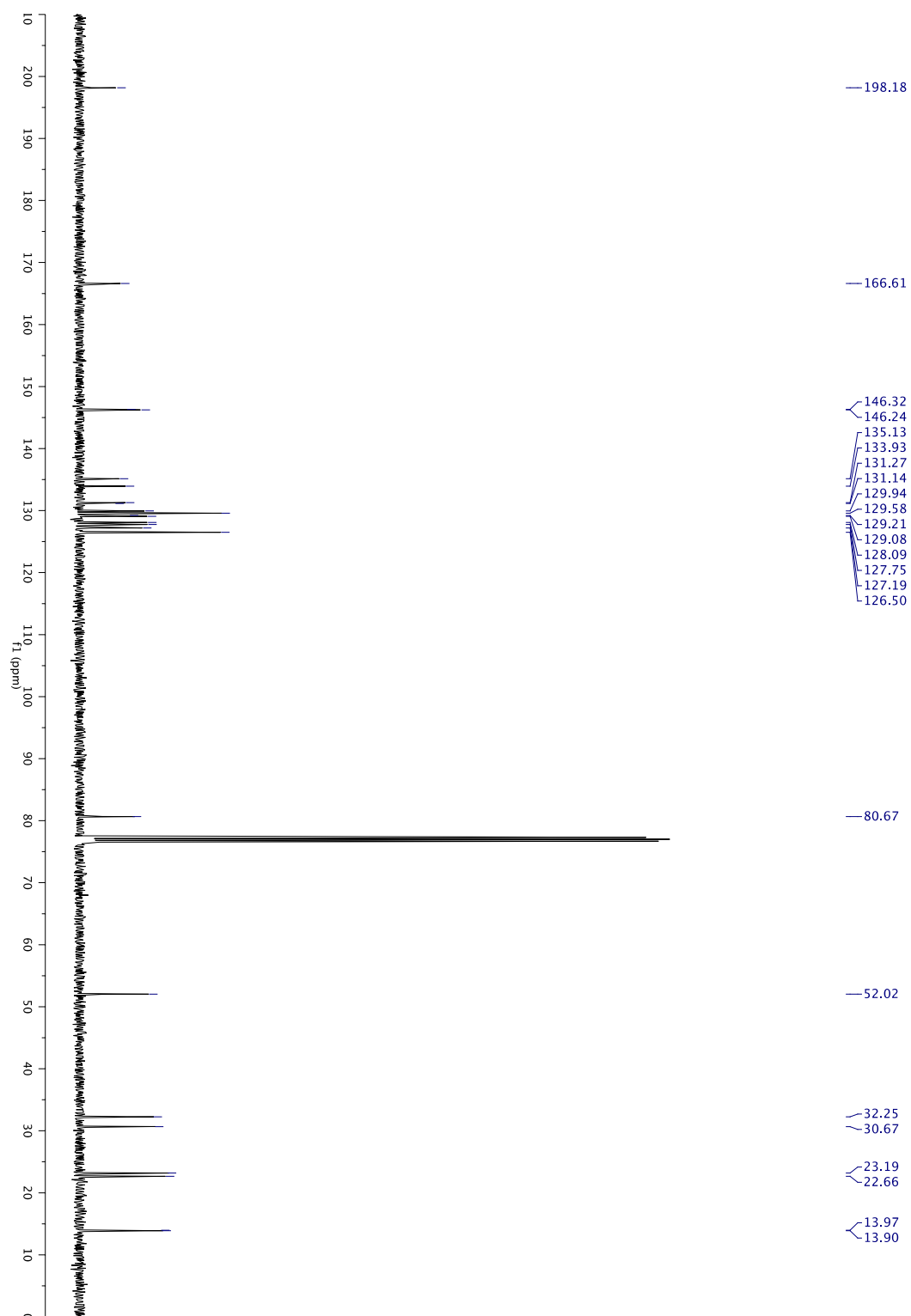
^{13}C NMR (100 MHz, CDCl_3) δ 198.2, 166.6, 146.3, 146.2, 135.1, 133.9, 131.3, 131.1, 130.0, 129.6, 129.2, 129.1, 128.1, 127.8, 127.2, 126.5, 80.7, 52.0, 32.3, 30.7, 23.2, 22.7, 14.0, 13.9.

HRMS (ESI) Calcd. for $\text{C}_{26}\text{H}_{28}\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 427.18800, Found: 427.18920.

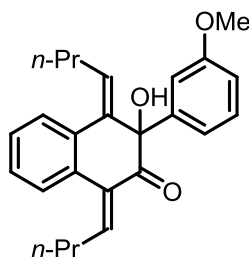
FTIR (neat): 2963, 1723, 1685, 1276, 1105, 1020, 967, 841, 770 cm^{-1} .

MP: 112-114 °C.





(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-3-(3-methoxyphenyl)-3,4-dihydronaphthalen-2(1*H*)-one (3e)



Detailed Procedures

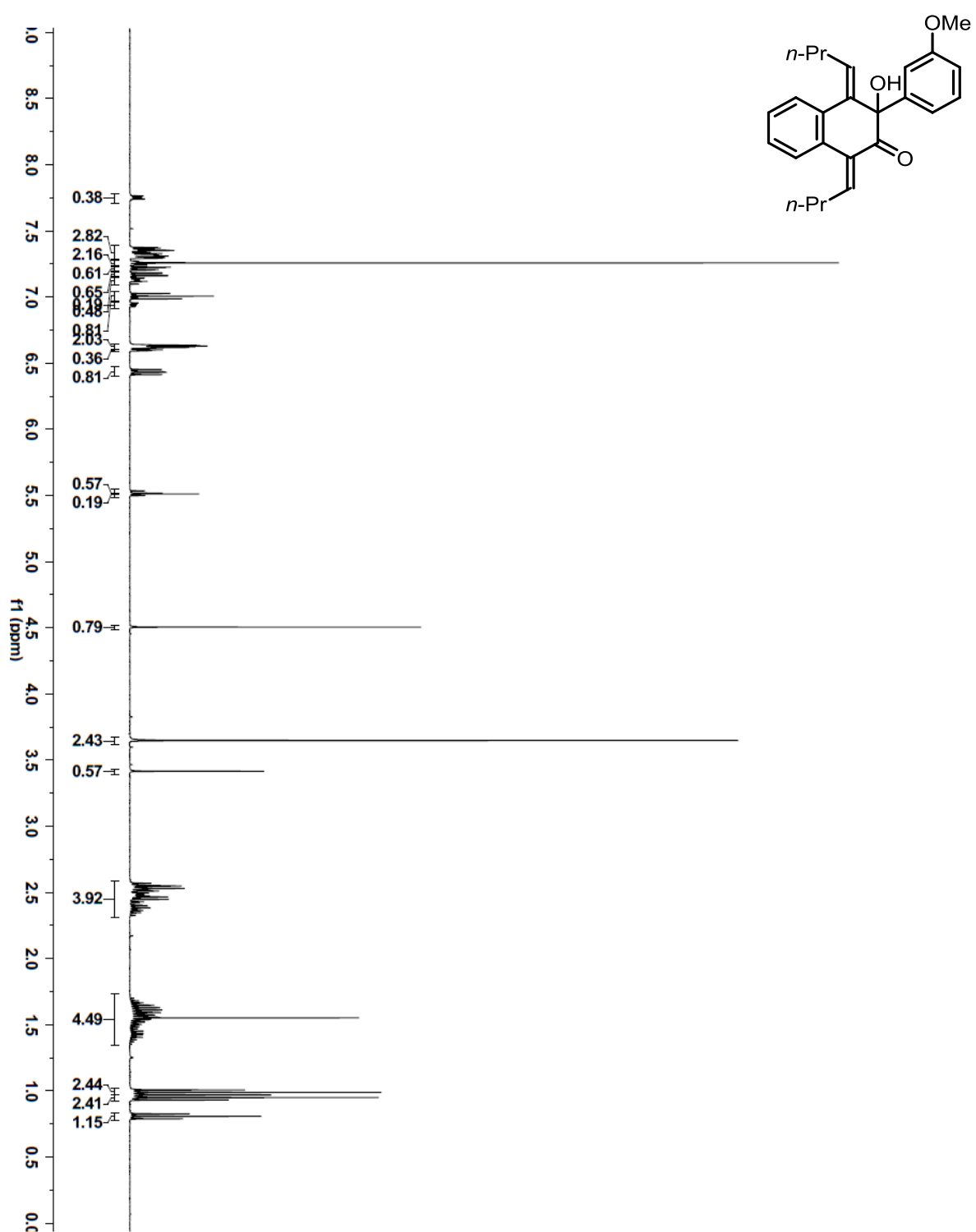
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2e** (50.0 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 60 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH₂Cl₂/hexane→80% CH₂Cl₂/hexane). The title compound **3e** was obtained as a pale yellow oil (81.4 mg) as a 4:1 mixture of isomers in 71% yield.

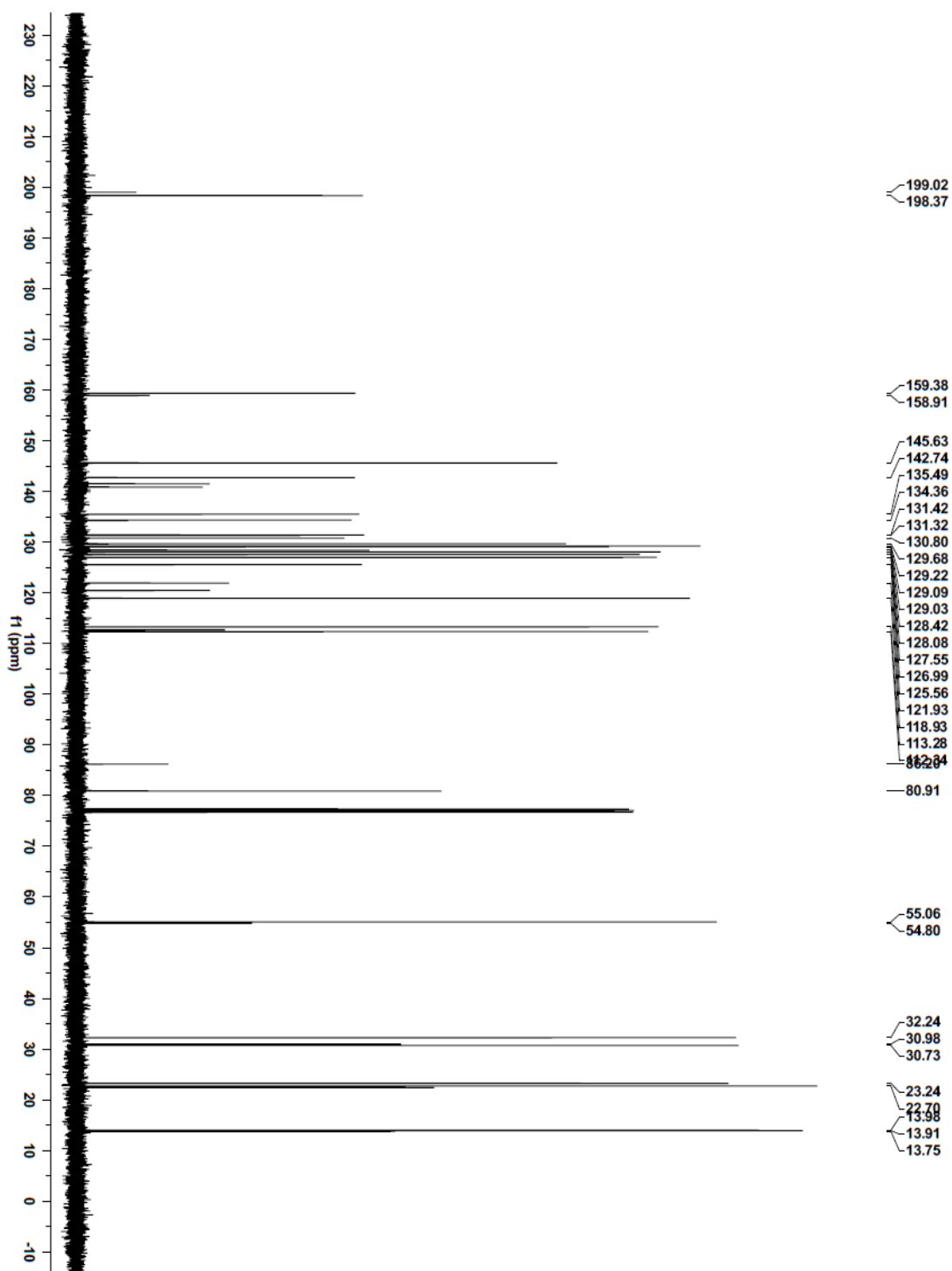
¹H NMR (400 MHz, CDCl₃) δ 7.70-7.80 (m, 0.4H), 7.30-7.40 (m, 2.8H), 7.24-7.27 (m, 0.6H), 7.22 (dd, *J* = 8.0, 4.0 Hz, 0.6H), 7.17 (dd, *J* = 8.0, 1.6 Hz, 0.6 H), 7.10-7.14 (m, 0.4 H), 7.01 (t, *J* = 8.0 Hz, 0.8H), 6.94 (ddd, *J* = 8.2, 2.6, 1.0 Hz, 0.2H), 6.61-6.64 (m, 2H), 6.60 (dd, *J* = 2.5, 1.0 Hz, 0.4H), 6.44 (dd, *J* = 8.0, 4.0 Hz, 0.8H), 5.52 (t, *J* = 8.0 Hz, 0.4 H), 5.51 (s, 0.2H), 4.51 (s, 0.8H), 3.65 (s, 2.4H), 3.42 (s, 0.6H), 2.30-2.60 (m, 4H), 1.40-1.70 (m, 4H), 0.99 (t, *J* = 8.0 Hz, 2.4H), 0.95 (t, *J* = 8.0 Hz, 2.4H), 0.81 (t, *J* = 8.0 Hz, 1.2H).

¹³C NMR (100 MHz, CDCl₃) δ 199.0, 198.4, 159.4, 158.9, 145.6, 142.7, 141.5, 140.8, 135.5, 134.4, 134.3, 131.4, 131.3, 130.8, 129.7, 129.2, 129.1, 129.0, 128.4, 128.1, 127.6, 127.0, 125.6, 121.9, 120.4, 118.9, 113.3, 112.7, 112.3, 86.2, 80.9, 55.1, 54.8, 32.2, 31.0, 30.7, 23.2, 22.7, 22.4, 14.0, 13.9, 13.8.

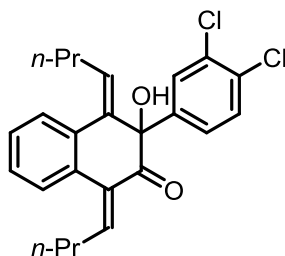
LRMS (ESI) Calcd. for C₂₇H₃₂O₅Na [M+Na]⁺: 399.2, Found: 399.2.

FTIR (neat): 3470, 2959, 1692, 1599, 1486, 1463, 1326, 1253 cm⁻¹.





(1E,4E)-1,4-Dibutylidene-3-(3,4-dichlorophenyl)-3-hydroxy-3,4-dihydronaphthalen-2(1H)-one (3f)



Detailed Procedures

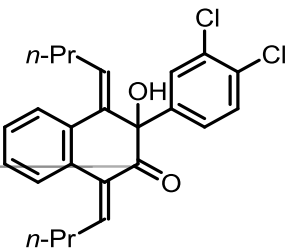
An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2f** (61.5 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 60 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH_2Cl_2 /hexane→50% CH_2Cl_2 /hexane). The title compound **3f** was obtained as a viscous yellow oil (79.7 mg) in 64% yield.

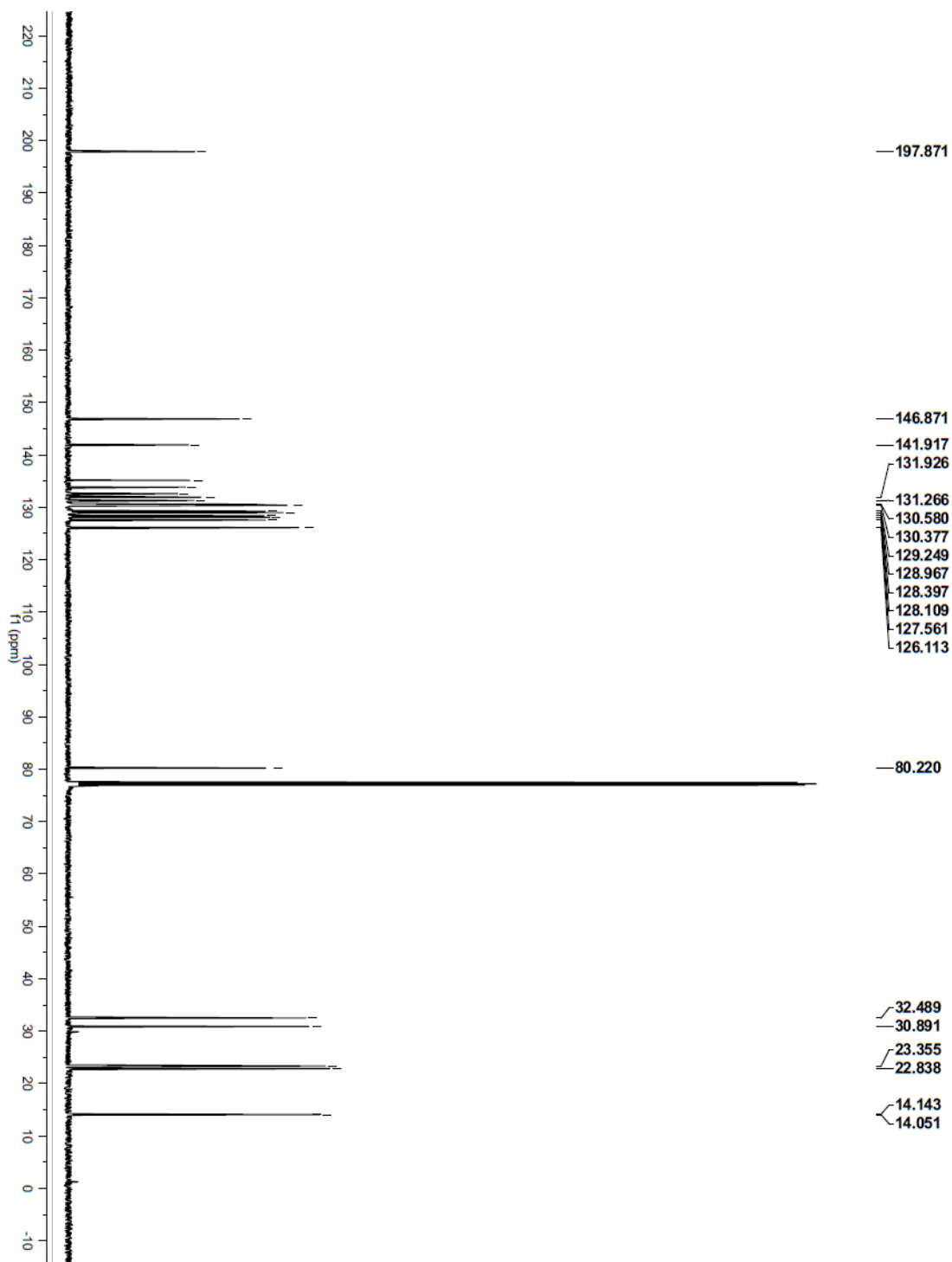
^1H NMR (400 MHz, CDCl_3) δ 7.35 (dd, J = 11.3, 4.9 Hz, 3H), 7.28 (d, J = 1.3 Hz, 1H), 7.21 (td, J = 7.3, 1.4 Hz, 1H), 7.15 (d, J = 5.1 Hz, 1H), 7.15 – 7.13 (m, 1H), 6.87 (dd, J = 8.4, 2.1 Hz, 1H), 6.43 (dd, J = 8.8, 6.4 Hz, 1H), 4.54 – 4.52 (m, 1H), 2.61 – 2.32 (m, 4H), 1.72 – 1.45 (m, 4H), 1.00 (t, J = 7.4 Hz, 3H), 0.94 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 197.9, 146.9, 141.9, 135.1, 133.8, 132.6, 131.9, 131.31, 131.27, 130.6, 130.4, 129.2, 129.0, 128.4, 128.1, 127.6, 126.1, 80.2, 32.5, 30.9, 23.4, 22.8, 14.1, 14.1.

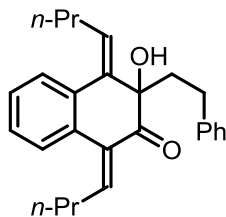
LRMS (ESI) Calcd. for $\text{C}_{24}\text{H}_{24}\text{Cl}_2\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 437.1, Found: 437.1.

FTIR (neat): 3460, 2959, 2930, 2871, 1693, 1604, 1559, 1465, 1381, 1338 cm^{-1} .





(1E,4E)-1,4-Dibutylidene-3-hydroxy-3-phenethyl-3,4-dihydronaphthalen-2(1H)-one (3g)



Detailed Procedures

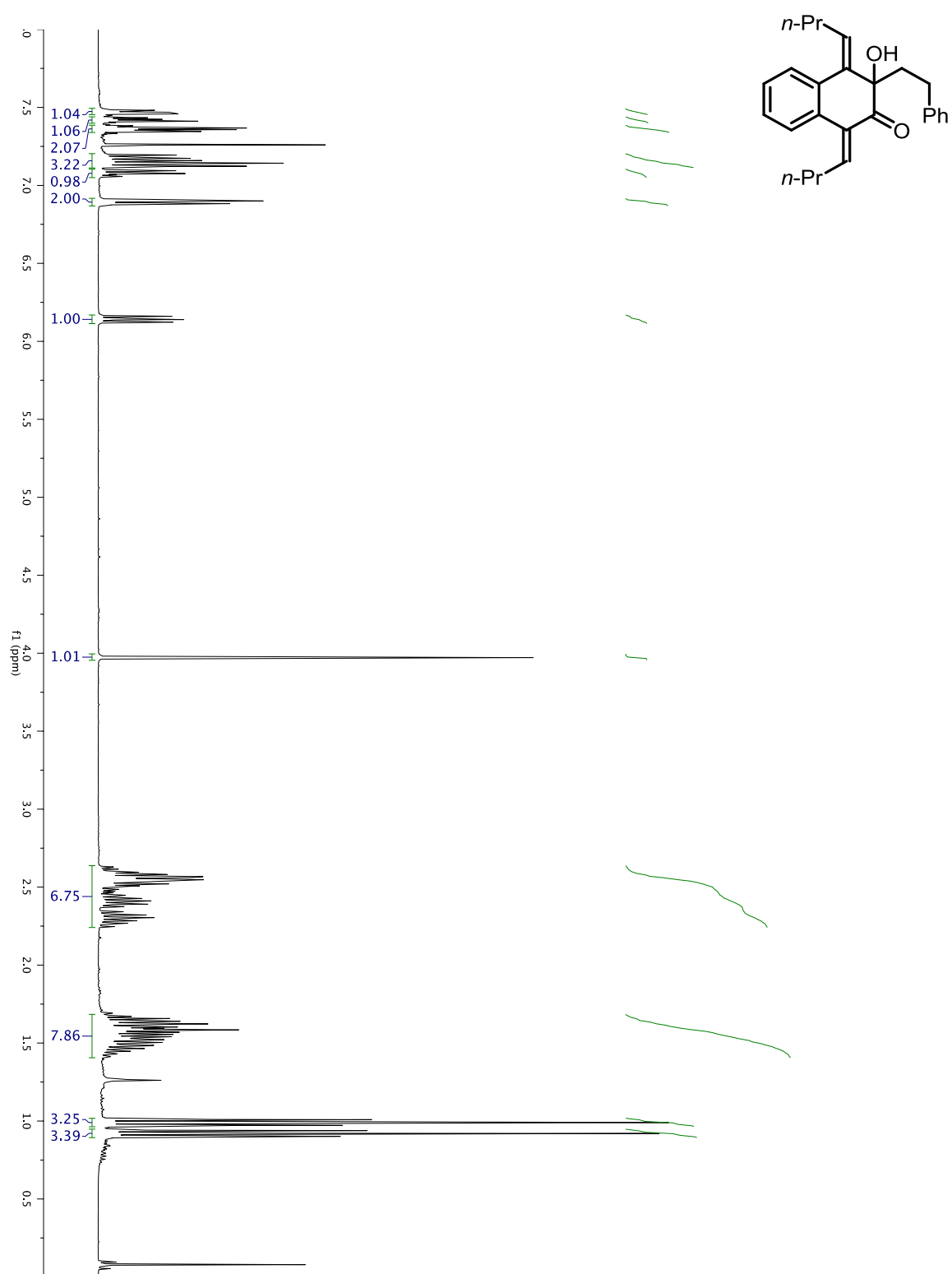
An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2g** (49.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 65 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane \rightarrow 30% CH_2Cl_2 /hexane). The title compound **3g** was obtained as a yellow viscous oil (33.5 mg) in 30% yield.

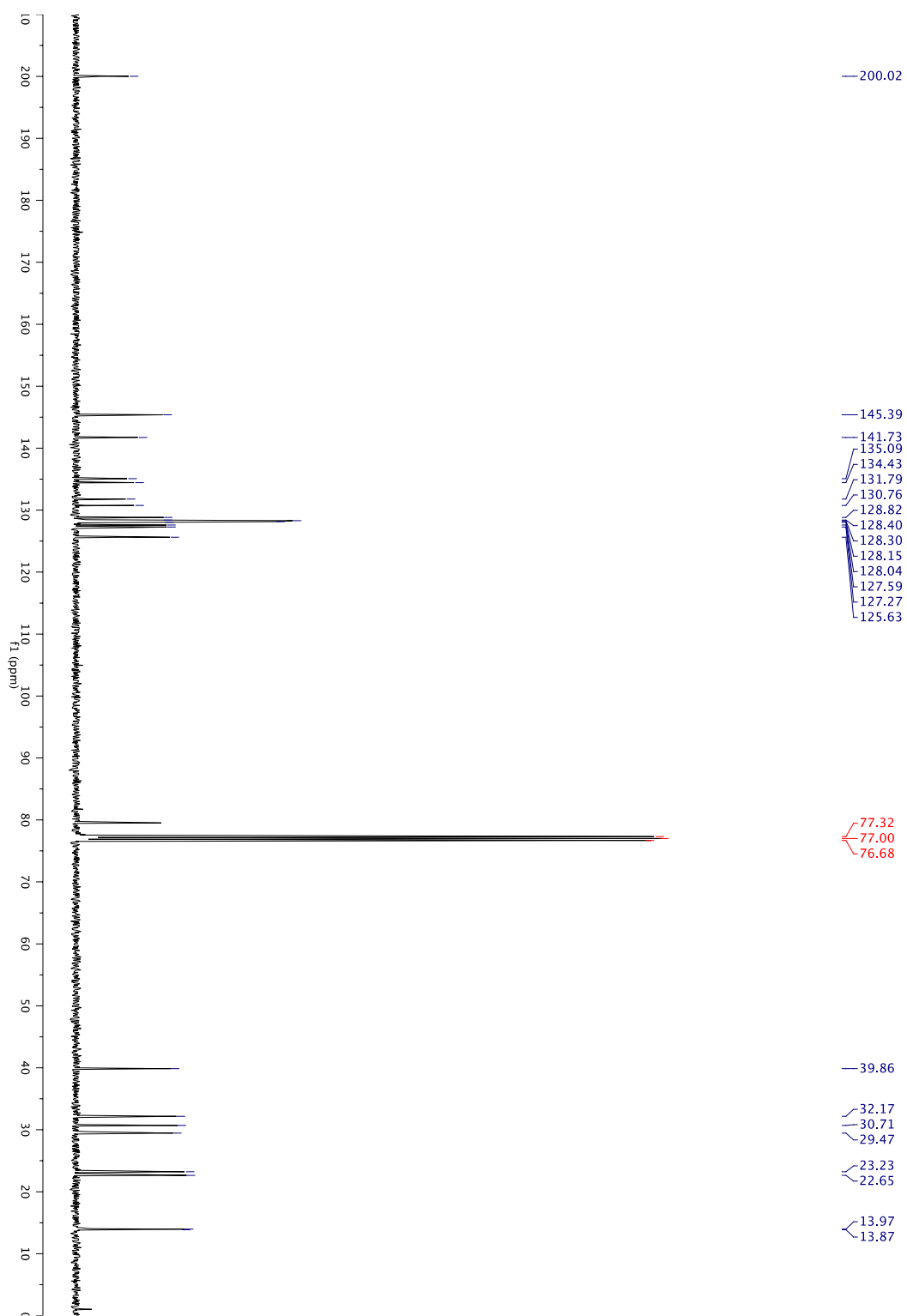
^1H NMR (400 MHz, CDCl_3) δ 7.49-7.45 (m, 1H), 7.44-7.40 (m, 1H), 7.39-7.33 (m, 2H), 7.21-7.11 (m, 3H), 7.11-7.05 (m, 1H), 6.92-6.87 (m, 2H), 6.14 (dd, J = 8.6, 6.5 Hz, 1H), 3.97 (s, 1H), 2.64-2.24 (m, 6H), 1.70-1.40 (m, 6H), 0.99 (t, J = 7.4 Hz, 3H), 0.92 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 200.0, 145.4, 141.7, 135.1, 134.4, 131.8, 130.8, 128.8, 128.4, 128.3, 128.2, 128.0, 127.6, 127.3, 125.6, 79.5, 39.9, 32.2, 30.7, 29.5, 23.2, 22.7, 14.0, 13.9.

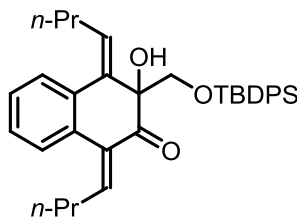
LRMS (ESI) Calcd. for $\text{C}_{26}\text{H}_{30}\text{O}_2\text{Na}$ $[\text{M}+\text{Na}]^+$: 397.2, Found: 397.2.

FTIR (neat): 2958, 2928, 2870, 1692, 1604, 1455, 1092, 909, 762, 698 cm^{-1} .





(1*E*,4*E*)-3-(((Tert-butyldiphenylsilyl)oxy)methyl)-1,4-dibutylidene-3-hydroxy-3,4-dihydronaphthalen-2(1*H*)-one (3h)



Detailed Procedures

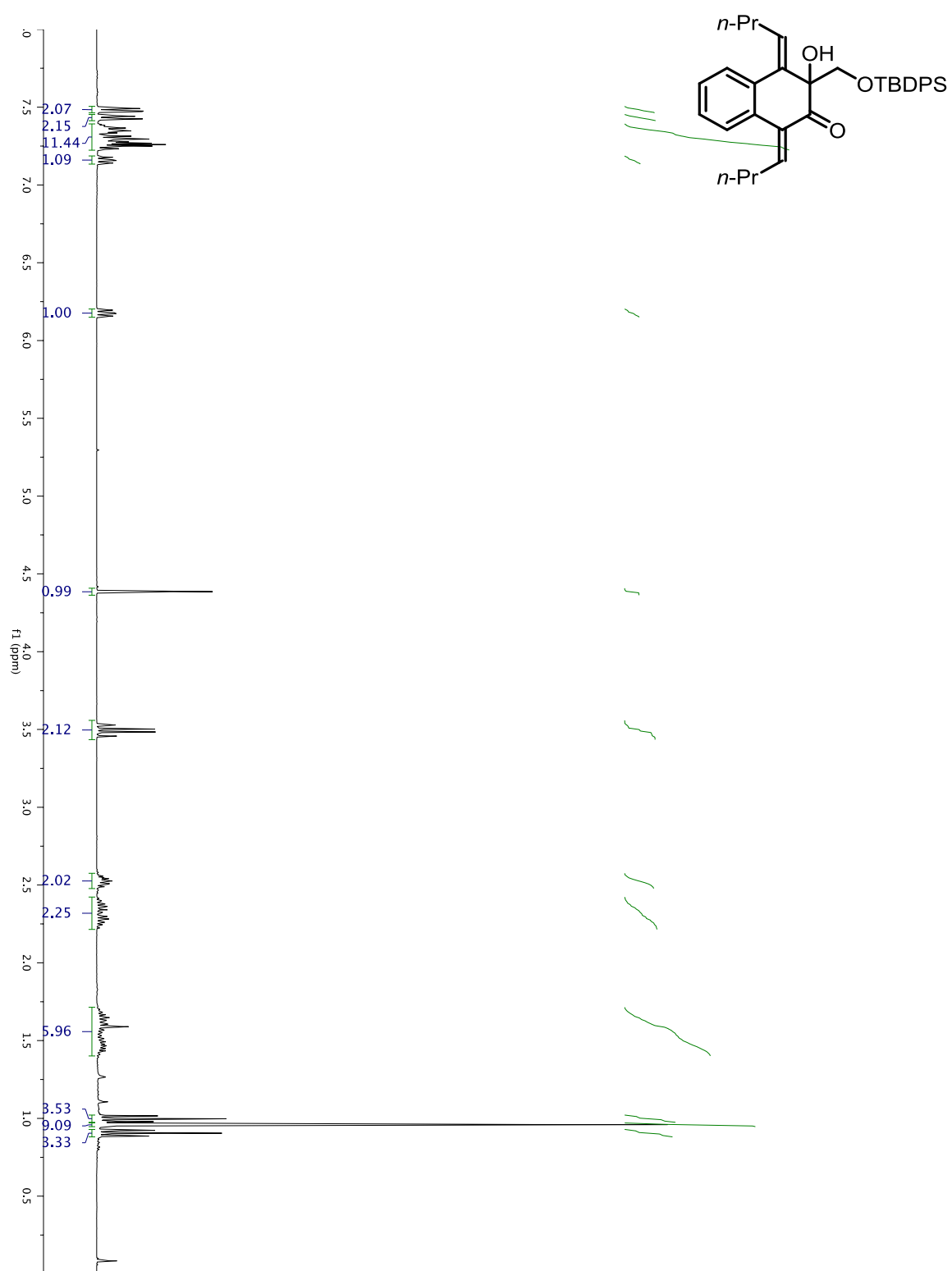
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (3.8 mg, 0.006 mmol, 2 mol%), CyJohnPhos (12.6 mg, 0.036 mmol, 12 mol%), and α -hydroxyketone **2h** (98.5 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1a** (94.6 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH₂Cl₂/hexane→30% CH₂Cl₂/hexane). The title compound **3h** was obtained as a viscous yellow oil (72.8 mg) in 45% yield.

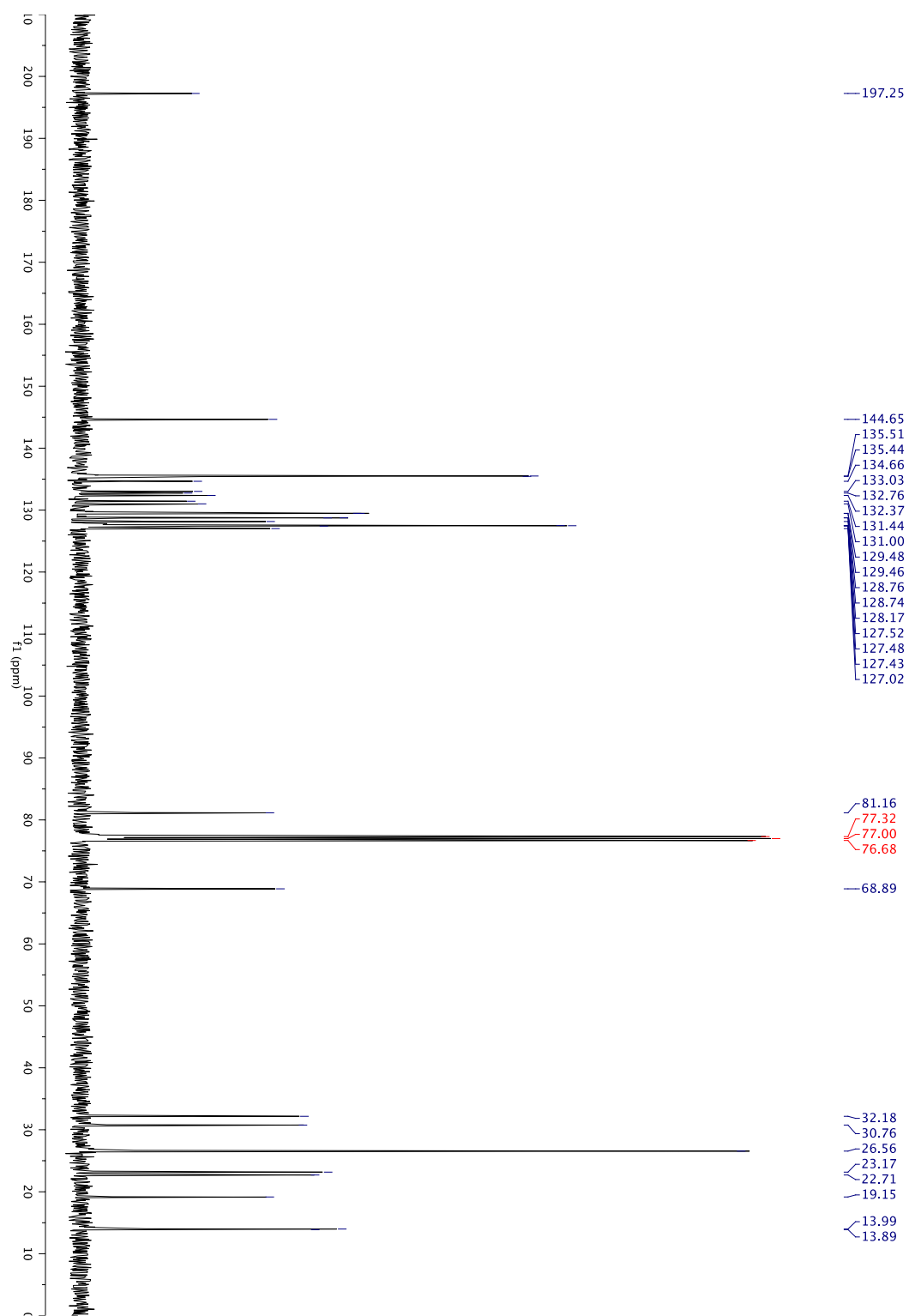
¹H NMR (400 MHz, CDCl₃) δ 7.51-7.46 (m, 2H), 7.45-7.41 (m, 2H), 7.39-7.22 (m, 10H), 7.16 (dd, *J* = 8.6, 6.2 Hz, 1H), 6.18 (dd, *J* = 8.7, 6.6 Hz, 1H), 4.39 (s, 1H), 3.54-3.45 (m, 2H), 2.59-2.46 (m, 2H), 2.42-2.21 (m, 2H), 1.71-1.40 (m, 4H), 1.00 (t, *J* = 7.4 Hz, 3H), 0.96 (s, 9H), 0.90 (t, *J* = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 197.3, 144.6, 135.5, 135.4, 134.7, 133.0, 132.8, 132.4, 131.4, 131.0, 129.5, 129.5, 128.8, 128.7, 128.2, 127.5, 127.5, 127.4, 127.0, 81.2, 68.9, 32.2, 30.8, 26.6, 23.2, 22.7, 19.2, 14.0, 13.9.

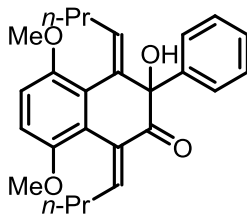
LRMS (ESI) Calcd. for C₃₅H₄₂SiO₃Na [M+Na]⁺: 561.3, Found: 561.4.

FTIR (neat): 2958, 2930, 2857, 1698, 1463, 1427, 1112, 909, 735, 701 cm⁻¹.





(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-5,8-dimethoxy-3-phenyl-3,4-dihydronaphthalen-2(1*H*)-one (4a)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2a** (40.8 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (20% CH₂Cl₂/hexane→100% CH₂Cl₂). The title compound **4a** was obtained as an orange solid (79.8 mg) in 65% yield.

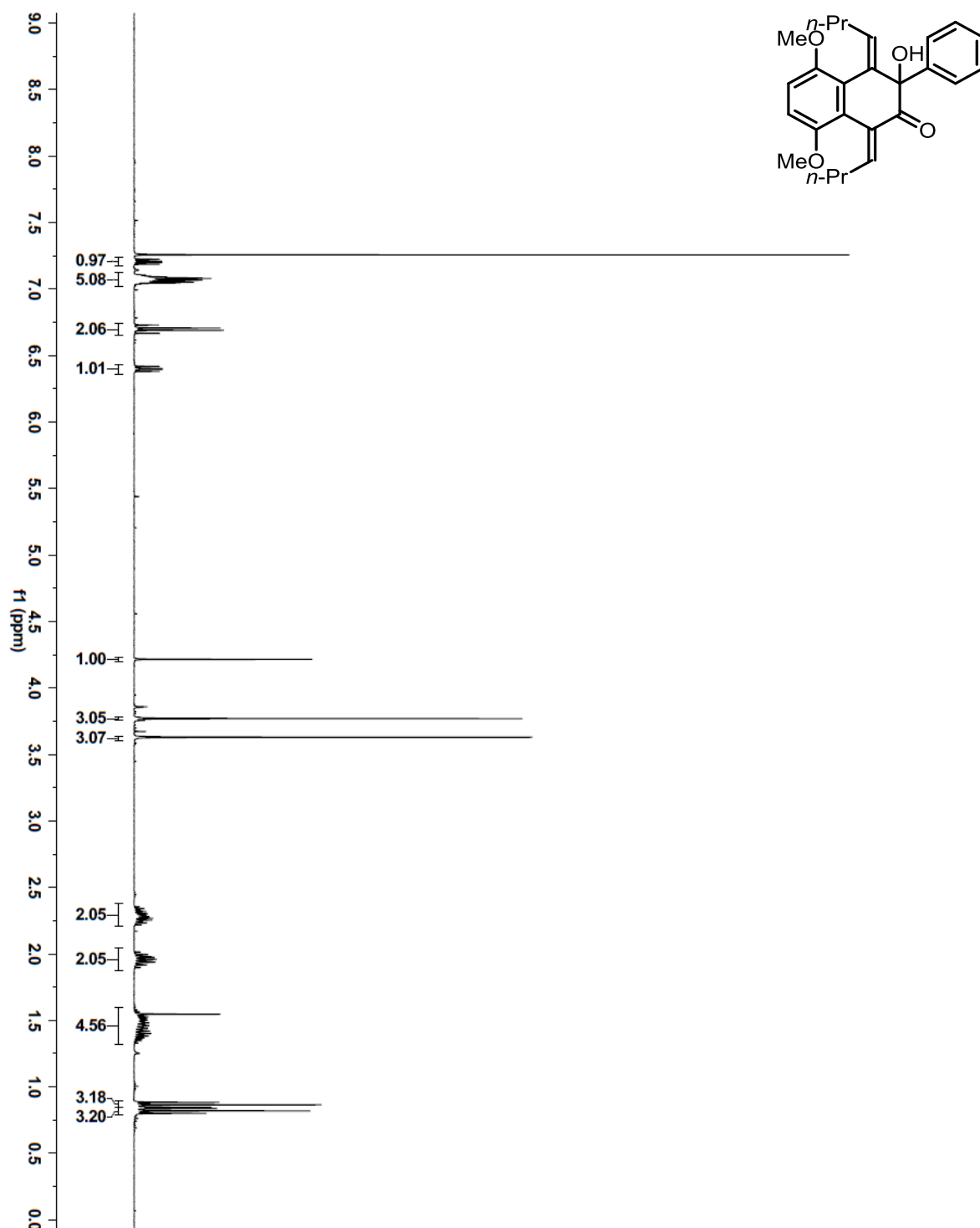
¹H NMR (400 MHz, CDCl₃) δ 7.21 (dd, *J* = 9.5, 5.6 Hz, 1H), 7.11-7.02 (m, 5H), 6.70 (q, *J* = 9.1 Hz, 2H), 6.40 (dd, *J* = 8.8, 6.2 Hz, 1H), 4.21 (s, 1H), 3.77 (s, 3H), 3.63 (s, 3H), 2.29 (m, 2H), 2.03 – 1.86 (m, 2H), 1.56 – 1.30 (m, 4H), 0.86 (t, *J* = 7.4 Hz, 3H), 0.82 (t, *J* = 7.4 Hz, 3H).

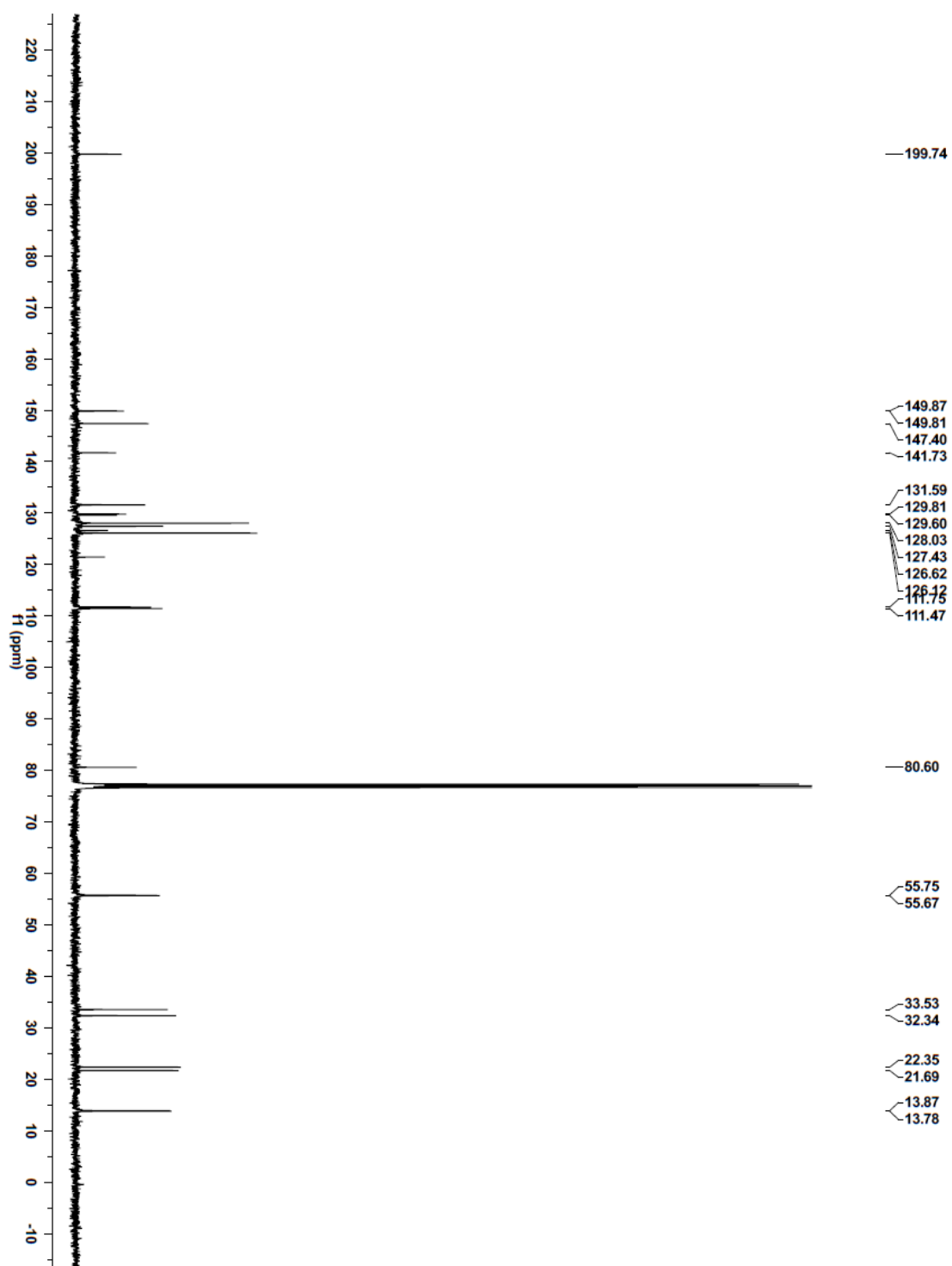
¹³C NMR (100 MHz, CDCl₃) δ 199.7, 149.9, 149.8, 147.4, 141.7, 131.6, 129.8, 129.6, 128.0, 127.4, 126.6, 126.1, 121.5, 111.8, 111.5, 80.6, 55.8, 55.7, 33.5, 32.3, 22.4, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for C₂₆H₃₀O₄Na [M+Na]⁺: 429.2, Found: 429.2.

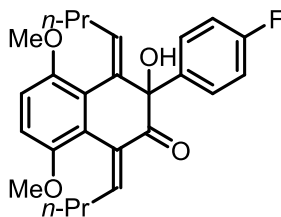
FTIR (neat): 3451, 2953, 2928, 1694, 1610, 1488, 1255 cm⁻¹.

MP: 125-127 °C.





(1E,4E)-1,4-Dibutylidene-3-(4-fluorophenyl)-3-hydroxy-5,8-dimethoxy-3,4-dihydronaphthalen-2(1H)-one (4b)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2b** (46.2 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→60% CH_2Cl_2 /hexane). The title compound **4b** was obtained as a pale yellow solid (107.8 mg) in 85% yield.

^1H NMR (400 MHz, CDCl_3) δ 7.21 (dd, J = 9.4, 5.5 Hz, 1H), 7.07 (dd, J = 8.6, 5.5 Hz, 2H), 6.79-6.67 (m, 4H), 6.39 (dd, J = 8.8, 6.3 Hz, 1H), 4.22 (s, 1H), 3.78 (s, 3H), 3.65 (s, 3H), 2.38-2.19 (m, 2H), 2.03-1.88 (m, 2H), 1.58-1.31 (m, 4H), 0.87 (t, J = 7.4 Hz, 3H), 0.82 (t, J = 7.4 Hz, 3H).

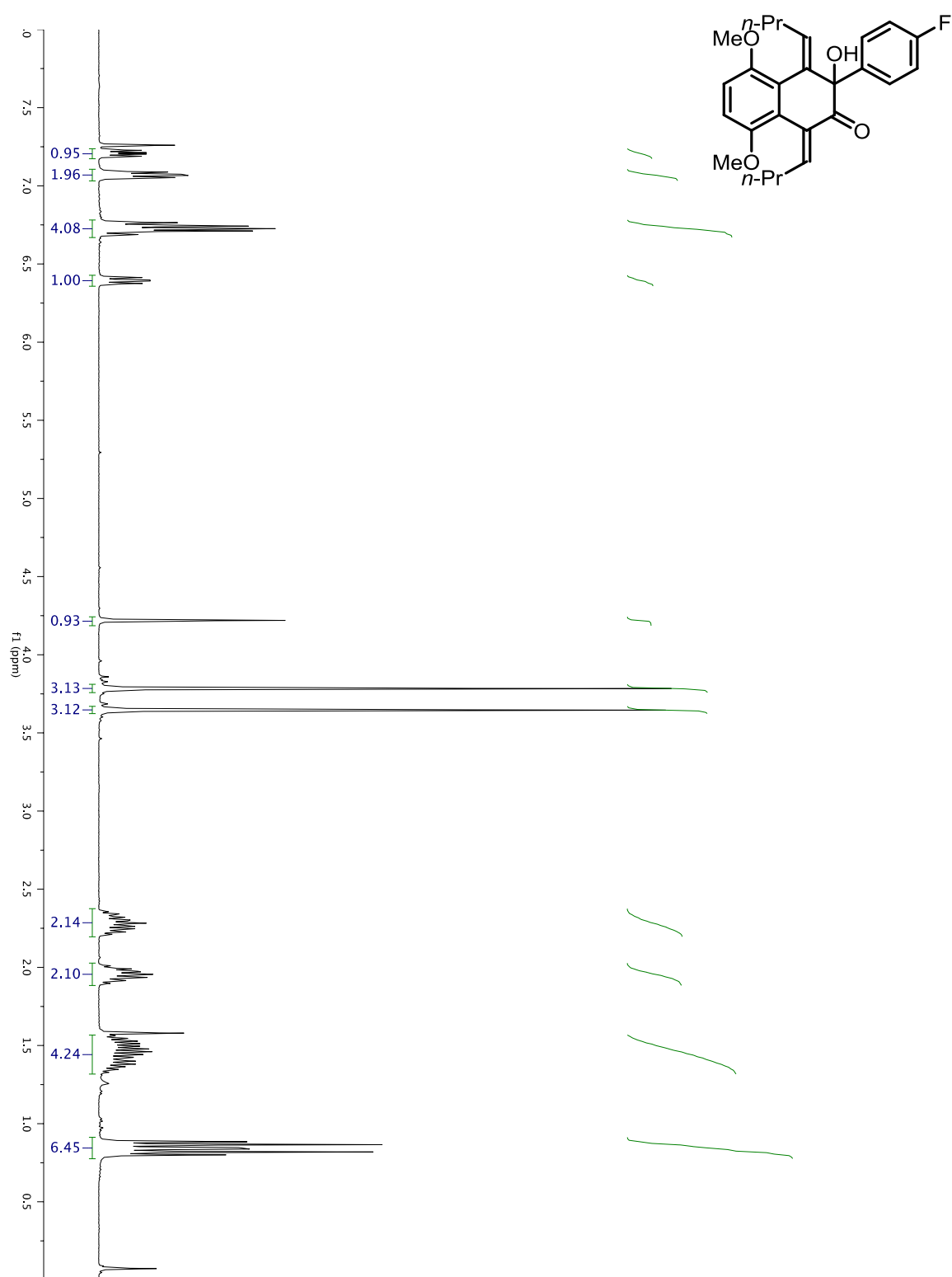
^{13}C NMR (100 MHz, CDCl_3) δ 199.5, 162.0 (d, J = 246.1 Hz, 1C), 149.9, 149.7, 147.8, 137.7, 131.9, 129.6, 129.4, 128.0 (d, J = 8.2 Hz, 2C), 126.4, 121.3, 114.9 (d, J = 21.3 Hz, 2C), 111.7, 111.4, 79.9, 55.7, 55.6, 33.6, 32.3, 22.3, 21.7, 13.9, 13.8.

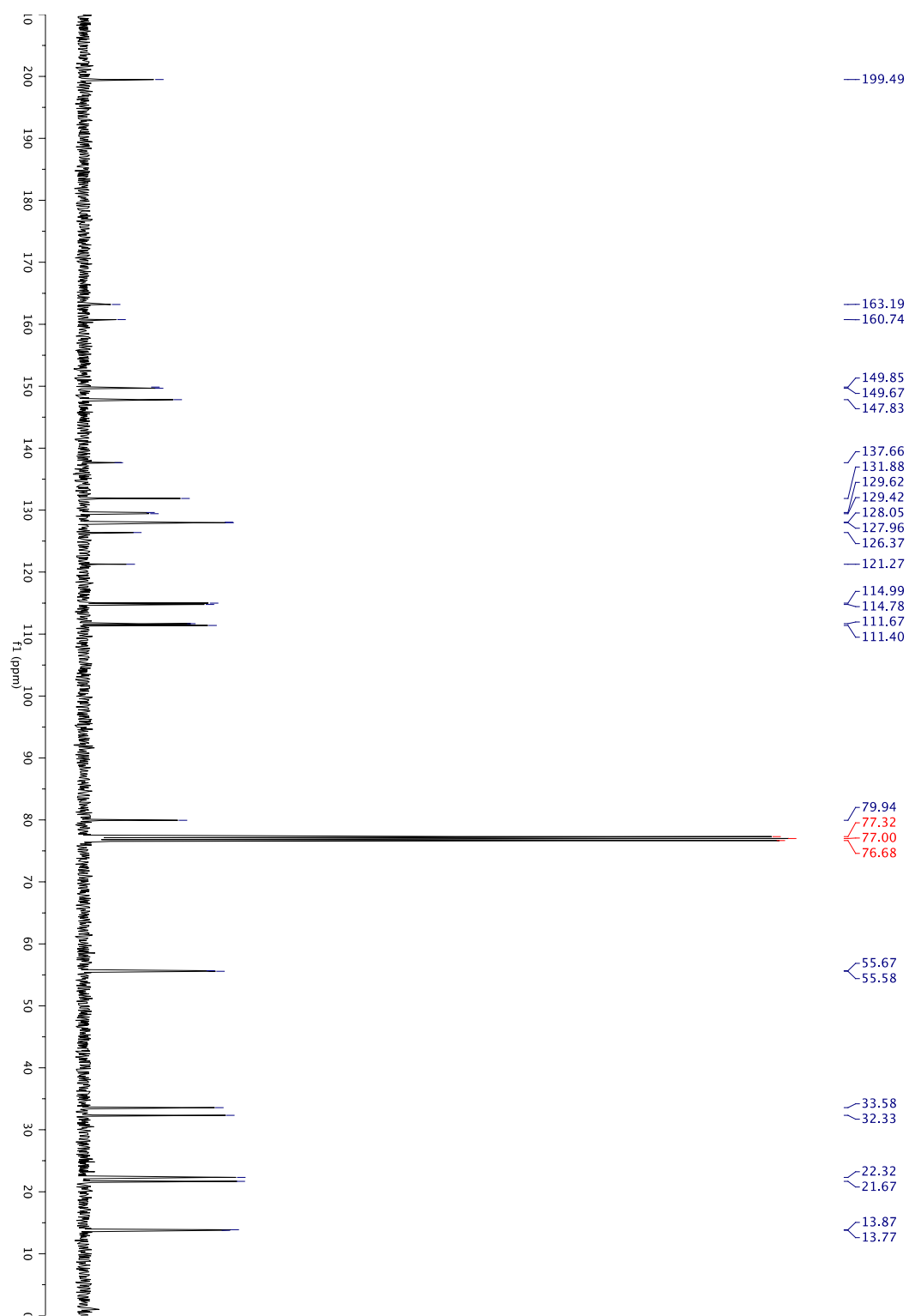
^{19}F NMR (376 MHz, CDCl_3) δ -114.4.

LRMS (ESI) Calcd. for $\text{C}_{26}\text{H}_{29}\text{FO}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 447.2, Found: 447.2.

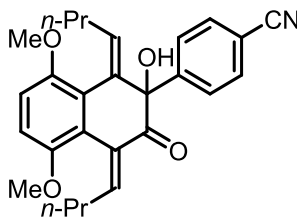
FTIR (neat): 3484, 2958, 2927, 1693, 1474, 1253, 1108, 1063, 981, 806 cm^{-1} .

MP: 119-121 °C.





4-((1*E*,4*E*)-1,4-Dibutylidene-2-hydroxy-5,8-dimethoxy-3-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)benzonitrile (4c**)**



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2c** (48.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→80% CH_2Cl_2 /hexane). The title compound **4c** was obtained as a yellow viscous oil (80.1 mg) in 62% yield.

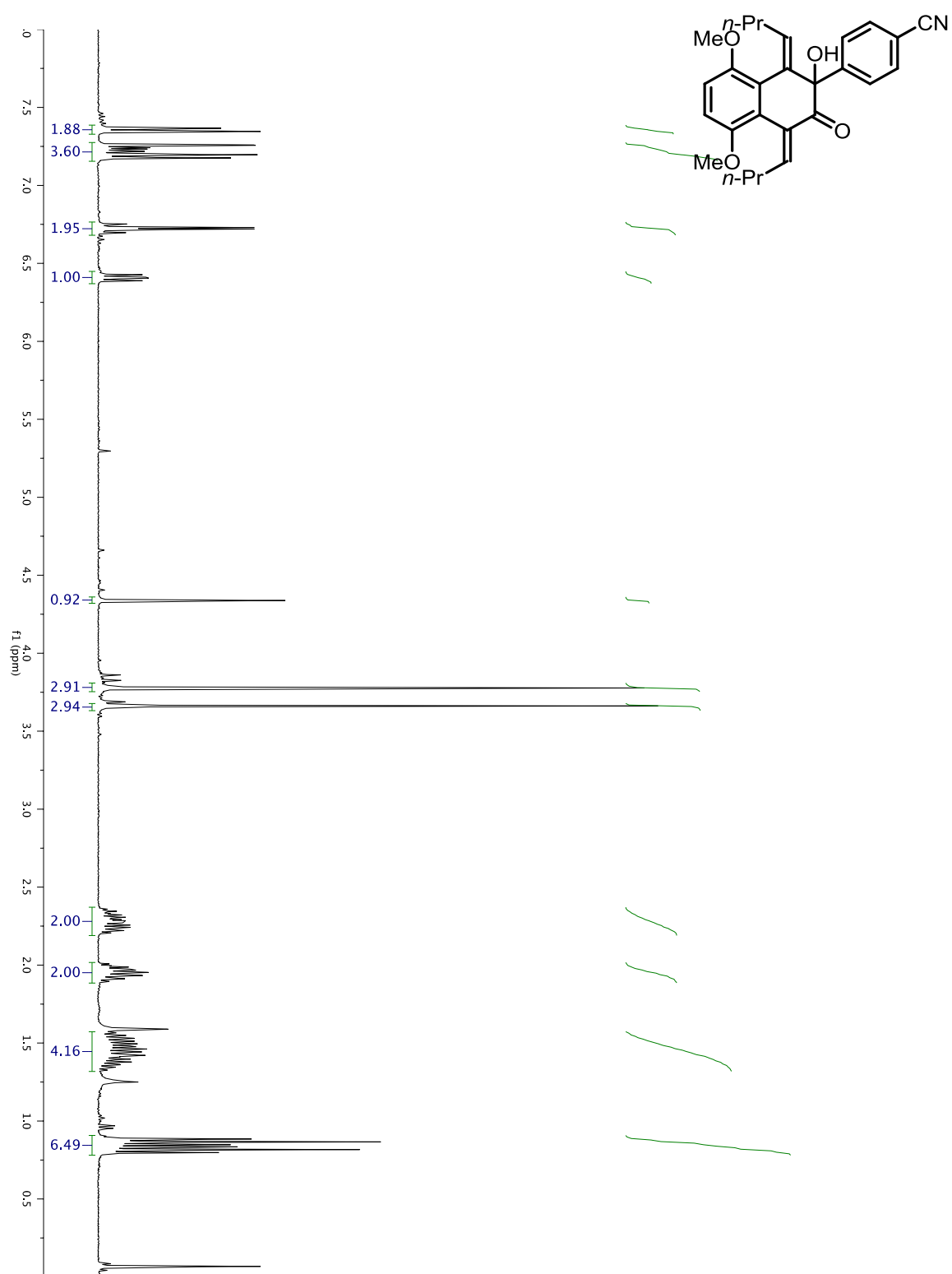
^1H NMR (400 MHz, CDCl_3) δ 7.39-7.32 (m, 2H), 7.27-7.15 (m, 3H), 6.77-6.68 (m, 2H), 6.41 (dd, $J = 8.9$, 6.3 Hz, 1H), 4.34 (s, 1H), 3.78 (s, 3H), 3.66 (s, 3H), 2.37-2.19 (m, 2H), 2.02-1.88 (m, 2H), 1.58-1.31 (m, 4H), 0.87 (t, $J = 7.4$ Hz, 3H), 0.82 (t, $J = 7.4$ Hz, 3H).

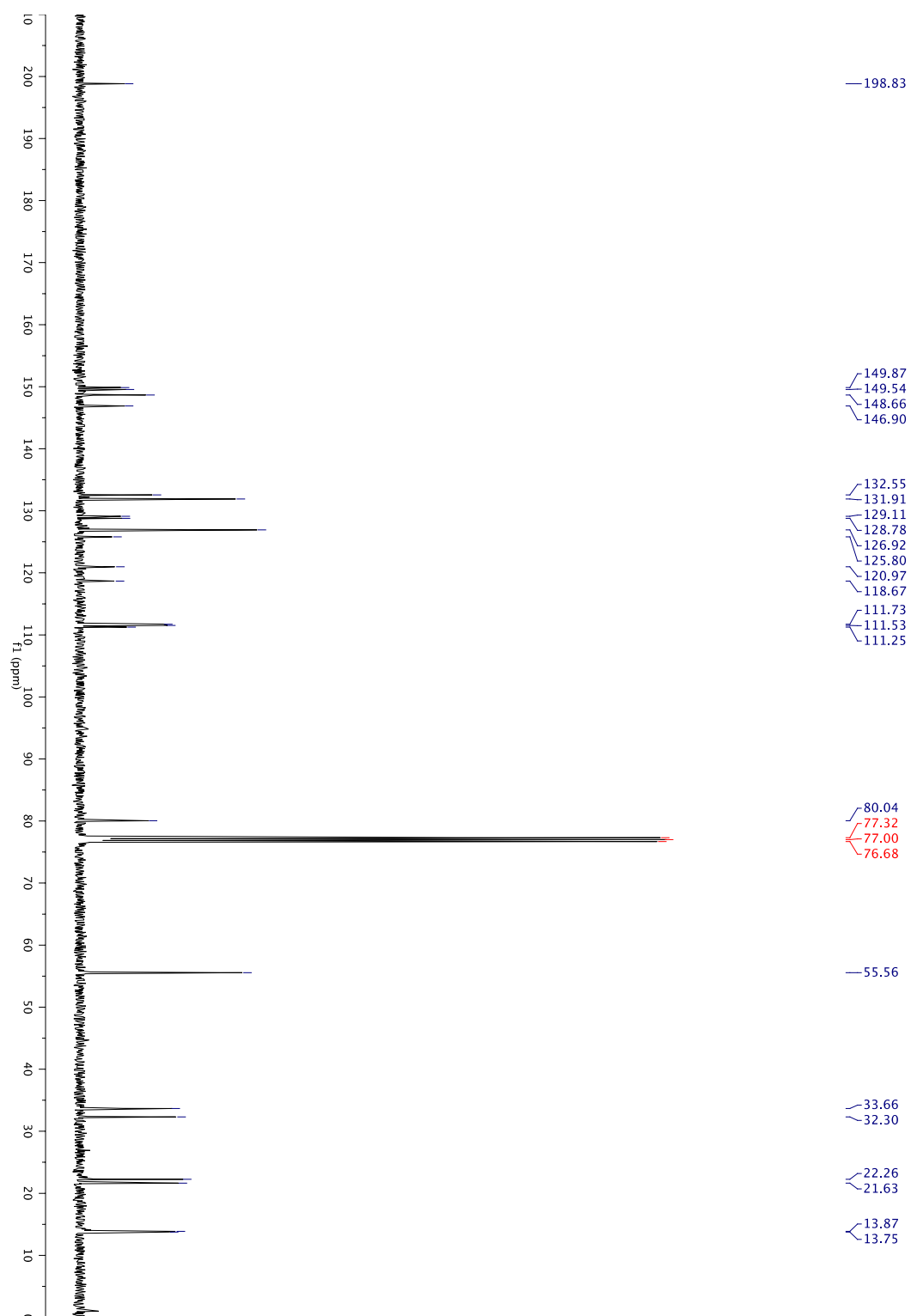
^{13}C NMR (100 MHz, CDCl_3) δ 198.8, 149.9, 149.5, 148.7, 146.9, 132.6, 131.9, 129.1, 128.8, 126.9, 125.8, 121.0, 118.7, 111.7, 111.5, 111.3, 80.0, 55.6, 33.7, 32.3, 22.3, 21.6, 13.9, 13.8.

LRMS (ESI) Calcd. for $\text{C}_{27}\text{H}_{29}\text{NO}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 454.2, Found: 454.2.

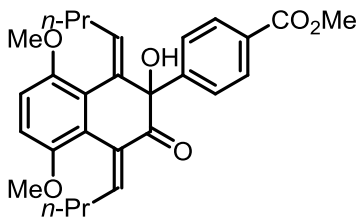
FTIR (neat): 3456, 2957, 2925, 1698, 1484, 1253, 1111, 1062, 980, 793 cm^{-1} .

MP: 109-111 °C.





Methyl 4-((1*E*,4*E*)-1,4-dibutylidene-2-hydroxy-5,8-dimethoxy-3-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)benzoate (4d)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2d** (58.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH₂Cl₂/hexane→100% CH₂Cl₂/hexane). The title compound **4d** was obtained as a yellow solid (113 mg) in 81% yield.

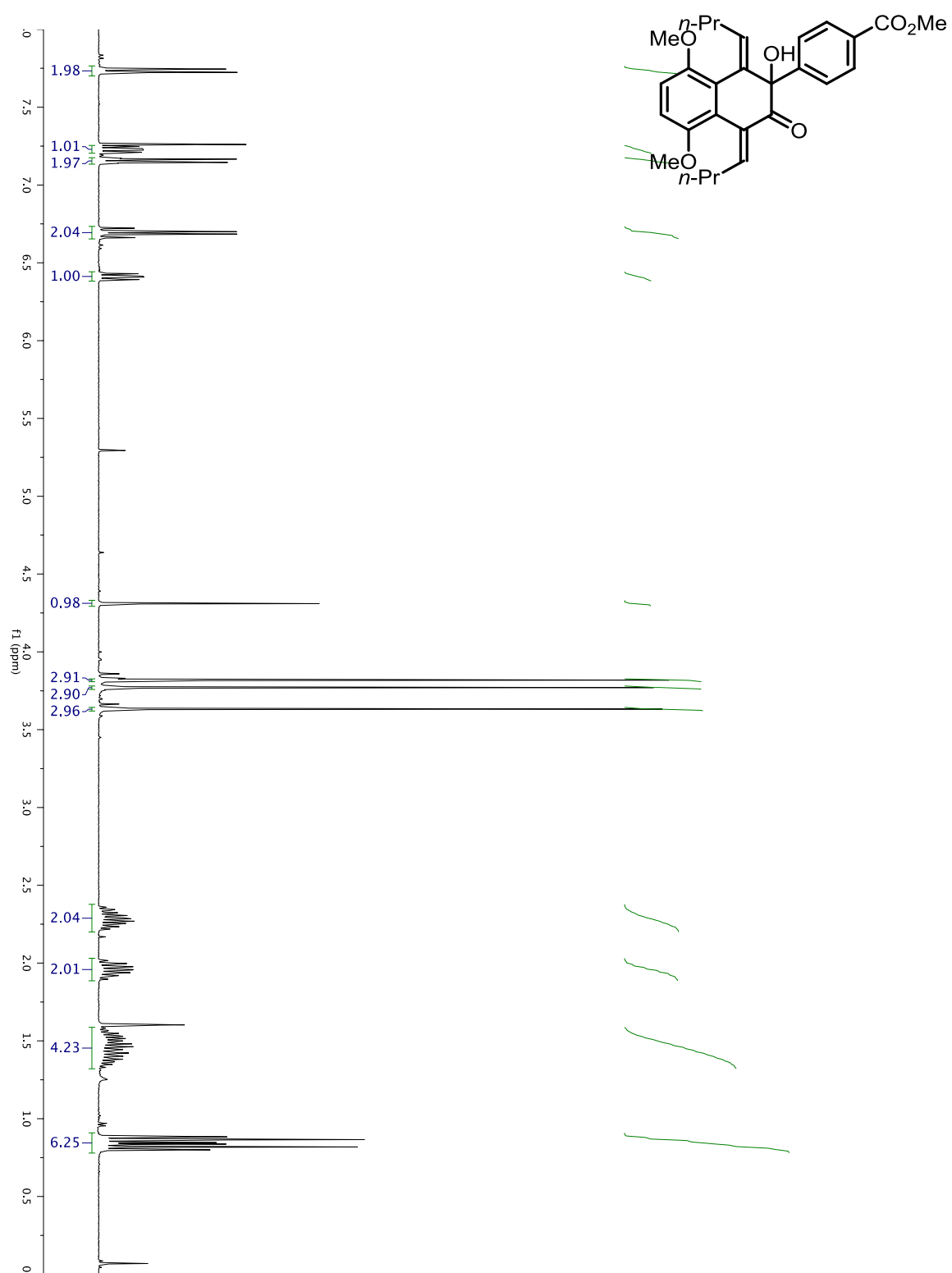
¹H NMR (400 MHz, CDCl₃) δ 7.76-7.71 (m, 2H), 7.23 (dd, *J* = 9.5, 5.5 Hz, 1H), 7.18-7.13 (m, 2H), 6.74-6.65 (m, 2H), 6.41 (dd, *J* = 8.8, 6.2 Hz, 1H), 4.31 (s, 1H), 3.82 (s, 3H), 3.77 (s, 3H), 3.63 (s, 3H), 2.38-2.20 (m, 2H), 2.03-1.88 (m, 2H), 1.59-1.31 (m, 4H), 0.87 (t, *J* = 7.4 Hz, 3H), 0.82 (t, *J* = 7.4 Hz, 3H).

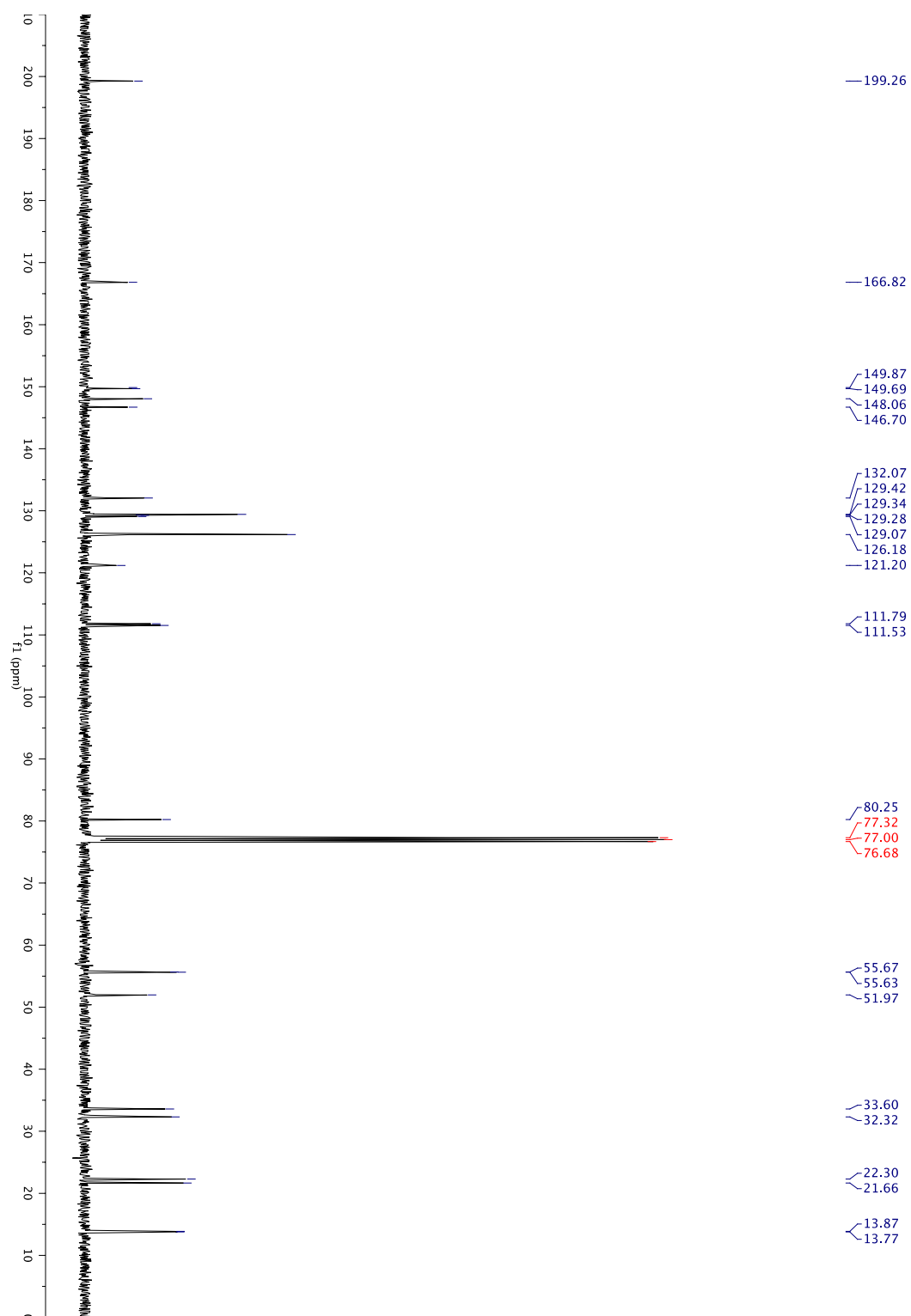
¹³C NMR (100 MHz, CDCl₃) δ 199.3, 166.8, 149.9, 149.7, 148.1, 146.7, 132.1, 129.4, 129.3, 129.3, 129.1, 126.2, 121.2, 111.8, 111.5, 80.3, 55.7, 55.6, 52.0, 33.6, 32.3, 22.3, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for $C_{28}H_{32}O_6Na$ $[M+Na]^+$: 487.2, Found: 487.2.

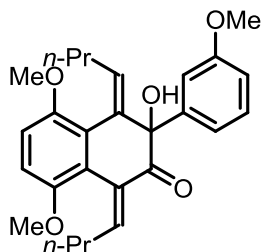
FTIR (neat): 3473, 2955, 2360, 1713, 1487, 1288, 1259, 1105, 1069, 804 cm⁻¹.

MP: 132-134 °C.





(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-5,8-dimethoxy-3-(3-methoxyphenyl)-3,4-dihydronaphthalen-2(1*H*)-one (4e)



Detailed Procedures

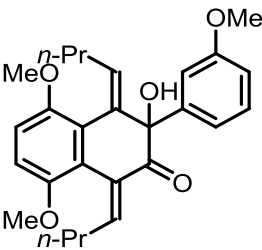
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2e** (50.0 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (20% CH₂Cl₂/hexane→100% CH₂Cl₂). The title compound **4e** was obtained as an orange oil (90.4 mg) in 69% yield.

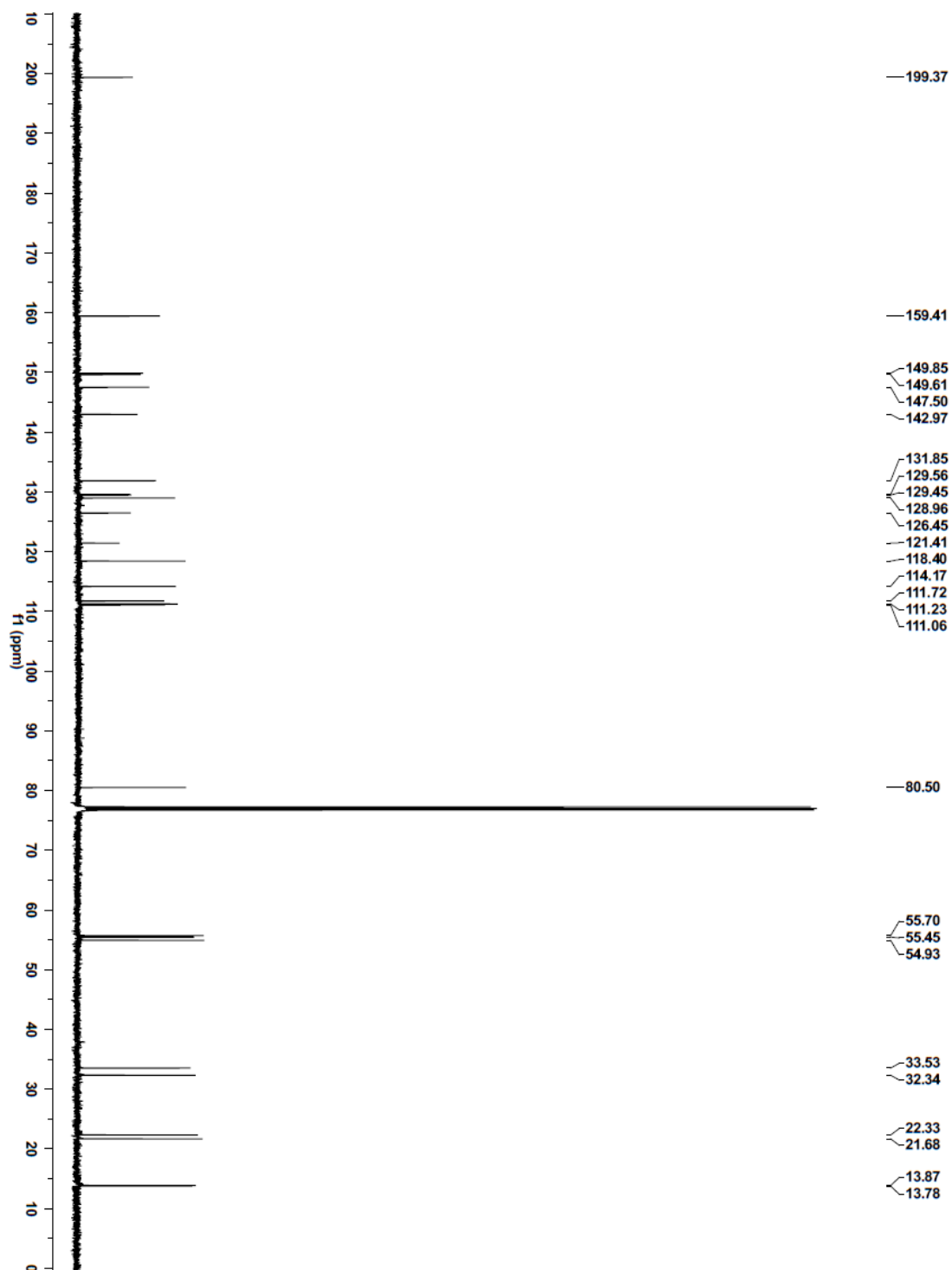
¹H NMR (400 MHz, CDCl₃) δ 7.20 (dd, *J* = 9.5, 5.5 Hz, 1H), 6.97 (t, *J* = 7.9 Hz, 1H), 6.75 – 6.67 (m, 3H), 6.64 (ddd, *J* = 7.7, 1.6, 0.9 Hz, 1H), 6.60 (ddd, *J* = 8.2, 2.6, 0.9 Hz, 1H), 6.39 (dd, *J* = 8.8, 6.3 Hz, 1H), 4.24 (s, 1H), 3.79 (s, 3H), 3.66 (s, 3H), 3.63 (s, 3H), 2.37-2.21 (m, 2H), 2.03-1.88 (m, 2H), 1.54-1.31 (m, 4H), 0.86 (t, *J* = 7.4 Hz, 3H), 0.82 (t, *J* = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 199.4, 159.4, 149.9, 149.6, 147.5, 143.0, 131.9, 129.6, 129.4, 129.0, 126.45, 121.41, 118.4, 114.2, 111.7, 111.2, 111.1, 80.5, 55.7, 55.5, 54.9, 33.5, 32.3, 22.3, 21.7, 13.9, 13.8.

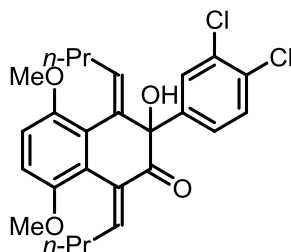
LRMS (ESI) Calcd. for C₂₇H₃₂O₅Na [M+Na]⁺: 459.2, Found: 459.2.

FTIR (neat): 3472, 2957, 2871, 2835, 1692, 1598, 1583, 1485, 1464, 1435, 1255 cm⁻¹.





(1*E*,4*E*)-1,4-Dibutylidene-3-(3,4-dichlorophenyl)-3-hydroxy-5,8-dimethoxy-3,4-dihydronaphthalen-2(1*H*)-one (4f)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2f** (61.5 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (20% CH_2Cl_2 /hexane \rightarrow 70% CH_2Cl_2 /hexane). The title compound **4f** was obtained as an orange solid (90.1 mg) in 72% yield.

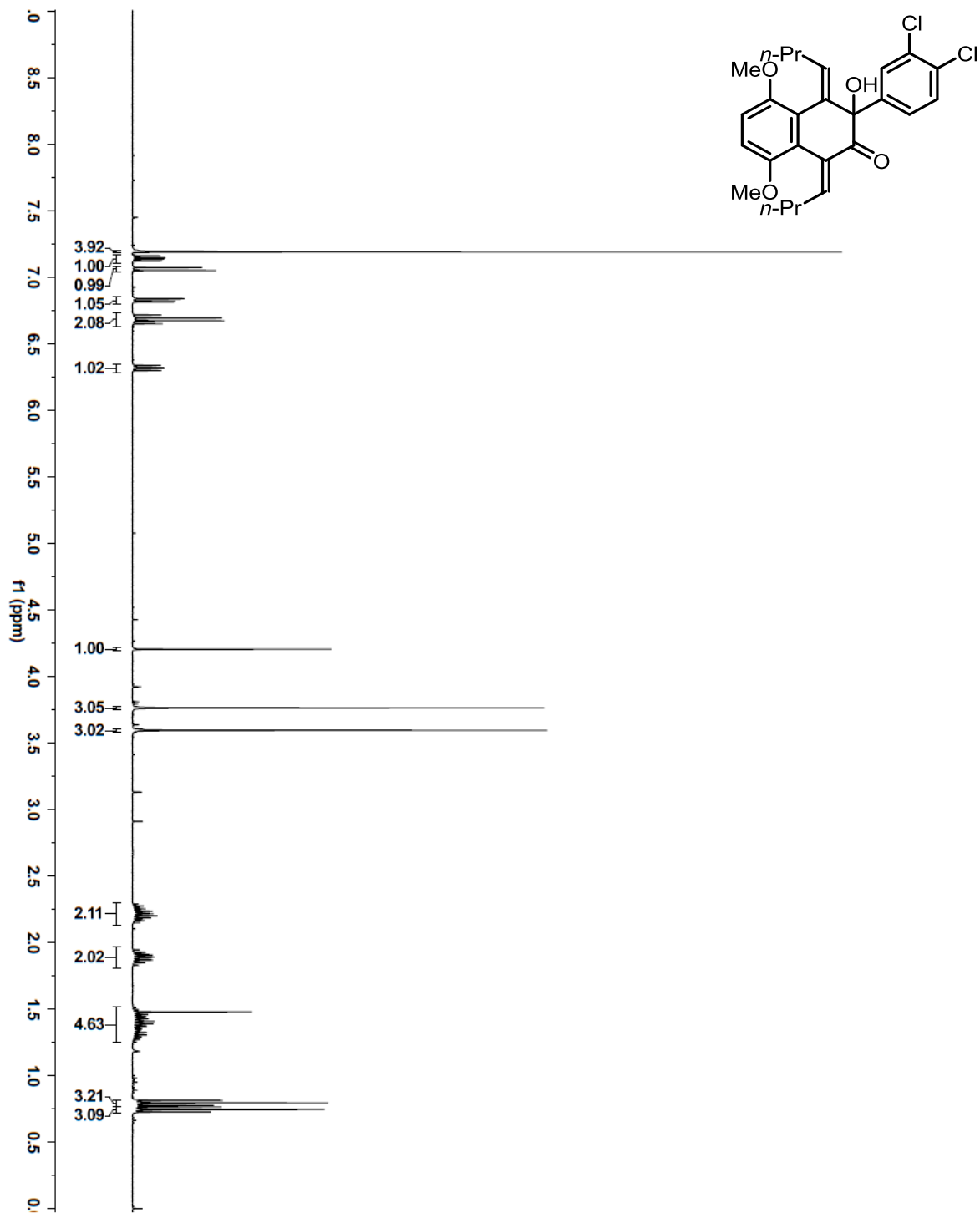
^1H NMR (400 MHz, CDCl_3) δ 7.19 (d, J = 1.7 Hz, 1H), 7.14 (dd, J = 9.5, 5.6 Hz, 1H), 7.06 (d, J = 8.4 Hz, 1H), 6.83 (dd, J = 8.4, 2.2 Hz, 1H), 6.68 (q, J = 9.1 Hz, 2H), 6.32 (dd, J = 8.8, 6.2 Hz, 1H), 4.20 (s, 1H), 3.76 (s, 3H), 3.59 (s, 3H), 2.30-2.13 (m, 2H), 1.81-1.95 (m, 2H), 1.48-1.24 (m, 4H), 0.80 (t, J = 7.4 Hz, 3H), 0.75 (t, J = 7.4 Hz, 3H).

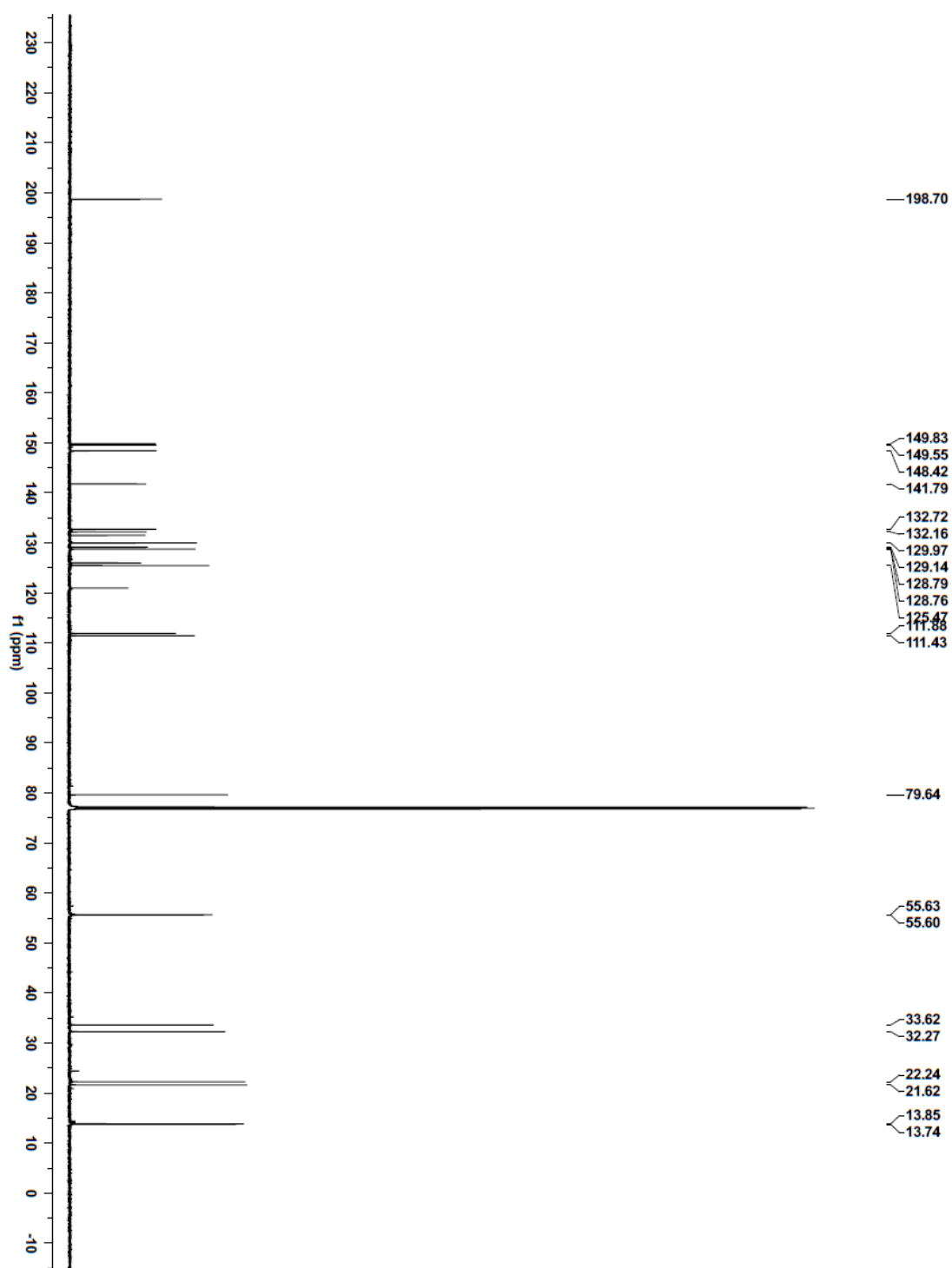
^{13}C NMR (151 MHz, CDCl_3) δ 198.7, 149.8, 149.6, 148.4, 141.8, 132.7, 132.2, 131.5, 130.0, 129.1, 128.8, 128.8, 126.0, 125.5, 121.0, 111.9, 111.4, 79.6, 55.6, 55.6, 33.6, 32.3, 22.2, 21.6, 13.9, 13.7.

LRMS (ESI) Calcd. for $\text{C}_{26}\text{H}_{28}\text{Cl}_2\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 497.1, Found: 497.1.

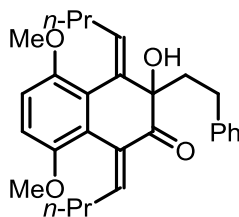
FTIR (neat): 3490, 2951, 1695, 1607, 1486 1464, 1256 cm^{-1} .

MP: 139-141 °C.





(1E,4E)-1,4-Dibutylidene-3-hydroxy-5,8-dimethoxy-3-phenethyl-3,4-dihydronaphthalen-2(1H)-one (4g)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (32.0 mg, 0.050 mmol, 5 mol%), RuPhos (140.0 mg, 0.30 mmol, 30 mol%), and α -hydroxyketone **2g** (164.2 mg, 1.00 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (405.6 mg, 1.50 mmol, 150 mol%), *m*-xylene (0.50 mL), and deionized water (0.50 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% EtOAc/hexane). The title compound **4g** was obtained as a yellow solid (262.7 mg) in 60% yield.

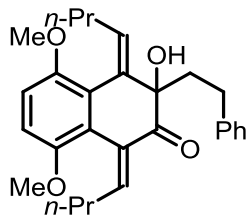
¹H NMR (400 MHz, CDCl_3) δ 7.19-7.12 (m, 2H), 7.11-7.05 (m, 1H), 7.02 (dd, J = 9.4, 5.6 Hz, 1H), 6.99-6.87 (m, 4H), 6.14 (dd, J = 8.8, 6.1 Hz, 1H), 3.86 (s, 3H), 3.77 (s, 3H), 3.64 (s, 1H), 2.69-2.48 (m, 2H), 2.36-2.15 (m, 2H), 2.02-1.86 (m, 2H), 1.57-1.24 (m, 6H), 0.86 (t, J = 7.4 Hz, 3H), 0.80 (t, J = 7.4 Hz, 3H).

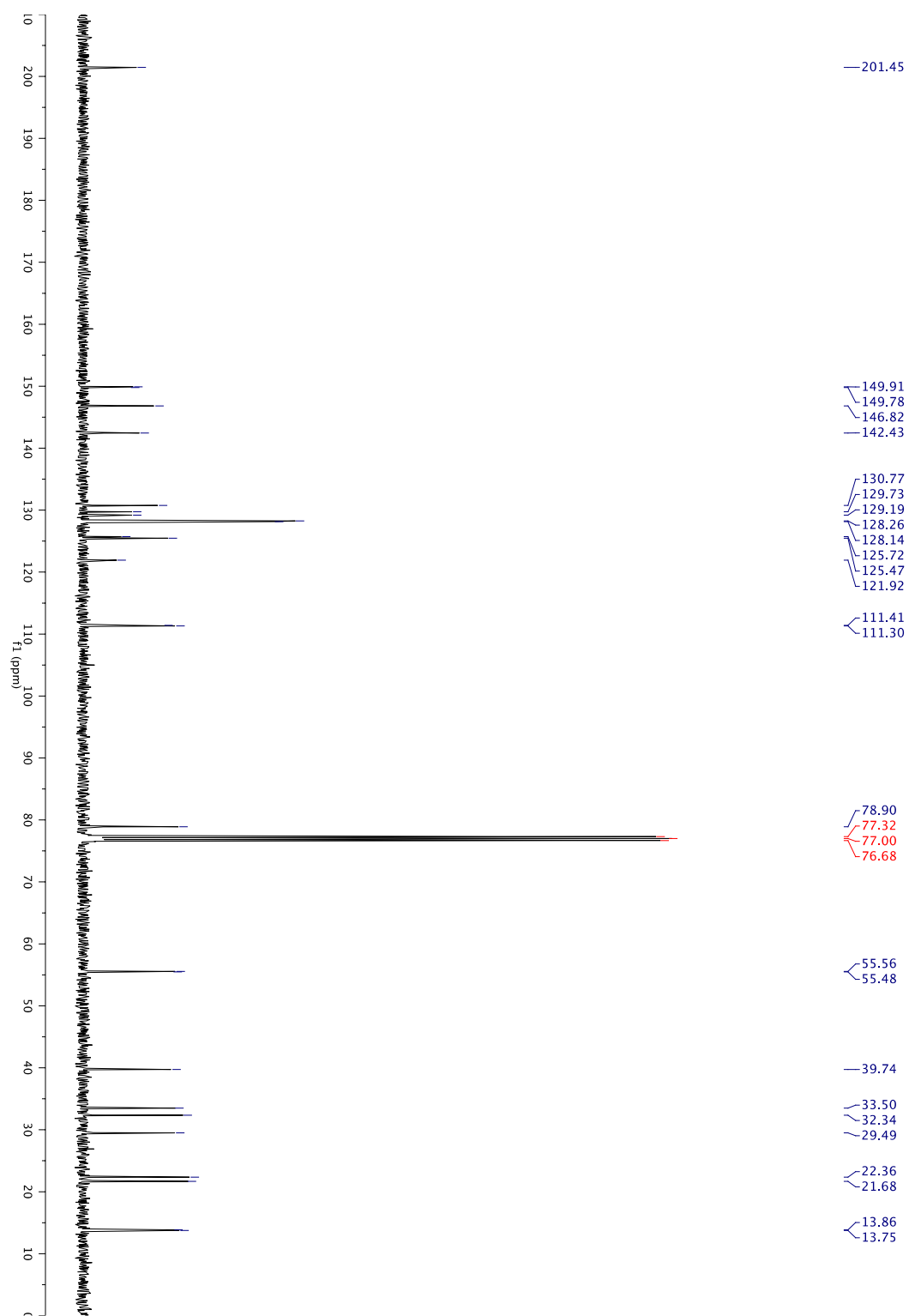
¹³C NMR (100 MHz, CDCl_3) δ 201.5, 149.9, 149.8, 146.8, 142.4, 130.8, 129.7, 129.2, 128.3, 128.1, 125.7, 125.5, 121.9, 111.4, 111.3, 78.9, 55.6, 55.5, 39.7, 33.5, 32.3, 29.5, 22.4, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for $\text{C}_{28}\text{H}_{34}\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 457.2, Found: 457.2.

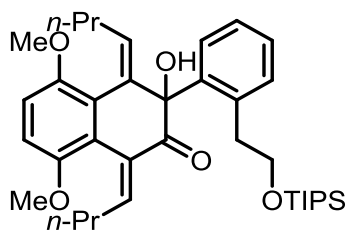
FTIR (neat): 2955, 2867, 2359, 2341, 1688, 1485, 1255, 1071, 1001, 708 cm^{-1} .

MP: 94-96 °C.





(1*E*,4*E*)-1,4-dibutylidene-3-hydroxy-5,8-dimethoxy-3-(2-(2-((triisopropylsilyl)oxy)ethyl)phenyl)-3,4-dihydronaphthalen-2(1*H*)-one (4i)



Detailed Procedures

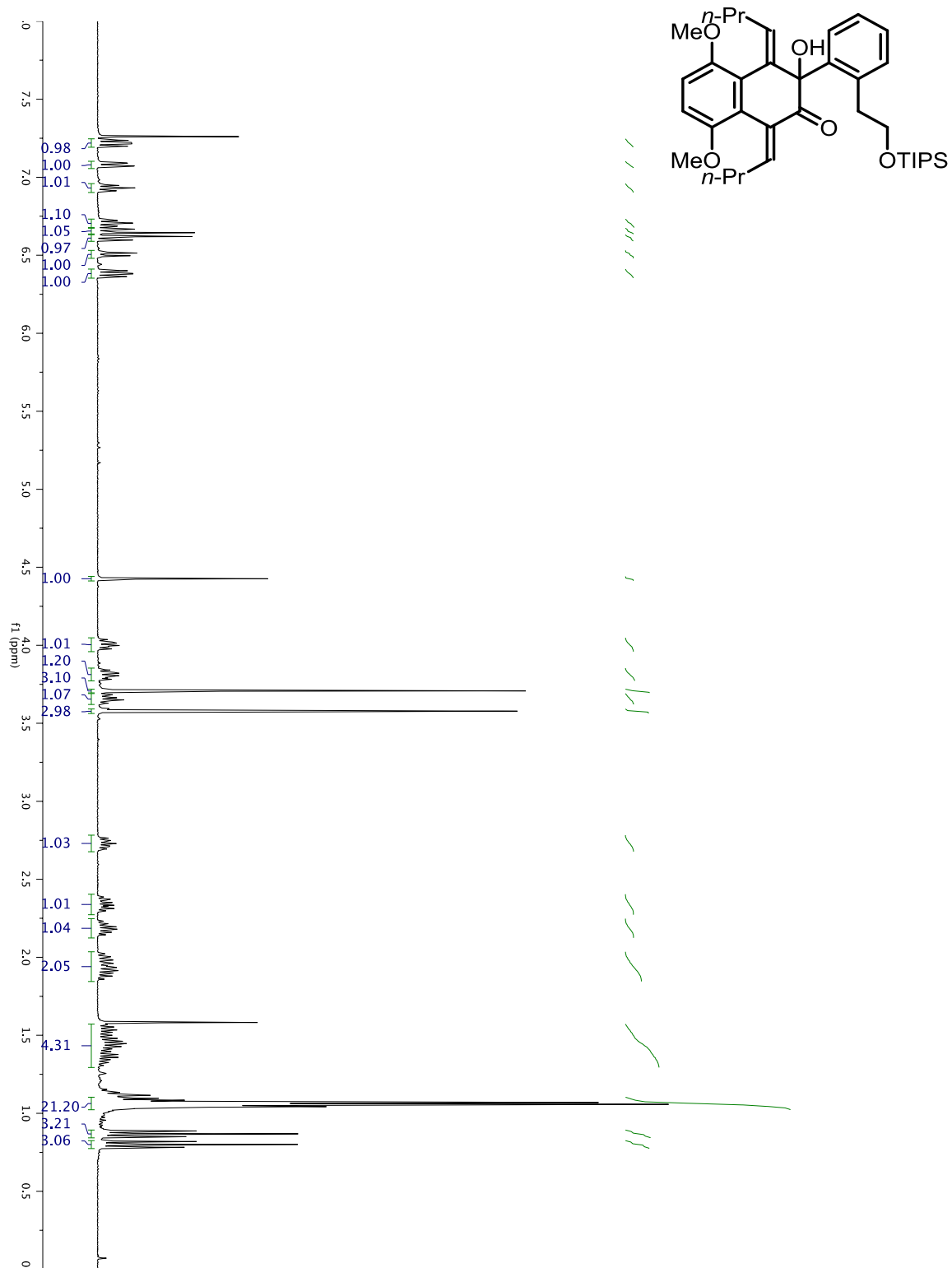
An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2i** (101.0 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1b** (121.7 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 80 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→40% CH_2Cl_2 /hexane). The title compound **4i** was obtained as a colorless oil (107.9 mg) in 59% yield.

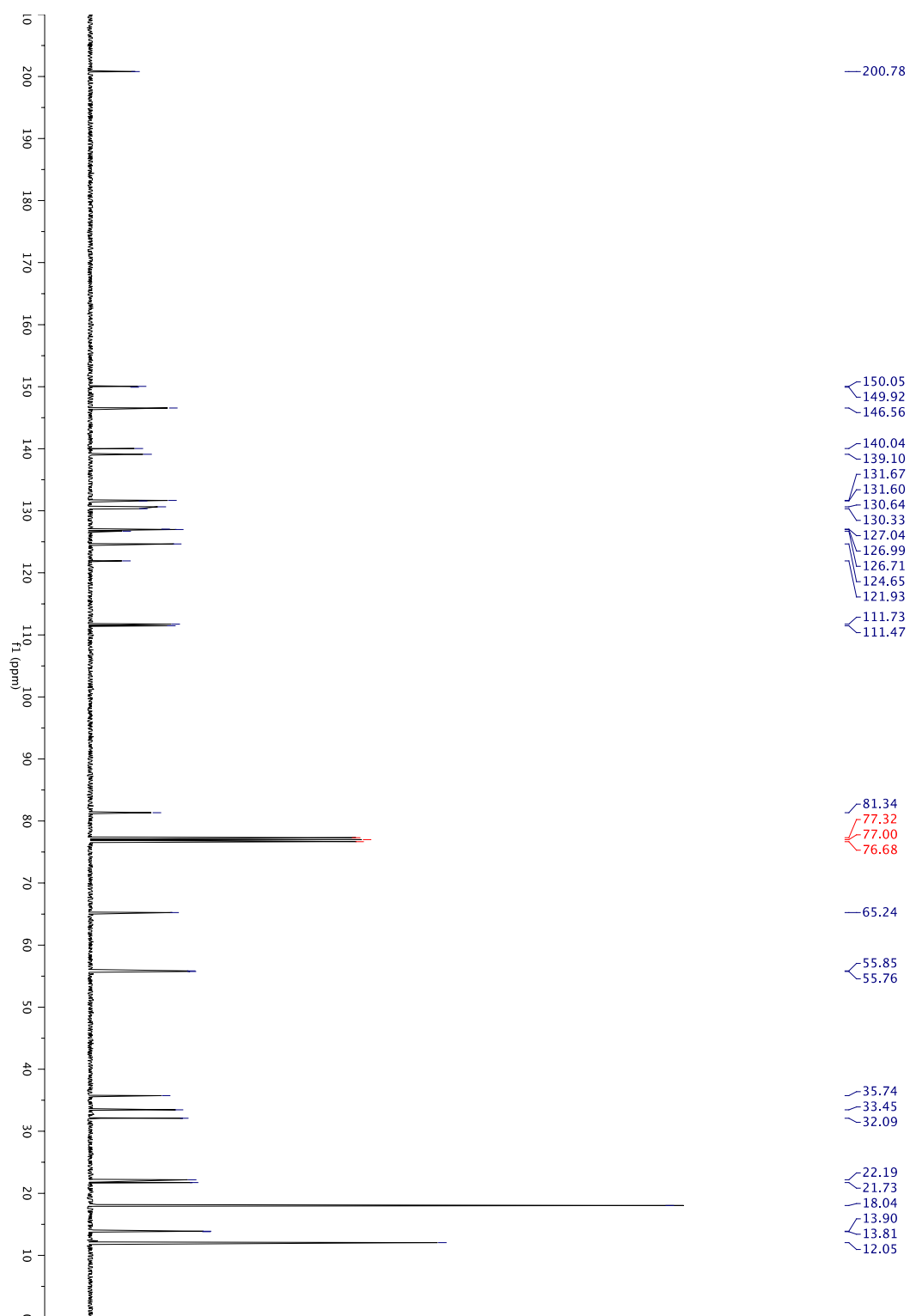
¹H NMR (400 MHz, CDCl_3) δ 7.22 (dd, $J = 9.5, 5.6$ Hz, 1H), 7.08 (dd, $J = 7.6, 1.4$ Hz, 1H), 6.93 (td, $J = 7.5, 1.3$ Hz, 1H), 6.70 (td, $J = 7.6, 1.5$ Hz, 1H), 6.66 (d, $J = 9.0$ Hz, 1H), 6.61 (d, $J = 9.1$ Hz, 1H), 6.51 (dd, $J = 7.8, 1.3$ Hz, 1H), 6.38 (dd, $J = 8.4, 6.7$ Hz, 1H), 4.43 (s, 1H), 4.05-3.96 (m, 1H), 3.85-3.77 (m, 1H), 3.71 (s, 3H), 3.69-3.62 (m, 1H), 3.58 (s, 3H), 2.78-2.68 (m, 1H), 2.40-2.28 (m, 1H), 2.24-2.13 (m, 1H), 2.04-1.84 (m, 2H), 1.57-1.29 (m, 4H), 1.12-1.02 (m, 21H), 0.87 (t, $J = 7.4$ Hz, 3H), 0.80 (t, $J = 7.4$ Hz, 3H).

¹³C NMR (100 MHz, CDCl_3) δ 200.8, 150.1, 149.9, 146.6, 140.0, 139.1, 131.7, 131.6, 130.6, 130.3, 127.0, 127.0, 126.7, 124.7, 121.9, 111.7, 111.5, 81.3, 65.2, 55.9, 55.8, 35.7, 33.5, 32.1, 22.2, 21.7, 18.0, 13.9, 13.8, 12.1.

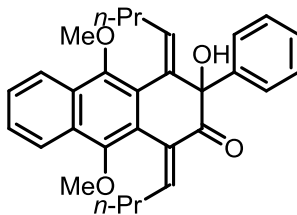
LRMS (ESI) Calcd. for $\text{C}_{37}\text{H}_{54}\text{O}_5\text{SiNa}$ $[\text{M}+\text{Na}]^+$: 629.4, Found: 629.3.

FTIR (neat): 2957, 2865, 1695, 1486, 1256, 1092, 1068, 1013, 735, 680 cm^{-1} .





(1E,4E)-1,4-Dibutylidene-3-hydroxy-9,10-dimethoxy-3-phenyl-3,4-dihydroanthracen-2(1H)-one (5a)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2a** (40.8 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 70 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% EtOAc/hexane). The title compound **5a** was obtained as a yellow solid (102.9 mg) in 75% yield.

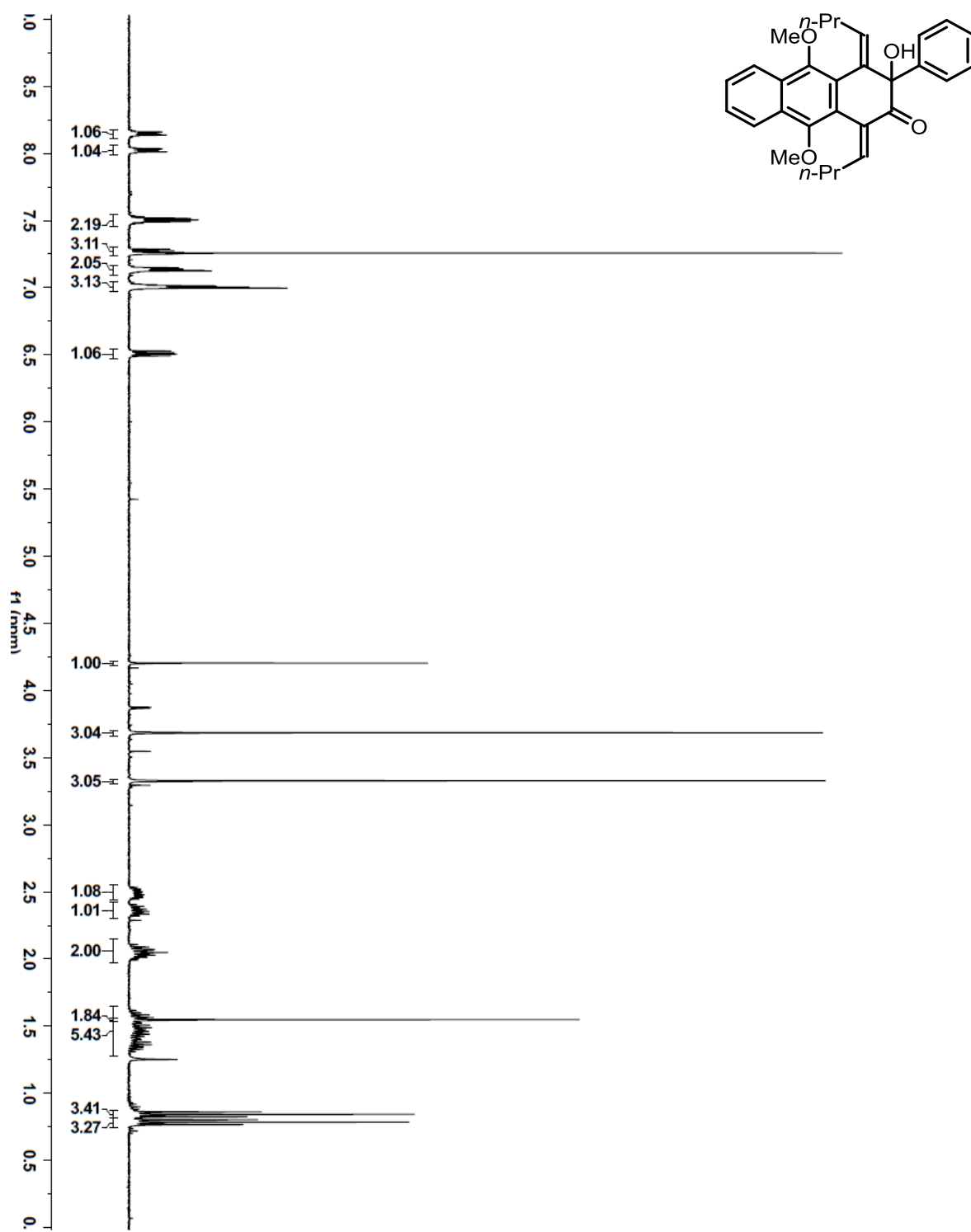
¹H NMR (400 MHz, CDCl_3) δ 8.18-8.11 (m, 1H), 8.05-7.99 (m, 1H), 7.54-7.46 (m, 2H), 7.27 (dd, J = 9.2, 4.2 Hz, 1H), 7.16-7.10 (m, 2H), 7.03-6.98 (m, 3H), 6.51 (dd, J = 9.4, 5.4 Hz, 1H), 4.20 (s, 1H), 3.69 (s, 3H), 3.33 (s, 3H), 2.56-2.43 (m, 1H), 2.41-2.30 (m, 1H), 1.63-1.31 (m, 4H), 0.84 (t, J = 7.4 Hz, 3H), 0.78 (t, J = 7.4 Hz, 3H).

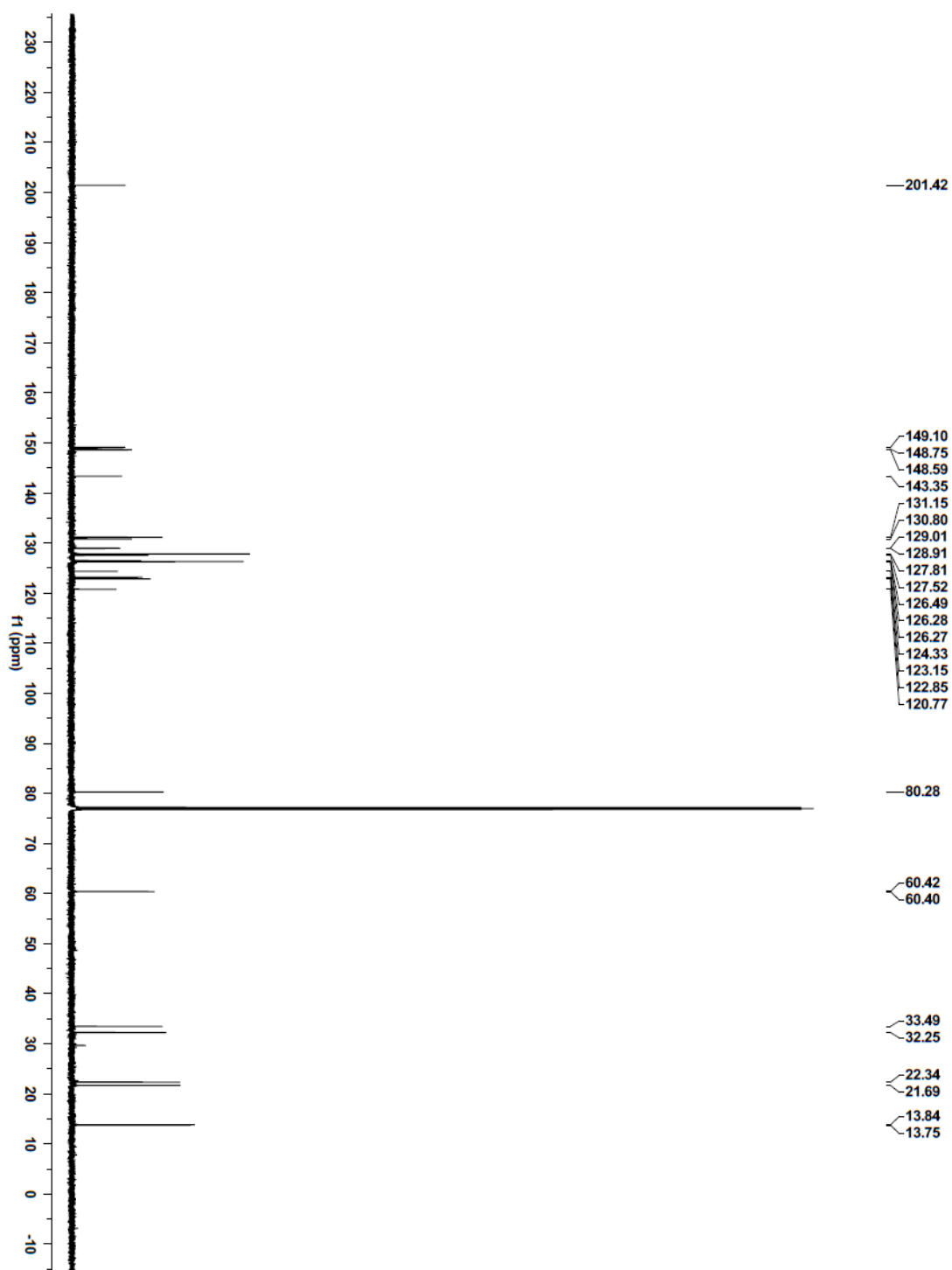
¹³C NMR (150 MHz, CDCl_3) δ 201.4, 149.1, 148.8, 148.6, 143.4, 131.2, 130.8, 129.0, 128.9, 127.8, 127.5, 126.5, 126.3, 126.3, 124.3, 123.2, 122.9, 120.8, 80.3, 60.4, 60.4, 33.5, 32.3, 22.3, 21.7, 13.8, 13.8.

LRMS (ESI) Calcd. for $\text{C}_{30}\text{H}_{32}\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 479.2, Found: 479.2.

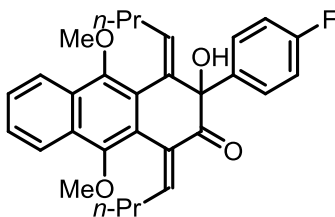
FTIR (neat): 3517, 2959, 2929, 1699, 1608, 1588, 1447, 1349 cm^{-1} .

MP: 100-106 °C.





(1E,4E)-1,4-Dibutylidene-3-(4-fluorophenyl)-3-hydroxy-9,10-dimethoxy-3,4-dihydroanthracen-2(1H)-one (5b)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2b** (46.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 70 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% EtOAc/hexane). The title compound **5b** was obtained as a yellow solid (90.1 mg) in 63% yield.

^1H NMR (400 MHz, CDCl_3) δ 8.18-8.12 (m, 1H), 8.06-8.00 (m, 1H), 7.56-7.49 (m, 2H), 7.30-7.25 (m, 1H), 7.15-7.08 (m, 2H), 6.74-6.66 (m, 2H), 6.50 (dd, $J = 9.4, 5.4$ Hz, 1H), 4.21 (s, 1H), 3.67 (s, 3H), 3.36 (s, 3H), 2.54-2.43 (m, 1H), 2.36 (ddt, $J = 13.5, 7.9, 5.6$ Hz, 1H), 2.12-1.96 (m, 2H), 1.62-1.30 (m, 4H), 0.84 (t, $J = 7.4$ Hz, 3H), 0.78 (t, $J = 7.4$ Hz, 3H).

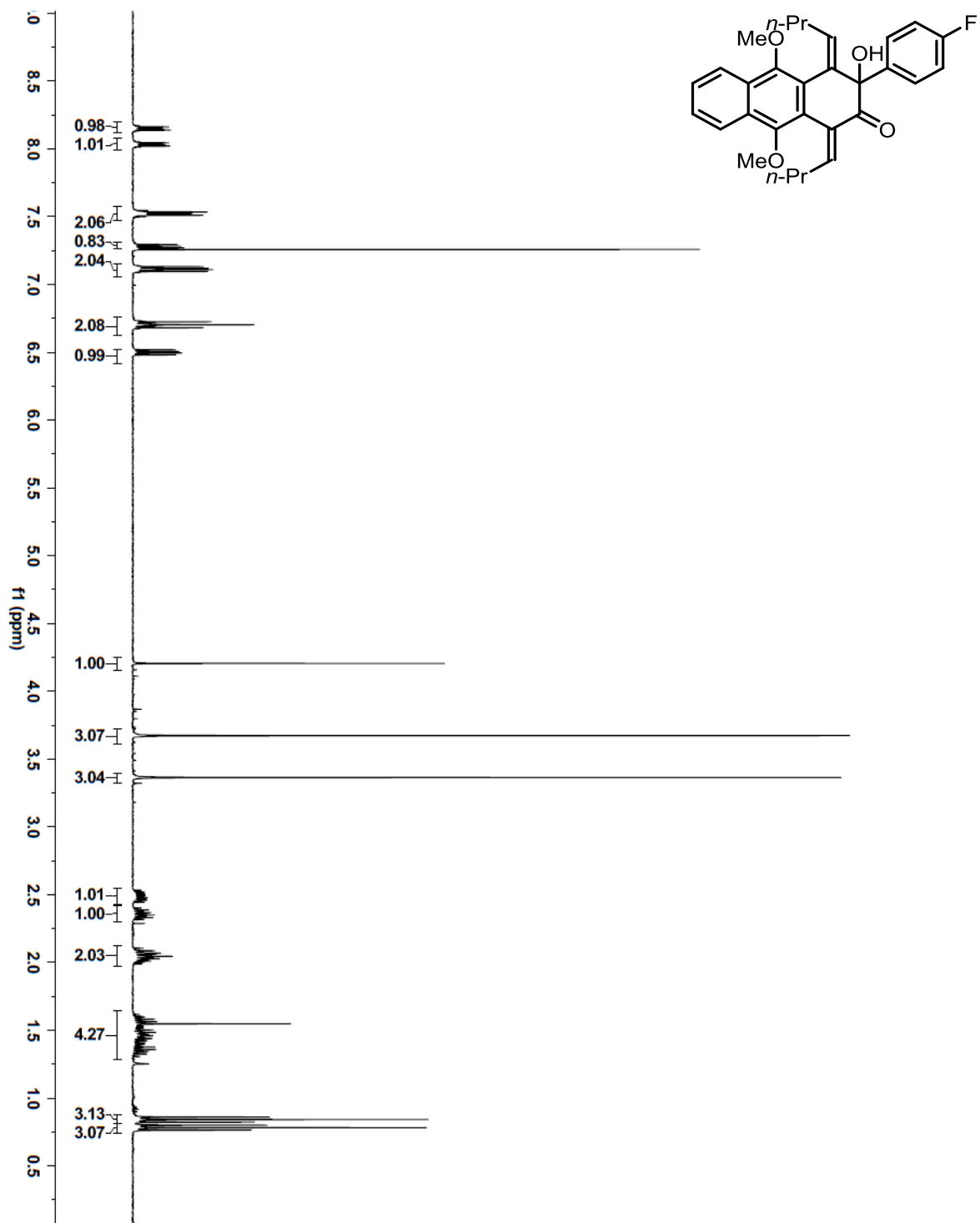
^{13}C NMR (100 MHz, CDCl_3) δ 201.0, 161.8 (d, $J = 247.1$ Hz, 1C), 149.2, 149.1, 148.8, 139.3 (d, $J = 3.3$ Hz, 1C), 131.1, 130.9, 130.9, 129.0, 128.9 (d, $J = 5.5$ Hz, 2C), 126.7, 126.4, 124.1, 123.1, 122.9, 120.5, 114.7 (d, $J = 24.4$ Hz, 2C), 79.7, 60.5, 33.6, 32.3, 22.3, 21.7, 13.9, 13.8.

^{19}F NMR (376 MHz, CDCl_3) δ -114.2.

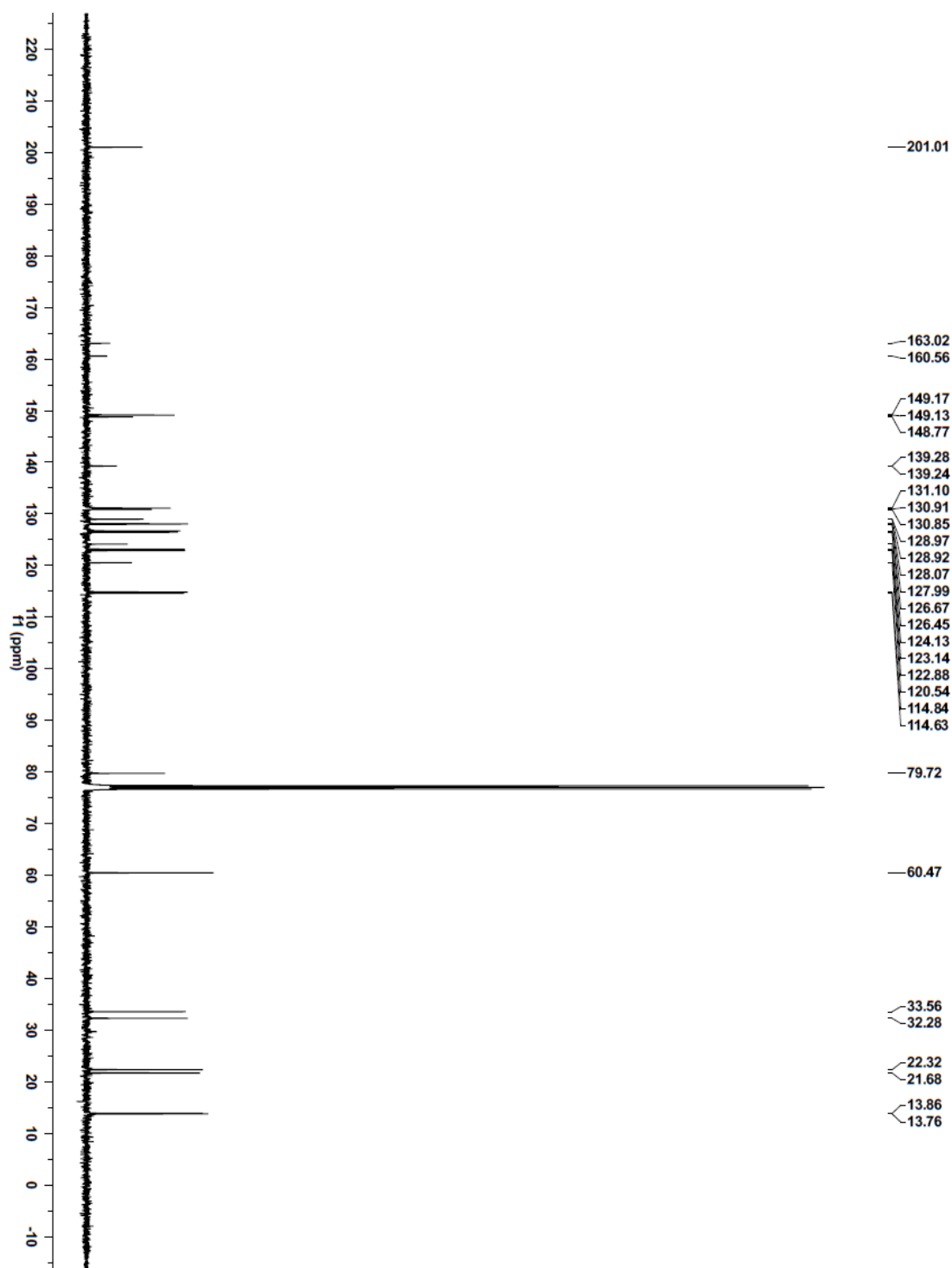
LRMS (ESI) Calcd. for $\text{C}_{30}\text{H}_{31}\text{FO}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 497, Found: 497.

FTIR (neat): 3470, 2959, 2931, 1695, 1604, 1587, 1507, 1456, 1380, 1351 cm^{-1} .

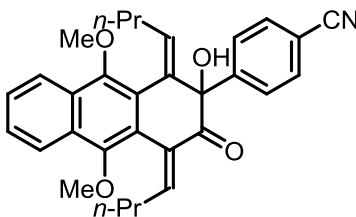
MP: 120-126 °C.



4-



(1*E*,4*E*)-1,4-Dibutylidene-2-hydroxy-9,10-dimethoxy-3-oxo-1,2,3,4-tetrahydroanthracen-2-yl)benzonitrile (5c**)**



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2c** (48.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (7% EtOAc/hexane). The title compound **5c** was obtained as a yellow solid (103.1 mg) in 71% yield.

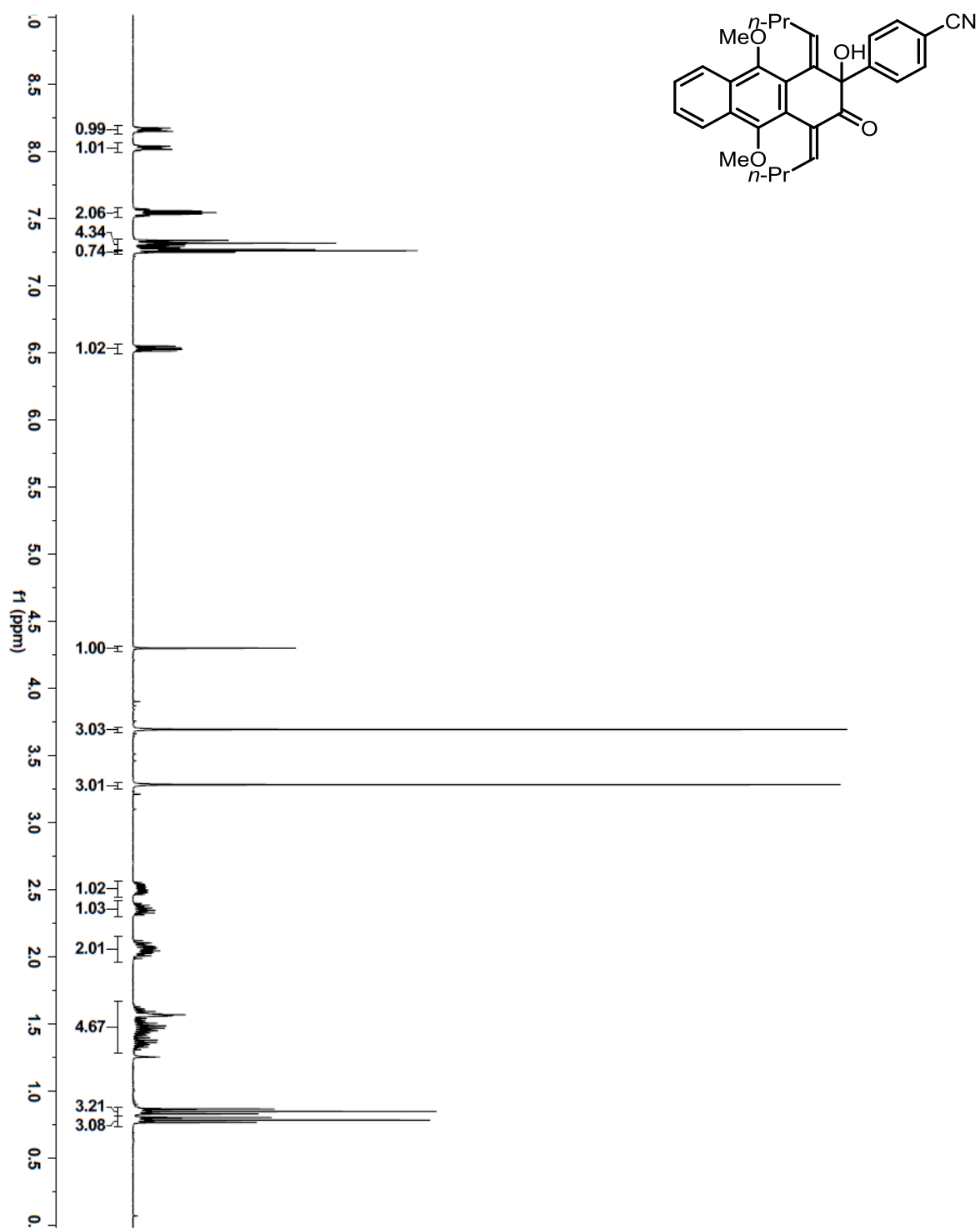
¹H NMR (400 MHz, CDCl₃) δ 8.18-8.14 (m, 1H), 8.06-7.99 (m, 1H), 7.58-7.50 (m, 2H), 7.35-7.24 (m, 5H), 6.53 (dd, *J* = 9.4, 5.4 Hz, 1H), 4.30 (s, 1H), 3.69 (s, 3H), 3.28 (s, 3H), 2.57-2.45 (m, 1H), 2.36 (ddt, *J* = 13.5, 8.0, 5.6 Hz, 1H), 2.15-1.97 (m, 2H), 1.64-1.28 (m, 4H), 0.85 (t, *J* = 7.4 Hz, 3H), 0.79 (t, *J* = 7.4 Hz, 3H).

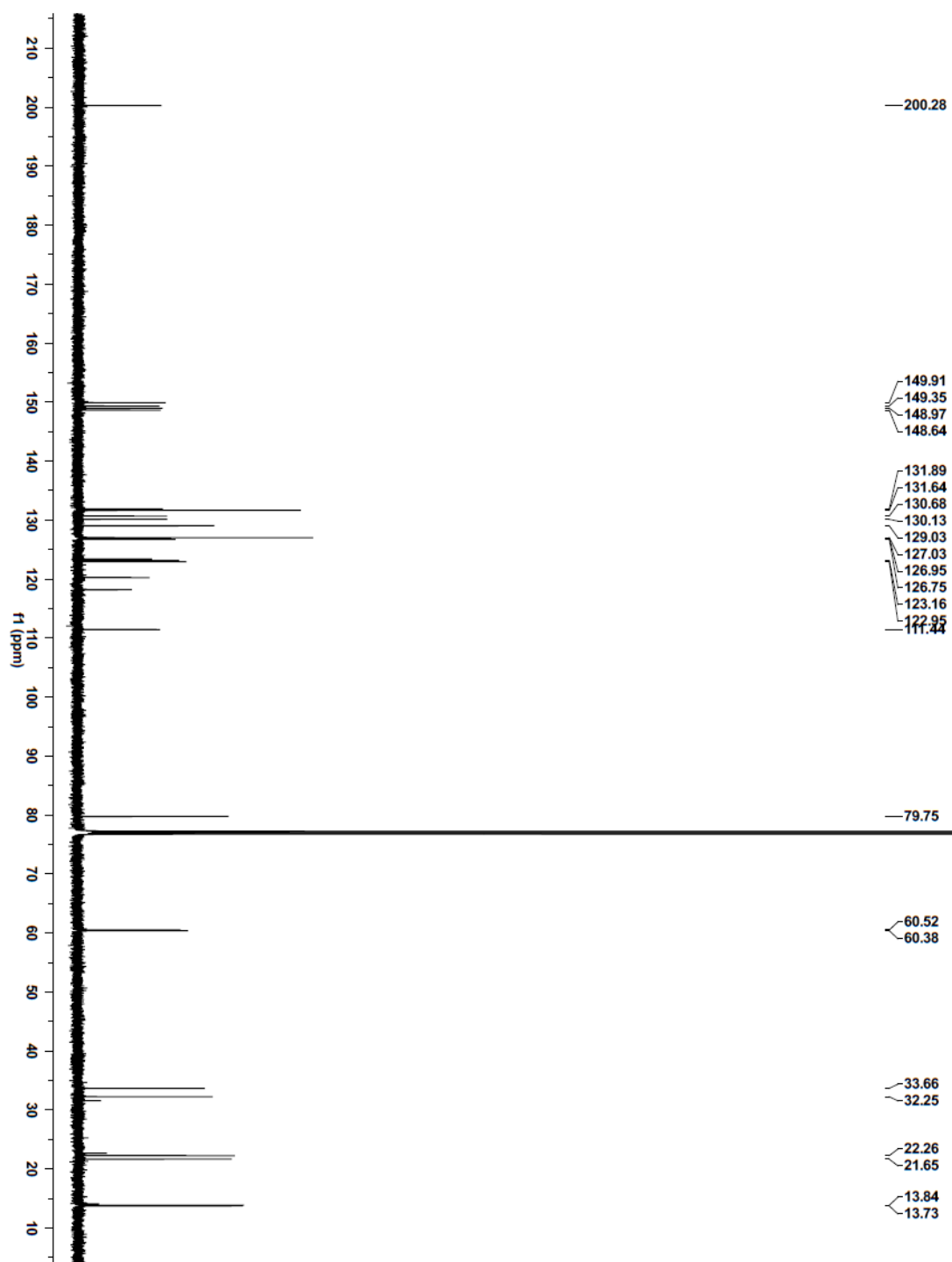
¹³C NMR (150 MHz, CDCl₃) δ 200.3, 149.9, 149.4, 149.0, 148.6, 131.9, 131.6, 130.7, 130.1, 129.0, 127.03, 126.95, 126.8, 123.4, 123.2, 123.0, 120.2, 118.2, 111.4, 79.8, 60.5, 60.4, 33.7, 32.3, 22.3, 21.7, 13.8, 13.7.

LRMS (ESI) Calcd. for C₃₁H₃₁NO₄Na [M+Na]⁺: 504.2, Found: 504.2.

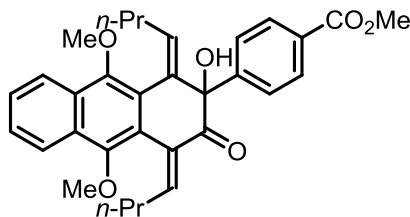
FTIR (neat): 3439, 2959, 2929, 2227, 1698, 1606, 1456, 1350 cm⁻¹.

MP: 162-164 °C.





Methyl 4-((1*E*,4*E*)-1,4-dibutylidene-2-hydroxy-9,10-dimethoxy-3-oxo-1,2,3,4-tetrahydroanthracen-2-yl)benzoate (5d**)**



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2d** (58.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (7% EtOAc/hexane). The title compound **5d** was obtained as a yellow solid (113.2 mg) in 73% yield. The material was recrystallized from hexanes:EtOAc (9:1) by slow evaporation providing crystals suitable for x-ray diffraction crystallography.

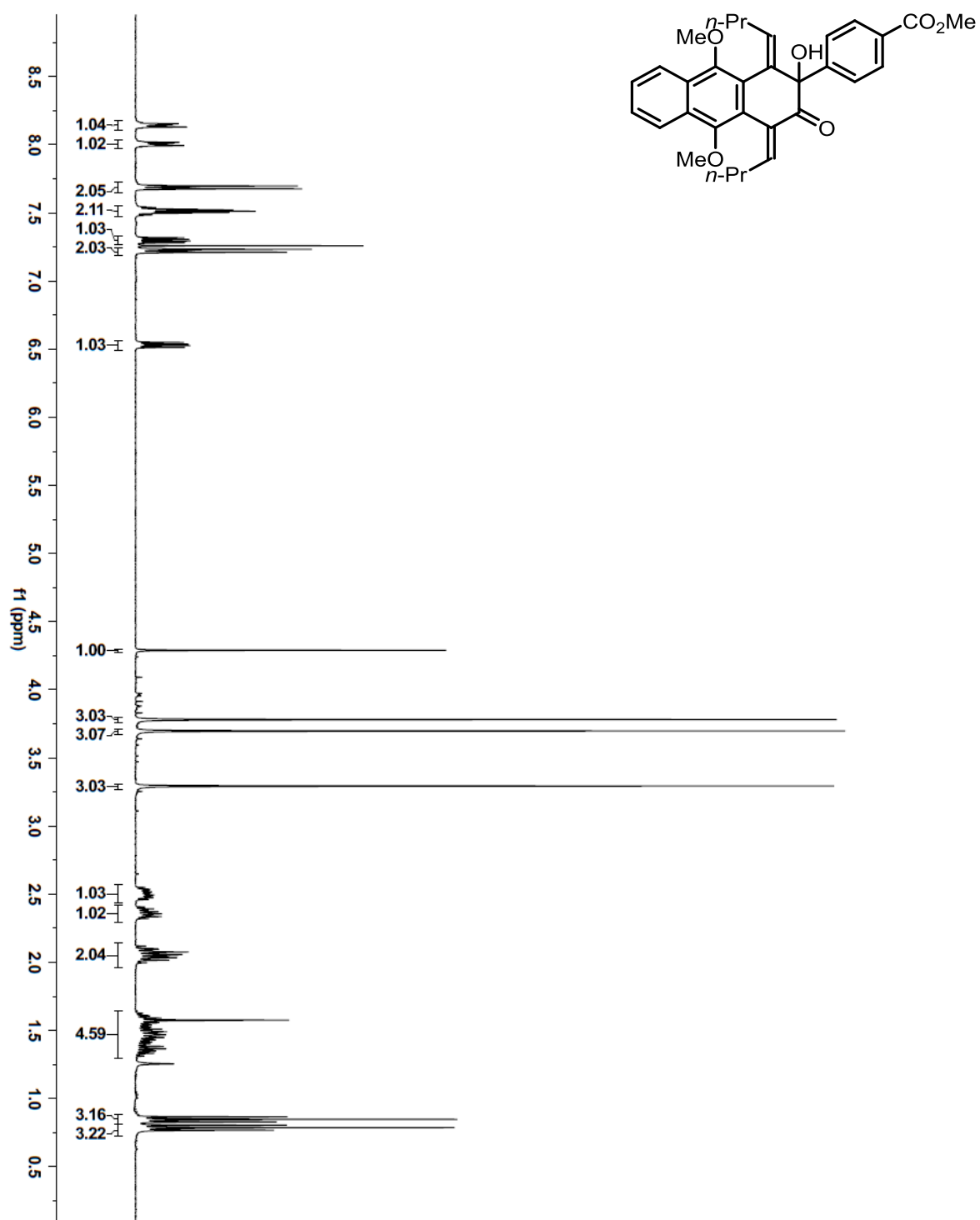
¹H NMR (400 MHz, CDCl₃) δ 8.16-8.11 (m, 1H), 8.03-7.97 (m, 1H), 7.72-7.65 (m, 2H), 7.55-7.47 (m, 2H), 7.30 (dd, *J* = 9.8, 4.9 Hz, 1H), 7.22 (d, *J* = 8.7 Hz, 2H), 6.53 (dd, *J* = 9.4, 5.4 Hz, 1H), 4.29 (s, 1H), 3.78 (s, 3H), 3.70 (s, 3H), 3.29 (s, 3H), 2.56-2.44 (m, 1H), 2.36 (ddt, *J* = 13.5, 7.9, 5.6 Hz, 1H), 2.13-1.98 (m, 2H), 1.65-1.30 (m, 4H), 0.85 (t, *J* = 7.4 Hz, 3H), 0.79 (t, *J* = 7.4 Hz, 3H).

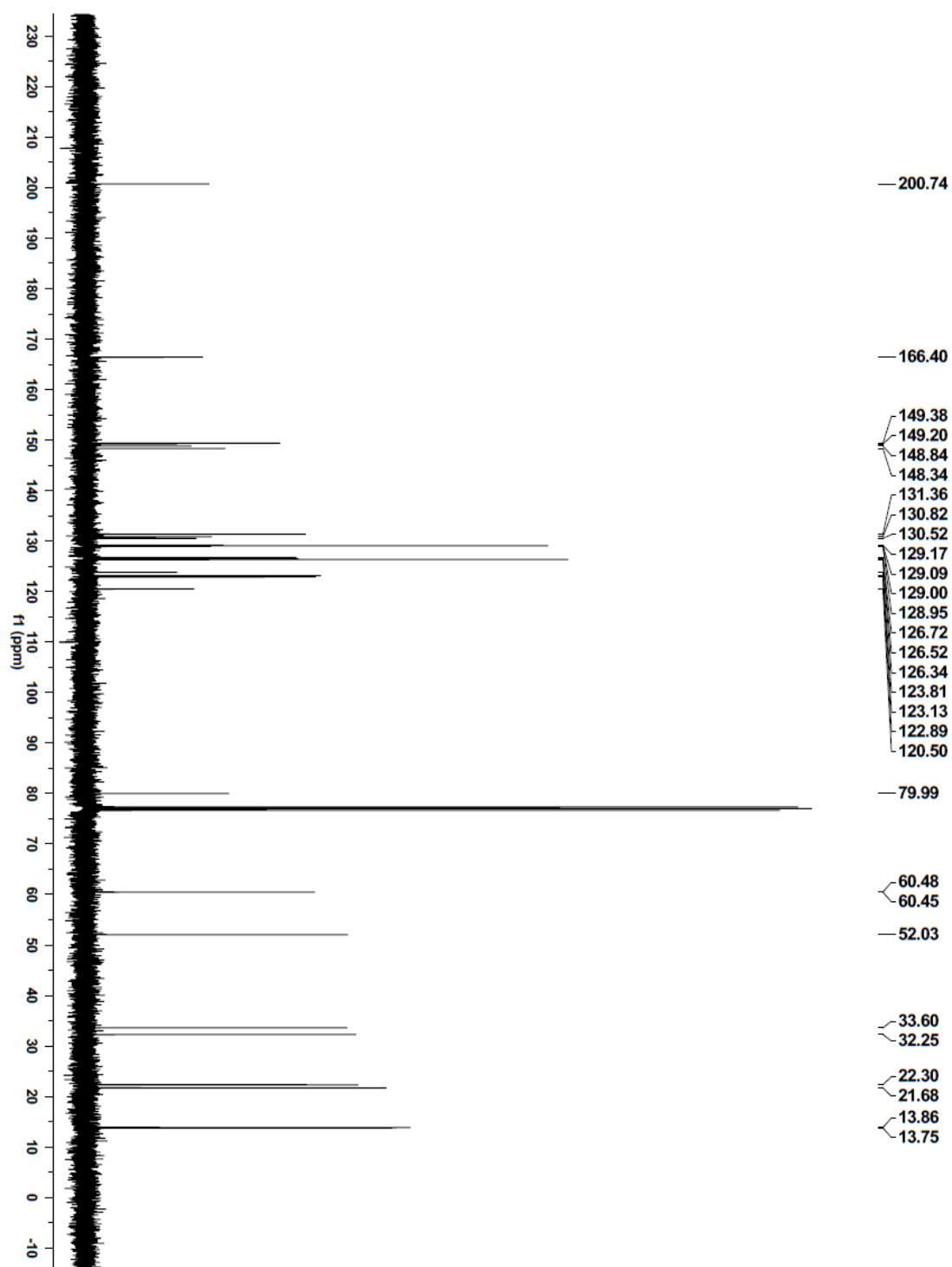
¹³C NMR (100 MHz, CDCl₃) δ 200.7, 166.4, 149.4, 149.2, 148.8, 148.3, 131.4, 130.8, 130.5, 129.2, 129.1, 129.0, 128.95, 126.7, 126.5, 126.3, 123.8, 123.1, 122.9, 120.5, 81.0, 60.5, 60.5, 52.0, 33.6, 32.3, 22.3, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for C₃₂H₃₄O₆Na [M+Na]⁺: 537.2, Found: 537.2.

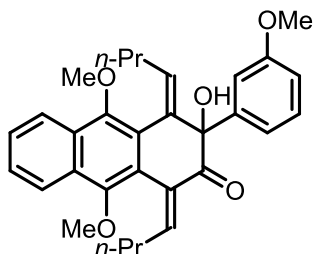
FTIR (neat): 3442, 2955, 2928, 1721, 1698, 1608, 1436, 1352 cm⁻¹.

MP: 195-197 °C.





(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-9,10-dimethoxy-3-(3-methoxyphenyl)-3,4-dihydroanthracen-2(1*H*)-one (5e)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2e** (49.9 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% EtOAc/hexane). The title compound **5e** was obtained as a pale crystalline solid (112.6 mg) in 77% yield.

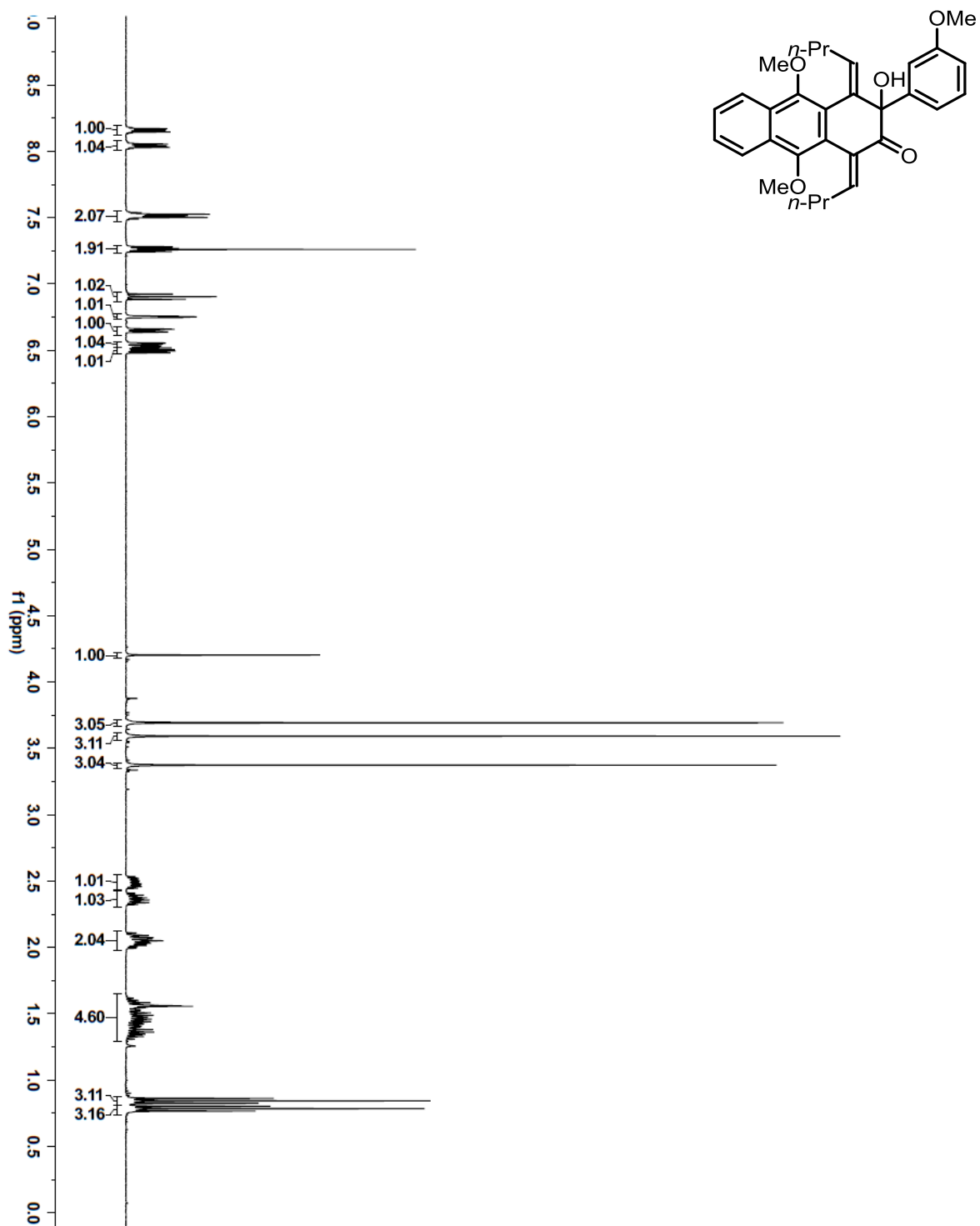
¹H NMR (400 MHz, CDCl₃) δ 8.19-8.13 (m, 1H), 8.07-8.01 (m, 1H), 7.55-7.47 (m, 2H), 7.26 (dd, *J* = 9.9, 4.8 Hz, 1H), 6.90 (t, *J* = 8.0 Hz, 1H), 6.77-6.74 (m, 1H), 6.65 (d, *J* = 7.8 Hz, 1H), 6.54 (dd, *J* = 8.2, 2.1 Hz, 1H), 6.50 (dd, *J* = 9.5, 5.4 Hz, 1H), 4.20 (s, 1H), 3.69 (s, 3H), 3.59 (s, 3H), 3.37 (s, 3H), 2.55-2.43 (m, 1H), 2.37 (ddt, *J* = 13.5, 8.0, 5.6 Hz, 1H), 2.12-1.97 (m, 2H), 1.65-1.29 (m, 4H), 0.84 (t, *J* = 7.4 Hz, 3H), 0.78 (t, *J* = 7.4 Hz, 3H).

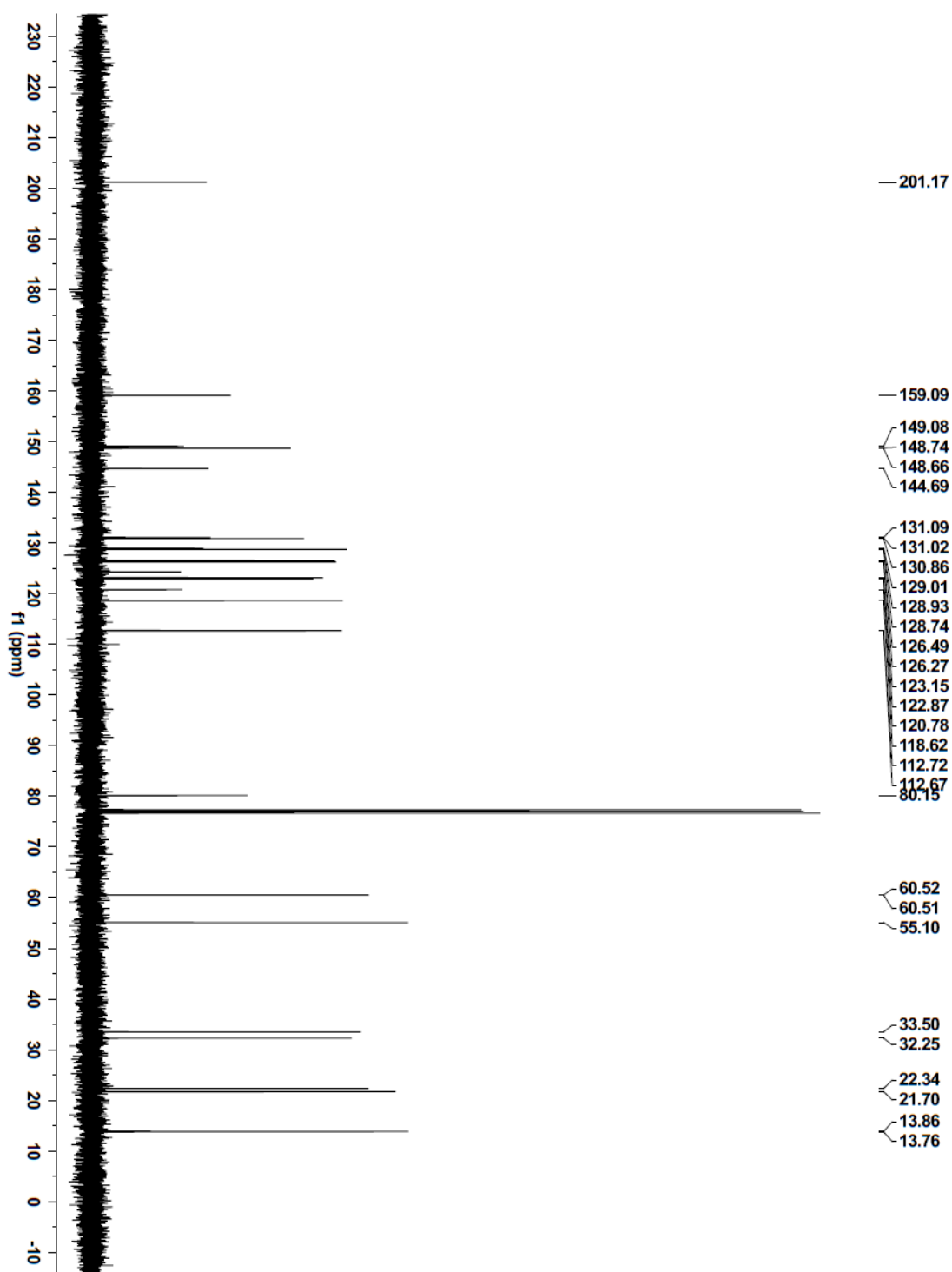
¹³C NMR (100 MHz, CDCl₃) δ 201.2, 159.1, 149.1, 148.7, 148.7, 144.7, 131.1, 131.0, 130.9, 129.0, 128.9, 128.7, 126.5, 126.3, 124.3, 123.2, 122.9, 120.8, 118.6, 112.7, 112.7, 80.2, 60.5, 60.5, 55.1, 33.5, 32.3, 22.3, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for C₃₁H₃₄O₅Na [M+Na]⁺: 509, Found: 509.

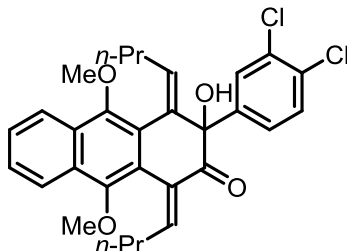
FTIR (neat): 3479, 2959, 2931, 1693, 1608, 1585, 1487, 1455, 1349 cm⁻¹.

MP: 134-137 °C.





(1*E*,4*E*)-1,4-Dibutylidene-3-(3,4-dichlorophenyl)-3-hydroxy-9,10-dimethoxy-3,4-dihydroanthracen-2(1*H*)-one (5f)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2f** (61.5 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 60 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (7% EtOAc/hexane). The title compound **5f** was obtained as a yellow solid (135.0 mg) in 86% yield.

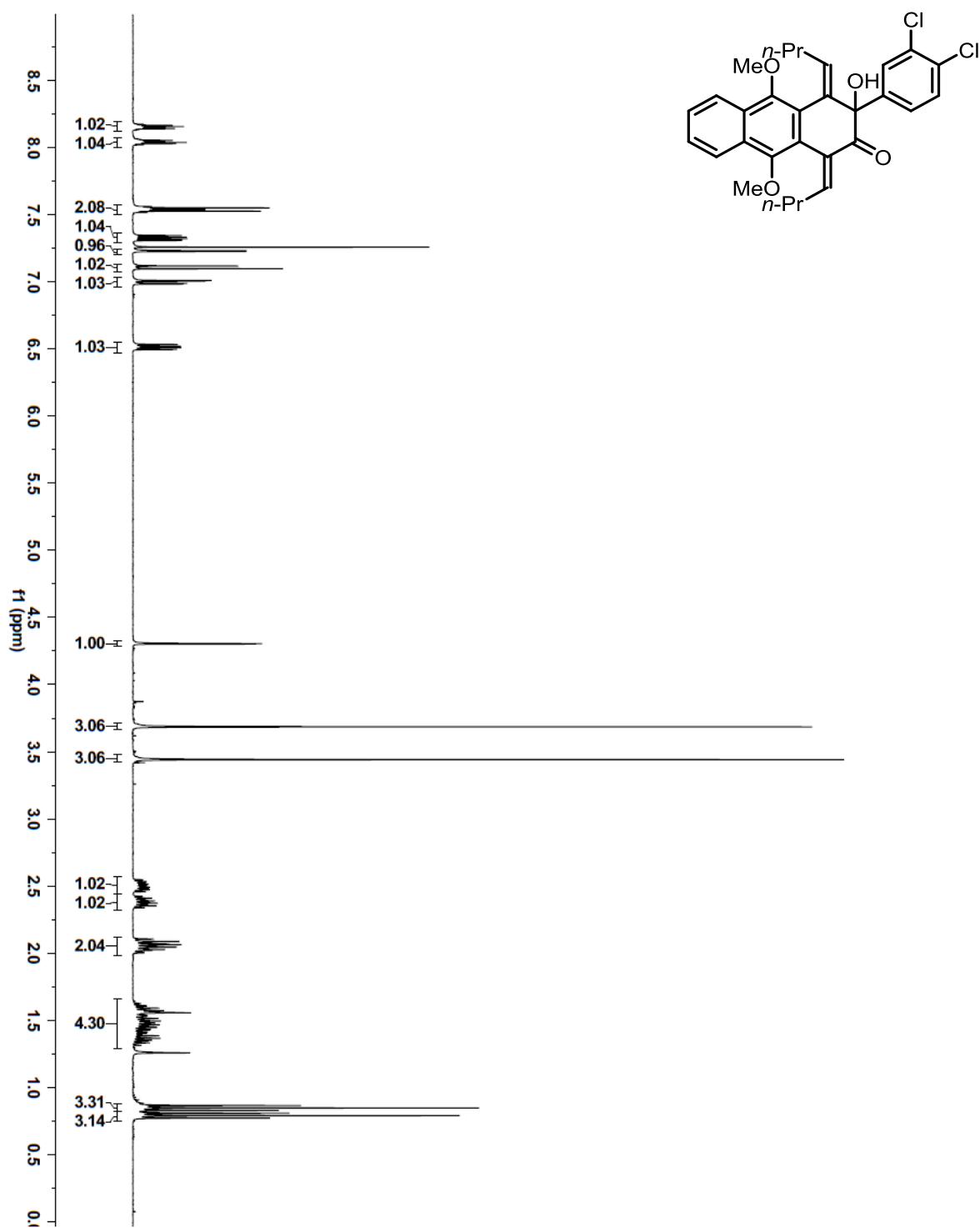
¹H NMR (400 MHz, CDCl_3) δ 8.19-8.12 (m, 1H), 8.07-8.01 (m, 1H), 7.57-7.50 (m, 2H), 7.33 (dd, J = 9.8, 4.8 Hz, 1H), 7.23 (d, J = 2.1 Hz, 1H), 7.11 (d, J = 8.4 Hz, 1H), 7.00 (dd, J = 8.4, 2.1 Hz, 1H), 6.52 (dd, J = 9.4, 5.4 Hz, 1H), 4.33-4.28 (m, 1H), 3.69 (s, 3H), 3.44 (s, 3H), 2.57-2.44 (m, 1H), 2.38 (ddt, J = 13.6, 8.1, 5.6 Hz, 1H), 2.05 (ddt, J = 9.8, 7.4, 4.8 Hz, 2H), 1.66-1.29 (m, 4H), 0.84 (t, J = 7.4 Hz, 3H), 0.79 (t, J = 7.4 Hz, 3H).

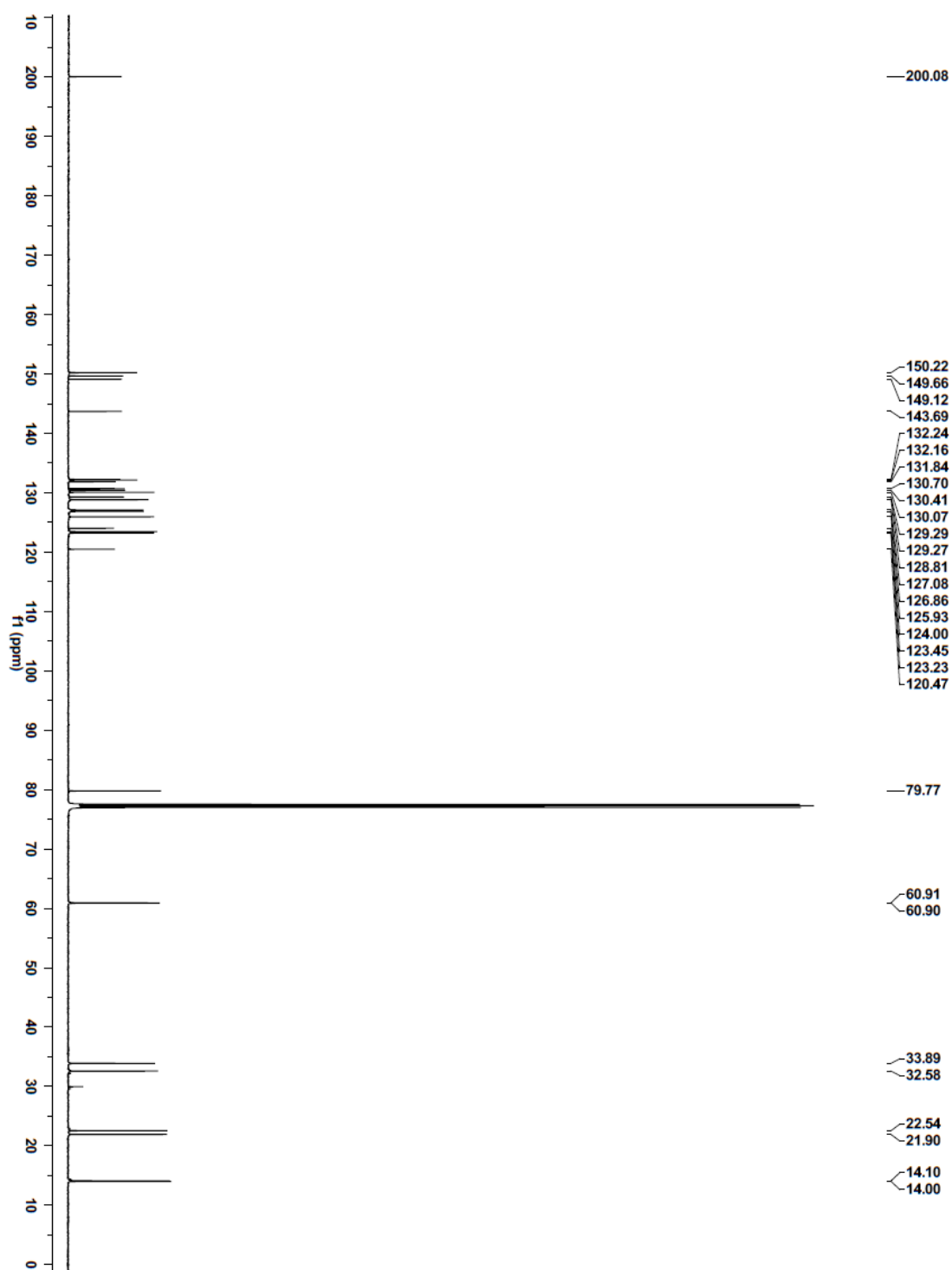
¹³C NMR (126 MHz, CDCl_3) δ 200.1, 150.2, 149.7, 149.1, 143.7, 132.2, 132.2, 131.8, 130.7, 130.4, 130.1, 129.3, 129.3, 128.8, 127.1, 126.9, 125.9, 124.0, 123.5, 123.2, 120.5, 79.8, 60.9, 60.9, 33.9, 32.6, 22.5, 21.9, 14.1, 14.0.

LRMS (ESI) Calcd. for $\text{C}_{30}\text{H}_{30}\text{Cl}_2\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 547.2, Found: 547.1.

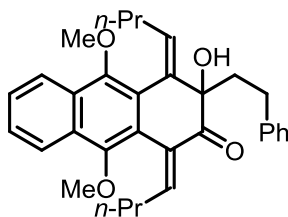
FTIR (neat): 3449, 2953, 2928, 1698, 1605, 1457, 1352 cm^{-1} .

MP: 123-126 °C.





(1*E*,4*E*)-1,4-Dibutylidene-3-hydroxy-9,10-dimethoxy-3-phenethyl-3,4-dihydroanthracen-2(1*H*)-one (5g)



Detailed Procedures

An oven-dried pressure tube equipped with a magnetic stir bar was charged with $\text{Ru}_3(\text{CO})_{12}$ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2g** (49.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 80 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH_2Cl_2 /hexane→50% CH_2Cl_2 /hexane). The title compound **5g** was obtained as a yellow solid (101.9 mg) in 70% yield.

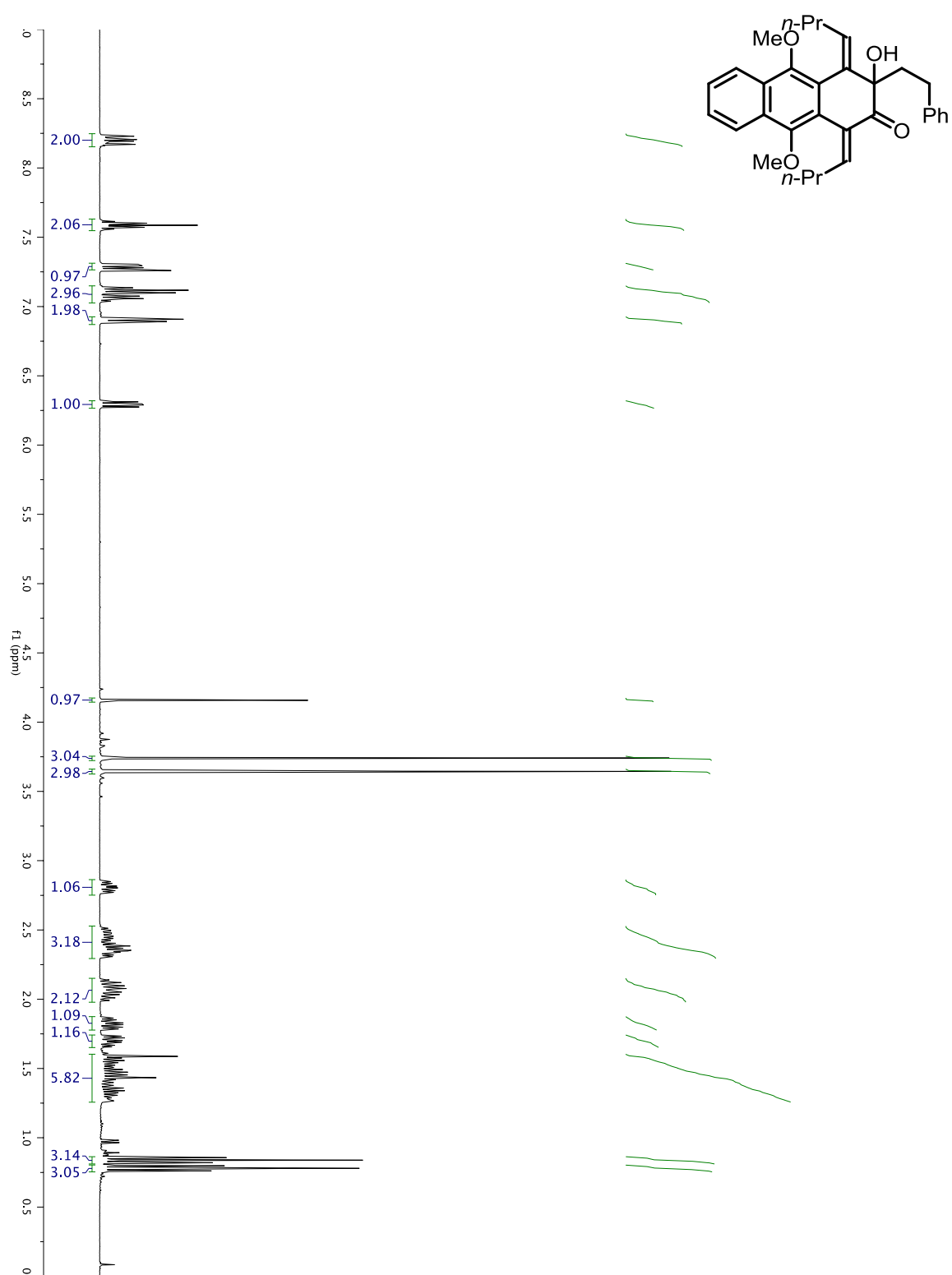
¹H NMR (400 MHz, CDCl_3) δ 8.25-8.15 (m, 2H), 7.63-7.54 (m, 2H), 7.29 (dd, J = 9.9, 4.7 Hz, 1H), 7.16-7.02 (m, 3H), 6.93-6.87 (m, 2H), 6.29 (dd, J = 9.4, 5.4 Hz, 1H), 4.16 (s, 1H), 3.74 (s, 3H), 3.64 (s, 3H), 2.86-2.76 (m, 1H), 2.53-2.29 (m, 3H), 2.15-1.98 (m, 2H), 1.88-1.77 (m, 1H), 1.75-1.64 (m, 1H), 1.62-1.23 (m, 4H), 0.84 (t, J = 7.4 Hz, 3H), 0.78 (t, J = 7.4 Hz, 3H).

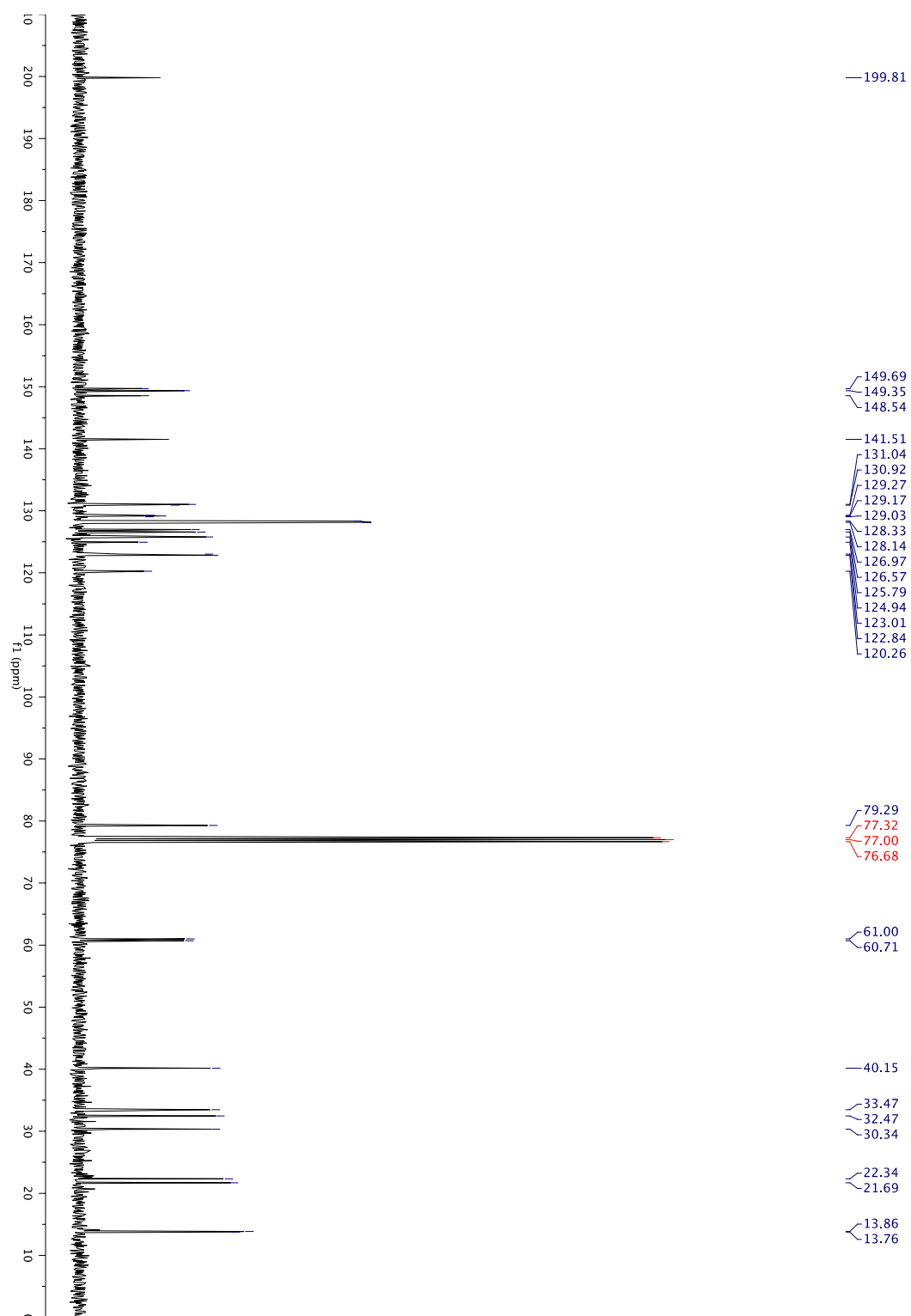
¹³C NMR (100 MHz, CDCl_3) δ 199.8, 149.7, 149.4, 148.5, 141.5, 131.0, 130.9, 129.27, 129.2, 129.0, 128.3, 128.1, 127.0, 126.6, 125.8, 124.9, 123.0, 122.8, 120.3, 79.3, 61.0, 60.7, 40.2, 33.5, 32.5, 30.3, 22.3, 21.7, 13.9, 13.8.

LRMS (ESI) Calcd. for $\text{C}_{32}\text{H}_{36}\text{O}_4\text{Na}$ $[\text{M}+\text{Na}]^+$: 507.3, Found: 507.3.

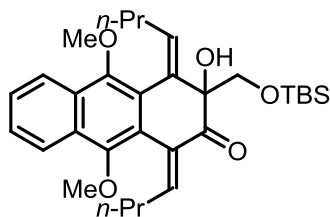
FTIR (neat): 3491, 2956, 2928, 1686, 1602, 1454, 1349, 1033, 774, 699 cm^{-1} .

MP: 96-98 °C.





(1*E*,4*E*)-3-(((Tert-butyldimethylsilyl)oxy)methyl)-1,4-dibutylidene-3-hydroxy-9,10-dimethoxy-3,4-dihydroanthracen-2(1*H*)-one (5h)



Detailed Procedures

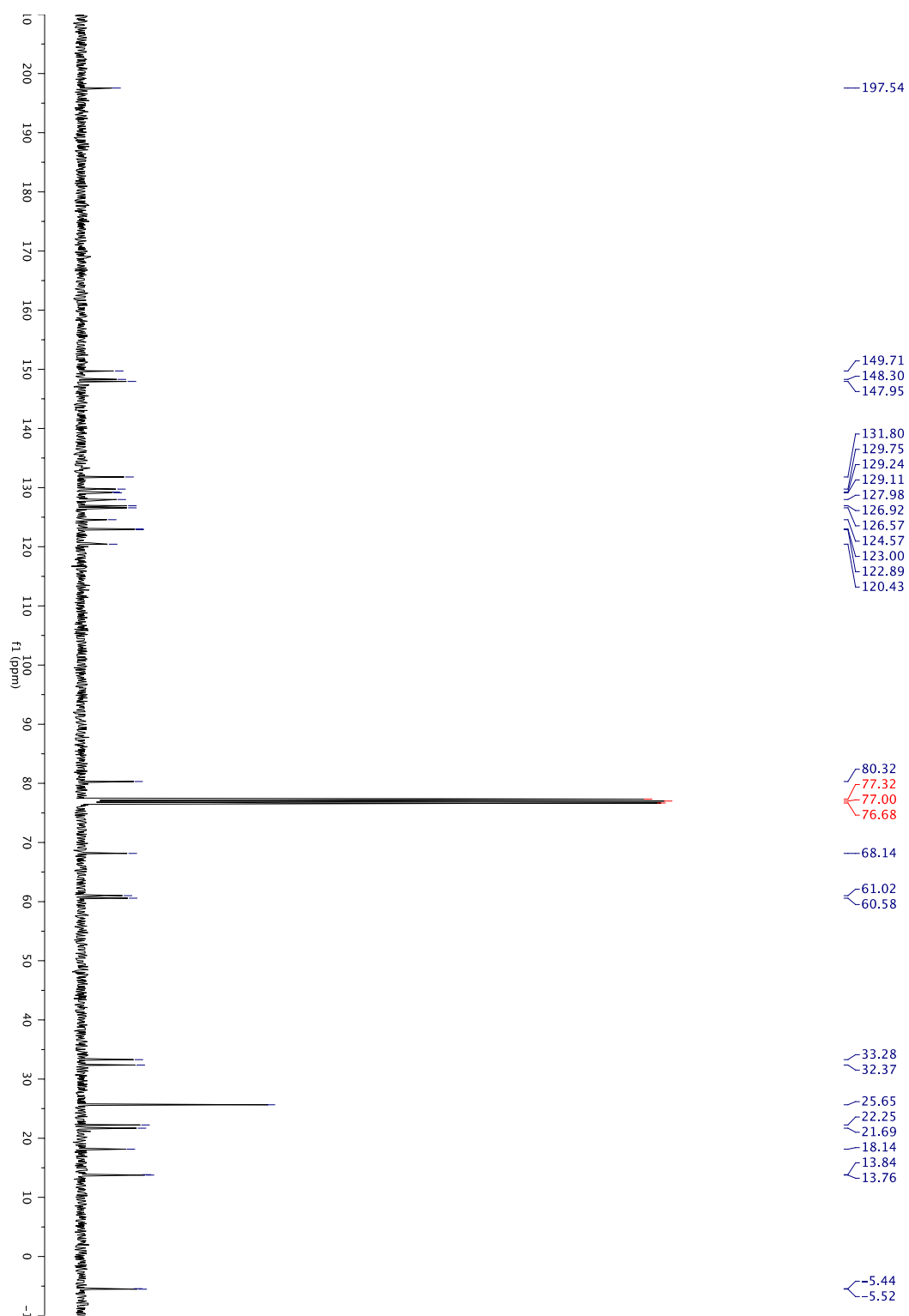
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2h** (61.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1c** (144.2 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 85 °C for 24 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (5% CH₂Cl₂/hexane→40% CH₂Cl₂/hexane). The title compound **5h** was obtained as a yellow amorphous solid (63.5 mg) in 40% yield.

¹H NMR (400 MHz, CDCl₃) δ 8.27-8.18 (m, 2H), 7.65-7.56 (m, 2H), 7.15 (dd, *J* = 9.9, 4.6 Hz, 1H), 6.29-6.23 (m, 1H), 4.21 (s, 1H), 3.73 (s, 3H), 3.65 (s, 3H), 3.54-3.43 (m, 2H), 2.48-2.28 (m, 2H), 2.13-1.94 (m, 2H), 1.57-1.23 (m, 4H), 0.84-0.74 (m, 15H), -0.07 (s, 3H), -0.15 (s, 3H).

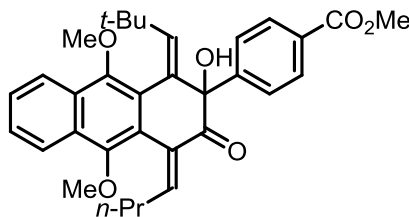
¹³C NMR (100 MHz, CDCl₃) δ 197.5, 149.7, 148.3, 148.0, 131.8, 129.8, 129.2, 129.1, 128.0, 126.9, 126.6, 124.6, 123.0, 122.9, 120.4, 80.3, 68.1, 61.0, 60.6, 33.3, 32.4, 25.7, 22.3, 21.7, 18.1, 13.8, 13.8, -5.4, -5.5.

LRMS (ESI) Calcd. for C₃₁H₄₄SiO₅Na [M+Na]⁺: 547.3, Found: 547.3.

FTIR (neat): 3468, 2956, 2928, 1699, 1458, 1350, 1256, 1120, 836, 778 cm⁻¹.



Methyl 4-((1*E*,4*E*)-4-butylidene-1-(2,2-dimethylpropylidene)-2-hydroxy-9,10-dimethoxy-3-oxo-1,2,3,4-tetrahydroanthracen-2-yl)benzoate (*t*-Bu-5d)



Detailed Procedures

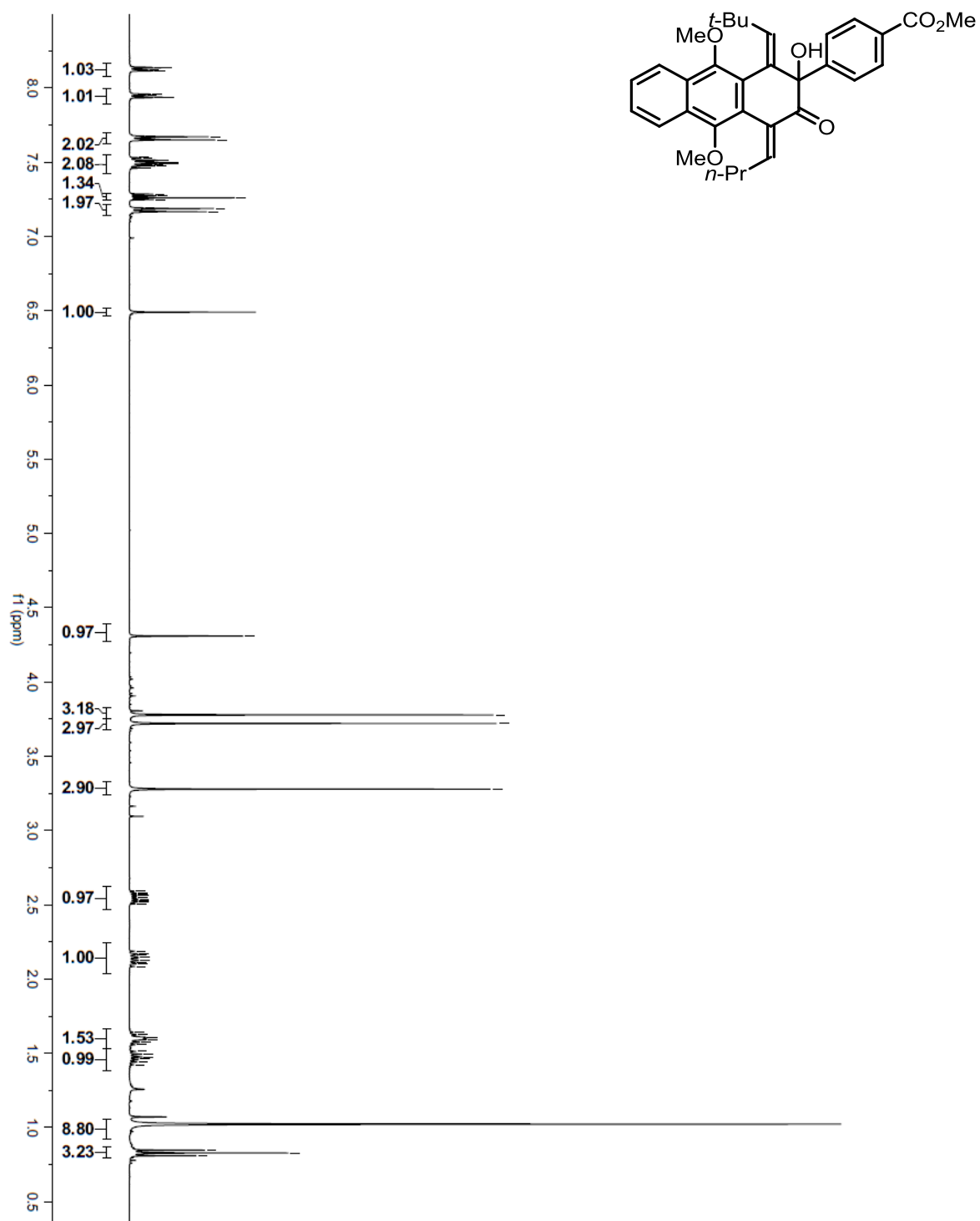
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (3.8 mg, 0.006 mmol, 3 mol%), RuPhos (16.8 mg, 0.036 mmol, 18 mol%), and α -hydroxyketone **2d** (38.8 mg, 0.20 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1d** (100.3 mg, 0.30 mmol, 150 mol%), *m*-xylene (0.10 mL), and deionized water (0.10 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 16 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (7% EtOAc/hexane). The title compound *t*-Bu-**5d** was obtained as a yellow solid (69.4 mg) in 66% yield. Recrystallization from hexanes provided colorless prismatic crystals suitable for x-ray diffraction crystallography.

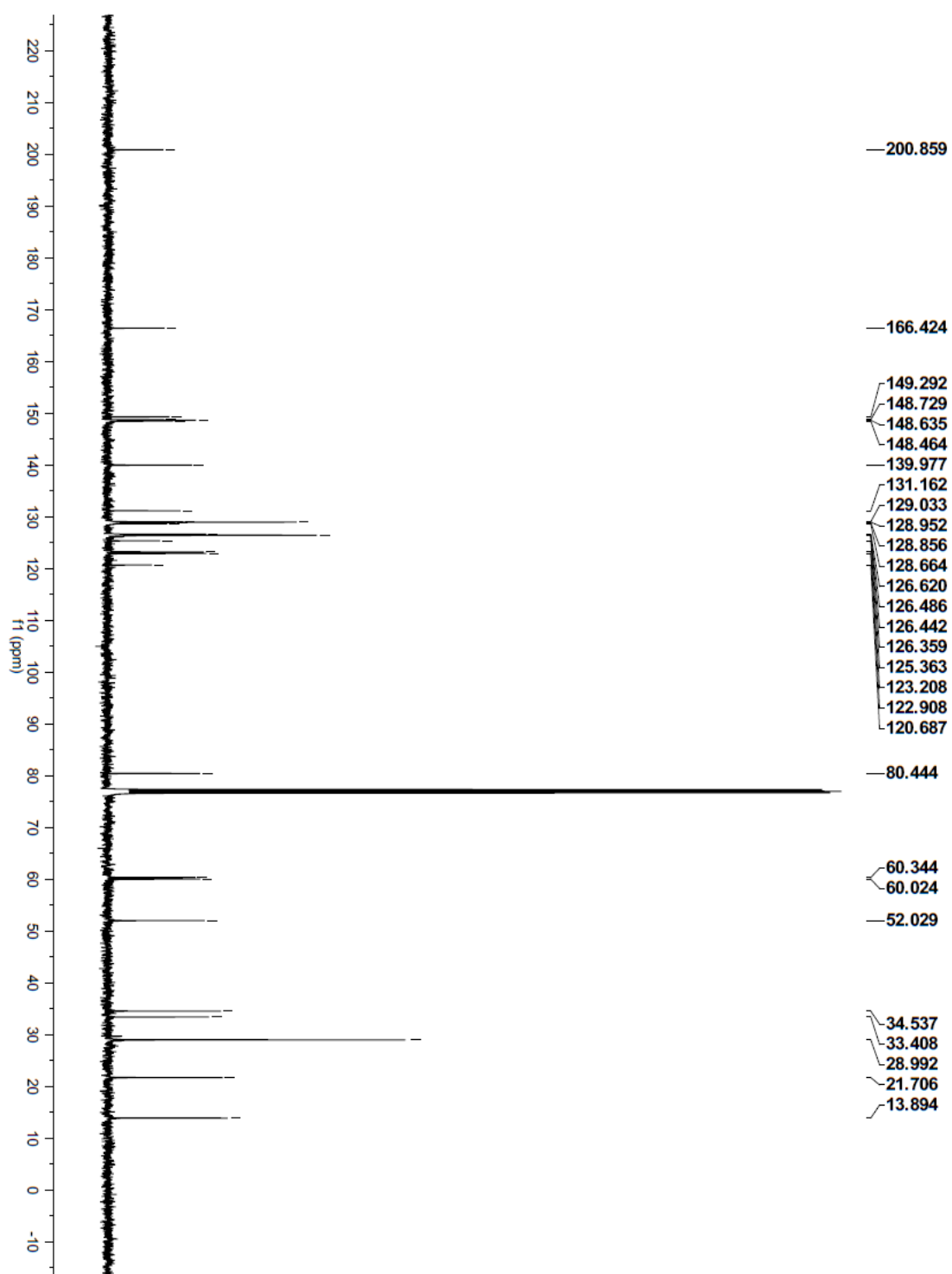
¹H NMR (400 MHz, CDCl₃) δ 8.08-8.17 (m, 1H), 7.89-7.99 (m, 1H), 7.66 (d, *J* = 8.4, 2H), 7.42-7.55 (m, 2H), 7.27 (dd, *J* = 10.0, 4.8 Hz, 1H), 7.18 (d, *J* = 7.18, 2H), 6.49 (s, 1H), 4.31 (s, 1H), 3.78 (s, 3H), 3.72 (s, 3H), 3.28 (s, 3H), 2.47-2.62 (m, 1H), 2.04-2.25 (m, 1H), 1.53-1.67 (m, 1H), 1.38-1.53 (m, 1H), 1.02 (s, 9H), 0.83 (t, *J* = 7.2 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 200.9, 166.4, 149.3, 148.7, 148.6, 148.5, 140.0, 131.2, 129.0, 129.0, 128.9, 128.7, 126.6, 126.5, 126.4, 126.4, 125.4, 123.2, 122.9, 120.7, 80.4, 60.3, 60.0, 52.0, 34.5, 33.4, 29.0, 21.7, 13.9.

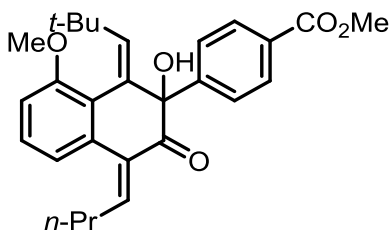
LRMS (CI) Calcd. for C₃₃H₃₆O₆Na [M+Na]⁺: 551.2, Found: 551.2.

FTIR (neat): 3478, 2956, 2862, 1724, 1692, 1608, 1436, 1351, 1274 cm⁻¹.





Methyl 4-((1*E*,4*E*)-4-butylidene-1-(2,2-dimethylpropylidene)-2-hydroxy-8-methoxy-3-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)benzoate (*des*-MeO-4d)



Detailed Procedures

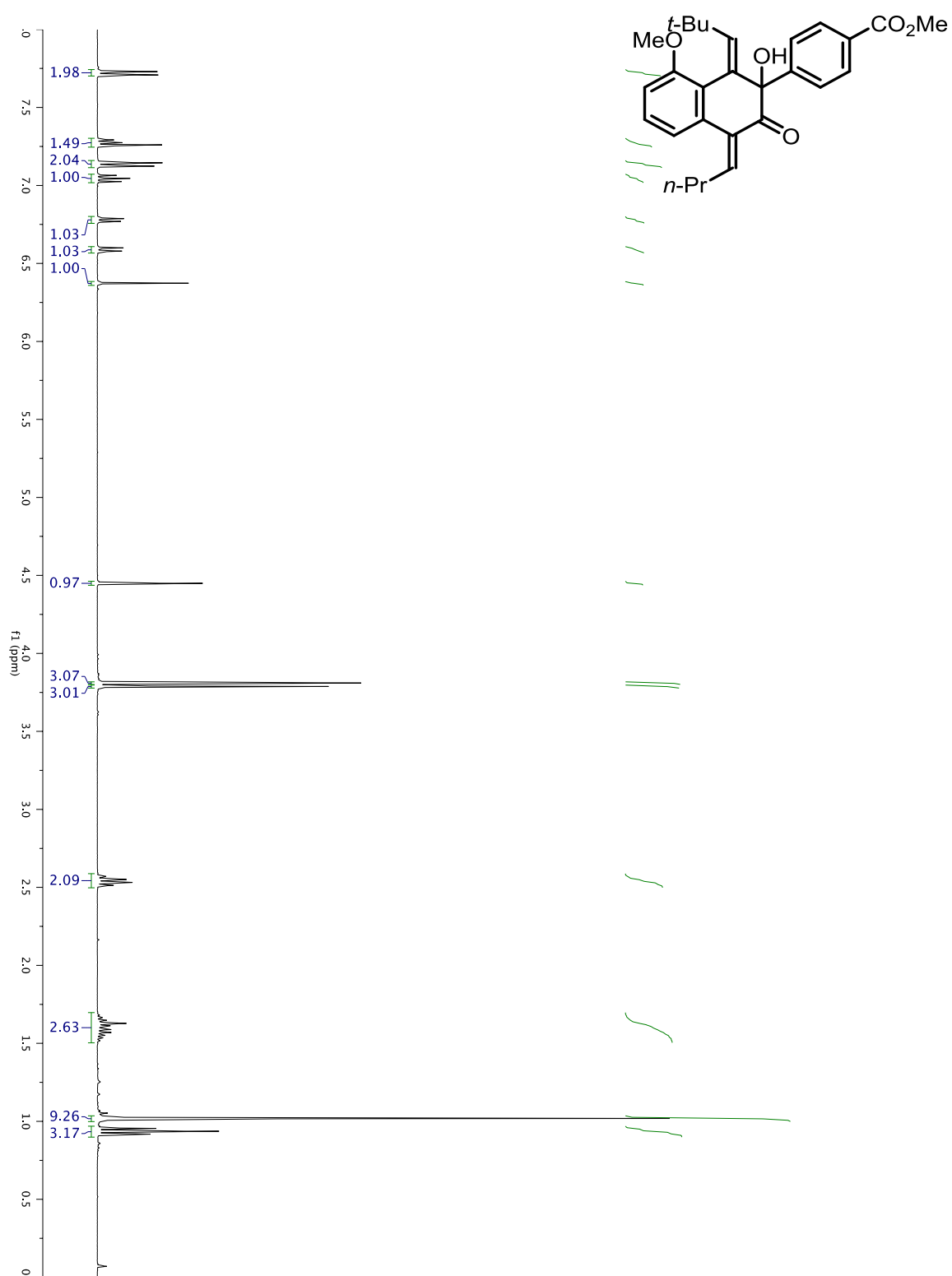
An oven-dried pressure tube equipped with a magnetic stir bar was charged with Ru₃(CO)₁₂ (5.7 mg, 0.009 mmol, 3 mol%), RuPhos (25.2 mg, 0.054 mmol, 18 mol%), and α -hydroxyketone **2d** (58.3 mg, 0.30 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. Diyne **1e** (114.5 mg, 0.45 mmol, 150 mol%), *m*-xylene (0.15 mL), and deionized water (0.15 mL) were added sequentially and the rubber septum was quickly replaced with a screw cap. The mixture was stirred in an oil bath at 75 °C for 16 h, at which point the resulting solution was allowed to cool to ambient temperature and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% CH₂Cl₂/hexane→90% CH₂Cl₂/hexane). The title compound *des*-MeO-**4d** was obtained as a yellow viscous oil (103.3 mg) in 77% yield.

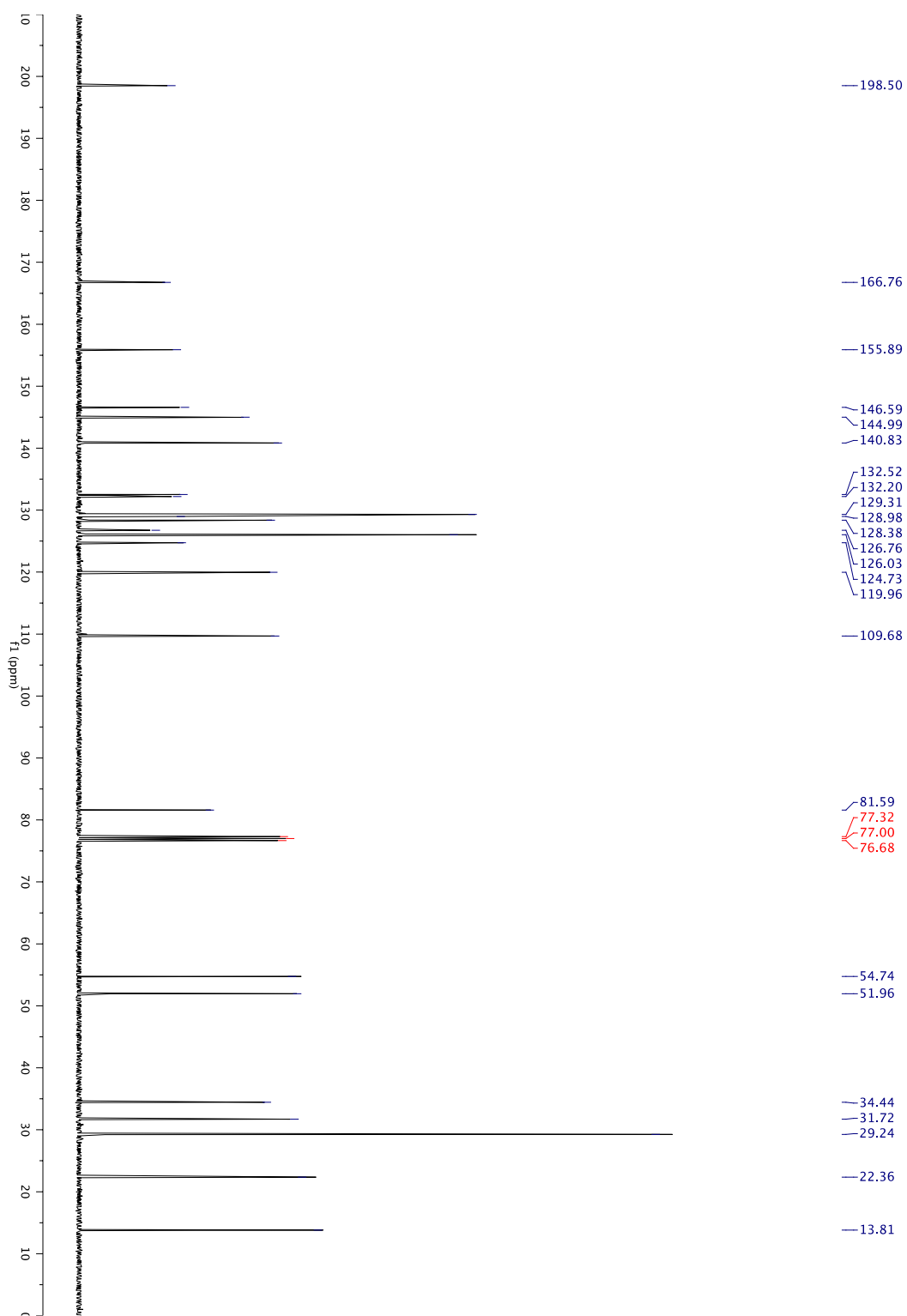
¹H NMR (400 MHz, CDCl₃) δ 7.75-7.69 (m, 2H), 7.30-7.25 (m, 1H), 7.16-7.11 (m, 2H), 7.04 (t, *J* = 8.3 Hz, 1H), 6.78 (dd, *J* = 7.8, 1.0 Hz, 1H), 6.59 (dd, *J* = 8.4, 0.9 Hz, 1H), 6.37 (s, 1H), 4.45 (s, 1H), 3.81 (s, 3H), 3.79 (s, 3H), 2.59-2.49 (m, 2H), 1.69-1.50 (m, 2H), 1.02 (s, 9H), 0.94 (t, *J* = 7.4 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 198.5, 166.8, 155.9, 146.6, 145.0, 140.8, 132.5, 132.2, 129.3, 129.0, 128.4, 126.8, 126.0, 124.7, 120.0, 109.7, 81.6, 54.7, 52.0, 34.4, 31.7, 29.2, 22.4, 13.8.

LRMS (CI) Calcd. for C₂₈H₃₂O₅Na [M+Na]⁺: 471.2, Found: 471.2.

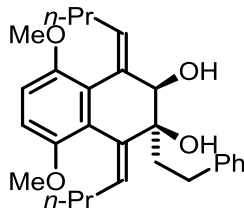
FTIR (neat): 2955, 1721, 1610, 1436, 1276, 1262, 1109, 909, 731, 710 cm⁻¹.





Detailed Procedures and Spectral Data for Compounds 7, S1, and 8-10:

(1*E*,4*E*)-1,4-Dibutylidene-5,8-dimethoxy-2-phenethyl-1,2,3,4-tetrahydronaphthalene-2,3-diol (7)



Detailed Procedures

A 100 mL round bottom flask was charged with a stir bar, **4g** (100 mg, 0.230 mmol, 100 mol%), toluene (10 mL) and anhydrous isopropanol (2 mL). The solution was degassed with bubbling argon for 5 min and trimethyl aluminum (2.0 M in toluene, 1.15 mL, 2.30 mmol, 1000 mol%) was added over 30 seconds with vigorous stirring. The solution was stirred for 10 minutes and then placed in an oil bath at 80 °C for 6 hours. The solution was cooled to 25 °C and acidified with 1.0 M HCl (50 mL) and diluted with diethyl ether (25 mL). After stirring overnight, the organic phase was washed with brine (25 mL) and dried over anhydrous sodium sulfate. The organic extract was filtered and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (10% EtOAc/hexane). The title compound **7** was obtained as a clear viscous oil, which eventually solidified over 7 days (84.5 mg) in 84% yield.

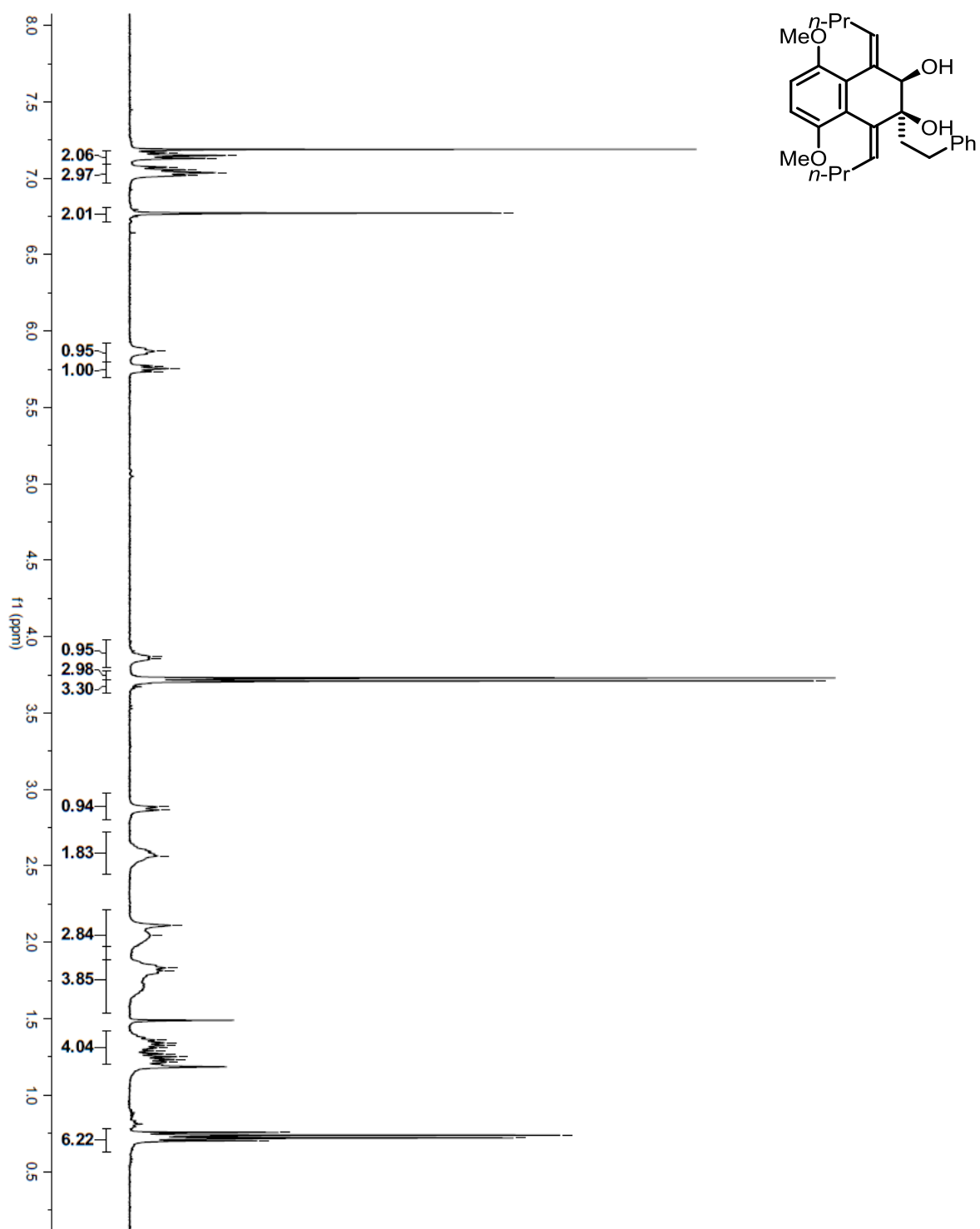
¹H NMR (400 MHz, CDCl₃) δ 7.09-7.18 (m, 2H), 6.97-7.09 (m, 3H), 6.77 (s, 2H), 5.80-5.92 (m, 1H), 5.76 (bt, *J* = 4.4, 1H), 3.86 (bd, *J* = 6.4 Hz, 1H), 3.73 (s, 3H), 3.71 (s, 3H), 2.88 (d, *J* = 8.0 Hz, 1H), 2.44-2.72 (m, 2H), 1.89-2.21 (m, 3H), 1.54-1.97 (m, 4H), 1.20-1.42 (m, 4H), 0.74 (t, *J* = 7.2 Hz, 3H), 0.72 (t, *J* = 7.2 Hz, 3H).

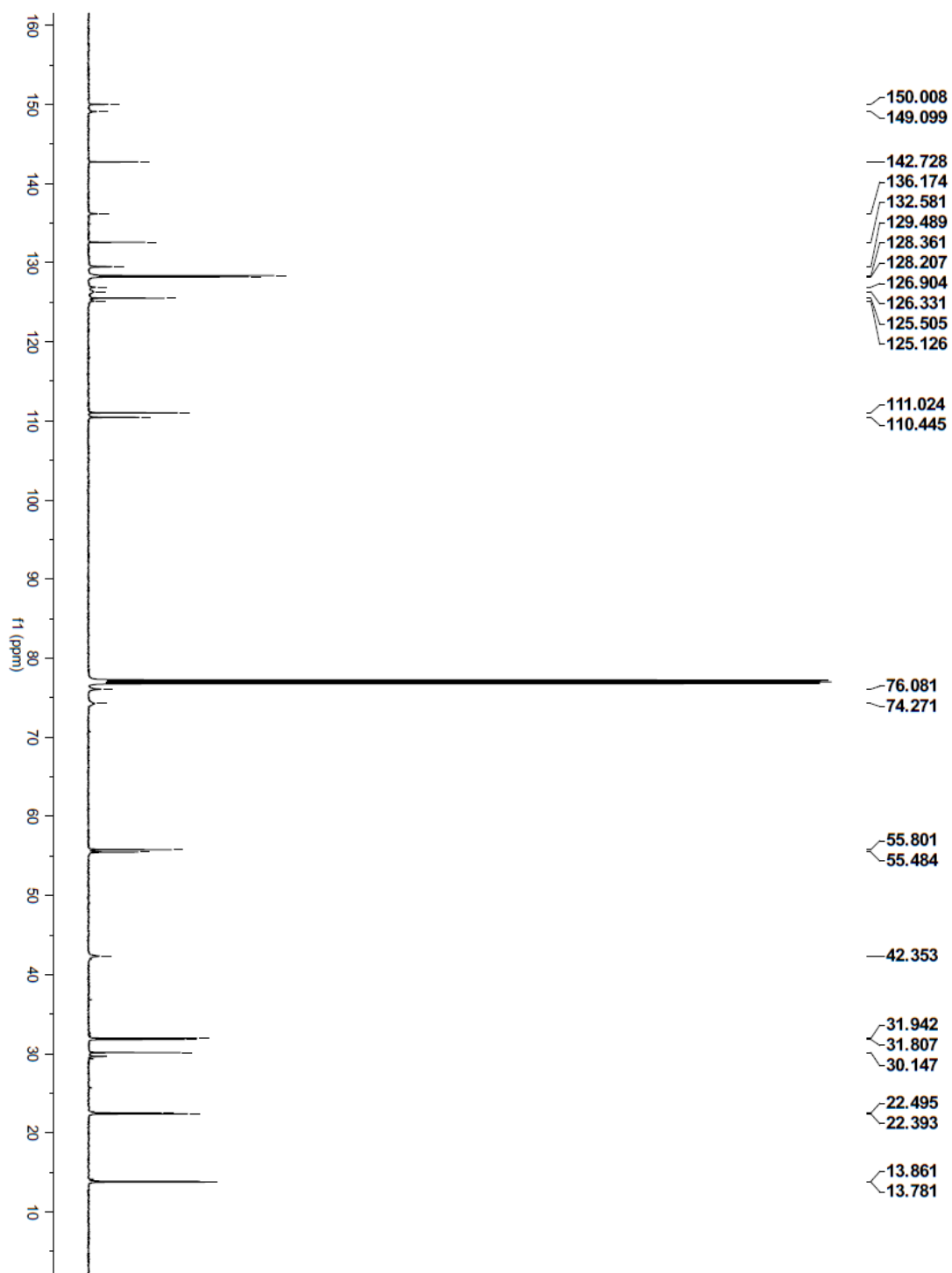
¹³C NMR (100 MHz, CDCl₃) δ 150.0, 149.1, 142.7, 136.2, 132.6, 129.5, 128.4, 128.2, 126.9, 126.3, 125.5, 125.1, 111.0, 110.4, 76.1, 74.3, 55.8, 55.5, 42.4, 31.9, 31.8, 30.2, 22.5, 22.4, 13.9, 13.8.

HRMS (ESI) Calcd. for C₂₈H₃₆O₄Na [M+Na]⁺: 459.25060, Found: 459.25140.

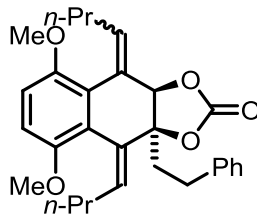
FTIR (neat): 3425, 2955, 2928, 2870, 2834, 1583, 1484, 1436, 1437, 1377, 1253 cm⁻¹.

MP: 45-47 °C.





(4*E*,9*E*)-4,9-Dibutylidene-5,8-dimethoxy-3a-phenethyl-3a,4,9,9a-tetrahydronaphtho[2,3-*d*][1,3]dioxol-2-one (S1)



Detailed Procedures

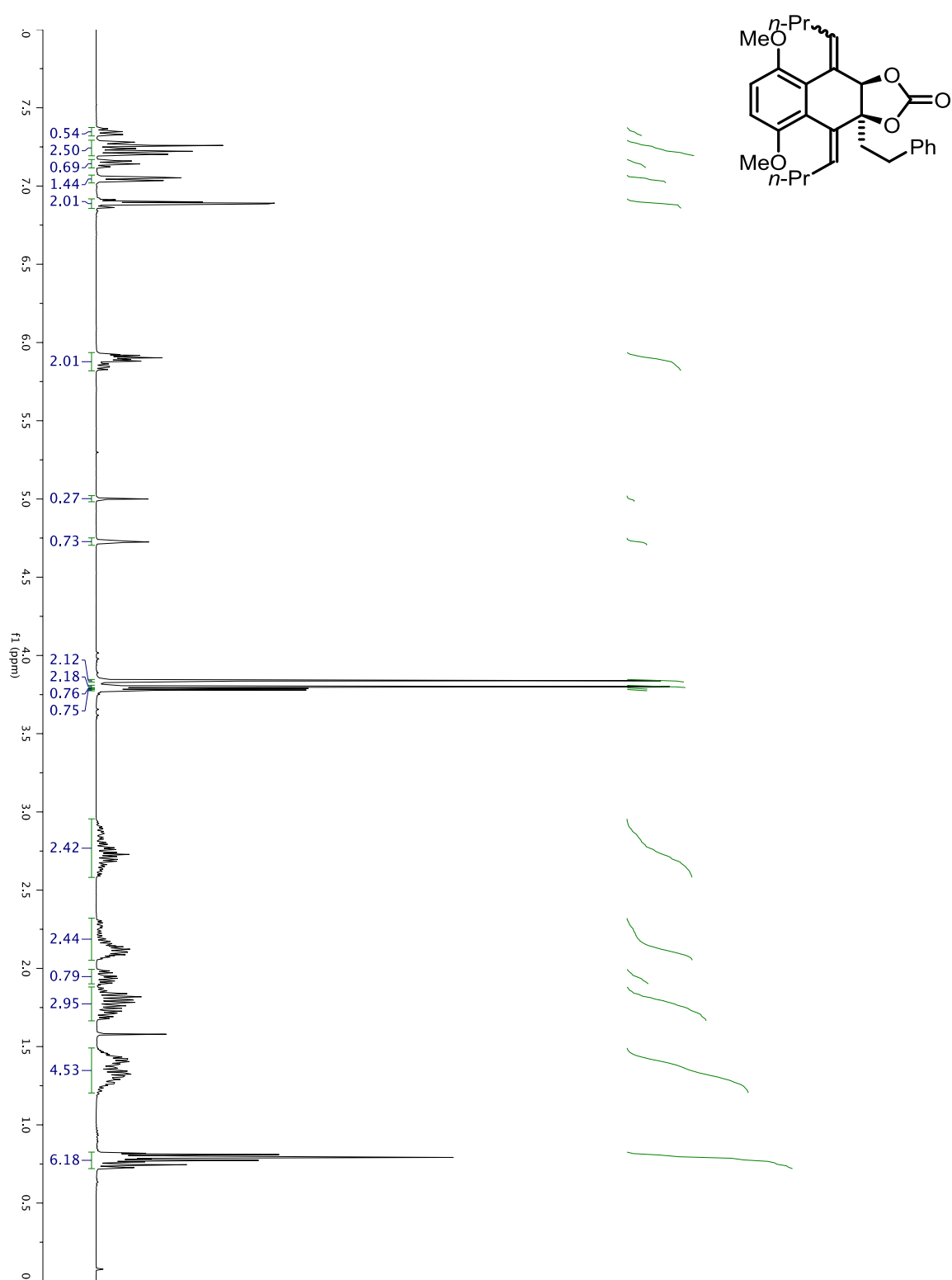
A solution of triphosgene (29 mg, 0.096 mmol, 120 mol%) and pyridine (33 μ L, 0.40 mmol, 500 mol%) in CH_2Cl_2 (0.5 mL) was stirred under argon at 25 °C for 5 minutes. This solution was then added dropwise *via* cannula to an argon-flushed dram vial cooled to 0 °C containing diol **7** (35 mg, 0.08 mmol, 100 mol%) in CH_2Cl_2 (0.5 mL), using further CH_2Cl_2 (0.5 mL) as a rinse. The resulting mixture was stirred at 0 °C for 2 h and then concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (2% EtOAc/hexane \rightarrow 10% EtOAc/hexane) to afford a 3:1 inseparable and inconsequential mixture of two diastereomers of the title compound **S1** as a pale yellow gum (32 mg) in 87% yield.

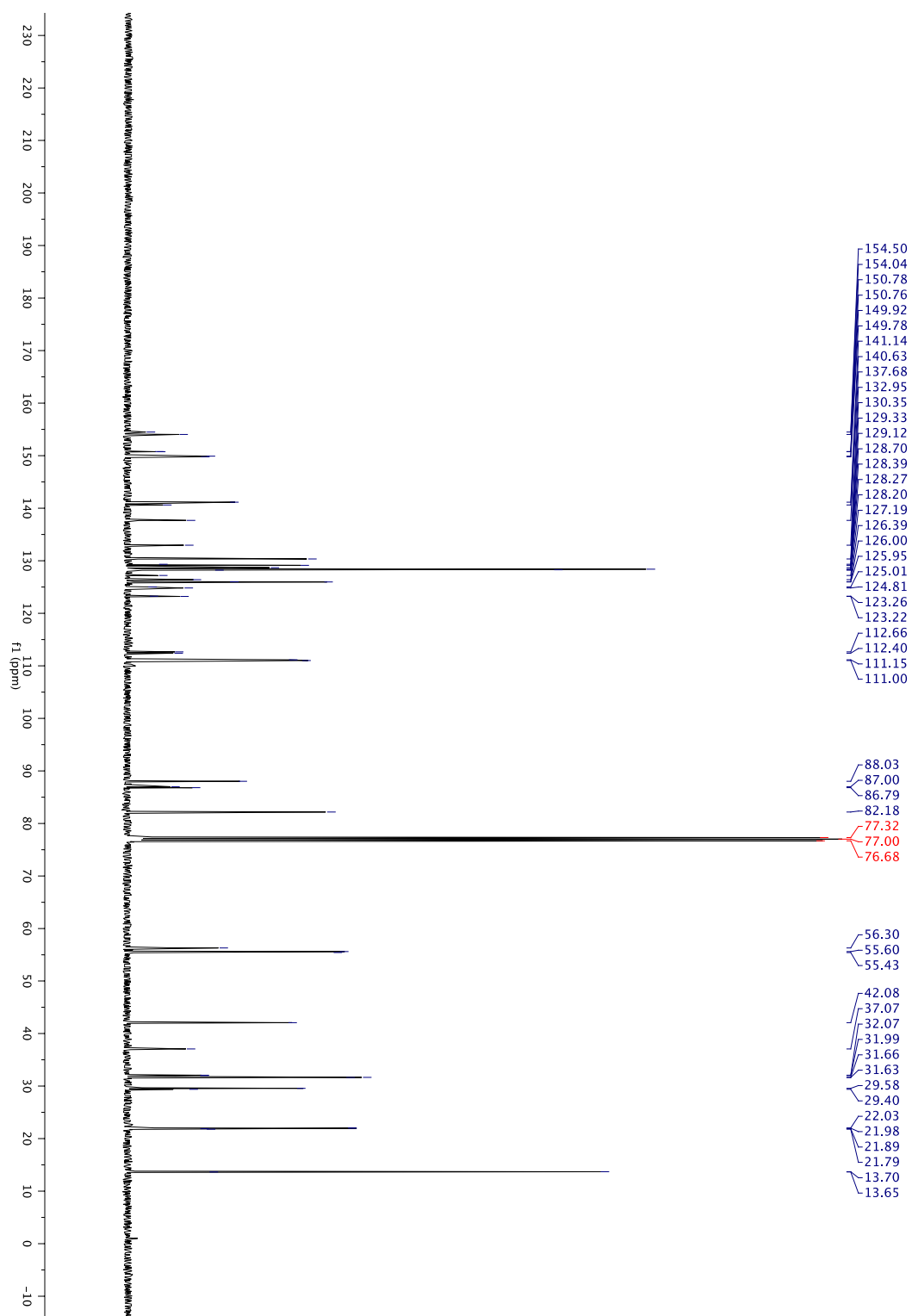
^1H NMR (400 MHz, CDCl_3) δ 7.38-7.31 (m, 0.54H), 7.30-7.19 (m, 2.33H), 7.17-7.11 (m, 0.69H), 7.07-7.02 (m, 1.44H), 6.92-6.85 (m, 2H), 5.94-5.82 (m, 2H), 5.00 (s, 0.27H), 4.73 (dq, J = 2.3, 1.3 Hz, 0.73H), 3.84 (s, 2.12H), 3.80 (s, 2.18H), 3.79 (s, 0.76H), 3.78 (0.75H), 2.95-2.57 (m, 2.42H), 2.32-2.05 (m, 2.44H), 1.95 (ddd, J = 14.1, 12.0, 5.1 Hz, 0.79H), 1.88-1.67 (m, 2.95H), 1.49-1.18 (m, 4H), 0.83-0.72 (m, 6H).

^{13}C NMR (100 MHz, CDCl_3) δ 154.5, 154.0, 150.8, 150.8, 149.9, 149.8, 141.1, 140.6, 137.7, 133.0, 130.4, 129.3, 129.1, 128.7, 128.4, 128.3, 128.2, 127.2, 126.4, 126.0, 126.0, 125.0, 124.8, 123.3, 123.2, 112.7, 112.4, 111.2, 111.0, 88.0, 87.0, 86.8, 82.2, 56.3, 55.6, 55.4, 42.1, 37.1, 32.1, 32.0, 31.7, 31.6, 29.6, 29.4, 22.0, 22.0, 21.9, 21.8, 13.7, 13.7.

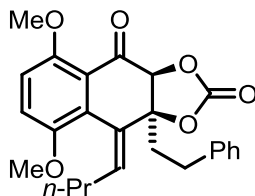
HRMS (ESI) Calcd. for $\text{C}_{29}\text{H}_{34}\text{O}_5\text{Na}$ $[\text{M}+\text{Na}]^+$: 485.22980, Found: 485.23000.

FTIR (neat): 2957, 2929, 1797, 1487, 1257, 1067, 1040, 736, 701 cm^{-1} .





(E)-9-Butylidene-5,8-dimethoxy-9a-phenethyl-9,9a-dihydronaphtho[2,3-*d*][1,3]dioxole-2,4(3a*H*)-dione (8)



Detailed Procedures

An oven-dried dram vial equipped with a magnetic stir bar was charged with $\text{RuCl}_3 \cdot 2\text{H}_2\text{O}$ (2 mg, 0.008 mmol, 20 mol%) and carbonate **S1** (17 mg, 0.04 mmol, 100 mol%). The vial was sealed with a rubber septum and purged with argon. 1,2-DCE (0.5 mL) and deionized water (0.4 mL) were injected successively, followed by the addition of NaIO_4 (34 mg, 0.16 mmol, 400 mol%). The mixture was stirred at 25 °C for 24 h, at which point the resulting solution was filtered through a short plug of silica gel using EtOAc (50 mL) as eluent. The filtrate was concentrated *in vacuo* and the residue was purified by column chromatography on silica gel (10% EtOAc/hexane→30% EtOAc/hexane). The title compound **8** was obtained as a pale yellow viscous oil (11.4 mg) in 72% yield.

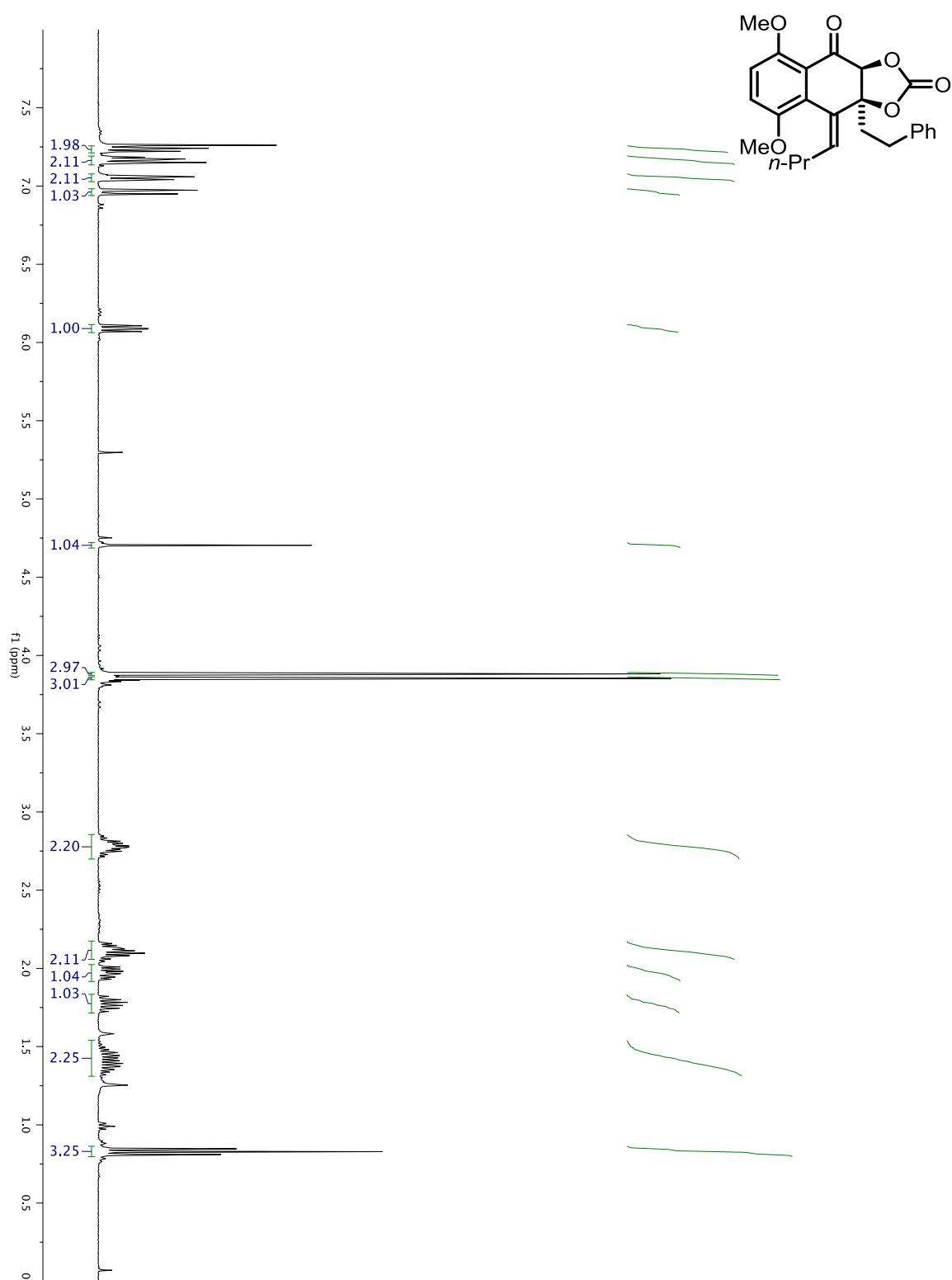
ATTENTION: Compound **8** was found to be unstable and was used immediately in the next step after isolation.

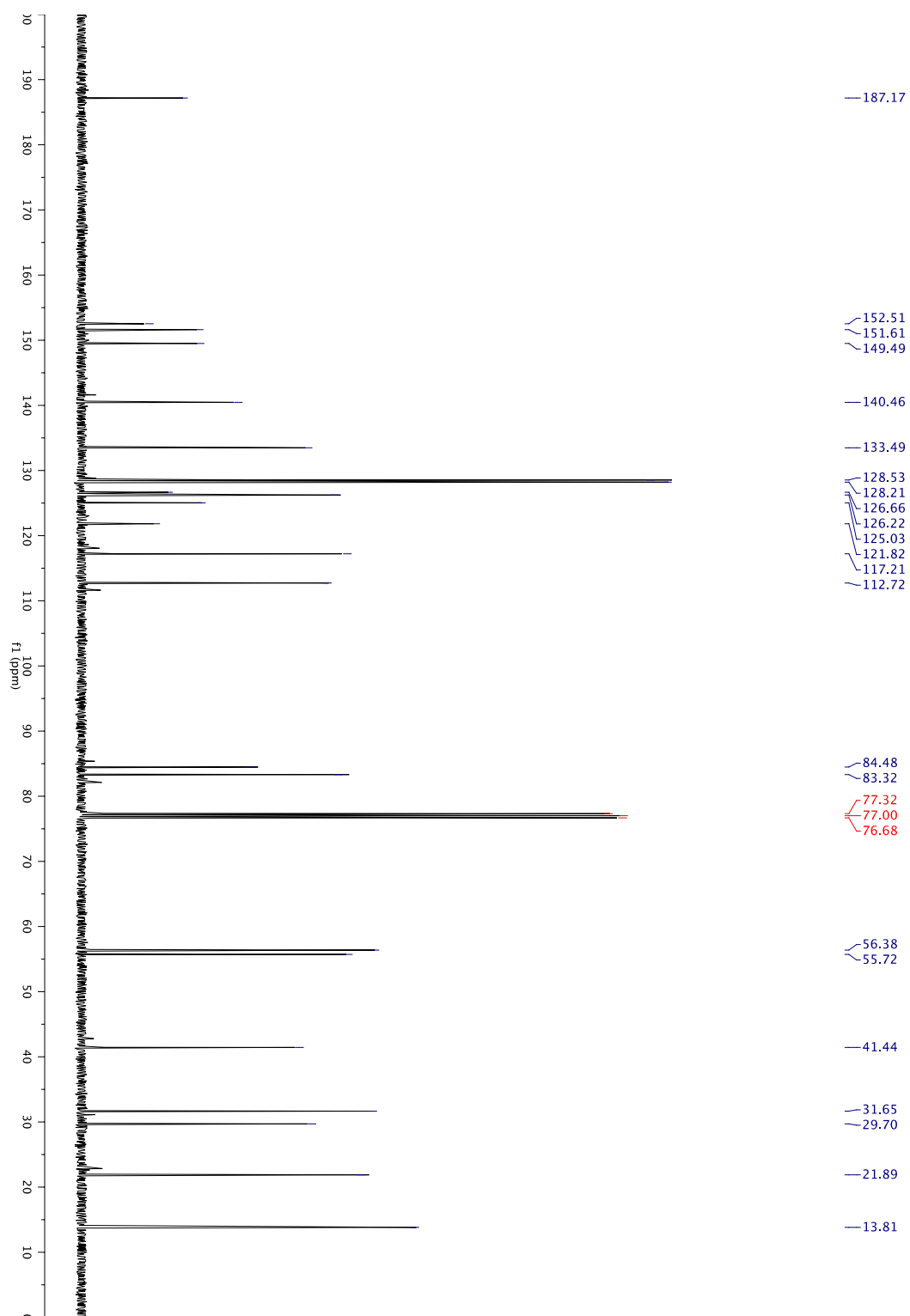
^1H NMR (400 MHz, CDCl_3) δ 7.26-7.21 (m, 2H), 7.19-7.14 (m, 2H), 7.07-7.03 (m, 2H), 6.96 (d, J = 9.2 Hz, 1H), 6.09 (dd, J = 8.4, 6.3 Hz, 1H), 4.70 (s, 1H), 3.88 (s, 3H), 3.85 (s, 3H), 2.86-2.70 (m, 2H), 2.17-2.04 (m, 2H), 2.02-1.92 (m, 1H), 1.83-1.71 (m, 1H), 1.53-1.31 (m, 2H), 0.83 (t, J = 7.4 Hz, 3H).

^{13}C NMR (100 MHz, CDCl_3) δ 187.2, 152.5, 151.6, 149.5, 140.5, 133.5, 128.5, 128.2, 126.7, 126.2, 125.0, 121.8, 117.2, 112.7, 84.5, 83.3, 56.4, 55.7, 41.4, 31.7, 29.7, 21.9, 13.8.

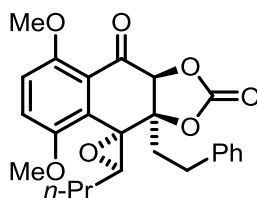
HRMS (CI) Calcd. for $\text{C}_{25}\text{H}_{26}\text{O}_6$ $[\text{M}]^+$: 422.1729, Found: 422.1740.

FTIR (neat): 2957, 2926, 1806, 1716, 1486, 1263, 1064, 1005, 731, 700 cm^{-1} .





5,8-Dimethoxy-3a-phenethyl-3'-propyl-3a,9a-dihydro-9H-spiro[naphtho[2,3-d][1,3]dioxole-4,2'-oxirane]-2,9-dione (9)



Detailed Procedures

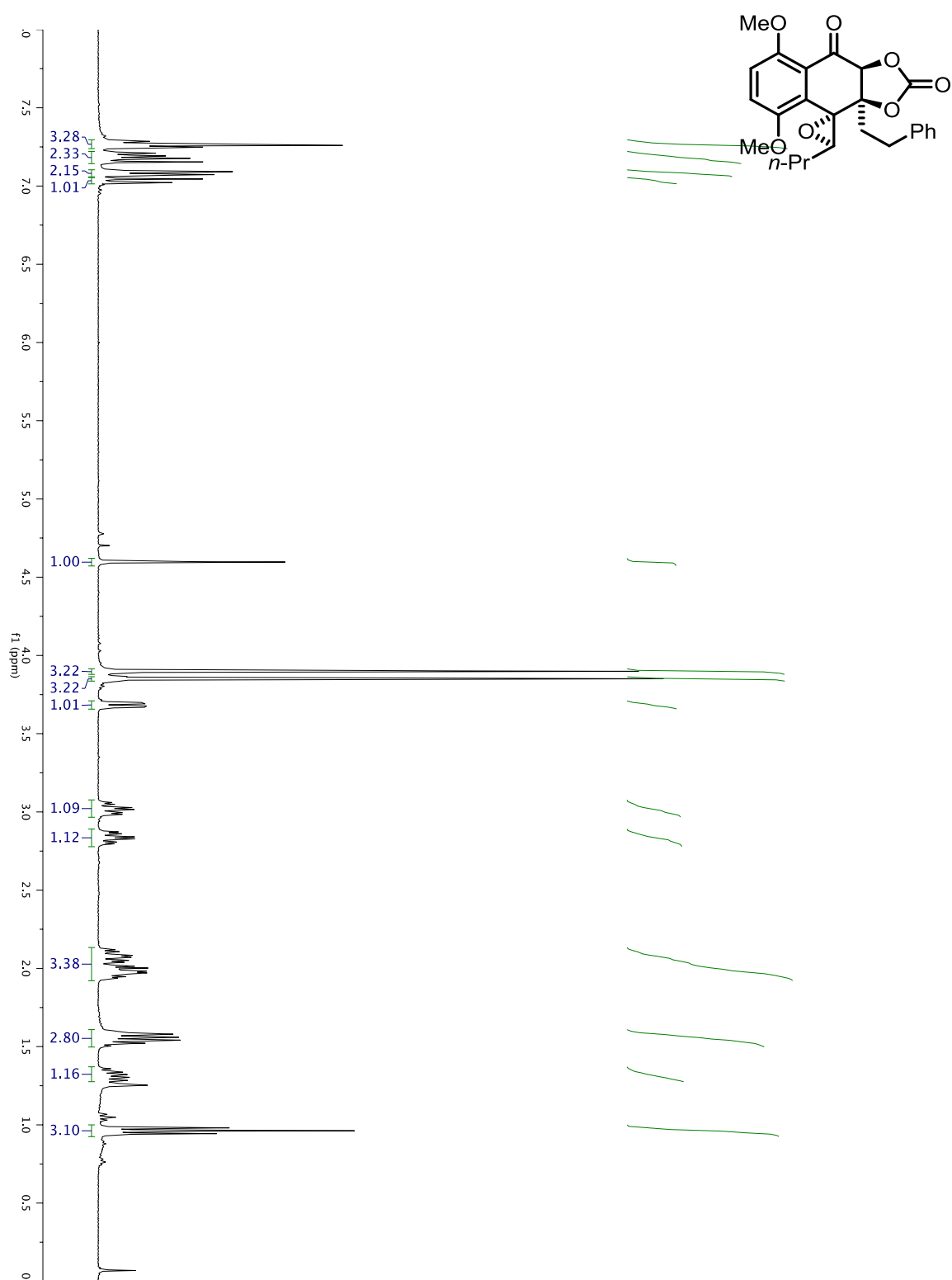
An oven-dried dram vial equipped with a magnetic stir bar was charged with ketone **8** (29 mg, 0.07 mmol, 100 mol%). The tube was sealed with a rubber septum and purged with argon. CH₂Cl₂ (0.3 mL) was injected into the vial followed by the addition of *m*-CPBA (35 mg, 70-75%, 0.14 mmol, 200 mol%). The mixture was stirred at 25 °C for 24 h. The mixture was diluted with CH₂Cl₂ (15 mL) and the organic layer was washed with saturated Na₂SO₃ solution (2 x 5 mL), saturated NaHCO₃ solution (2 x 5 mL), dried (Na₂SO₄), filtered and concentrated *in vacuo*. The residue was purified by column chromatography on silica gel (20% EtOAc/hexane→60% EtOAc/hexane). The title compound **9** was obtained as an off-white amorphous solid (23.9 mg) in 80% yield.

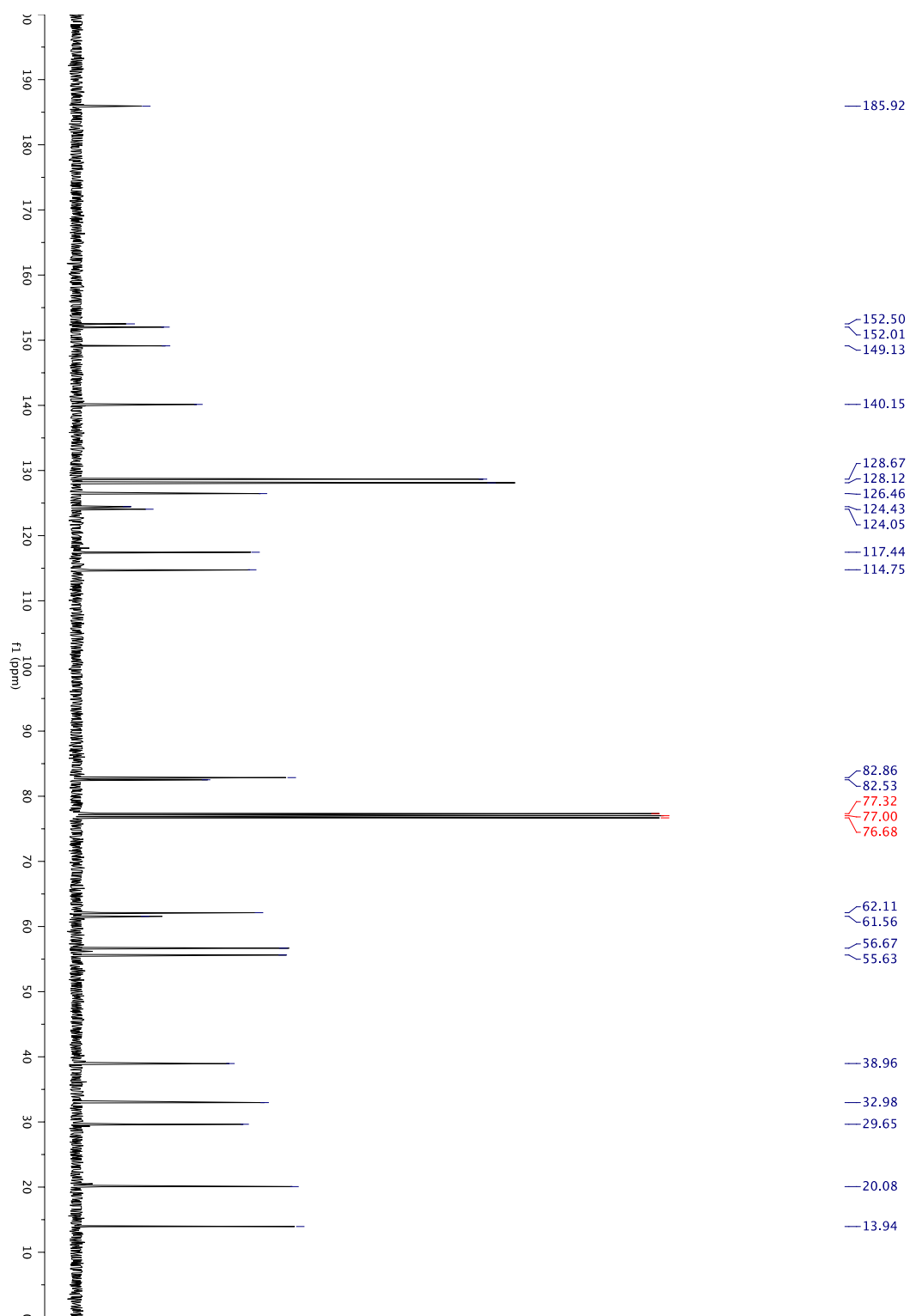
¹H NMR (400 MHz, CDCl₃) δ 7.30-7.24 (m, 2H), 7.22-7.14 (m, 2H), 7.11-7.06 (m, 2H), 7.03 (d, *J* = 9.3 Hz, 1H), 4.60 (s, 1H), 3.90 (s, 3H), 3.85 (s, 3H), 3.68 (dd, *J* = 8.8, 3.5 Hz, 1H), 3.02 (dt, *J* = 12.9, 4.7 Hz, 1H), 2.83 (dt, *J* = 12.9, 4.9 Hz, 1H), 2.13-1.92 (m, 3H), 1.61-1.49 (m, 2H), 1.37-1.26 (m, 1H), 0.96 (t, *J* = 7.3 Hz, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 185.9, 152.5, 152.0, 149.1, 140.2, 128.7, 128.1, 126.5, 124.4, 124.1, 117.4, 114.8, 82.9, 82.5, 62.1, 61.6, 56.7, 55.6, 39.0, 33.0, 29.7, 20.1, 13.9.

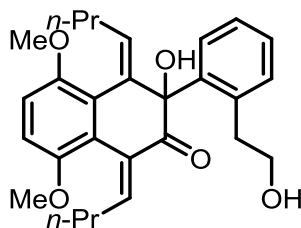
HRMS (ESI) Calcd. for C₂₅H₂₆O₇ [M+Na]⁺: 461.15710, Found: 461.15770.

FTIR (neat): 2928, 1809, 1724, 1491, 1265, 1005, 951, 811, 730, 701 cm⁻¹.





(1*E*,4*E*)-1,4-dibutylidene-3-hydroxy-3-(2-(2-hydroxyethyl)phenyl)-5,8-dimethoxy-3,4-dihydronaphthalen-2(1*H*)-one (10)



Detailed Procedures

To an argon-flushed 10 mL round bottom flask equipped with a stir bar was added **4i** (250 mg, 0.41 mmol, 100 mol%), THF (2.5 mL), and deionized water (0.5 mL). After 5 minutes of stirring, *p*-TsOH·H₂O (235 mg, 1.24 mmol, 300 mol%) was added into the flask and the mixture was stirred at 25 °C for 4 hours. Water (10 mL) was added and the mixture was extracted with Et₂O (3 x 20 mL). The combined organic layer was washed with brine (15 mL), dried (Na₂SO₄), and concentrated *in vacuo*. The resulting residue was purified by column chromatography on silica gel (10% EtOAc/hexane→40% EtOAc/hexane). The title compound **10** was obtained as a white solid (175.6 mg) in 95% yield.

¹H NMR (400 MHz, CDCl₃) δ 7.31-7.24 (m, 1H), 7.06 (d, *J* = 7.7 Hz, 1H), 7.02-6.96 (m, 1H), 6.78-6.71 (m, 1H), 6.69-6.59 (m, 2H), 6.55-6.50 (m, 1H), 4.78 (s, 1H), 4.01-3.92 (m, 1H), 3.82-3.63 (m, 5H), 3.61 (s, 3H), 2.98 (br s, 1H), 2.76 (dt, *J* = 13.5, 4.4 Hz, 1H), 2.42-2.30 (m, 1H), 2.26-2.14 (m, 1H), 2.04-1.86 (m, 2H), 1.62-1.29 (m, 4H), 0.91-0.84 (m, 3H), 0.82-0.76 (m, 3H).

¹³C NMR (100 MHz, CDCl₃) δ 200.0, 149.9, 149.8, 147.5, 139.9, 139.3, 131.6, 131.0, 131.0, 129.8, 127.7, 127.0, 126.2, 125.0, 121.8, 111.6, 111.5, 81.3, 64.1, 55.8, 55.5, 34.7, 33.5, 32.1, 22.1, 21.7, 13.9, 13.8.

HRMS (ESI) Calcd. for C₂₈H₃₄O₅Na [M+Na]⁺: 473.22980, Found: 473.22960.

FTIR (neat): 2955, 2928, 1700, 1487, 1255, 1105, 1066, 798, 694 cm⁻¹.

