

Supplementary Materials

Design of Dipolar Push–Pull Fluorophores Based on Furanone–Nitrile Acceptors for Ratiometric Hydrogen Sulfide Sensing

*Yan-Chi Tseng and Chih-Hsin Chen**

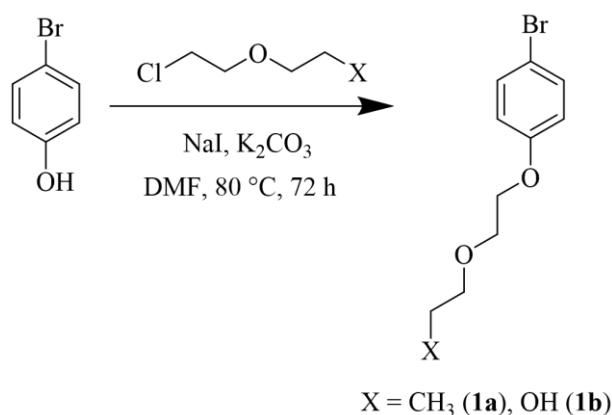
Department of Chemistry, Tamkang University, New Taipei City 25137, Taiwan

Content

- 1. Synthetic routes of probes*
- 2. Supporting figures*

1. Synthetic routes of probes

1.1 Synthesis of 1a and 1b



Scheme S1. Synthetic routes to 1a and 1b.

A 100 mL round-bottom flask was charged with 4-bromophenol (3.46 g, 20.00 mmol), 2-chloroethyl propyl ether (2.40 mL, 2.94 g, 32.00 mmol) or diethylene glycol monochlorohydrin (2.95 mL, 4.06 g, 32.00 mmol), sodium iodide (3.00 g, 20.00 mmol), and potassium carbonate (3.33 g, 32.00 mmol) in *N,N*-dimethylformamide (DMF) (50 mL). The reaction mixture was stirred at 80 °C for 72 h. After completion, the mixture was extracted with deionized water and ethyl acetate (EA). The organic layer was separated, dried over anhydrous MgSO_4 , filtered, and concentrated under reduced pressure. The crude residue was purified by column chromatography using hexane (Hex)/EA (5:1, v/v) to afford a pale-yellow oil.

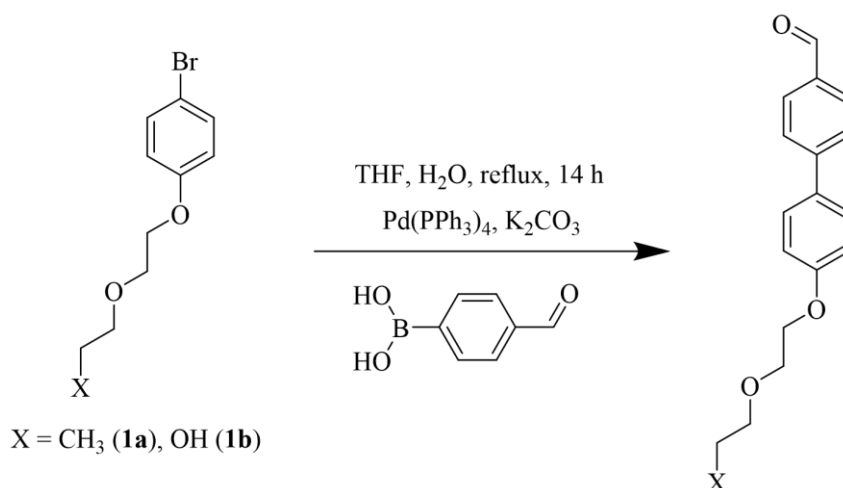
1.1.1 Yield and NMR of 1-bromo-4-(2-propoxyethoxy)benzene (1a)

Yield: 70%, ^1H NMR (300 MHz, CDCl_3): δ 7.37 (d, $J=8.82$, 2H), 6.61 (d, $J=8.82$, 2H), 4.07 (m, 2H), 3.76 (m, 2H), 3.48 (t, $J=6.72$, 2H), 1.64 (m, 2H), 0.92 (t, $J=7.41$, 3H).

1.1.2 Yield and NMR of 2-(2-(4-bromophenoxy)ethoxy)ethan-1-ol (1b)

Yield: 73%, ^1H NMR (300 MHz, CDCl_3): δ 7.37 (d, $J=8.94$ Hz, 2H), 6.61 (d, $J=8.97$ Hz, 2H), 4.09 (m, 2H), 3.84 (m, 2H), 3.74 (m, 2H), 3.67 (m, 2H).

1.2 Synthesis of 2a and 2b



Scheme S2. Synthetic routes to of 2a and 2b.

A 100 mL two-necked round-bottom flask was charged with compound 1a or 1b (8.06 mmol), 4-formylphenylboronic acid (1.44g, 9.67 mmol), tetrakis(triphenylphosphine)-palladium(0) (0.48 g, 0.40 mmol), and potassium carbonate (5.52 g, 40.30 mmol) in a mixed solvent of tetrahydrofuran (THF) (40 mL) and deionized water (20 mL). The reaction mixture was refluxed under a nitrogen atmosphere for 14 h. After completion, the mixture was extracted with deionized water and EA. The organic layer was collected, dried over anhydrous MgSO_4 , filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography using Hex/EA (3:1, v/v) to afford a pale-yellow oil.

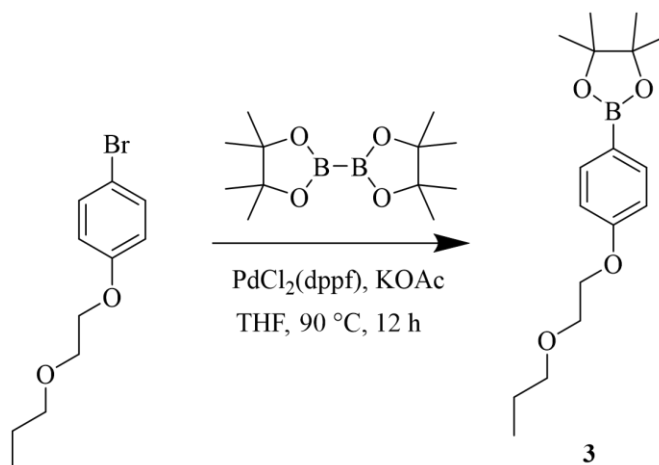
1.2.1 Yield and NMR of 4'-(2-propoxyethoxy)-[1,1'-biphenyl]-4-carbaldehyde (2a)

Yield: 70%, ^1H NMR (300 MHz, CDCl_3): δ 10.03 (s, 1H), 7.93 (d, $J = 8.34$, 2H), 7.72 (d, $J = 8.19$, 2H), 7.58 (d, $J = 8.88$, 2H), 7.04 (d, $J = 8.82$, 2H), 4.18 (m, 2H), 3.82 (m, 2H), 3.51 (t, $J = 6.69$, 2H), 1.63 (m, 2H), 0.94 (t, $J = 7.50$, 3H).

1.2.2 Yield and NMR of 4'-(2-(2-hydroxyethoxy)ethoxy)-[1,1'-biphenyl]-4-carbaldehyde (2b)

Yield: 73%, ^1H NMR (300 MHz, CDCl_3): δ 10.03 (s, 1H), 7.37 (d, $J = 8.94$, 2H), 6.61 (d, $J = 8.97$, 2H), 4.09 (m, 2H), 3.84 (m, 2H), 3.74 (m, 2H), 3.67 (m, 2H).

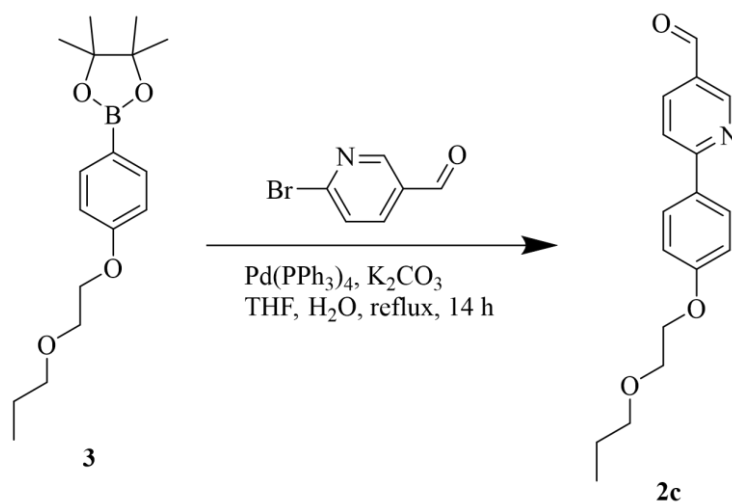
1.3 Synthesis of 4,4,5,5-tetramethyl-2-(4-(2-propoxyethoxy)phenyl)-1,3,2-dioxaborolane (3)



Scheme S3. Synthetic routes to 3.

A 100 mL two-necked round-bottom flask was charged with compound 1a (1.30 g, 5.04 mmol), bis(pinacolato)diboron (1.90 g, 7.55 mmol), [1,1'-bis(diphenylphosphino)ferrocene]dichloropalladium(II) ($\text{Pd}(\text{dppf})\text{Cl}_2$, 0.36 g, 0.50 mmol), and potassium acetate (2.37 g, 15.12 mmol) in THF (40 mL). The reaction mixture was refluxed under a nitrogen atmosphere for 12 h. After completion, the mixture was extracted with deionized water and EA. The organic layer was separated, dried over anhydrous MgSO_4 , filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography to afford a pale-yellow oil (0.60 g, 55%). ^1H NMR (300 MHz, CDCl_3): δ 7.74 (d, $J = 8.64$, 2H), 6.91 (d, $J = 8.67$, 2H), 4.14 (m, 2H), 3.79 (m 2H), 3.48 (t, $J = 6.78$, 2H), 1.63 (m, 2H), 1.32 (s, 12H), 0.94 (t, $J = 7.38$, 3H).

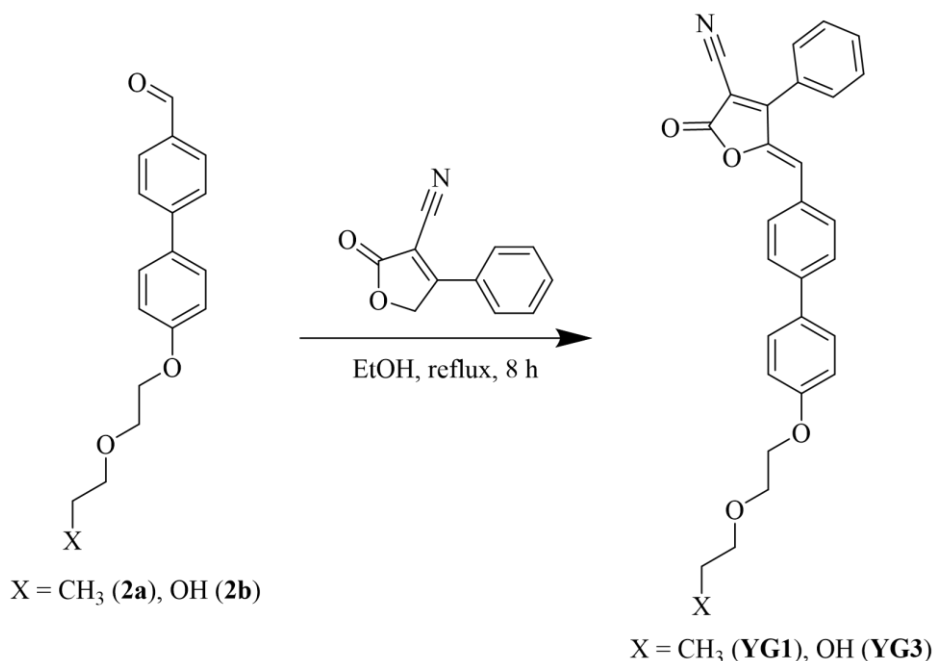
1.4 Synthesis of 6-(4-(2-propoxyethoxy)phenyl)nicotinaldehyde (2c)



Scheme S4. Synthesis route of 2c.

A 100 mL two-necked round-bottom flask was charged with compound 3 (1.20 g, 3.92 mmol), 5-bromopyridine-2-carbaldehyde (0.72 g, 3.87 mmol), tetrakis(triphenylphosphine)palladium(0) (0.48 g, 0.40 mmol), and potassium carbonate (5.52 g, 40.30 mmol) in a mixed solvent of THF (40 mL) and deionized water (20 mL). The reaction mixture was refluxed under a nitrogen atmosphere for 14 h. After completion, the mixture was extracted with deionized water and ethyl acetate (EA). The organic layer was collected, dried over anhydrous MgSO_4 , filtered, and concentrated under reduced pressure. The crude product was purified by column chromatography using Hex/EA (3:1, v/v) to afford a pale-yellow oil (0.55 g, 49%). ^1H NMR (300 MHz, CDCl_3): δ 10.09 (s, 1H), 8.97 (m, 1H), 8.00 (d, $J = 1.53$, 2H), 7.58 (d, $J = 8.79$, 2H), 7.07 (d, $J = 8.79$, 2H), 4.18 (m, 2H), 3.82 (m, 2H), 3.51 (t, $J = 6.78$, 2H), 1.63 (m, 2H), 0.93 (t, $J = 7.44$, 3H).

1.5 Synthesis of YG1 and YG3



Scheme S5. Synthesis routes to YG1 and YG3.

A 100 mL two-necked round-bottom flask was charged with compound 2a or 2b (6.96 mmol) and 4-phenyl-2-oxo-2,5-dihydrofuran-3-carbonitrile (1.54 g, 8.36 mmol) in ethanol (50 mL). The reaction mixture was refluxed overnight. After completion, the resulting mixture was filtered under reduced pressure, and the crude solid was recrystallized from ethanol. The collected solid was then dried to afford an orange solid.

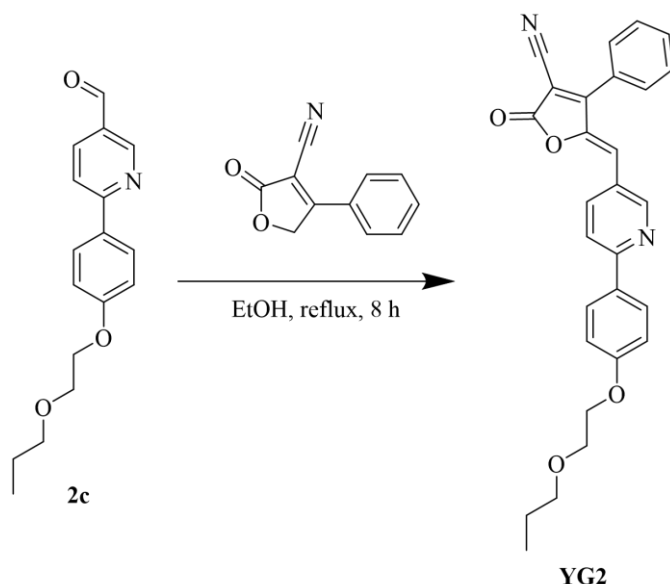
1.5.1 Yield and NMR of (Z)-2-oxo-4-phenyl-5-((4'-(2-propoxyethoxy)-[1,1'-biphenyl]-4-yl)methylene)-2,5-dihydrofuran-3-carbonitrile (YG1)

Yield: 55%, ^1H NMR (600 MHz, CDCl_3): δ 7.84 (d, 2H), 7.63 (m, 7H), 7.60 (d, 2H), 7.02 (d, 2H), 6.47 (s, 1H), 4.16 (m, 2H), 3.82 (m, 2H), 3.51 (t, 2H), 1.63 (m, 2H), 0.94 (t, 3H). ^{13}C NMR (600 MHz, CDCl_3): δ 164.01, 159.36, 146.68, 143.55, 132.54, 132.29, 132.03, 130.33, 129.59, 128.96, 128.19, 127.60, 127.08, 121.19, 115.19, 111.66, 98.78, 73.31, 69.06, 67.60, 22.81, 10.47. HR-MS (EI^+) m/z calculated for $[\text{C}_{29}\text{H}_{25}\text{NO}_4]^+$: 451.1785, found: 451.1784. Elemental analysis calculated for $\text{C}_{29}\text{H}_{25}\text{NO}_4$ (%): C, 77.14; H, 5.58; N, 3.10. Found: C, 76.17; H, 5.44; N, 3.13.

1.5.2 Yield and NMR of (Z)-5-((4'-(2-(2-hydroxyethoxy)ethoxy)-[1,1'-biphenyl]-4-yl)methylene)-2-oxo-4-phenyl-2,5-dihydrofuran-carbonitrile (YG3)

Yield: 71%, ^1H NMR (600 MHz, CDCl_3): δ 7.90 (d, $J = 8.40$, 2H), 7.64 (m, 7H), 7.60 (d, $J = 8.64$, 2H), 7.02 (d, $J = 8.64$, 2H), 6.49 (s, 1H), 4.20 (m, 2H), 3.91 (m, 2H), 3.79 (m, 2H), 3.70 (m, 2H). ^{13}C NMR (600 MHz, CDCl_3): δ 164.03, 163.99, 159.14, 145.72, 143.44, 132.54, 132.31, 130.41, 129.60, 128.97, 128.27, 127.60, 127.11, 121.12, 115.16, 111.64, 98.84, 72.60, 69.63, 67.55, 61.79. HR-MS (FAB^+) m/z calculated for $[\text{C}_{28}\text{H}_{23}\text{NO}_5]^+$: 453.1576, found: 453.1577. Elemental analysis calculated for $\text{C}_{28}\text{H}_{23}\text{NO}_5$ (%): C, 74.16; H, 5.11; N, 3.09. Found: C, 72.93; H, 5.10; N, 3.00.

1.6 Synthesis of (Z)-2-oxo-4-phenyl-5-((6-(4-(2-propoxyethoxy)phenyl)pyridin-3-yl)methylene)-2,5-dihydrofuran-3-carbonitrile (YG2)



Scheme S6. Synthesis route to YG2.

A 100 mL two-necked round-bottom flask was charged with compound 2c (0.40 g, 1.40 mmol) and compound 4-phenyl-2-oxo-2,5-dihydrofuran-3-carbonitrile (0.32 g, 1.72 mmol) in ethanol (20 mL). The reaction mixture was refluxed overnight. After completion, the resulting mixture was filtered under reduced pressure, and the crude solid was recrystallized from ethanol. The collected solid was then dried to afford an orange solid (0.45 g, 70%). ^1H NMR (600 MHz, CDCl_3): δ 8.87 (m, 1H), 8.37 (m, 1H), 7.98 (dd, $J = 4.17$, 2H), 7.63 (m, 5H), 7.57 (d, $J = 4.32$, 2H), 7.04 (d, $J = 4.32$, 1H), 6.78 (s, 1H), 4.16 (m, 2H), 3.82 (m, 2H), 3.51 (t, $J = 3.39$, 2H), 1.63 (m, 2H), 0.94 (t, $J = 3.72$, 3H). ^{13}C NMR (600 MHz, CDCl_3): δ 164.36, 163.29, 159.69, 148.92, 148.12, 147.26, 136.51, 134.00, 132.50, 129.54, 128.91, 128.82, 128.17, 126.96, 120.92, 115.40, 111.18, 99.94, 73.20, 68.89, 67.53, 22.68, 10.35. HR-MS (MALDI) m/z calculated for $[\text{C}_{28}\text{H}_{24}\text{N}_2\text{O}_4 + \text{H}]^+$: 453.1814, found: 453.1832. Elemental analysis calculated for $\text{C}_{28}\text{H}_{24}\text{N}_2\text{O}_4$ (%): C, 74.32; H, 5.35; N, 6.19. Found: C, 72.99; H, 5.34; N, 6.04.

3. Supporting figures

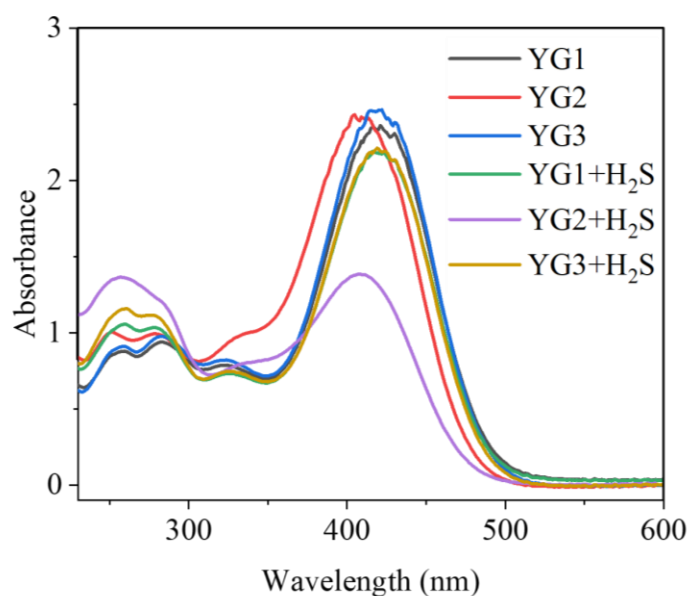


Figure S1. UV–Vis absorption spectra of YG1, YG2, and YG3 (1.0×10^{-4} M in acetonitrile/water = 99:1, v/v) recorded before and after addition of H_2S (1.0×10^{-4} M).

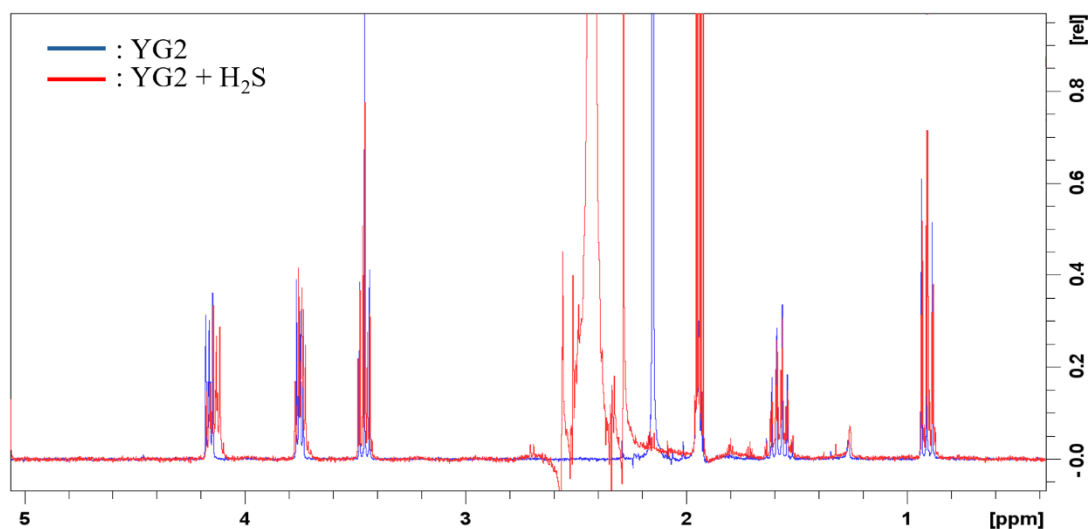


Figure S2. Overlaid ^1H NMR spectra of YG2 before and after reaction with H_2S (CD_3CN ; post-reaction solvent $\text{CD}_3\text{CN}/\text{H}_2\text{O} = 97:3$, v/v), showing disappearance of the vinyl proton and formation of a new methine signal.

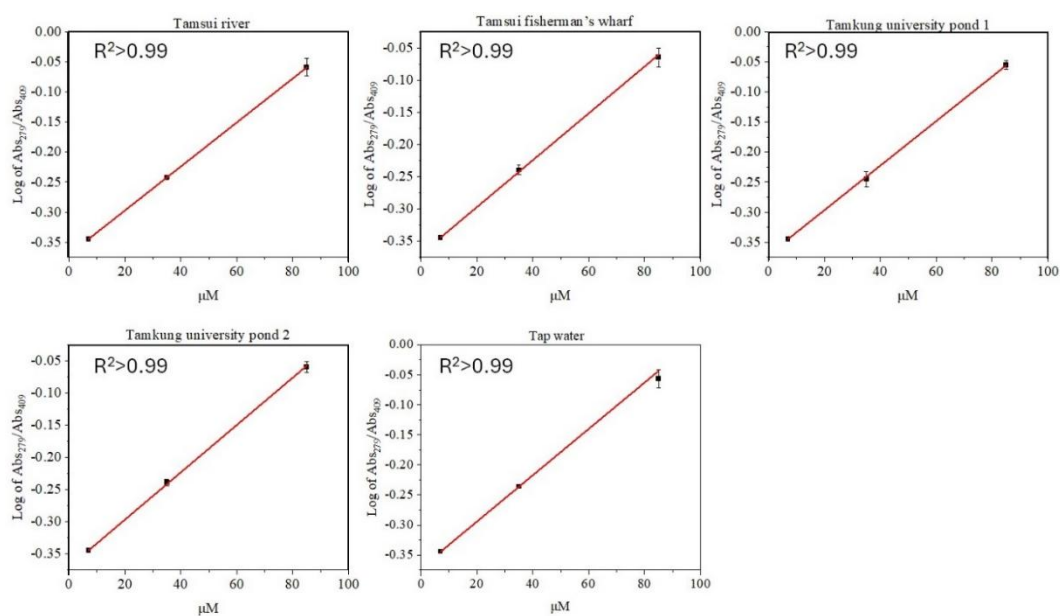


Figure S3. Linear calibration plots of $\log(\text{Abs}_{279}/\text{Abs}_{409})$ versus H_2S concentration for YG2 ($1.0 \times 10^{-4} \text{ M}$) in different real water samples.

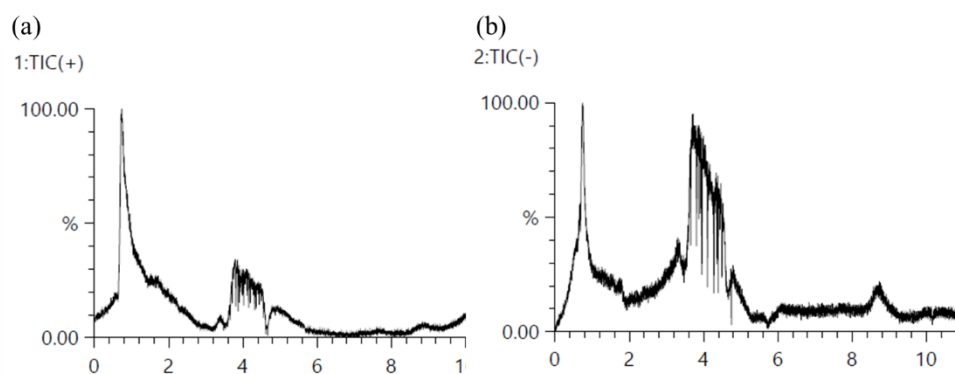


Figure S4. Total ion chromatograms (TIC) of the post-reaction solution of YG2 after exposure to H₂S recorded in (a) positive-ion and (b) negative-ion modes under identical LC/MS conditions. Both TIC traces display multiple chromatographic components without a single dominant molecular ion peak, indicating increased compositional complexity in the post-reaction mixture. These data are provided for qualitative comparison only. The reaction product(s) were not isolated, and no structural assignment or mechanistic conclusion is drawn from the LC/MS results.

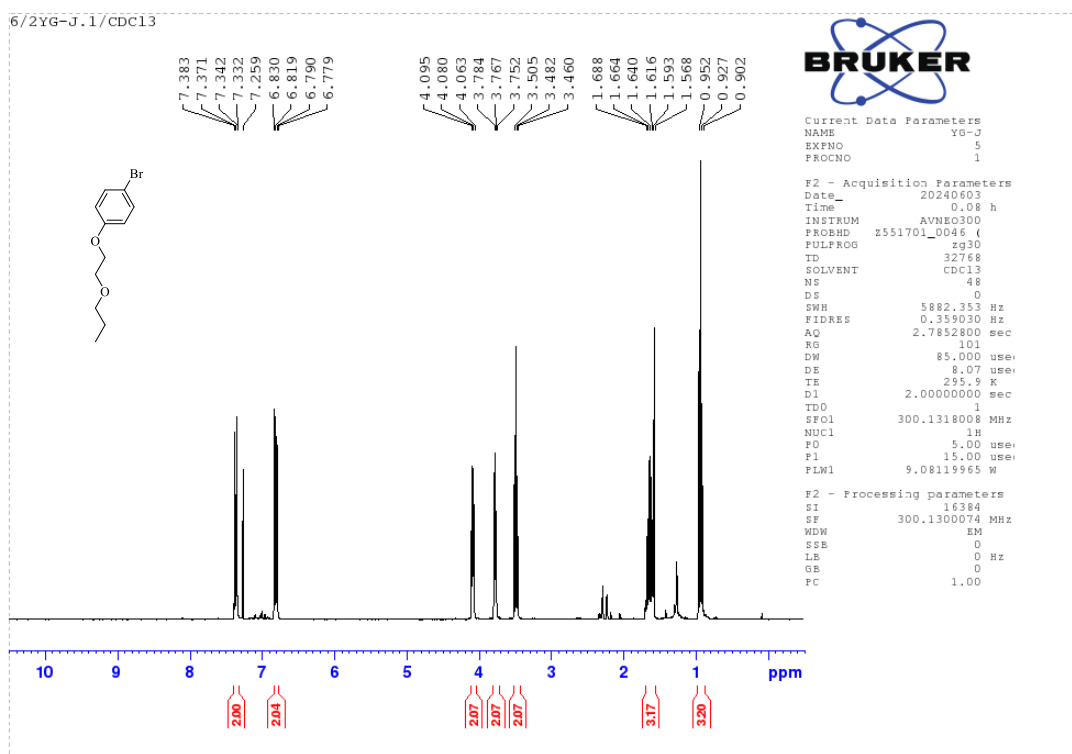


Figure S5. ¹H NMR (300 MHz, CDCl₃) of 1a.

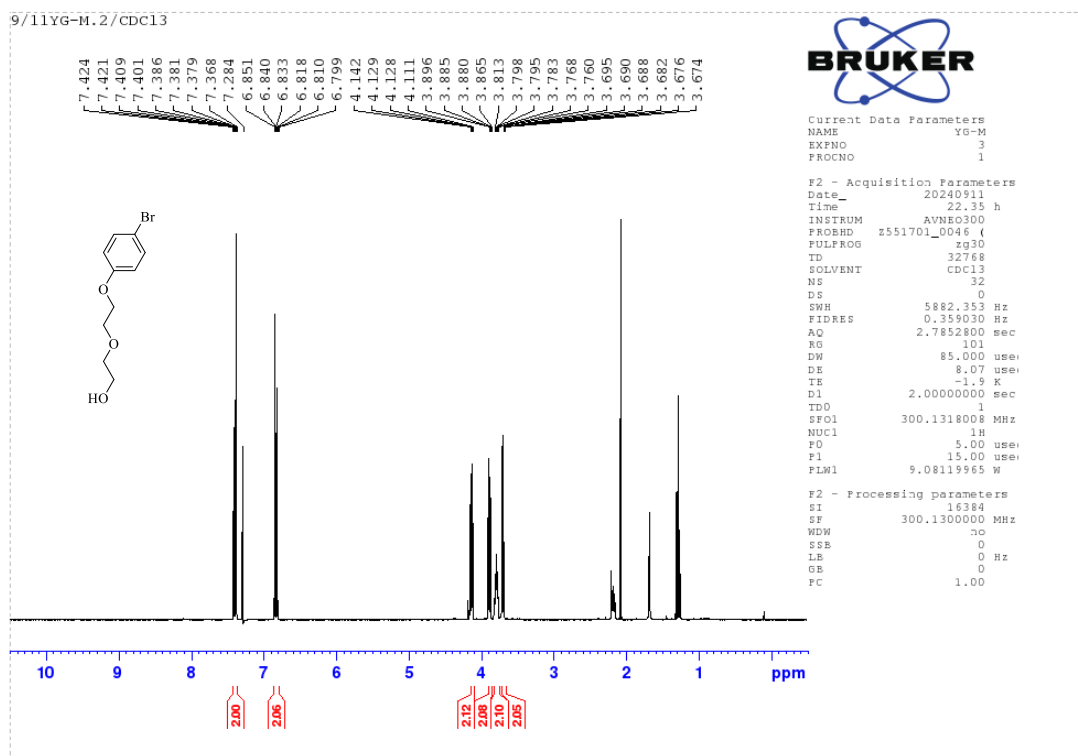


Figure S6. ^1H NMR (300 MHz, CDCl_3) of 1b.

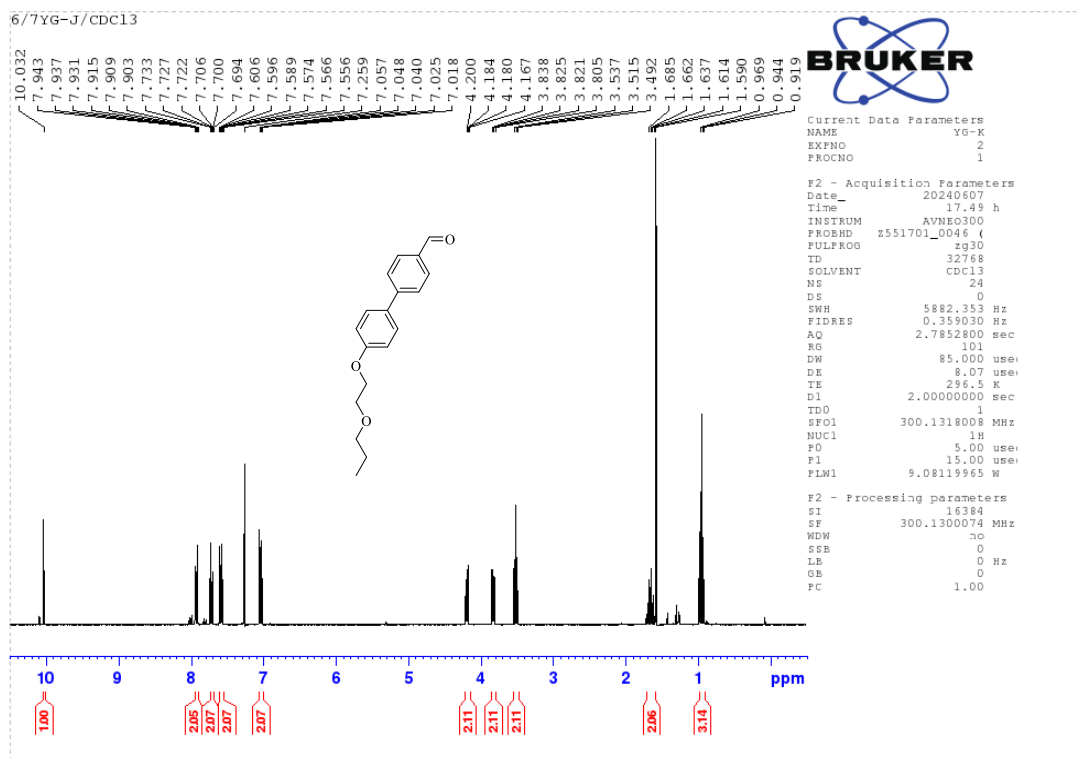


Figure S7. ^1H NMR (300 MHz, CDCl_3) of 2a.

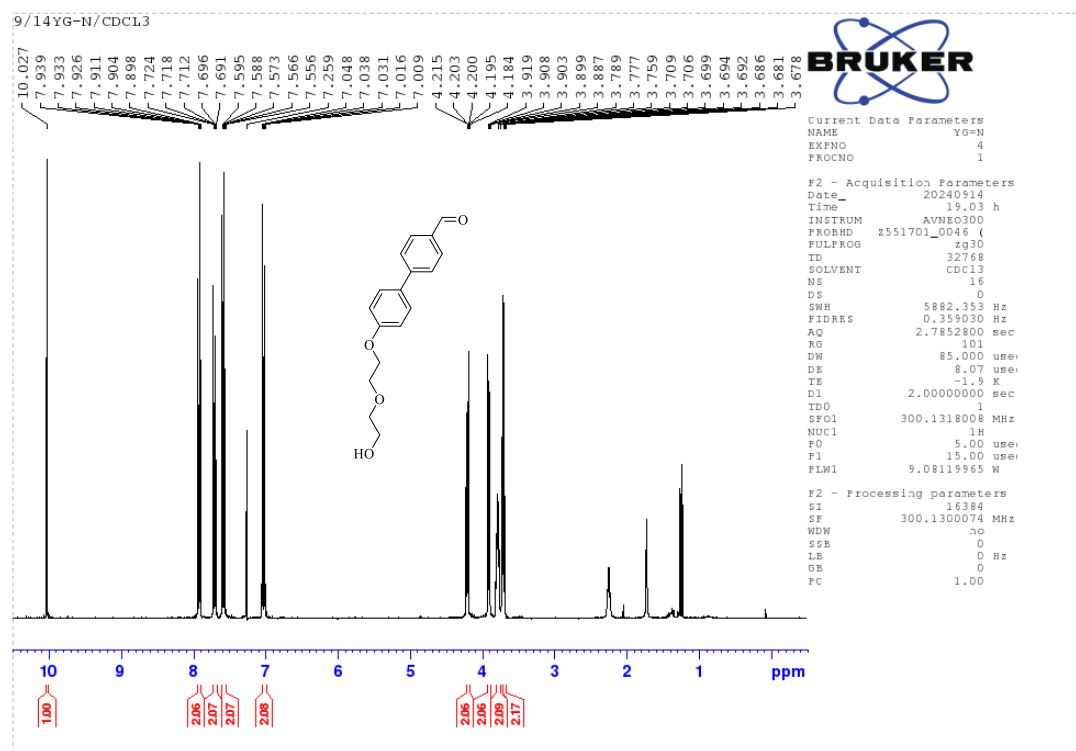


Figure S8. ¹H NMR (300 MHz, CDCl₃) of 2b.

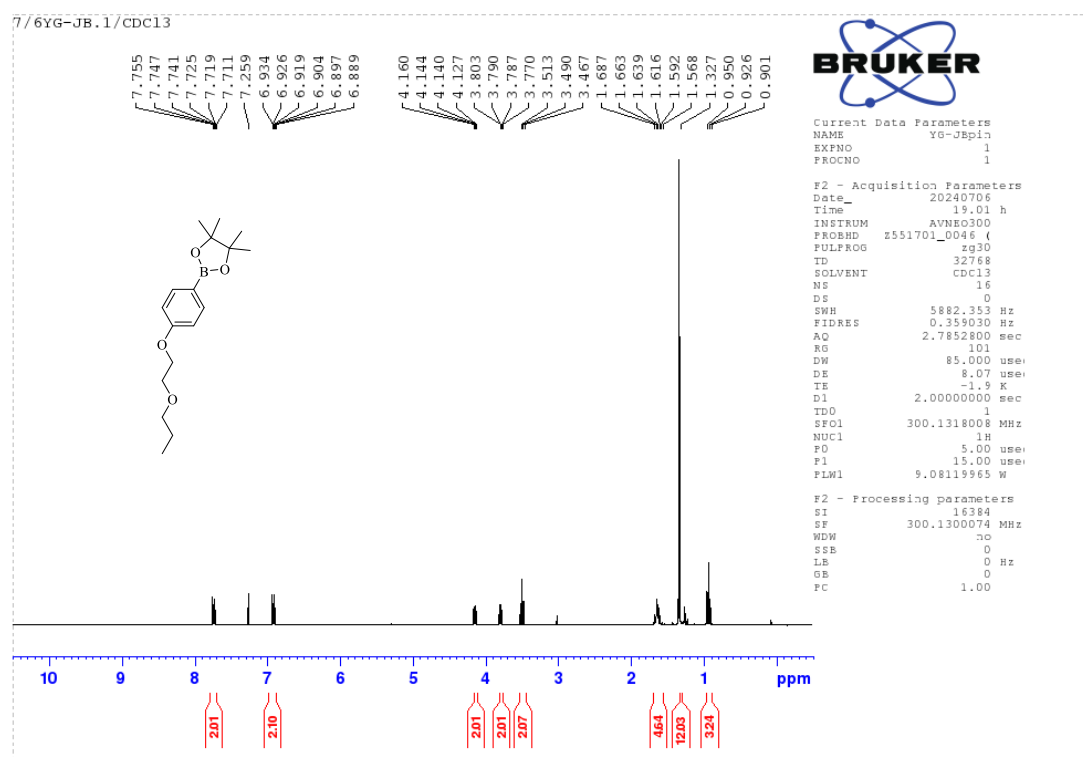


Figure S9. ¹H NMR (300 MHz, CDCl₃) of 3.

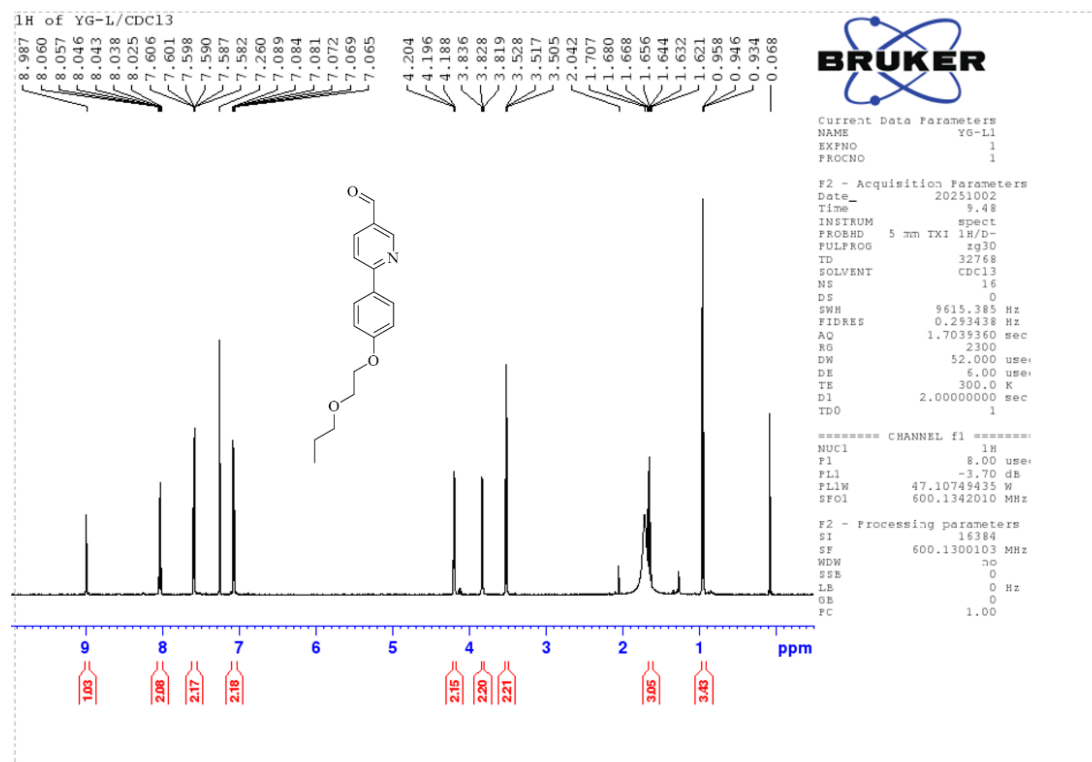


Figure S10. ¹H NMR (300 MHz, CDCl₃) of 2c.

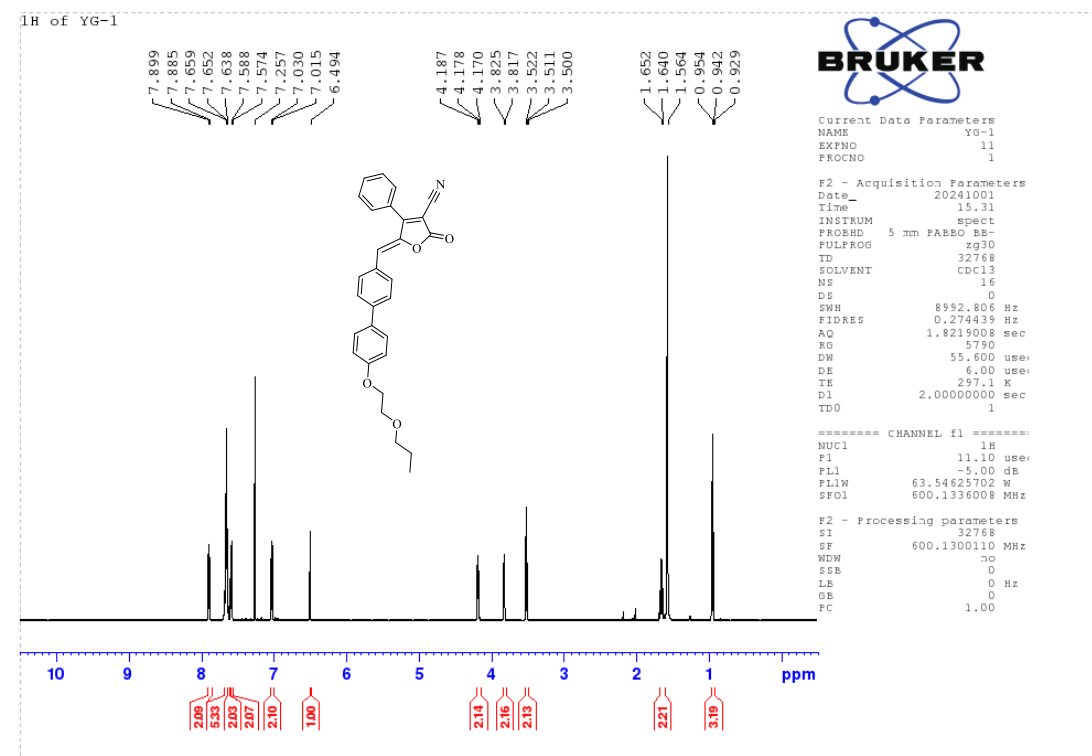


Figure S11. ¹H NMR (600 MHz, CDCl₃) of YG1.

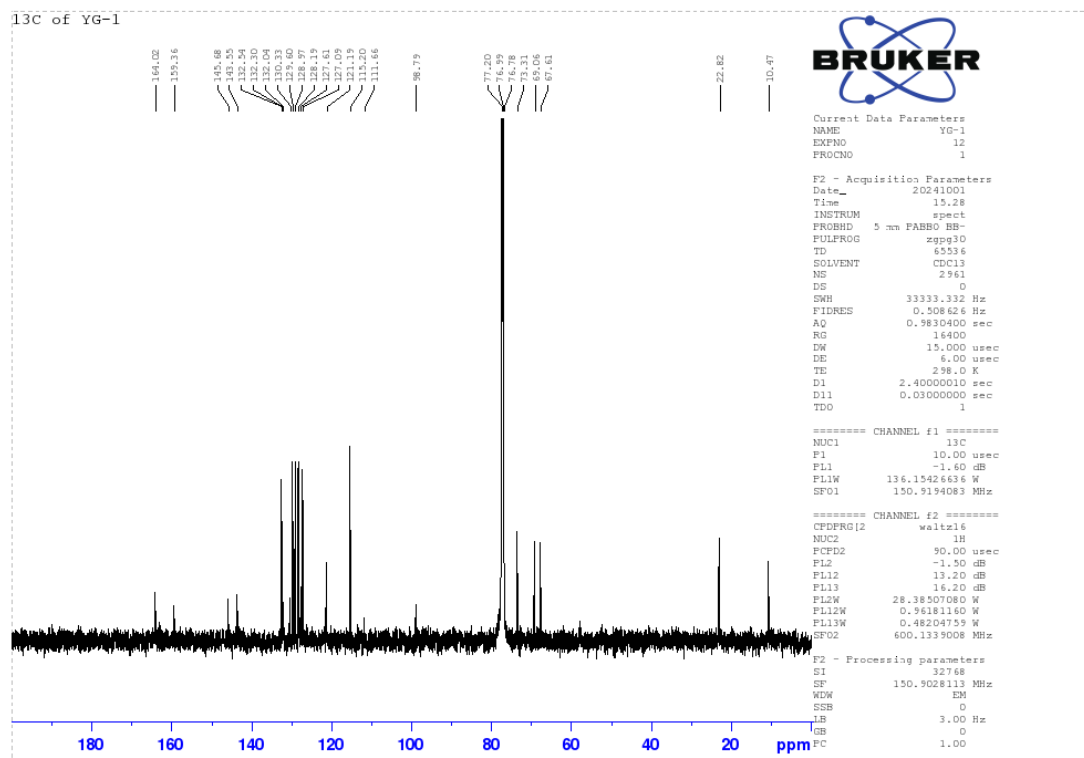


Figure S12. ¹³C NMR (600 MHz, CDCl₃) of YG1.

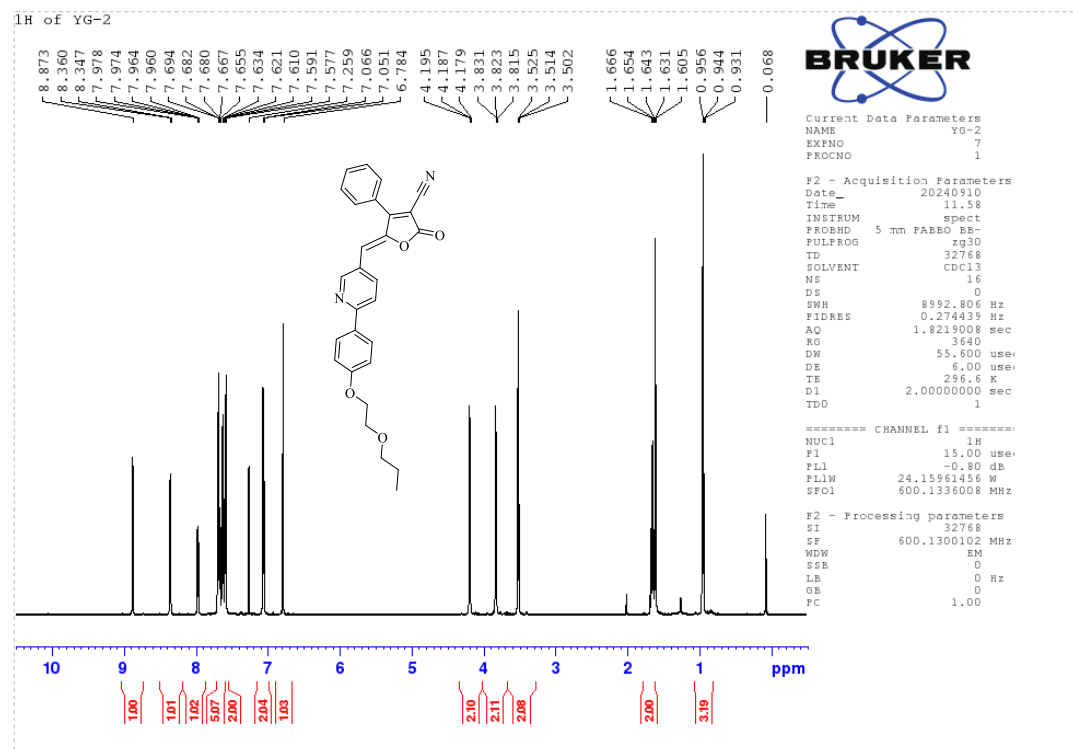


Figure S13. ¹H NMR (600 MHz, CDCl₃) of YG2.

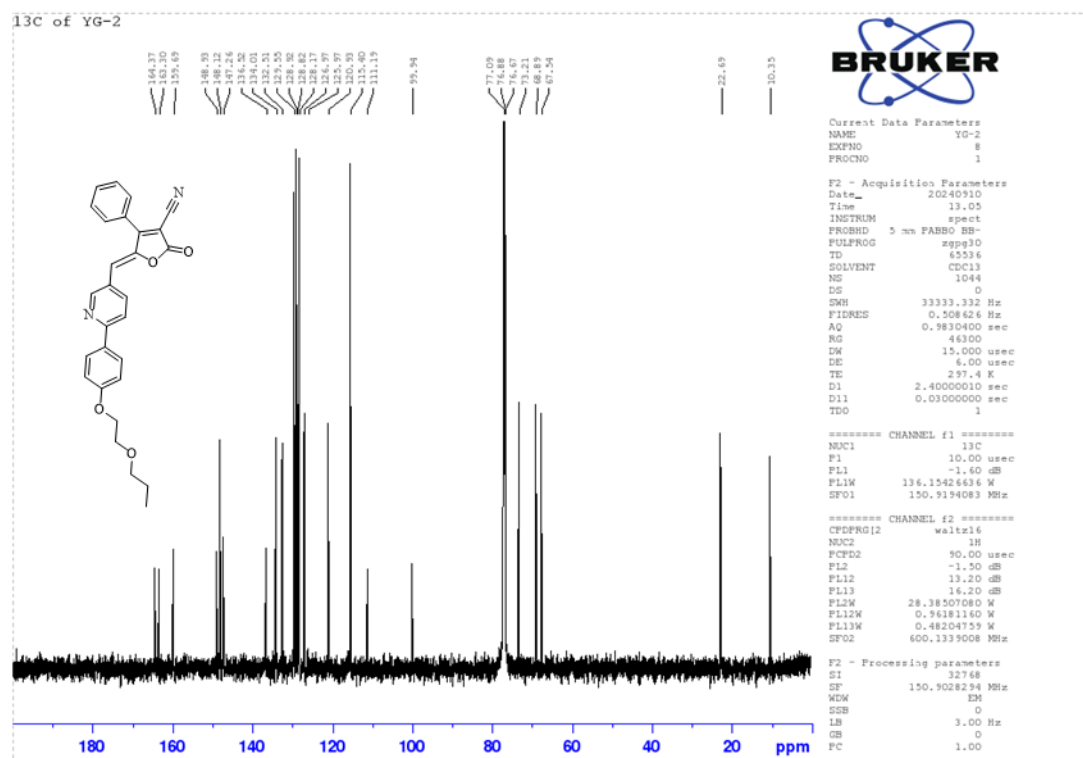


Figure S14. ¹³C NMR (600 MHz, CDCl₃) of YG2.

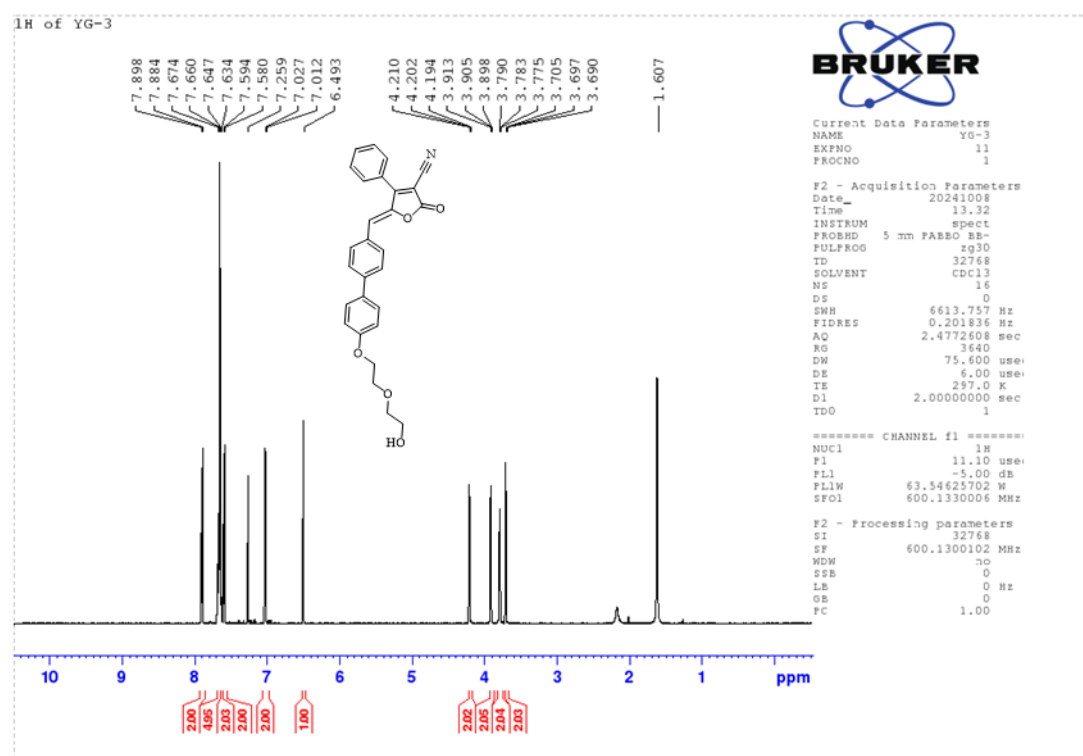


Figure S15. ¹H NMR (600 MHz, CDCl₃) of YG3.

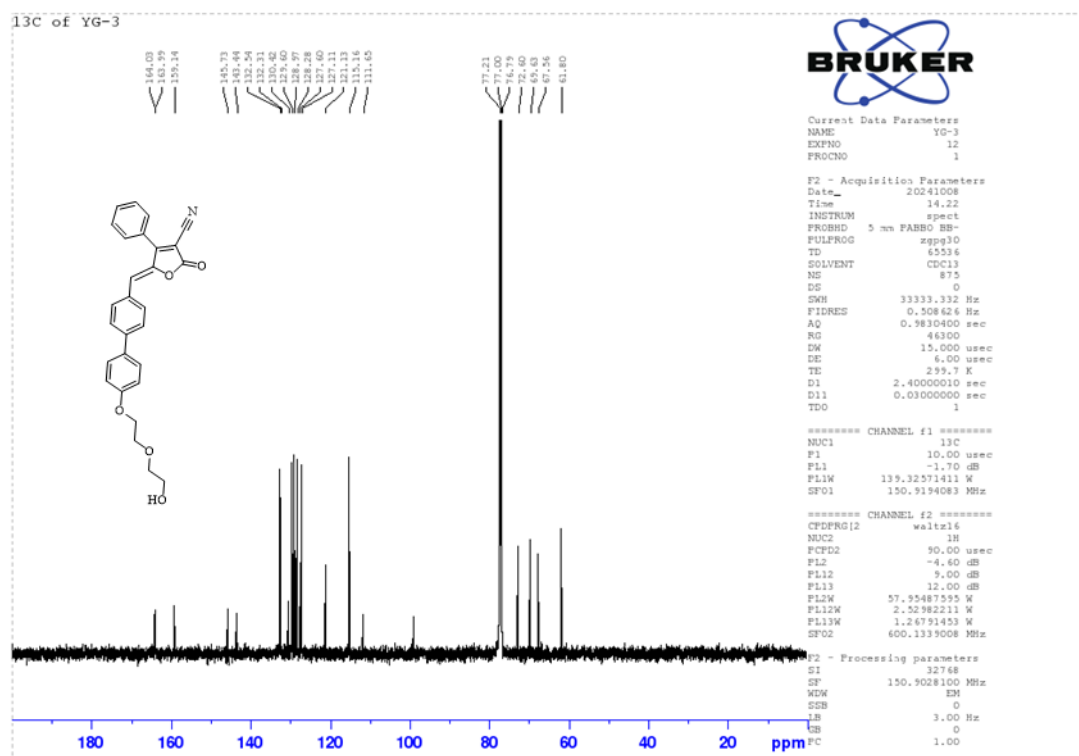


Figure S16. ¹³C NMR (600 MHz, CDCl₃) of YG3.

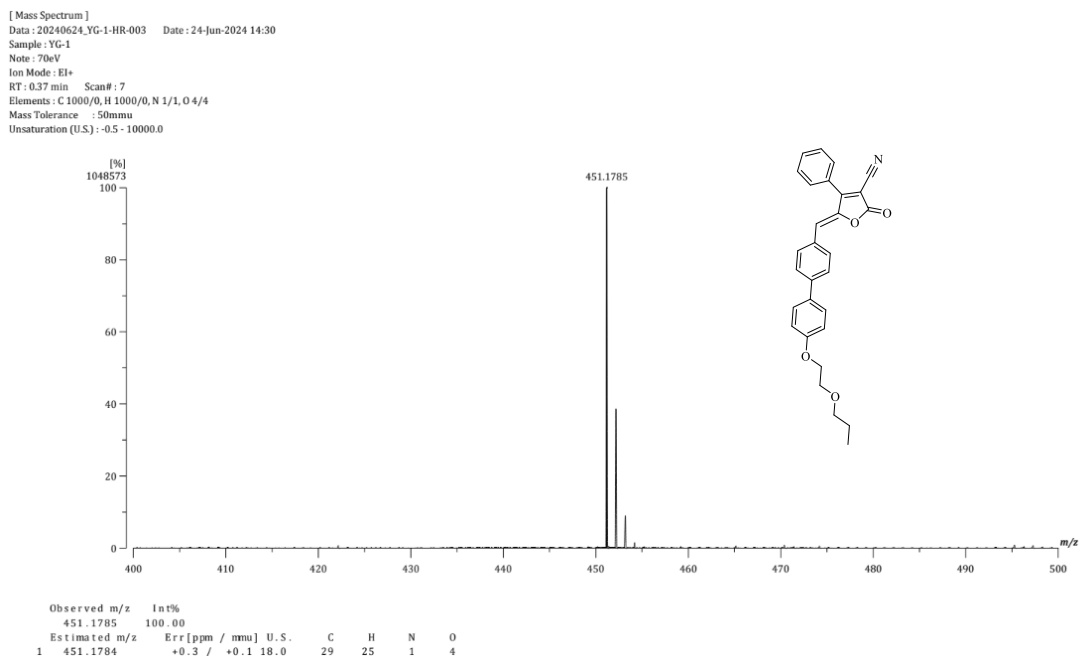


Figure S17. HRMS of YG1.

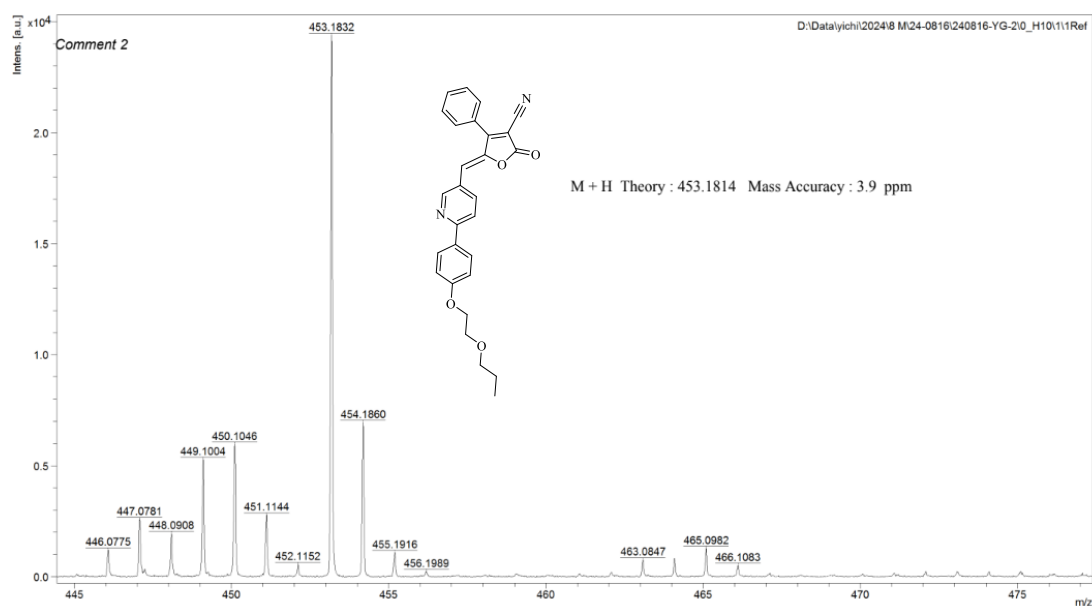


Figure S18. HR-MS of YG2.

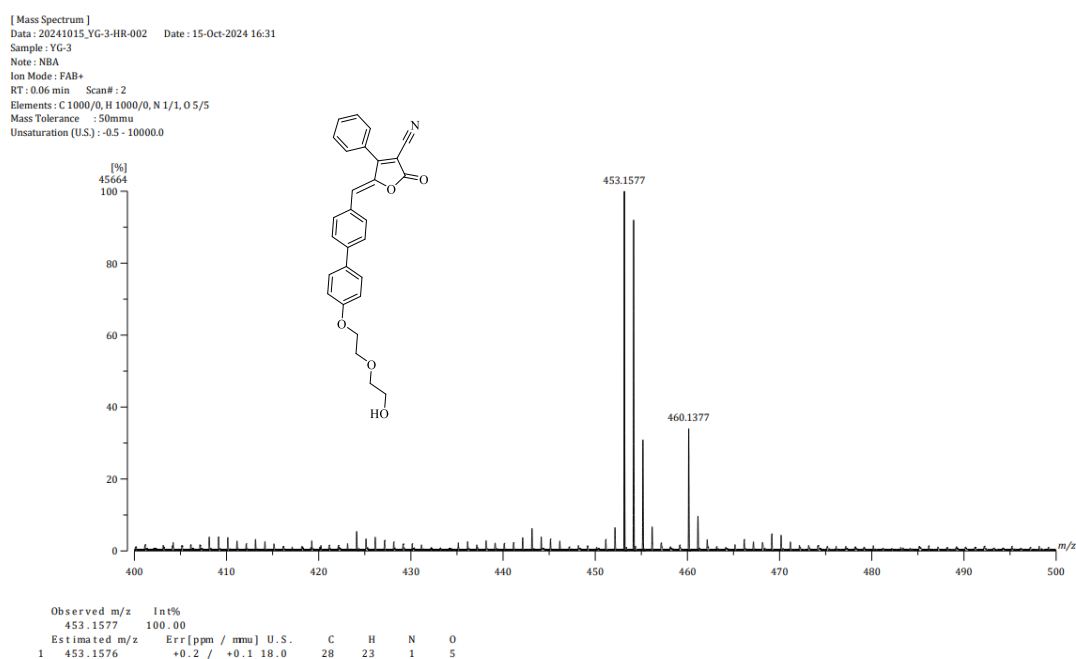


Figure S19. HR-MS of YG3.