Supplementary Material (ESI) for Chemical Communications

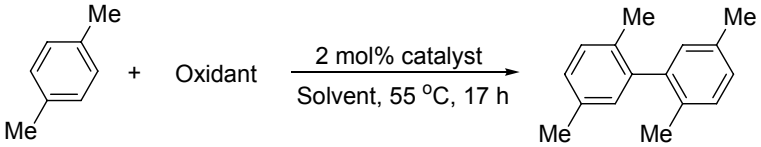
Supporting Information

A General Gold-Catalyzed Direct Oxidative Coupling of Non-activated Arenes

Anirban Kar,[a] Naveenkumar Mangu,[a] Hanns Martin Kaiser,[a,b] Matthias Beller[a,b] and Man Kin Tse[a,b]*

[a]*Leibniz-Institut für Katalyse e.V. an der Universität Rostock, Albert-Einstein-Str. 29a, 18059 Rostock, Germany*
[b]*Universität Rostock, Center for Life Science Automation (CELISCA), Friedrich-Barnewitz-Str. 8, D-18119 Rostock-Warnemünde, Germany*
E-mail: man-kin.tse@catalysis.de; fax: +49-381-1281-51193; tel.: +49-381-1281-193

Table S1. Catalyst screening of oxidative homo-coupling of *p*-xylene[a]



entry	catalyst	solvent	oxidant	yield [%][b]	TON[c]	TOF [h^{-1}][d]
1	$HAuCl_4$	HOAc	$PhI(OAc)_2$	**74**	37	2.2
2	$Au(OAc)_3$	HOAc	$PhI(OAc)_2$	39	20	1.1
3	AuCN	HOAc	$PhI(OAc)_2$	0	0	0
4	$AuCl(PPh_3)$	HOAc	$PhI(OAc)_2$	**76**	38	2.2
5	nil	HOAc	$PhI(OAc)_2$	0	0	0
6[e]	$FeCl_3$	HOAc	$PhI(OAc)_2$	0	0	0
7	NH_4FeCl_4	HOAc	$PhI(OAc)_2$	0	0	0
8	$AgNO_3$	HOAc	$PhI(OAc)_2$	0	0	0
9	$CuCl_2$	HOAc	$PhI(OAc)_2$	0	0	0
10	BF_3•OEt_2	HOAc	$PhI(OAc)_2$	0	0	0
11[e]	$HAuCl_4$	*p*-xylene	$PhI(OAc)_2$	58	29	1.7
12[e]	$HAuCl_4$	CH_3CN	$PhI(OAc)_2$	0	0	0
13[e]	$HAuCl_4$	CH_3NO_2	$PhI(OAc)_2$	12	6	0.4
14[e]	$HAuCl_4$	$ClCH_2CH_2Cl$	$PhI(OAc)_2$	42	21	1.2
15	$HAuCl_4$	TFA	$PhI(OAc)_2$	>1	>1	>0.1
16[	$HAuCl_4$	Ac_2O	$PhI(OAc)_2$	71	36	2.1
17	$HAuCl_4$	HOAc	$PhI(OCOCF_3)_2$	69	35	2.1
18	$HAuCl_4$	HOAc	$K_2S_2O_8$	0	0	0
19	$HAuCl_4$	HOAc	Oxone®	0	0	0
20	$HAuCl_4$	HOAc	35% CH_3CO_3H	0	0	0
21	$HAuCl_4$	HOAc	$Cu(OAc)_2$	0	0	0
22	$HAuCl_4$	HOAc	45% IBX	1	>1	>0.1

[a] Reaction conditions: Oxidant (1.0 mmol), *p*-xylene (10.0 mmol), dodecane (55 µL, internal standard) and catalyst (0.02 mmol, 2.0 mol%) were heated in the appropriate solvent (1.0 mL) at 55 °C in air for 17 h. [b] Calibrated GC yields were reported; % Yield = (no. of moles of biaryl)/(no. of moles of oxidant) x 100%. [c] Turnover number (TON) = (no. of moles of biaryl produced)/(no. of moles of catalyst). [d] Turnover frequency (TOF) = (no. of moles of biaryl produced)/[(no. of moles of catalyst) x (reaction time in hour)]. [e] 2 mL of solvent was used.

General: NMR spectra were recorded on a Bruker ARX 300 spectrometer, operating at 300 MHz for ^{1}H NMR, 75 MHz for ^{13}C NMR were reported downfield from $CDCl_3$ (δ: 7.27 ppm) for ^{1}H NMR. For ^{13}C NMR, chemical shifts were reported in the scale relative to the solvent of $CDCl_3$ (δ: 77.0 ppm) used as an internal reference. Mass spectra were in general recorded on an AMD 402/3 or a HP 5989A mass selective detector. Column chromatographies were performed with silica gel Fluka 60 (70-230 mesh ASTM).

General Procedure for $HAuCl_4$ Catalyzed Homo-coupling of Arenes: To a 10 mL vial arene (10 mmol), $PhI(OAc)_2$ (1 mmol), $HAuCl_4$ (0.02 mmol) and acetic acid (1 mL) were added. The mixture was stirred for 17 h at 55 ºC and then quenched with water (10 mL). The reaction mixture was extracted with EtOAc (3 x 10 mL) and the combined organic layer was washed

with saturated $NaHCO_3$ (2 x 20 mL), brine (10 ml), dried over Na_2SO_4, filtered and concentrated. The residue was purified by column chromatography to afford the desired product.

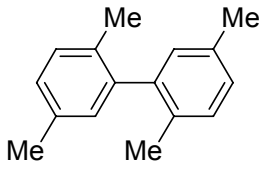


Table 1; Entry 1[1]

R_f = 0.63 (Hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 2.04 (s, 6 H), 2.35 (s, 6 H), 6.90-7.00 (m, 2 H), 7.05-7.2 (m, 4 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 19.30, 20.93, 127.70, 129.59, 129.94, 132.59, 134.82, 141.58; ATR-IR (cm^{-1}): 3017m, 2917m, 2859s, 1610m, 1501s, 1446w, 1376s, 1145s, 1037w, 890s, 882s, 812s, 754s, 7646s, 475m; MS (EI): *m/z* (rel. int.) 211 (11), 210 (66), 196 (15), 195 (100), 180 (33), 179 (23), 178 (21), 165 (31); HRMS calcd. for $C_{16}H_{18}$ *m/z* 210.14030, found m/z 210.13994.

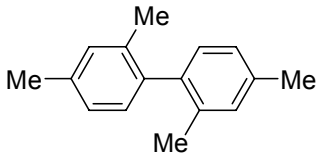


Table 1; Entry 4[2]

R_f = 0.60 (Hexane); colorless oil; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 2.05 (s, 6 H), 2.39 (s, 6 H), 6.90-7.20 (m, 6 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 19.79, 21.11, 126.19, 129.43, 130.52, 135.80, 136.51, 138.63; ATR-IR (cm^{-1}): 3013w, 2919w, 2858w, 1612s, 1487s, 1443w, 1377s, 1233s, 1035w, 1007s, 874s, 815s, 768s, 724s; MS (EI): *m/z* (rel. int.) 211 (15), 210 (90), 209 (7), 195 (100), 180 (39), 179 (27), 178 (22), 165 (35), 89 (11); HRMS calcd. for $C_{16}H_{18}$ *m/z* 210.14030, found m/z 210.14022.

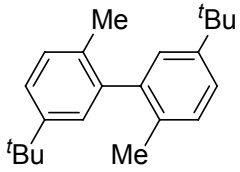


Table 1; Entry 5[3]

R_f = 0.64 (Hexane); colorless oil; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 1.34 (s, 18 H), 2.05 (s, 3 H), 7.18-7.25 (m, 4 H), 7.28-7.33 (m, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 19.37, 31.45, 34.41, 123.83, 126.64, 129.44, 132.78, 141.50, 148.30; ATR-IR (cm^{-1}): 2960w, 2867s, 1607s, 1491s, 1463m, 1391w, 1260m, 1202s, 1151m, 1113s, 894s, 847s, 818s, 738m, 682m; MS (EI): *m/z* (rel. int.) 295 (5), 294 (22), 280 (23), 279 (100), 57 (11); HRMS calcd. for $C_{22}H_{30}$ *m/z* 294.23420, found m/z 294.23429.

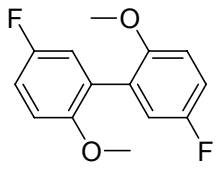


Table 1; Entry 6[4]

R_f = 0.14 (Hexane:ethyl acetate = 100:3); white solid; mp = 123-124 °C (hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.73 (s, 6 H), 6.88 (dd, J = 8.9, 4.6 Hz, 2 H), 6.96 (dd, J = 8.9, 2.8 Hz, 2 H), 7.00 (ddd, J = 8.8, 8.0, 3.2 Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 56.29, 112.08 (d, $^3J_{CF}$ = 8.4 Hz), 114.81 (d, $^2J_{CF}$ = 22.6 Hz), 118.11 (d, $^2J_{CF}$ = 23.2 Hz), 127.77 (dd, J_{CF} = 8.0, 1.6

Hz), 153.034 (d, $^{4}J_{CF}$ = 1.9 Hz), 156.64 (d, $^{1}J_{CF}$ = 238.2 Hz); ATR-IR (cm^{-1}): 3126w, 3072w, 3020w, 2958w, 2940w, 2910w, 2837w, 1869w, 1592w, 1506m, 1486s, 1464m, 1441m, 1425m, 1406w, 1293m, 1271m, 1256m, 1245s, 1219m, 1180s, 1158s, 1136m, 1035s, 1023s, 947m, 937w, 868s, 844m, 818s, 749s, 722s, 696m; MS (EI): *m/z* (rel. int.) 251 (14), 250 (100), 235 (24), 220 (40), 204 (32), 164 (10); HRMS calcd. for $C_{14}H_{12}F_2O_2$ *m/z* 250.07999, found m/z 250.079793; elemental analysis calcd. for $C_{14}H_{12}F_2O_2$ C 67.20 H 4.83, found C 67.02 H 4.68.

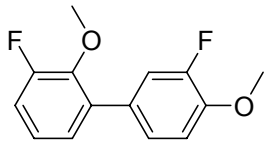


Table 1; Entry 7 (Minor isomer)

R_f = 0.21 (Hexane); colorless oil; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.72 (d, $^{5}J_{HF}$ = 1.5 Hz, 3 H), 3.92 (s, 3 H), 6.97-67.10 (m, 4 H), 7.24 (ddd, *J* = 8.4, 2.1, 1.1 Hz, 1 H), 7.30 (dd, *J* = 12.5, 2.2 Hz, 1 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 56.22, 61.17 (d, $^{4}J_{CF}$ = 4.4 Hz), 113.01 (d, $^{4}J_{CF}$ = 1.9 Hz), 115.86 (d, $^{2}J_{CF}$ = 19.4 Hz), 116.99 (d, $^{2}J_{CF}$ = 19.4 Hz), 123.76 (d, $^{3}J_{CF}$ = 8.4 Hz), 124.96 (d, $^{3}J_{CF}$ = 3.7 Hz), 125.48 (d, $^{4}J_{CF}$ = 2.6 Hz), 130.22 (dd, J_{CF} = 6.8, 3.0 Hz), 135.11 (unresolved dd), 145.04 (d, $^{2}J_{CF}$ = 10.8 Hz), 147.06 (d, $^{2}J_{CF}$ = 10.8 Hz), 151.93 (d, $^{1}J_{CF}$ = 245.2 Hz), 156.07 (d, $^{1}J_{CF}$ = 246.3 Hz); MS (EI): *m/z* (rel. int.) 251 (17), 250 (100), 235 (33), 220 (34), 204 (39), 175 (12), 164 (24); HRMS calcd. for $C_{14}H_{12}F_2O_2$ *m/z* 250.07999, found m/z 250.79764.

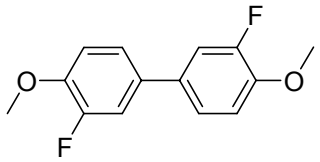


Table 1; Entry 7 (Major isomer)[5]

R_f = 0.11 (Hexane); white solid; mp = 155-156 °C (hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.85 (s, 6 H), 6.90-6.95 (m, 2 H), 7.13-7.21 (m, 4 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 56.33, 113.67 (d, $^{4}J_{CF}$ = 2.6 Hz), 114.37 (d, $^{2}J_{CF}$ = 19.3 Hz), 122.17 (d, $^{3}J_{CF}$ = 3.3 Hz), 132.94 (dd, J_{CF} = 6.5, 2.0 Hz), 146.94 (d, $^{2}J_{CF}$ = 10.3 Hz), 152.54 (d, $^{1}J_{CF}$ = 245.9 Hz); ATR-IR (cm^{-1}): 3051w, 3030w, 2977w, 2950w, 2922w, 2845w, 2582w, 2031w,1618m, 1575m, 1499s, 1463s, 1440s, 1404m, 1303s, 1260s, 1209s, 1179s, 1133s, 1043s, 1013s, 863s, 839s, 800s, 760s; MS (EI): *m/z* (rel. int.) 251 (13), 250 (73), 236 (15), 235 (100), 207 (14), 192 (17), 164 (17); HRMS calcd. for $C_{14}H_{12}F_2O_2$ *m/z* 250.07999, found m/z 250.080037; elemental analysis calcd. for $C_{14}H_{12}F_2O_2$ C 67.20 H 4.83, found C 67.64, H 4.67.

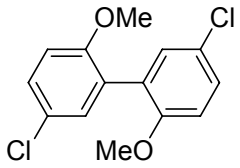


Table 1; Entry 8[4,6]

R_f = 0.29 (Ethyl Acetate: Hexane = 1:19); white solid; ; mp = 109-110 °C; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.77 (s, 6 H), 6.90 (d, *J* = 8.6 Hz, 2 H), 7.21 (d, *J* = 2.8 Hz, 2 H), 7.30 (dd, *J* = 8.6, 2.8, Hz, 2 H); *m/z* (rel. int.) = 286 (11), 285 (9), 284 (6), 283 (15), 282 (100), 232 (49), 217 (19), 189 (11); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 55.97, 112.23, 125.18, 127.94, 128.62, 131.01, 155.56; ATR-IR (cm^{-1}): 3004m, 2934m, 2835s, 1766w, 1729w, 1590,1499w, 1487w, 1469m, 1443m, 1288w, 1271m, 1242b, 1230m, 1181s, 1147s, 1134s, 1096s, 1021s, 889s, 878, 865s, 810, 753s, 727m, 654s; HRMS calcd. for $C_{14}H_{12}Cl_2O_2$ *m/z* 282.02089, found m/z 282.02140.

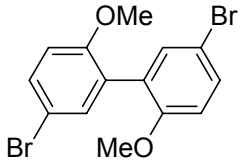


Table 1; Entry 9[4,9]

R_f = 0.28 (Ethyl acetate: hexane = 1:19); white solid; ; mp = 105-107 °C; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.78 (s, 6 H), 6.85 (d, *J* = 8.8 Hz, 2 H), 7.34 (d, *J* = 2.6, Hz, 2 H), 7.44 (dd, *J* = 8.8, 2.6, Hz, 2 H); *m/z* (rel. int.) = 374 (49), 373 (16), 372 (100), 371 (9), 370 (51), 278 (41), 276 (41), 263 (25), 261 (27), 235 (16), 233 (15), 139 (20), 138 (12), 126 (27), 63 (12); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 55.91, 112.48, 112.71, 128.35, 131.62, 133.77, 156.09; ATR-IR (cm^{-1}): 3077s, 3017m, 2936w, 2835w, 1599w, 1584w, 1496w, 1479w, 1458m, 1435s, 1410w, 1377s, 1289s, 1257w, 1242w, 1221w, 1180w, 1148s, 1138s, 1082s, 1029w, 1018w, 883s, 868w, 842w, 815w, 806w, 742s, 724w, 670w; HRMS calcd. for $C_{14}H_{12}Br_2O_2$ *m/z* 369.91986, found m/z 369.91955.

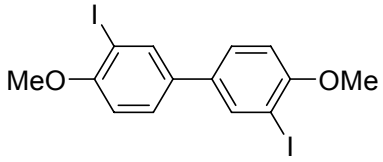


Table 1; Entry 10 (Major isomer)[4,8]

R_f = 0.20 (Ethyl acetate: hexane = 1:19); white solid; mp = 150-152 °C; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.92 (s, 6 H), 6.87 (d, *J* = 8.6 Hz, 2 H), 7.46 (d, *J* = 8.6, 2.3, Hz, 2 H), 7.98 (d, *J* = 2.3, Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 55.47, 87.41, 110.96, 127.73, 133.90, 137.57, 157.45; ATR-IR (cm^{-1}): 2963s, 2933m, 2833m, 1594s, 1565s, 1549s, 1474w, 1434m, 1404s, 1375w, 1269w, 1244s, 1183s, 1144w, 1049s, 1027w, 941s, 872w, 842s, 805w, 792w, 719s, 706s, 693s, 661s; MS (EI): *m/z* (rel. int.) 468 (3), 467 (16), 466 (100), 451 (42), 309 (149, 167 (12), 126 (18); HRMS calcd. for $C_{16}H_{16}I_2O_2$ *m/z* 465.89212, found m/z 465.891914.

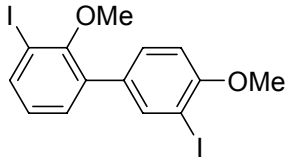


Table 1; Entry 10 (Minor isomer)

R_f = 0.31 (Ethyl acetate: hexane = 1:19); viscous liquid; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.44 (s, 3 H), 3.94 (s, 3 H), 6.84-6.94 (m, 2 H), 7.24-7.31 (m, 1 H), 7.56 (dd, *J* = 8.5, 2.2 Hz, 1 H), 7.75 (dd, *J* = 7.9, 1.6 Hz, 1 H), 7.56 (d, *J* = 2.2 Hz, 1 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 56.40, 60.29, 85.67, 93.15, 110.50, 126.19, 130.09, 131.11, 132.09, 133.83, 138.49, 139.61, 156.74, 157.62; ATR-IR (cm^{-1}): 3001w, 2929m, 2837s, 1724s, 1594s, 1546m, 1492s, 1455m, 1413s, 1373s, 1281m, 1249m, 1233m, 1180s, 1146m, 1074s, 1053s, 1016m, 999w, 888s, 814s, 781m, 755s, 731s, 664s; MS (EI): *m/z* (rel. int.) 468 (2), 467 (16), 466 (100), 324 (35), 309 (17), 139 (14), 126 (12); HRMS calcd. for $C_{16}H_{16}I_2O_2$ *m/z* 465.89212, found m/z 465.892060.

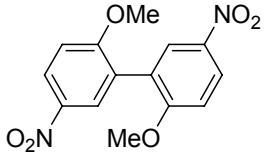


Table 1; Entry 11[9]

R_f = 0.16 (Hexane: ethyl acetate = 8:2); Yellow solid; mp = 266-268 °C (hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.90 (s, 6 H), 7.07 (d, *J* = 9.2 Hz, 2 H), 8.18 (d, *J* = 2.8 Hz, 2 H), 8.32 (d, *J* = 9.2, 2.8 Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 56.39, 110.63, 125.85, 125.89, 127.19, 141.15, 161.85; ATR-IR (cm-1): 3129w, 2921w, 2847s, 1896s, 1611s, 1580w, 1510s, 1470m, 1453w, 1422w, 1335s, 1259s, 1182s, 1146, 1112w, 1097w, 1034s, 1013s, 900s, 863s, 823s, 786s, 747m, 713s; MS (EI): *m*/*z* (rel. int.) 305 (21), 304 (100), 245 (14), 228 (16), 73 (13), 44 (46), 32 (72).

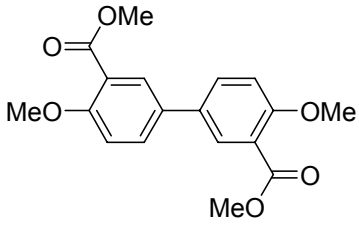


Table 1; Entry 12 (Major isomer)

R_f = 0.19 (Hexane: ethyl acetate = 7:3); white solid; mp = 115-117 °C (hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.93 (s, 6 H), 3.95 (s, 6 H), 7.05 (d, *J* = 8.8 Hz, 2 H), 7.66 (dd, *J* = 8.8, 2.4 Hz, 2 H), 8.00 (d, *J* = 2.4, Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 52.13, 56.17, 112.49, 120.29, 129.79, 131.48, 131.86, 158.37, 166.60; ATR-IR (cm^{-1}): 3033s, 2925w, 2840s, 1704s, 1611s, 1567s, 1489s, 1433m, 1380s, 1313s, 1258s, 1236w, 1181s, 1154s, 1094s, 1059s, 1013s, 960s, 900s, 841s, 801s, 778s, 705s, 678s; MS (EI): *m*/*z* (rel. int.) 331 (20), 330 (100), 315 (12) 300 (7), 299 (36), 297 (15), 285 (10), 139 (9); HRMS calcd. for $C_{18}H_{18}O_6$ *m/z* 330.1098, found *m/z* 330.1103.

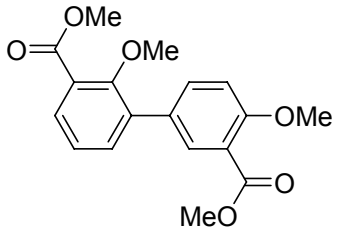


Table 1; Entry 12 (Minor isomer)

R_f = 0.27 (Hexane: ethyl acetate = 7:3); colorless oil; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 3.50 (s, 3 H), 3.91 (s, 3 H), 3.95 (s, 3 H), 3.98 (s, 3 H), 7.05 (d, *J* = 8.7 Hz, 1 H), 7.22 (t, *J* = 7.1 Hz, 1 H), 7.50 (dd, *J* = 5.7, 2.0 Hz, 1 H), 7.71-7.78 (m, 2 H), 8.01 (d, *J* = 2.0 Hz, 1 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 52.08, 52.31, 56.11, 61.54, 111.92, 119.92, 124.04, 125.71, 129.43, 130.38, 132.27, 134.24, 134.60, 135.07, 157.14, 158.59, 166.45, 166.81; MS (EI): *m*/*z* (rel. int.) 331 (22), 330 (100), 299 (42), 297 (22), 256 (12), 239 (19), 238 (13), 209 (10), 139 (13), 126 (129, 44 (11), 32 (11);

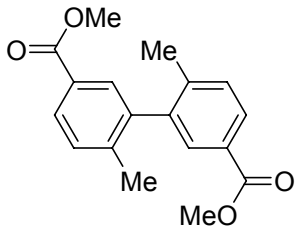


Table 1; Entry 13[10]

R_f = 0.36 (Hexane: ethyl acetate = 9:1); white solid; mp = 134-136 °C (hexane); ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 2.11 (s, 6H), 3.90 (s, 6 H), 7.36 (d, *J* = 8.0 Hz, 2 H), 7.79 (d, *J* = 1.8, Hz, 2 H), 7.96 (dd, *J* = 8.0, 1.8 Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 20.04, 52.01, 127.84, 128.78, 130.14, 130.42, 140.65, 141.41, 167.02; ATR-IR (cm^{-1}): 3429s, 3024s, 2954w, 1721s, 1606s, 1574s, 1433s, 1295m, 1254w, 1231w, 1189m, 1110w, 1045s, 997m, 966m, 912s, 853s, 834s, 790w, 761w; MS (EI): *m/z* (rel. int.) 299 (18), 298 (92), 283 (11), 268 (17), 267 (100), 239 (13), 180 (31), 179 (25), 178 (209, 165 (40), 118 (26), 103 (13), 89 (13); HRMS calcd. for $C_{18}H_{18}O_4$ *m/z* 298.11996, found m/z 298.119669.

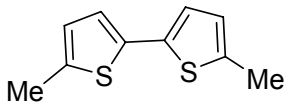


Table 1; Entry 14[11]

R_f = 0.63 (Hexane); white solid; mp = 62-65 °C; ^{1}H NMR (300.1 MHz, $CDCl_3$): δ = 2.48 (d, *J* = 1.1 Hz, 6 H), 6.65 (qd, *J* = 3.8, 1.1 Hz, 2 H), 6.89 (d, *J* = 3.8 Hz, 2 H); ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 15.30, 122.84, 125.72, 135.49, 138.45; ATR-IR (cm^{-1}): 3066s, 2972w, 2914m, 2850m, 2736s, 1717s, 1570s, 1531s, 1450w, 1381m, 1202s, 1155m, 1051s, 1036w, 871s, 858s, 778w, 737s, 667s; MS (EI): *m/z* (rel. int.) 195 (18), 194 (100), 193 (73), 179 (10), 161 (33), 96 (8), 32 (30); HRMS calcd. for $C_{10}H_{10}S_2$ *m/z* 194.02184, found m/z 194.022189.

References:

1 H. Feng; C. Gang, Z. Haiquan, Z. Yan, X. Zengqi, Y. Bing, M. Yuguang, L. Shiyong, S. Jiacong *Chem. Commun*. **2003**, *17*, 2206 - 2207.

2 a) T. Hirofumi, I. Minako, M. Tomohiro, K. Yasuyuki *Tetrahedron Lett*. **2002**, 43, 9241 - 9244. b) C. S. Chao, C. H. Cheng, C. T. Chang *J. Org. Chem*. **1983**, 48, 4904-4907.

3 M. Tashiro, T. Yamato *J. Org. Chem.* **1979**, *44*, 3037-3041.

4 S. F. Aver'yanov, A. P. Rudenko *Russ. J. Org. Chem*. **1995**, *31*, 1089-1098.

5 D. R. Dickerson, G. C. Finger, R. H. Shiley *J. Fluorine Chem.* **1973/1974**, 3, 113-116.

6 P. Bovicelli, R. Antonioletti, A. Onori, G. Delogu, Fabbri, D. M. A. Dettori *Tetrahedron* **2006**, *62*, 635-639.

7 a) H. Gilman, J. Swiss, L. C. Cheney *J. Am. Chem. Soc.* **1940**, *62*, 1963-1967; b) M. R. Agharahimi, N. A. LeBel *J. Org. Chem.* **1995**, **60**, 1856-1863.

8 A.-S. Carlstroem, T. Frejd *J. Org. Chem.* **1991**, *56*, 1289-1293.

9 F. Kaoru, Y. Toshihide; F. Eiichi *Org. Magn. Reson*. **1981**, *17*, 250-256.

10 J. Kenner, E. Witham *J. Chem. Soc., Trans.* **1913**, *103*, 232-238.

11 a) W. Steinkopf, W. Hanske *Justus Liebigs Ann. Chem.* **1939**, *541*, 238-260; b) M. Kentaro, I. Haruka, M. Atsunori *J. Am. Chem. Soc.* **2004**, *126*, 5074-5075.