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Palladium-Mediated Carbosubstitutions in Spiranes

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Abstract: Carbosubstitutions in spirene triflates can be effected by Pd-catalyzed couplings with stannylated or zincated arenes. Differential carbosubstitution resulted from stepwise triflation and coupling in spiro[4,4]-nonane-1,6-dione. Catalytic hydrogenation of the 1,6-diphenyl-1,6-diene gave the *cic,cis*-disubstituted spirane. Metal hydride reduction of intermediate monoketone gave mainly the *cis*-alcohol. © 1999 Elsevier Science Ltd. All rights reserved.

Spirane skeletons are embedded in a variety of natural products. Syntheses of this class of natural products have yielded highly functionalized intermediate spiranes.[1] Stereochemical and chiroptical properties of substituted simple spirane systems have also been the focus for studies, particularly dienes with resemblance to allenes. In this context, successful chiral resolutions have been reported.[2]

The framework of the spiranes is rigid. Use of the stiff scaffold of spiranes for stereocontrol of pharmacophoric groups in bioorganic molecules, or the use of appropriately substituted spiranes as chiral auxiliaries in dissymmetric catalytic operations, have received little attention. The enantiomers of *cis,cis*-spiro[4,4]nonan-1,6-diols, however, have been investigated for their ability to induce stereoselectivity in metal hydride reductions of phenyl alkyl ketones,[3] and in hydroformylation of styrene.[4]

In our work, spiranes were to be substrates for carbylation reactions. Recent syntheses of spirane systems include palladium promoted intramolecular Heck reactions in spiroannulations to carbo- or heterocyclic structures,[5] cascade reactions,[5,6] radical promoted spiroannulations,[7] spiroannulation of ketals,[8] rearrangements reactions,[9] nickel mediated spiroannulations with acetylenes,[10] rhodium-catalyzed hydroacylations,[11] copper or samarium mediated spiroannulations,[12,13] acid or base catalyzed aldol condensations as well as alkylations.[14,15] We have reported on spiroannulations in the preparation of substituted spiro[4,4]nonanes by carbenoid rhodium insertion into C-H bonds.[16] Spiroannulation has also been effected by palladium catalysis.[17] A series of ruthenium(II)-catalyzed spiroannulations of dihydropyrazines have given heterocyclic spiranes as intermediates in the stereoselective preparation of cyclic α-amino acids.[18]

From our program on the preparation and substitution reactions in simple spiranes we herein report studies on substitution and stereoselectivities in reactions in the spiro[4,4]nonane system. In the program we are primarily interested in substitutions next to the spiro center in the α,α′-positions and use the readily available 1,6-dione **1** as substrate.[19] Reactions involving carbonium intermediates at the α-carbon are likely to end up in skeletal rearrangements, and S_N2 reactions are excluded for steric reasons. Addition of a metal hydride or organometallics to an α,α′-dioxospirane gives diols which are sensitive to ring opening reactions, especially when the carbon substituent is an arene or the system is an annelated arene derivative.[20,21] In this work we have chosen an alternative approach which avoids the intermediacy of 1,3-diols. Palladium-catalyzed cross-coupling carbylation reactions of enolate derived substrates are reported. The initial substrate in the reaction sequences were to be the corresponding triflates (*vide infra*).

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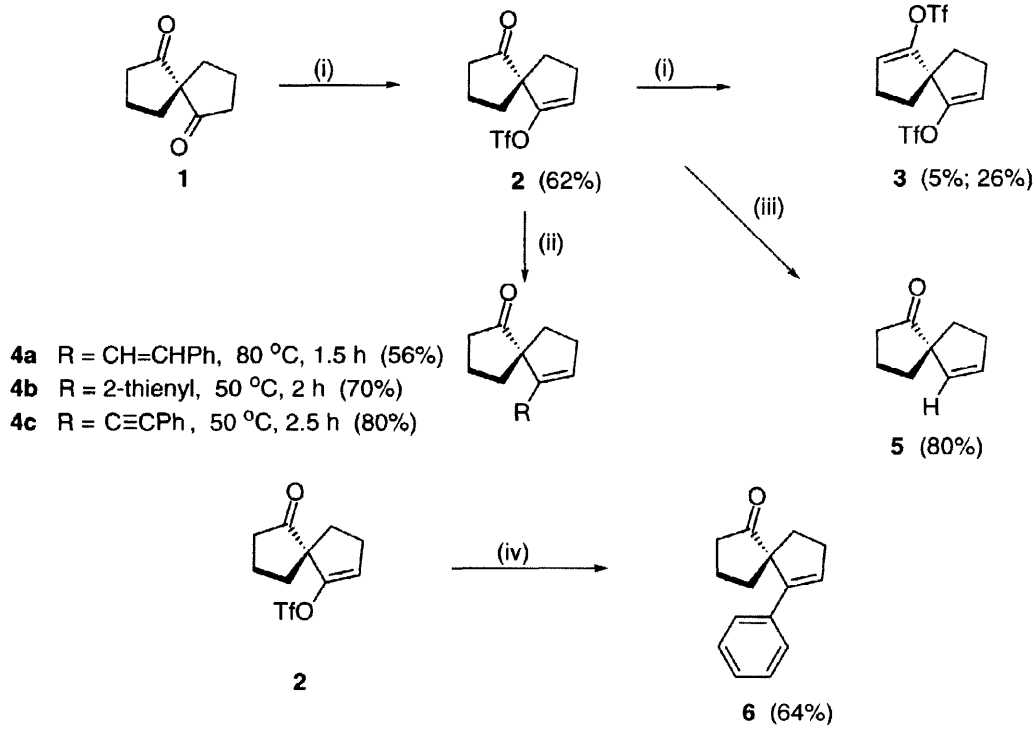
Triflation of the 1,6-diketone **1** under our best conditions was effected by triflic anhydride using pyridine in dichloromethane, initially at -78 °C (Scheme 1). The reaction was slow. After four days at ambient temperature the monotriflated product **2** was isolated in 62% yield and the ditriflate **3** was isolated in 5% yield. The triflates were stable to flash chromatography. Using the same reaction conditions with the monotriflate **2** as substrate gave only 26% of the ditriflated material **3**; most of the substrate **2** (50%) was recovered. The monotriflation allows for differential carbylations at the two carbonyl carbons in the diketone **1**. Thus coupling of the monotriflated product **2** gave a monoketone which could subsequently be triflated for a further coupling reaction (*vide infra*).



(i) Tf_2O, pyridine, CH_2Cl_2, -78 – 20 °C, 4 d; (ii) $RSnBu_3$, 6-10 mol% $Pd(Ph_3P)_4$, LiCl, dioxane; (iii) $HSnBu_3$, 5 mol% $Pd(Ph_3P)_4$, LiCl, dioxane, 50 °C, 2.5 h; (iv) $PhSnBu_3$, 5 mol% $Pd(dba)_2$, NMP, 20 °C, 4

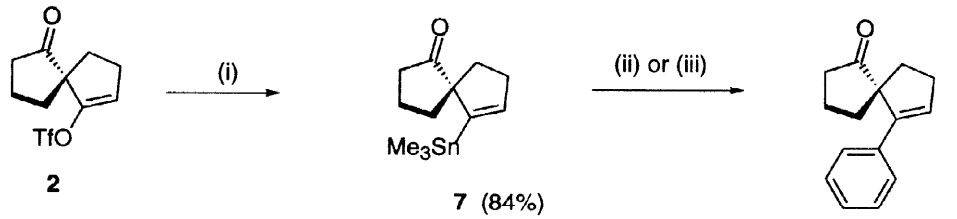
Scheme 1

Stille couplings between the monotriflate **2** and β-styryl-, 2-thienyl and phenylethynylstannanes was effected with tetrakis(triphenylphosphine)palladium by warming a solution in dioxane containing lithium chloride (Scheme 1). The ethenyl (**4a**), the ethynyl (**4c**) and the heteroaryl (**4b**) products were isolated in good yields. Coupling under these conditions failed for the corresponding phenylstannane reagent. The phenyl derivative **6**, however,was formed in 64% yield using a more active, less strongly coordinated Pd-catalyst, generated from $Pd(dba)_2$ and *N*-methyl-2-pyrrolidinone (NMP) as the weak coordinating donor.

The ready coupling reactions offer an opportunity to convert a carbonyl group in **1** into an endocyclic olefinic bond. Thus formation of the cycloalkene **5** was effected in high yield by coupling the monotriflate **2** with tributylstannane.

Conditions for reversing the polarization in the coupling of spiranes have also been studied. The reverse polarization is of interest when halides or triflates are the natural substrates for coupling reactions with spiranes.

Stannylation was used to effect metallation in the spirane, and the desired product **7** was available from a Pd-mediated coupling reaction with the triflate **2** and and hexamethyldistannane (Scheme 2). The stannylated product **7** was isolated in 80% yield and was stable to flash chromatography. Coupling reactions between the spirostannane **7** and iodobenzene or phenyl triflate furnished the phenyl derivative **6**. Triphenylarsine was the ptimum ligand for Pd in this reaction which was effected in the presence of copper iodide and NMP.

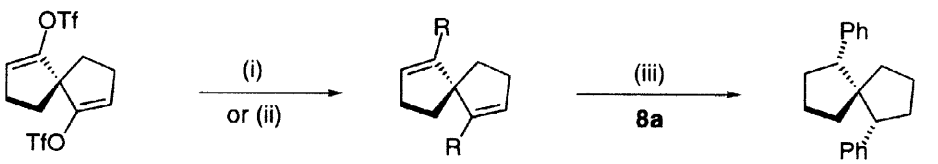


2 **7** (84%) **6** [(ii) 40%; (iii) 35%]

(i) $(Me_3Sn)_2$, 2 mol% $Pd(Ph_3P)_4$, LiCl, dioxane, 50 °C, 14 h
(ii) PhOTf, 4 mol% $PdCl_2(PhCN)_2$, $AsPh_3$, LiCl, CuI, NMP, 80 °C, 14 h
(III) PhI, 4 mol% $PdCl_2(PhCN)_2$, $AsPh_3$, CuI, NMP, 80 °C, 14 h

Scheme 2

In the studies of arylation of the ditriflate **3**, stannylated 2-thiophene furnished the dithienyl derivative **8b** in low yield whereas the monocoupling had proceeded well using the thienylstannane (Scheme 1, **4b**). For diphenylation, phenylzinc bromide was used as a reactive reagent for the preparation of the diphenyl spirane **8a**.



3

8a R = Ph (56%)
8b R = 2-thienyl (20%)

9 (67%)

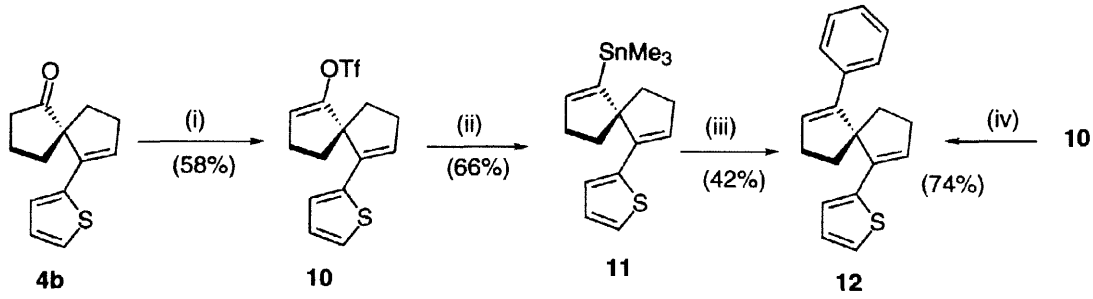
(i) PhZnBr, 10 mol% $Pd(Ph_3P)_4$, THF, 80 °C, 14 h; (ii) $Bu_3(2\text{-}C_4H_3S)Sn$, 10 mol% $Pd(Ph_3P)_4$, LiC dioxane, 50 °C, 14 h; (iii) H_2 (4 bar), Pd/C, EtOH, 5 d.

Scheme 3

Saturation of the double bonds in the 1,6-diene **8a** was postulated to proceed by hydrogen addition to the less hindered side of each spirane ring. Thus saturation of the double bond in the one ring forces the phenyl substituent into a *cis* relationship with respect to the remaining doubly bonded substituted carbon. The approach of the second double bond to the catalyst surface will be *trans* to the reduced function. Delivery of hydrogen from the catalyst surface will therefore force the second phenyl substituent into a *cis* relationship, the product being the *cis,cis*-diphenyl derivative **9**. Unequivocal structural determination was effected by a single crystal X-ray analysis (*vide infra*) which showed the product to have the relative *cis*-structure **9**.

Triflation of the monsubstituted ketone **4b** was effected using triflic anhydride and proceeded in acceptable yield. It will be recalled that ditriflation of the diketone **1** was difficult to effect (*vide supra*). Sequential substitution starting with the diketone **1** is demonstrated with the coupling reaction between the triflate **10** and phenylzinc bromide which proceeded very well to yield the differentially disubstituted spirane **12**. Reverse polarization has also been effected by the preparation of the stannane **11** using hexamethyldistannane

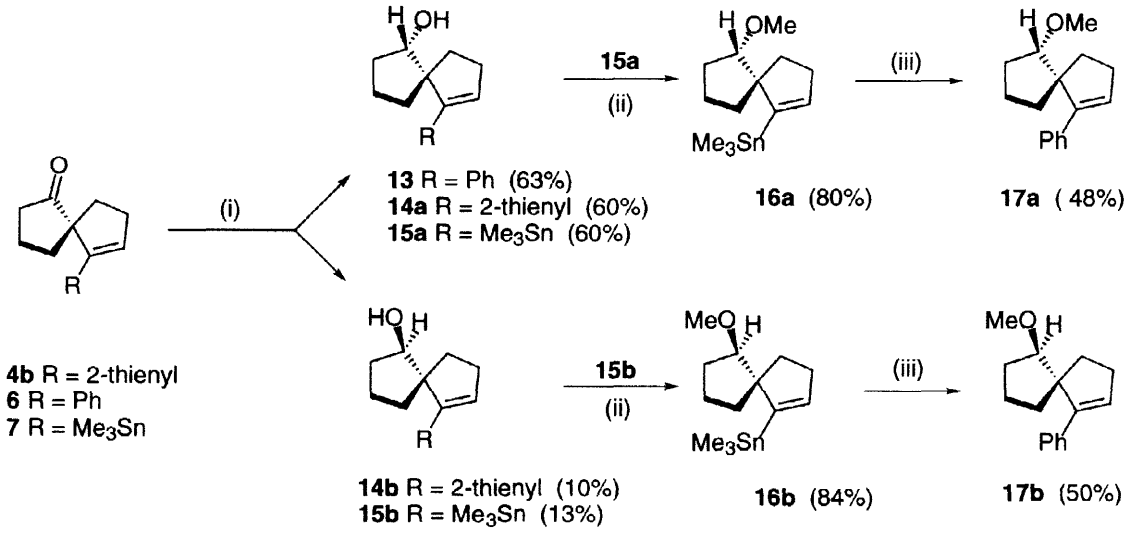
with Pd-catalysis. The latter was subsequently coupled with phenyl triflate in a Pd-mediated reaction with triphenylarsine as coordinating ligand to furnish the differentially disubstituted spirane **12**.



(i) Tf_2O, pyridine, CH_2Cl_2, -78 – 20 °C, 24 h; (ii) $(Me_3Sn)_2$, 5 mol% $Pd(Ph_3P)_4$, LiCl, dioxane, 50 °C, 2 h; (ii) PhOTf, 4 mol% $PdCl_2(PhCN)_2$, $AsPh_3$, LiCl, CuI, NMP, 80 °C, 14 h; (iv) PhZnBr, 10 mol% $Pd(Ph_3P)_4$, THF, 80 °C, 14 h

Scheme 4

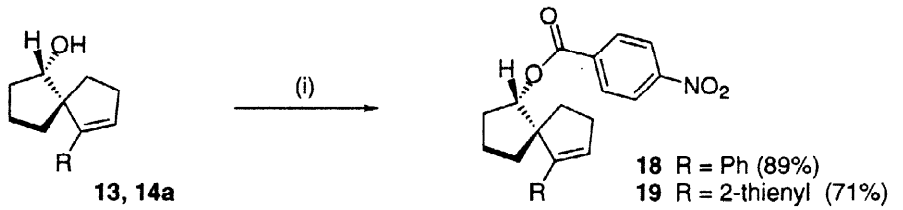
In metal hydride reductions of the carbonyl double bond in the substrates **4b**, **6** and **7**, the metal hydride was expected to approach the carbonyl carbon from the less hindered side away from the substituted double bond. Hence the hydroxyl group formed must have a *cis* relationship to the substituted double bond as in the structures **13**, **14a**, **15a**. From the phenyl derivative **6** only the *cis*-alcohol **13** was isolated. From the thienyl derivative **4b** both the *cis* and the *trans* products **14a**:**14b** were isolated in the ratio 6:1 in a total yield of 70%. The isomer ratio (**15a**:**15b**) and yields were similar from the trimethylstannyl derivative **7**. The stannyl isomers **15a** and **15b** were separated by flash chromatography and *O*-methylated, and the ether products **16a** and **16b** subjected to coupling reactions with phenyl triflate using triphenylarsine as ligand for palladium in the presence of copper iodide to yield the phenyl derivatives **17a** and **17b**, respectively.



(i) $NaBH_4$, $CeCl_3 \cdot 7H_2O$, MeOH, 0 °C, 20 min; (ii) NaH, MeI, DMF, THF, 0 - 20 °C
(iii) PhOTf, 5 mol% $PdCl_2(PhCN)_2$, $AsPh_3$, CuI, NMP, 80 °C, 2 h

Scheme 5

The phenyl and thiophene alcohols **13** and **14a** were transformed into the crystalline *p*-nitrobenzoates **18** and **19** and the relative stereochemistry determined by single crystal X-ray analysis.



13, 14a

18 R = Ph (89%)
19 R = 2-thienyl (71%)

(i) 4-Nitrobenzoyl chloride, DMAP, CH_2Cl_2, 20 °C, 14 h

Scheme 6

In conclusion we have described Pd-catalytic methodologies for carbosubstitution in the spiro[4,4]nonane system. Catalytic hydrogenation of the 1,6-diphenyl-1,6-diene to the corresponding *cis,cis*-diphenyl derivative was used to demonstrate a route leading to *cis,cis* α,α′- disubstitution in the spirane.

X-Ray data:

The compounds **9**, **18** and **19** crystallized in the centric space group $P2_1/c$. In the following only one of the enantiomers is shown.

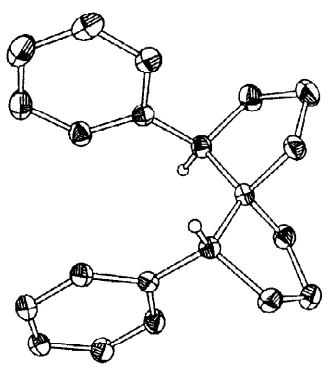


Fig.1

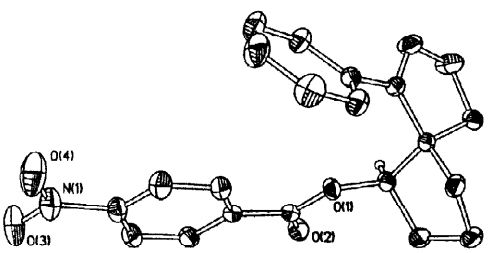


Fig.2

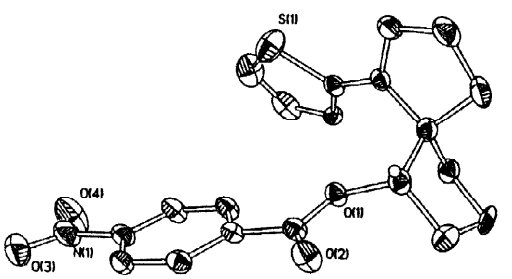


Fig.3

Fig. 1. ORTEP plot of *cis,cis*-1,6-bis(phenyl)-spiro[4,4]nonane (**9**). In the thermal-ellipsoidal plot of the X-ray structure of compound **9**, ellipsoids are shown at 50% probability. Only the H-atoms at stereogenic centres are shown. The molecule has an approximate two-fold axis of symmetry. Bond lengths and angles are normal.

Fig. 2. ORTEP plot of *cis*-6-phenyl-spiro[4,4]nona-6-en-1-yl *p*-nitrobenzoate (**18**). The thermal-ellipsoid plot of the X-ray structure of compound **18** shows the relative stereochemistry. Only one of the two crystallographically independent molecules is shown. For clarity H-atoms are omitted except that at the stereogenic centre.

Fig. 3. ORTEP plot of *cis*-6-(2-thienyl)-spiro[4,4]nona-6-en-1-yl *p*-nitrobenzoate (**19**). The thermal-ellipsoid plot of the X-ray structure of compound **19** shows the relative stereochemistry.

EXPERIMENTAL

X-ray crystallographic analysis data for the compounds **9**, **18**, and **19**.

X-ray data were collected on a Siemens SMART CCD diffractometer[22] using graphite monochromated Mo*K*α radiation (λ = 0.71073 Å). Data collection method: ω-scan, range 0.6°, crystal to detector distance 5 cm. Data reduction and cell determination were carried out with the SAINT and XPREP programs.[22] Absorption corrections were applied by the use of the SADABS program.[23] The structure was determined and refined using the SHELXTL program package.[24] The non-hydrogen atoms were refined with anisotropic thermal parameters; hydrogen positions were calculated from geometrical criteria and for **9** and **19** refined with isotropic thermal parameters. Atomic coordinates, bond lengths and angles, and thermal parameters have been deposited at the Cambridge Crystallographic Data Centre.

Crystal data for $C_{21}H_{24}$ (**9**). M = 276.40, monoclinic, $P2_1/c$, a = 10.295(1), b = 12.940(1), c = 11.998(1) Å, β = 103.46(5)°, V = 1554.4(1) Å^3, Z = 4, D_x = 1.181 Mg.m^{-3}, μ = 0.066 mm^{-1}, F(000) = 600, T = 150 K, measured 18939 reflections in 2θ range 4.1 - 66.3°, R_{int} = 0.033. 286 parameters refined against 5878 F^2, R = 0.049 for $I_o > 2\sigma(I_o)$ and 0.068 for all data (residual Δρ < 0.40 e.Å^{-3}).

Crystal data for $C_{22}H_{21}NO_4$ (**18**). M = 363.40, monoclinic, $P2_1/c$, a = 11.668(1), b = 8.021(1), c = 38.802(1) Å, β = 91.81(5)°, V = 3629.4(2) Å^3, Z = 8, D_x = 1.330 Mg.m^{-3}, μ = 0.092 mm^{-1}, F(000) = 1536, T = 150 K, measured 34233 reflections in 2θ range 3.6 - 56.6°, R_{int} = 0.056. 489 parameters refined against 9004 F^2, R = 0.084 for $I_o > 2\sigma(I_o)$ and 0.102 for all data (residual Δρ < 0.43 e.Å^{-3}).

Crystal data for $C_{20}H_{19}NO_4S$ (**19**). M = 369.42, monoclinic, $P2_1/c$, a = 13.078(1), b = 9.538(1), c = 14.432(1) Å, β = 101.18(5)°, V = 1766.04(2) Å^3, Z = 4, D_x = 1.389 Mg.m^{-3}, μ = 0.209 mm^{-1}, F(000) = 776, T = 150 K, measured 17926 reflections in 2θ range 3.2 - 61.0°, R_{int} = 0.020. 329 parameters refined against 5318 F^2, R = 0.077 for $I_o > 2\sigma(I_o)$ and 0.084 for all data (residual Δρ < 0.44 e.Å^{-3})

The mass spectra under electron impact conditions were recorded at 70 eV (EI). Methane was used for chemical ionisation (CI). The spectra are presented as *m/z* (% rel. int.). The ^{1}H NMR spectra were recorded at 200 MHz and the ^{13}C NMR spectra at 50 MHz. Dry dioxane and dry THF were distilled from sodium and benzophenone. Dry dichloromethane and dry NMP were distilled from calcium hydride. Dry DMF was distilled from BaO.

6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one (**2**) and 1,6-bistrifluoromethanesulfonyloxy-spiro[4,4]nona-1,6-diene (**3**). Triflic anhydride (0.96 mL, 5.82 mmol) was added neat with a syringe to a solution of spiro[4,4]nona-1,6-dione[19] (590 mg, 3.88 mmol) and pyridine (460 mg, 5.82 mmol) in dry dichloromethane (60 mL) at -78 °C under argon. The reaction mixture was allowed to reach ambient temperature and stirred at this temperature for 4 d. The solvent was evaporated and the crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1.

6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one (**2**) was obtained as a colourless oil; yield 683 mg (62%). HRMS: M 284.0341. Calc. for $C_{10}H_{11}F_3O_3S$: 284.0330.^{1}H NMR ($CDCl_3$): δ 1.7-2.5 (m, 10H, CH_2), 5.87 (t, J 2.56 Hz, 1H, CH=).^{13}C NMR ($CDCl_3$): δ 19.6 (CH_2), 26.10 (CH_2), 33.7 (CH_2), 34.1 (CH_2), 36.9 (CH_2), 60.2 (C), 118.3 (q, $J_{C,F}$ 318 Hz, CF_3), 118.8 (CH=), 148.1 (C=), 216.9 (CO). IR (liq.film): 2896, 2865, 1745, 1213, 1141 cm^{-1}. MS(EI): 284 (M^+, 0.2), 228 (57), 151 (100), 123 (24), 105 (29), 95 (91), 79 (26), 67 (59).

1,6-Bis(trifluoromethanesulfonyloxy)-spiro[4,4]nona-1,6-diene (**3**) was obtained as a colourless oil; yield 81 mg

(5%). ^{1}H NMR ($CDCl_3$): δ 1.8-2.5 (m, 8H, CH_2), 5.80 (t, *J* 2.6 Hz, 2H, CH=). ^{13}C NMR ($CDCl_3$): δ 26.3 (CH_2), 33.4 (CH_2), 58.2 (C), 116.9 (CH=), 118.2 (q, $J_{C,F}$ 317 Hz, CF_3), 147.9 (C=). IR (liq.film): 2949, 2867, 1425, 1213, 1142 cm^{-1}. MS(EI): 416 (M^+, 0.4), 283 (25), 149 (27), 133 (18), 105 (27), 95 (19), 69 (36), 55 (100).

1,6-Bistrifluoromethanesulfonyloxy-spiro[4,4]nona-1,6-diene (**3**) by triflation of substrate **2**. Triflic anhydride (0.44 mL, 2.64 mmol) was added neat with a syringe to a solution of 6-trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (500 mg, 1.76 mmol) and pyridine (209 mg, 2.64 mmol) in dry dichloromethane (40 mL) at -78 °C under argon. The reaction mixture was allowed to reach ambient temperature and stirred at this temperature for 4 d. The solvent was evaporated and the crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 190 mg (26%). 50% of the substrate **2** was recovered.

6-*trans*-β-Styryl-spiro[4,4]nona-6-en-1-one (**4a**). 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (365 mg, 1.29 mmol), tributyl(β-styryl)stannane (606 mg, 1.54 mmol), $Pd(Ph_3P)_4$ (104 mg, 0.09 mmol) and LiCl (163 mg, 3.86 mmol) were dissolved in dry dioxane (10 mL) under argon at ambient temperature. The solution was stirred at 80 °C for 1.5 h and evaporated. A saturated solution of potassium fluoride in methanol (20 mL) was added to the residue, the resulting mixture stirred at ambient temperature for 4 h and evaporated together with a small amount of silica gel. The residue was added on top of a silica gel column and the product isolated by flash chromatography eluting with hexane:EtOAc 5:1; yield 170 mg (56%) of a colourless oil. Found: C, 85.84; H, 7.21. Calc. for $C_{17}H_{18}O$: C, 85.67; H, 7.61. ^{1}H NMR ($CDCl_3$): δ 1.8-2.5 (m, 10H, CH_2), 6.10 (t, *J* 2.6 Hz, 1H, CH=), 6.23 (d, *J* 16.5 Hz, 1H, CH=), 6.67 (d, *J* 16.5 Hz, 1H, CH=), 7.19-7.37 (Ar, m, 5H). ^{13}C NMR ($CDCl_3$): δ 20.9 (CH_2), 31.2 (CH_2), 34.5 (CH_2), 38.0 (CH_2), 38.5 (CH_2), 63.0 (C), 122.1 (CH=), 125.6 , 126.8, 127.8, 136.4 (Ar), 128.6 (CH=), 134.0 (CH=), 142.5 (C), 220.8 (CO). MS(EI): 238 (M^+, 56), 182 (50), 181 (43), 167 (60), 151 (100), 142 (67), 123 (96), 105 (51).

6-(2-Thienyl)-spiro[4,4]nona-6-en-1-one (**4b**). 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (150 mg, 0.53 mmol), tributyl(2-thienyl)stannane (246 mg, 0.66 mmol), $Pd(Ph_3P)_4$ (31 mg, 0.03 mmol) and LiCl (72 mg, 1.69 mmol) were dissolved in dry dioxane (10 mL) under argon and stirred at 50 °C for 2 h and evaporated. The reaction mixture was workred up as above; yield 80 mg (70%) of a colourless oil. Found: C, 71.33; H, 6.60. Calc. for $C_{13}H_{14}OS$: C, 71.52; H, 6.46. HRMS: *M* 218.0768. Calc. for $C_{13}H_{14}OS$: 218.0765. ^{1}H NMR ($CDCl_3$): δ 1.9-2.6 (m, 10H, CH_2), 6.20 (t, *J* 2.7 Hz, 1H, CH=), 6.69 (d, *J* 3.5 Hz, 1H, CH=), 6.91 (dd, *J* 5.1, 3.5 Hz, 1H, CH=), 7.12 (dd, *J* 5.1, 1.1 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ 20.1 (CH_2), 30.7 (CH_2), 34.3 (CH_2), 37.3 (CH_2), 37.9 (CH_2), 64.6 (C), 123.8 (CH=), 123.9 (CH=), 127.1 (CH=), 131.4 (CH=), 138.1 (C), 138.3 (C), 222.1 (CO). MS(EI): 218 (M^+, 100), 163 (14), 162 (98), 161 (57), 147 (23), 134 (12), 128 (16), 115 (11).

6-Phenylethynyl-spiro[4,4]nona-6-en-1-one (**4c**). 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (275 mg, 0.97 mmol), (phenylethynyl)tributylstannane (454 mg, 1.16 mmol), $Pd(Ph_3P)_4$ (112 mg, 0.097 mmol) and LiCl (123 mg, 2.90 mmol) were dissolved in dry dioxane (10 mL) under argon. The solution was stirred at 80 °C for 1 h and evaporated. The reaction mixture was worked up as above; yield 182 mg (80%) of a colourless oil. Found: C, 86.00; H, 6.43. Calc. for $C_{17}H_{16}O$: C, 86.40; H, 6.82. ^{1}H NMR ($CDCl_3$): δ 1.7-2.5 (m, 10H, CH_2), 6.30 (t, *J* 2.8 Hz, 1H, CH=), 7.26-7.42 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$): δ 19.9 (CH_2), 31.6 (CH_2), 35.3 (CH_2), 35.6 (CH_2), 37.7 (CH_2), 64.4 (C), 84.2 (C), 91.7 (C), 122.9 (C), 127.1 (C), 128.1 (CHx2), 131.3 (CH), 140.0 (CH), 220.6 (C=O). MS(EI): 236 (M^+, 44), 209 (16), 208 (100), 180 (52), 179

(65), 178 (44), 165 (47), 139 (13).

Spiro[4,4]nona-6-en-1-one (**5**). 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (780 mg, 2.75 mmol), tributylstannane (1.5 mL, 5.49 mmol), $Pd(Ph_3P)_4$ (159 mg, 0.137 mmol) and LiCl (349 mg, 8.24 mmol) were dissolved in dry THF (40 mL) under argon. The solution was stirred at 50 °C for 2.5 h and evaporated. A saturated solution of potassium fluoride in methanol (20 mL) was added to the residue, the resulting mixture stirred at ambient temperature for 4 h and evaporated together with a small amount of silica gel. The residue was added on top of a silica gel column and the product isolated by flash chromatography eluting with hexane:EtOAc 5:1; yield 300 mg (80%) of a colourless oil. HRMS: *M* 136.0889. Calc. for $C_9H_{12}O$: 136.0888. ^1H NMR ($CDCl_3$): δ 1.7-2.6 (m, 10H, CH_2), 5.44-5.49 (m, 1H, CH=), 5.92-5.97 (m, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ 20.6 (CH_2), 32.5 (CH_2), 34.6 (CH_2), 37.3 (CH_2), 37.7 (CH_2), 63.4 (C), 131.5 (CH=), 133.3 (CH=), 220.6 (CO). IR (liq.film): 3049, 2955, 2925, 2853, 1738 cm^{-1}. MS(EI): 136 (M^+, 31), 92 (6), 81 (7), 80 (100), 79 (42), 77 (11), 41 (5), 39 (13).

6-Phenyl-spiro[4,4]nona-6-ene-1-one (**6**) from the Triflate **2**. 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (74 mg, 0.26 mmol) and $Pd(dba)_2$ (7 mg, 0.013 mmol) were dissolved in dry NMP (2 mL). Phenyltributyltin (0.1 mL, 0.31 mmol) was added with a syringe after 10 min. The solution was stirred at ambient temperature for 4 h before treatment with 1 M aqueous KF solution (1 mL) for 30 min, diluted with ethyl acetate and filtered. The filtrate was washed with water (3x), dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 35 mg (64%) of a colourless oil. The physical data are given below.

6-Phenyl-spiro[4,4]nona-6-en-1-one (**6**) from the Stannane **7**. A: Phenyl triflate: 6-Trimethylstannyl-spiro[4,4]nona-6-en-1-one **7** (150 mg, 0.5 mmol), phenyl triflate (113 mg, 0.5 mmol), LiCl (64 mg, 1.5 mmol), $PdCl_2(PhCN)_2$ (8 mg, 0.02 mmol), $AsPh_3$ (25 mg, 0.08 mmol) and CuI (10 mg, 0.05 mmol) were mixed in dry NMP (4 mL) under argon and the mixture stirred at ambient temperature for 15 min. The stirring was continued at 80 °C overnight. Ethyl acetate was added, the mixture washed with water and brine, dried ($MgSO_4$) and evaporated at reduced pressure. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 43 mg (40%) of a colourless oil. The physical data are given below.

B: Iodobenzene: 6-Trimethylstannyl-spiro[4,4]nona-6-en-1-one **7** (150 mg, 0.5 mmol), iodobenzene (102 mg, 0.5 mmol), $PdCl_2(PhCN)_2$ (8 mg, 0.02 mmol), $AsPh_3$ (25 mg, 0.08 mmol) and CuI (10 mg, 0.05 mmol) were mixed in dry NMP (4 mL) under argon and stirred at ambient temperature for 15 min. The stirring was continued at 80 °C overnight. Ethyl acetate was added, the mixture washed with water and brine, dried ($MgSO_4$) and evaporated under high vacuum. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 37 mg (35%) of a colourless oil. HRMS: *M* 212.1191. Calc. for $C_{15}H_{16}O$: 212.1201. ^1H NMR ($CDCl_3$): δ 1.83-2.56 (m, 10H, CH_2), 6.18 (t, *J* 2.3 Hz, 1H, CH=), 7.1-7.3 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$, 125 MHz): δ 19.9 (CH_2), 30.6 (CH_2), 34.7 (CH_2), 37.61 (CH_2), 37.67 (CH_2), 64.5 (C), 127.01 (CH), 127.04 (CH), 128.2 (CH), 132.0 (CH), 135.8 (C), 144.7 (C), 221.9 (CO). IR (liq.film): 3054, 2955, 2926, 1733, 1622 cm^{-1}. MS(EI): 212 (M^+, 83), 157 (16), 156 (100), 155 (60), 141 (33), 128 (30), 115 (30).

6-Trimethylstannyl-spiro[4,4]nona-6-en-1-one (**7**). 6-Trifluoromethanesulfonyloxy-spiro[4,4]nona-6-en-1-one **2** (331 mg, 1.17 mmol), hexamethyldistannane (382 mg, 1.17 mmol), $Pd(Ph_3P)_4$ (27 mg, 0.023 mmol) and LiCl (148 mg, 3.51 mmol) were dissolved in dry dioxane (10 mL) under argon and stirred at 50 °C overnight and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 294 mg (84%) of a colourless oil. Found: C, 48.62; H, 6.63. Calc. for $C_{12}H_{20}OSn$: C, 48.20; H, 6.74. ^1H

NMR ($CDCl_3$): δ 0.11 (s, 9H, CH_3), 1.64-2.50 (m, 10H, CH_2), 6.09 (t, *J* 2.2 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ -8.0 (CH_3), 21.0 (CH_2), 34.2 (CH_2), 36.7 (CH_2), 37.5 (CH_2), 38.0 (CH_2), 68.3 (C), 143.6 (CH), 145.7 (C), 221.2 (CO). MS(CI-CH_4): 299 (*M*+1, 2), 289 (17), 287 (15), 285 (100), 284 (34), 283 (74), 282 (28), 281 (44).

1,6-Bis(phenyl)-spiro[4,4]nona-1,6-diene (**8a**). BuLi (1.6 M; 1.2 mL, 1.93 mmol) was added with a syringe to a solution of bromobenzene (302 mg, 1.93 mmol) in dry THF (5 mL) under argon at -78 °C. The solution was stirred for 2 h at -78 °C before a solution of $ZnBr_2$ (434 mg, 1.93 mmol) in dry THF (5 mL) was added. The reaction mixture was stirred for 1 h at -78 °C and warmed to ambient temperature. A solution of 1,6-bis(trifluoromethanesulfonyloxy)-spiro[4,4]nona-1,6-diene **3** (267 mg, 0.64 mmol) and $Pd(Ph_3P)_4$ (74 mg, 0.064 mmol) in dry THF (5 mL) was added to the Zn-complex and the reaction mixture was refluxed overnight. The reaction was quenched with 5% NH_4Cl, extracted with diethyl ether (2x), washed with brine, dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with 2% EtOAc in hexane; yield 98 mg (56%) of a white solid, mp. 70 °C. HRMS: *M* 272.1578. Calc. for $C_{21}H_{20}$: 272.1565. ^1H NMR ($CDCl_3$): δ 2.0-2.5 (m, 8H, CH_2), 6.20 (t, *J* 2.5Hz, 2H, CH=), 7.15-7.27 (m, 6H, Ph), 7.46-7.52 (m, 4H, Ph). ^{13}C NMR ($CDCl_3$): δ 30.8 (CH_2), 38.0 (CH_2), 64.5 (C), 126.1 (CHx2), 127.4 (CH), 127.7 (CH), 135.9 (C=), 147.2 (C=). IR (liq.film): 3055, 3032, 2940, 2843, 1597 cm^{-1}. MS(EI): 272 (M^+, 100), 181 (56), 167 (12), 155 (24), 142 (15), 128 (12), 115 (26), 91 (16).

1,6-Bis(thienyl)-spiro[4,4]nona-1,6-diene (**8b**).[20] Bis(trifluoromethanesulfonyloxy)-spiro[4,4]nona-1,6-diene **3** (142 mg, 0.34 mmol), tri-*n*-butyl(2-thienyl)stannane (318 mg, 0.85 mmol), $Pd(Ph_3P)_4$ (40 mg, 0.034 mmol) and LiCl (87 mg, 2.04 mmol) were mixed in dry dioxane (10 mL) under argon and stirred at 50 °C overnight and evaporated. A saturated solution of potassium fluoride in methanol (20 mL) was added to the residue, the resulting mixture stirred at ambient temperature for 4 h and evaporated together with a small amount of silica gel. The residue was added on top of a silica gel column and the product isolated by flash chromatography eluting with hexane:EtOAc 20:1; yield: 19 mg (20%) of a white solid, mp. 72 °C. ^1H NMR ($CDCl_3$): δ 2.05-2.34 (m, 4H, CH_2), 2.51-2.58 (m, 4H, CH_2), 6.19 (t, *J* 2.7 Hz, 2H, CH=), 6.84 (dd, *J* 3.7, 5.1 Hz, 2H, CH=), 7.00 (d, *J* 3.7 Hz, 2 H, CH=), 7.07 (dd, *J* 1.0, 5.1 Hz, 2H, CH=). ^{13}C NMR ($CDCl_3$): δ 30.4 (CH_2), 36.3 (CH_2), 65.7 (C), 123.6 (CH), 123.8 (CH), 127.3 (CH), 128.2 (CH), 139.5 (C), 142.0 (C).

cis,cis-1,6-Bis(phenyl)-spiro[4,4]nonane (**9**). 1,6-Bis(phenyl)-spiro[4,4]nona-1,6-diene **8a** (200 mg, 0.74 mmol) in ethanol (20 mL) was hydrogenated over 10% palladium on charcoal (50 mg, 0.05 mmol) at 4 bar in a Parr apparatus at ambient temperature for 5 d. The catalyst was filtered off and the solvent evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 30:1. Recrystallization of the product from diethyl ether and ethanol gave a white solid, mp. 77 °C; yield 136 mg (67%). HRMS: *M* 276.1879. Calc. for $C_{21}H_{24}$: 276.1878. ^1H NMR ($CDCl_3$): δ 1.7-2.2 (m, 12H, CH_2), 2.75-2.79 (m, 2H, CH), 6.64-6.69 (m, 4H, Ph), 6.96-7.07 (m, 6H, Ph). ^{13}C NMR ($CDCl_3$): δ 22.1 (CH_2), 33.9 (CH_2), 39.5 (CH_2), 53.6 (CH_2), 60.7 (C), 124.6 (CH), 127.0 (CH), 128.0 (CH), 145.8 (C). IR (liq.film): 3026, 2943, 2921, 2874, 1454 cm^{-1}. MS(EI): 276 (M^+, 100), 157 (50), 144 (51), 143 (38), 129 (34), 117 (22), 104 (24), 91 (38).

The structure has been confirmed by single crystal X-ray analysis (Fig. 1).

6-(2-Thienyl)-1-trifluoromethanesulfonyloxy-spiro[4,4]nona-1,6-diene (**10**). Triflic anhydride (0.45 mL, 2.75 mmol) was added neat with a syringe to a solution of 6-(2-thienyl)-spiro[4,4]nona-6-en-1-one **4b** (400 mg, 1.83 mmol) and pyridine (217 mg, 2.75 mmol) in dry CH_2Cl_2 (40 mL) at -78 °C under argon. The reaction mixture

was allowed to warm slowly up to ambient temperature over 24 h. The solvent was evaporated and the crude product was purified by flash chromatography eluting with hexane:EtOAc 10:1; yield 375 mg (58%) of a pale yellow oil. Found: C, 48.01; H, 3.97. Calc. for $C_{14}H_{13}F_3O_3S_2$: C, 47.99; H, 3.74. HRMS: *M* 350.0260. Calc. for $C_{14}H_{13}F_3O_3S_2$: 350.0258. ^{1}H NMR ($CDCl_3$): δ 2.0-2.6 (m, 8H, CH_2), 5.75 (t, *J* 2.5 Hz, 1H, CH=), 6.13 (t, *J* 2.6 Hz, 1H, CH=), 6.94-7.02 (m, 2H, CH= in thiophene), 7.17 (dd, *J* 5, 1.2 Hz, 1H, CH= in thiophene). ^{13}C NMR ($CDCl_3$): δ 26.9 (CH_2), 30.8 (CH_2), 33.7 (CH_2), 37.6 (CH_2), 61.7 (C), 114.0 (CH=), 117.9 (q, $J_{C,F}$ 315 Hz, CF_3), 122.7 (CH=), 123.5 (CH=), 126.7 (CH=), 130.0 (CH=), 137.4 (C), 137.7 (C), 151.2 (C). MS(EI): 350 (M^+, 100), 217 (31), 189 (33), 162 (19), 161 (25), 147 (21), 133 (20), 97 (24).

6-(2-Thienyl)-1-trimethylstannyl-spiro[4,4]nona-1,6-diene (**11**) 6-(2-Thienyl)-1-trifluoromethanesulfonyloxy-spiro[4,4]nona-1,6-diene **10** (250 mg, 0.71 mmol), hexamethyldistannane (234 mg, 0.71 mmol), $Pd(Ph_3P)_4$ (41 mg, 0.036 mmol) and LiCl (91 mg, 2.14 mmol) were dissolved in dry dioxane (10 mL) under argon and stirred at 50 °C for 2 h and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 20:1; yield 172 mg (66%) of a colourless oil. Found: C, 52.98; H, 6.22. Calc. for $C_{16}H_{22}SSn$: C, 52.65; H, 6.07. ^{1}H NMR ($CDCl_3$): δ 1.9-2.5 (m, 8H, CH_2), 5.96 (t, *J* 2.2 Hz, 1H, CH=), 6.05 (t, *J* 2.6 Hz, 1H, CH=), 6.89 (dd, *J* 3.6, 5 Hz, 1H, CH in thiophene), 6.98 (d, *J* 3.4 Hz, 1H, CH in thiophene), 7.09 (dd, *J* 1.1, 5 Hz, 1H, CH in thiophene). ^{13}C NMR ($CDCl_3$): δ -9.2 (CH_3), 30.5 (CH_2), 33.7 (CH_2), 35.0 (CH_2), 39.1 (CH_2), 69.1 (C), 123.4 (CH), 123.8 (CH), 126.9 (CH), 127.0 (CH), 140.2 (C), 140.5 (CH), 142.6 (CH), 153.5 (C). MS(EI): 365 (M^+, 12), 353 (20), 351 (100), 350 (40), 349 (83), 348 (33), 347 (48), 201 (30).

1-Phenyl-6-(2-thienyl)-spiro[4,4]nona-1,6-diene (**12**) from Triflate **10**. BuLi (1.6 M; 0.4 mL, 0.64 mmol) was added with a syringe to a solution of bromobenzene (101 mg, 0.64 mmol) in dry THF (3 mL) under argon at -78 °C. The solution was stirred at -78 °C for 3 h before a solution of $ZnBr_2$ (145 mg, 0.64 mmol) in dry THF (2 mL) was added. The reaction mixture was stirred at -78 °C for 1 h and warmed to ambient temperature. A solution of 6-(2-thienyl)-1-trifluoromethanesulfonyloxy-spiro[4,4]nona-1,6-diene **10** (150 mg, 0.43 mmol) and $Pd(Ph_3P)_4$ (50 mg, 0.043 mmol) in dry THF (5 mL) was added to the Zn-complex and the reaction mixture was refluxed overnight. The reaction was quenched with 5% NH_4Cl, extracted with diethyl ether (2x), the organic solution washed with brine, dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with 2% EtOAc in hexane; yield 86 mg (74%) of a white solid, mp.(decomp.) > 150 °C. Found: C, 81.45; H, 6.55. Calc. for $C_{19}H_{18}S$: C, 81.96; H, 6.52. HRMS: *M* 278.1083. Calc. for $C_{19}H_{18}S$: 278.1129. ^{1}H NMR ($CDCl_3$): δ 2.0-2.6 (m, 8H, CH_2), 6.14 (t, *J* 2.7 Hz, 1H, CH=), 6.29 (t, *J* 2.6 Hz, 1H, CH=), 6.84 (dd, *J* 5.0, 3.6 Hz, 1H, CH= in thiophene), 7.01 (br d, *J* 2.9 Hz, 1H, CH= in thiophene), 7.07 (br d, *J* 5.0 Hz, 1H, CH= in thiophene), 7.15-7.25 (m, 3H, Ph), 7.48-7.53 (m, 2H, Ph). ^{13}C NMR ($CDCl_3$): δ 30.8 (CH_2), 30.9 (CH_2), 37.2 (CH_2), 37.5 (CH_2), 64.9 (C), 123.0 (CH), 123.3 (CH), 126.0 (CH), 126.1 (CH), 126.7 (CH), 126.9 (CH), 127.5 (CH), 128.5 (CH), 135.5 (C), 138.9 (C), 142.0 (C), 146.2 (C). MS(EI): 278 (M^+, 100), 187 (22), 181 (25), 161 (15), 155 (9), 128 (9), 123 (11), 115 (16).

1-Phenyl-6-(2-thienyl)-spiro[4,4]nona-1,6-diene (**12**) from Stannane **11**. 6-(2-Thienyl)-1-trimethylstannyl-spiro[4,4]nona-1,6-diene **11** (100 mg, 0.27 mmol), phenyl triflate (62 mg, 0.27 mmol), LiCl (35 mg, 0.82 mmol), $PdCl_2(PhCN)_2$ (4 mg, 0.01 mmol), $AsPh_3$ (13 mg, 0.04 mmol) and CuI (5 mg, 0.027 mmol) were mixed in dry NMP (3 mL) under argon and stirred at ambient temperature for 15 min. The stirring was continued at 80 °C overnight. Ethyl acetate was added, the mixture washed with water and brine, dried ($MgSO_4$) and evaporated at reduced pressure. The crude product was purified by flash chromatography eluting 2% EtOAc in

hexane; yield 32 mg (42%)

cis-6-Phenyl-spiro[4,4]nona-6-en-1-ole (**13**). Sodium borohydride (10 mg, 0.26 mmol) was added to a solution of 6-phenyl-spiro[4,4]nona-6-en-1-one (55 mg, 0.26 mmol) and $CeCl_3 \cdot 7H_2O$ (97 mg, 0.26 mmol) in methanol (5 mL) at 0 °C. The cooling bath was removed and the solution was stirred for 10 min. Water was added and the product was extracted into diethyl ether, the solution dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1; yield 35 mg (63%) of a colourless oil. HRMS: *M* 214.1361. Calc. for $C_{15}H_{18}O$: 214.1358. ^1H NMR ($CDCl_3$): δ 1.5-2.5 (m, 10H, CH_2), 4.07-4.11 (m, 1H, CH), 6.01 (t, *J* 2.6Hz, 1H, CH=), 7.24-7.45 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$): δ 22.2 (CH_2), 29.7 (CH_2), 33.4 (CH_2), 34.0 (CH_2), 39.8 (CH_2), 62.8 (C), 80.3 (CH), 126.9 (CH), 128.18 (CH), 128.23 (CH), 132.4 (CH), 138.8 (C), 147.6 (C). MS(EI): 214 (M^+, 100), 196 (45), 156 (52), 155 (95), 144 (70), 143 (97), 141 (48), 128 (59).

cis-6-(2-Thienyl)-spiro[4,4]nona-6-en-1-ole (**14a**) and *trans*-6-(2-thienyl)-spiro[4,4]nona-6-en-1-ole (**14b**). Sodium borohydride (31 mg, 0.82 mmol) was added in portions to a solution of 6-(2-thienyl)-spiro[4,4]nona-6-en-1-one **4b** (178 mg, 0.82 mmol) and $CeCl_3 \cdot 7H_2O$ (304 mg, 0.82 mmol) in methanol (10 mL) at 0 °C. The cooling bath was removed after 5 min and the solution stirred at ambient temperature for 20 min. Water was added and the product was extracted into diethyl ether, the solution dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1.

cis-6-(2-Thienyl)-spiro[4,4]nona-6-en-1-ole (**14a**); yield 108 mg (60%) of a colourless oil. HRMS: *M* 220.0920. Calc. for $C_{13}H_{16}OS$: 220.0922. ^1H NMR ($CDCl_3$): δ 1.4-2.5 (m, 10H, CH_2), 4.07-4.09 (m, CH, 1H), 6.19 (t, *J* 2.6 Hz, 1H, CH=), 6.94-6.98 (m, 1H, thiophene), 7.14-7.17 (m, 2H, thiophene). ^{13}C NMR ($CDCl_3$): δ 23.2 (CH_2), 30.3 (CH_2), 33.9 (CH_2), 34.7 (CH_2), 40.7 (CH_2), 62.8 (C), 79.8 (CH), 123.7 (CH), 124.6 (CH), 126.7 (CH), 131.8 (CH), 139.7 (C), 140.0 (C). MS(EI): 220 (M^+, 100), 202 (28), 175 (21), 163 (26), 161 (58), 150 (58), 149 (42), 115 (20).

trans-6-(2-Thienyl)-spiro[4,4]nona-6-en-1-ole (**14b**); yield 18 mg (10%) of a colourless oil. HRMS: *M* 220.0934. Calc. for $C_{13}H_{16}OS$: 220.0922. ^1H NMR ($CDCl_3$): δ 1.4-2.6 (m, 10H, CH_2), 4.37-4.46 (m, 1H, CH), 6.12 (t, *J* 2.5 Hz, 1H, CH=), 6.97-6.99 (m, 2H, thiophene), 7.16-7.19 (m, 1H, thiophene). ^{13}C NMR ($CDCl_3$): δ 19.7 (CH_2), 31.0 (CH_2), 31.2 (CH_2), 32.2 (CH_2), 34.5 (CH_2), 61.4 (C), 76.6 (CH), 123.2 (CH), 123.3 (CH), 126.6 (CH), 131.4 (CH), 138.3 (C), 138.8 (C). MS(EI): 220 (M^+, 100), 202 (42), 175 (26), 163 (32), 161 (62), 150 (55), 149 (42), 115 (22).

cis-6-Trimethylstannyl-spiro[4,4]nona-6-en-1-ole (**15a**) and *trans*-6-trimethylstannyl-spiro[4,4]nona-6-en-1-ole (**15b**). Sodium borohydride (169 mg, 4.46 mmol) was added in portions to a solution of 6-trimethylstannyl-spiro[4,4]nona-6-en-1-one **7** (1.333 g, 4.46 mmol) and $CeCl_3 \cdot 7H_2O$ (1.661 g, 4.46 mmol) in methanol (40 mL) at 0 °C. The cooling bath was removed after 5 min and the solution was stirred at ambient temperature for 30 min. Water was added and the product was extracted into diethyl ether, the solution dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 10:1.

cis-6-Trimethylstannyl-spiro[4,4]nona-6-en-1-ole (**15a**); yield 808 mg (60%) of a white solid, mp. 36 °C. Found: C, 47.62; H, 7.32. Calc. for $C_{12}H_{22}OSn$: C, 47.89; H, 7.37. ^1H NMR ($CDCl_3$): δ 0.12 (s, 9H, CH_3), 1.3-2.4 (m, 10H, CH_2), 3.75-3.77 (m, 1H, CH), 6.01 (t, *J* 2.2 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ -7.8 (CH_3), 21.3 (CH_2), 33.3 (CH_2), 34.4 (CH_2), 34.7 (CH_2), 36.7 (CH_2), 66.3 (C), 81.2 (CH), 142.9 (CH=), 149.8 (C=). IR (liq.film): 3468 (br.), 3020, 2958, 2936, 1436 cm^{-1}. MS(CI, CH_4): 302 (M^++1, 2), 287 (100), 286 (34), 285 (75), 284 (31), 283 (47), 121 (67), 119 (23).

trans-6-trimethylstannyl-spiro[4,4]nona-6-en-1-ole (**15b**); yield 177 mg (13%) of a colourless oil. Found: C, 47.57; H, 7.12. Calc. for $C_{12}H_{22}OSn$: C, 47.89; H, 7.37. ^1H NMR ($CDCl_3$): δ 0.17 (s, 9H, CH_3), 1.39-1.73 (m, 6H, CH_2), 1.93-2.19 (m, 2H, CH_2), 2.38-2.46 (m, 2H, CH_2), 3.89-3.97 (m, 1H, CH), 5.99 (t, *J* 2.2 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ -8.6 (CH_3), 19.4 (CH_2), 29.7 (CH_2), 30.7 (CH_2), 34.3 (CH_2), 36.1 (CH_2), 65.9 (C), 79.0 (CH), 142.9 (CH=), 149.8 (C=). IR (liq.film): 3401 (br.), 3017, 2957, 2875, 1059 cm^{-1}. MS(CI, CH_4): 302 (M^++1, 2), 287 (68), 285 (100), 284 (39), 283 (67), 165 (36), 137 (63), 119 (33).

cis-1-Methoxy-6-trimethylstannyl-spiro[4,4]nona-6-ene (**16a**). Sodium hydride (50% in mineral oil; 314 mg, 13.08 mmol) was added to a solution of *cis*-6-trimethylstannyl-spiro[4,4]nona-6-en-1-ole **15a** (983 mg, 3.27 mmol) in dry THF (40 mL) and dry DMF (5 mL) under argon at 0 °C. The cooling bath was removed after 10 min and the solution was stirred at ambient temperature for 2 h. MeI (232 mg, 1.64 mmol) was added and the solution stirred at ambient temperature overnight. The solvent was evaporated and diethyl ether was added. The solution was washed with water and brine, dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 20:1; yield 827 mg (80%) of a colourless oil. Found: C, 49.70; H, 7.42. Calc. for $C_{13}H_{24}OSn$: C, 49.57; H, 7.68. ^1H NMR ($CDCl_3$): δ 0.08 (s, 9H, CH_3), 1.4-1.9 (m, 8H, CH_2), 2.3-2.45 (m, 2H, CH_2), 3.17 (s, 3H, CH_3O), 3.22 (broad s, 1H, CH), 5.93 (t, *J* 2.2 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ -7.7 (CH_3), 21.1 (CH_2), 28.1 (CH_2), 33.0 (CH_2), 34.5 (CH_2), 36.7 (CH_2), 55.3 (CH_3), 66.0 (C), 90.7 (CH), 141.0 (CH=), 150.3 (C=). IR (liq.film): 3020, 2961, 2935, 2875, 1099 cm^{-1}. MS(CI, CH_4): 301 ([M^+-CH_3], 100), 300 (50), 299 (91), 298 (41), 297 (59), 269 (85), 267 (65), 265 (37).

trans-1-Methoxy-6-trimethylstannyl-spiro[4,4]nona-6-ene (**16b**) was prepared as above from *trans*-6-trimethylstannyl-spiro[4,4]nona-6-en-1-ole **15b** in 84% yield; colourless oil. Found: C, 49.81; H, 7.37. Calc. for $C_{13}H_{24}OSn$: C, 49.57; H, 7.68. ^1H NMR ($CDCl_3$): δ 0.17 (s, 9H, CH_3), 1.4-1.7 (m, 6H, CH_2), 2.0-2.2 (m, 2H, CH_2), 2.3-2.45 (m, 2H, CH_2), 3.31 (s, 3H, CH_3O), 3.53-3.62 (m, 1H, CH), 5.92 (t, *J* 2.2 Hz, 1H, CH=). ^{13}C NMR ($CDCl_3$): δ -8.6 (CH_3), 19.3 (CH_2), 28.7 (CH_2), 29.6 (CH_2), 33.7 (CH_2), 35.9 (CH_2), 57.8 (CH_3), 64.8 (C), 87.2 (CH), 142.0 (CH=), 150.8 (C=). MS(CI, CH_4): 301 ([M^+-CH_3], 52), 299 (43), 297 (27), 269 (35), 151 (35), 149 (100), 119 (32), 91 (28).

cis-1-Methoxy-6-phenyl-spiro[4,4]nona-6-ene (**17a**). *cis*-1-Methoxy-6-trimethylstannyl-spiro[4,4]nona-6-ene **16a** (200 mg, 0.63 mmol), phenyl triflate (143 mg, 0.63 mmol), LiCl (81 mg, 1.90 mmol), $PdCl_2(PhCN)_2$ (10 mg, 0.03 mmol), $AsPh_3$ (31 mg, 0.1 mmol) and CuI (12 mg, 0.06 mmol) were mixed in dry NMP (4 mL) under argon and stirred at ambient temperature for 15 min. The stirring was continued at 80 °C for 2 h. Ethyl acetate was added and the mixture washed with water and brine, the ethyl acetate solution dried ($MgSO_4$) and evaporated at reduced pressure. The crude product was purified by flash chromatography eluting with hexane:EtOAc 20:1; yield 70 mg (48%) of a colourless oil. HRMS: *M* 228.1516. Calc. for $C_{16}H_{20}O$: 228.1514. ^1H NMR ($CDCl_3$): δ 1.5-2.5 (m, 10H, CH_2), 3.23 (s, 3H, OCH_3), 3.60-3.65 (m, 1H, CH), 5.97 (t, *J* 2.3Hz, 1H, CH=), 7.21-7.34 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$): δ 23.0 (CH_2), 30.2 (CH_2), 31.5 (CH_2), 35.8 (CH_2), 41.6 (CH_2), 57.4 (CH_3), 61.7 (C), 88.7 (CH), 125.7 (CH), 126.9 (CH), 128.1 (CH), 130.0 (CH), 138.3 (C), 148.4 (C). IR (liq.film): 3051, 2936, 2870, 1441, 1097 cm^{-1}. MS(EI): 228 (M^+, 51), 196 (100), 168 (47), 167 (62), 155 (75), 144 (34), 141 (43), 115 (36).

trans-1-Methoxy-6-phenyl-spiro[4,4]nona-6-ene (**17b**) was prepared as above from *trans*-1-methoxy-6-trimethylstannyl-spiro[4,4]nona-6-ene **16b** in 50% yield; colourless oil. HRMS: *M* 228.1517. Calc. for $C_{16}H_{20}O$: 228.1514. ^1H NMR ($CDCl_3$): δ 1.5-2.5 (m, 10H, CH_2), 3.30 (s, 3H, OCH_3), 3.65-3.73 (m, 1H, CH), 5.81 (t, *J* 2.3Hz, 1H, CH=), 7.21-7.34 (m, 5H, Ph). ^{13}C NMR ($CDCl_3$): δ 19.4 (CH_2), 28.6 (CH_2),

30.4 (CH_2), 31.5 (CH_2), 33.8 (CH_2), 57.7 (CH_3), 60.7 (C), 84.1 (CH), 126.3 (CH), 127.5 (CH), 128.0 (CH), 130.2 (CH), 137.5 (C), 147.2 (C). MS(EI): 228 (M^+, 45), 196 (100), 169 (32), 168 (44), 156 (34), 155 (69), 144 (35), 141 (40).

cis-6-Phenyl-spiro[4,4]nona-6-en-1-yl *p*-nitrobenzoate (**18**). *cis*-6-Phenyl-spiro[4,4]nona-6-en-1-ole **13** (20 mg, 0.09 mmol), DMAP (23 mg, 0.187 mmol) and 4-nitrobenzoyl chloride (35 mg, 0.187 mmol) were dissolved in dry dichloromethane (2 mL) and stirred at ambient temperature overnight. Diethyl ether was added and the mixture was washed with saturated aqueous $NaHCO_3$, brine, the organic solution dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography eluting with hexane:EtOAc 10:1. Recrystallization of the product from diethyl ether gave a white solid, mp. 81 °C; yield 30 mg (89%). HRMS: *M* 363.1458. Calc. for $C_{22}H_{21}NO_4$: 363.1471. ^1H NMR ($CDCl_3$): δ 1.7-2.6 (m, 10H, CH_2), 5.32 (m, 1H, CH), 5.90 (t, *J* 2.4 Hz, 1H, CH=), 7.11-7.23 (m, 5H, Ph), 7.37-7.41 (m, 2H, Ph), 7.97-8.01 (m, 2H, Ph). ^{13}C NMR ($CDCl_3$): δ 22.6 (CH_2), 29.5 (CH_2), 31.6 (CH_2), 31.8 (CH_2), 38.4 (CH_2), 61.4 (C), 83.3 (CH), 122.9 (CH), 126.3 (CH), 128.0 (CH), 128.2 (CH), 130.5 (CH), 133.2 (CH), 135.6 (C), 139.7 (C), 146.3 (C), 150.0 (C), 164.1 (CO). IR (liq.film): 2960, 2927, 2853, 1719, 1527 cm^{-1}. MS(EI): 363 (M^+, 4), 197 (20), 196 (100), 195 (25), 169 (17), 168 (14), 167 (18), 156 (16).

The structure has been confirmed by single crystal X-ray analysis (Fig. 2).

cis-6-(2-Thienyl)-spiro[4,4]nona-6-ene-1-yl *p*-nitrobenzoate (**19**) was prepared as above from *cis*-6-(2-thienyl)-spiro[4,4]nona-6-en-1-ole **14a**. The crude product was purified by flash chromatography eluting with hexane:EtOAc 5:1. Recrystallization of the product from diethyl ether gave a white solid, mp. 140 °C; yield 101 mg (71%). HRMS: *M* 369.10745. Calc. for $C_{20}H_{19}NO_4S$: 369.1035. ^1H NMR ($CDCl_3$): δ 1.7-2.5 (m, 10H, CH_2), 5.33-5.37 (m, 1H, CH), 6.11 (t, *J* 2.6 Hz, 1H, CH=), 6.85 (dd, *J* 5.1, 3.6, 1H, thiophene), 6.97-7.06 (m, 2H, thiophene), 7.54-7.59 (m, 2H, Ph), 8.02-8.07 (m, 2H, Ph). ^{13}C NMR ($CDCl_3$): δ 23.6 (CH_2), 30.2 (CH_2), 32.7 (CH_2), 36.2 (CH_2), 40.3 (CH_2), 61.2 (C), 82.6 (CH), 122.4 (CH), 123.1 (CH), 123.6 (CH), 126.2 (CH), 129.8 (CH), 132.7 (CH), 135.0 (C), 138.4 (C), 140.6 (C), 149.1 (C), 163.2 (CO). MS(EI): 369 (M^+, 17), 203 (16), 202 (100), 201 (22), 175 (20), 174 (18), 173 (16), 161 (12).

The structure has been confirmed by single crystal X-ray analysis (Fig. 3).

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