

Bisphosphites having an outer naphthyl-phenyl unit and a central 2,3'-biphenol unit

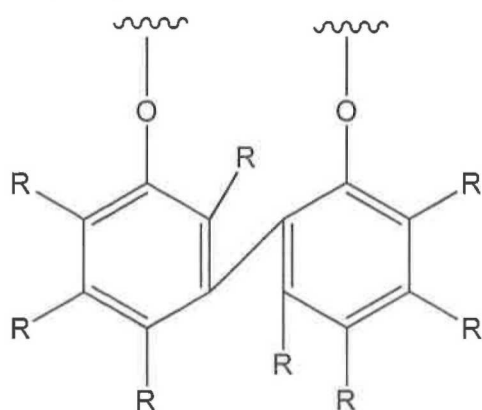
The invention relates to bisphosphites having an outer naphthyl-phenyl unit and a central 2,3'-biphenol unit.

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A bisphosphite has a central unit, called the backbone, and two outer units bonded to the central unit via the phosphorus atom.

10 The bisphosphites according to the invention have at least one outer naphthyl-phenyl unit. It is also possible for the two outer units to have a naphthyl-phenyl unit. The central unit has a 2,3'-biphenol unit.

A 2,3'-biphenol unit is understood to mean a biphenol unit having the following structure:



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The numbering of the carbon atoms in the rings in the IUPAC name of the compound may lead to different position figures from 2 and 3 depending on additional substituents.

20 DE 10 2006 058 682 A1 discloses bisphosphites having different yet symmetrical outer units, for example compound Ib on page 8 of DE 10 2006 058 682 A1.

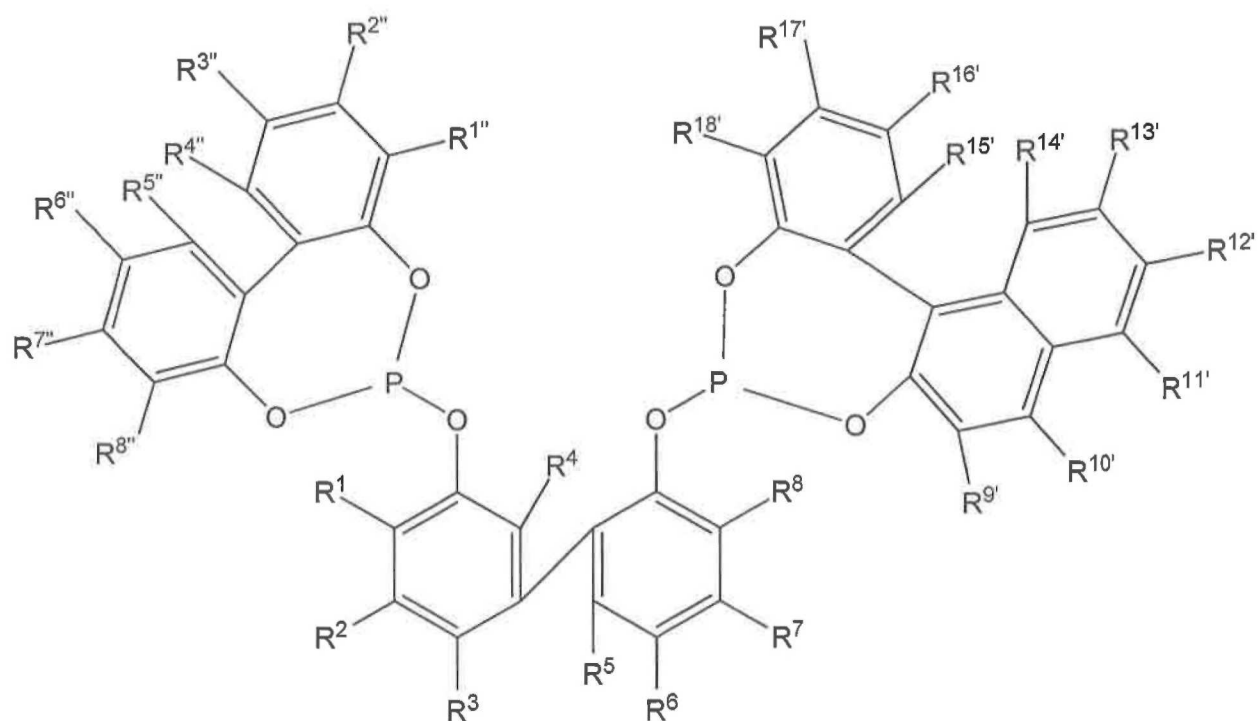
It is a feature of most of the bisphosphites known in the prior art that they have a 2,2'-biphenol as central unit, i.e. in the backbone. The use of a 2,3'-biphenol as central unit is entirely unknown.

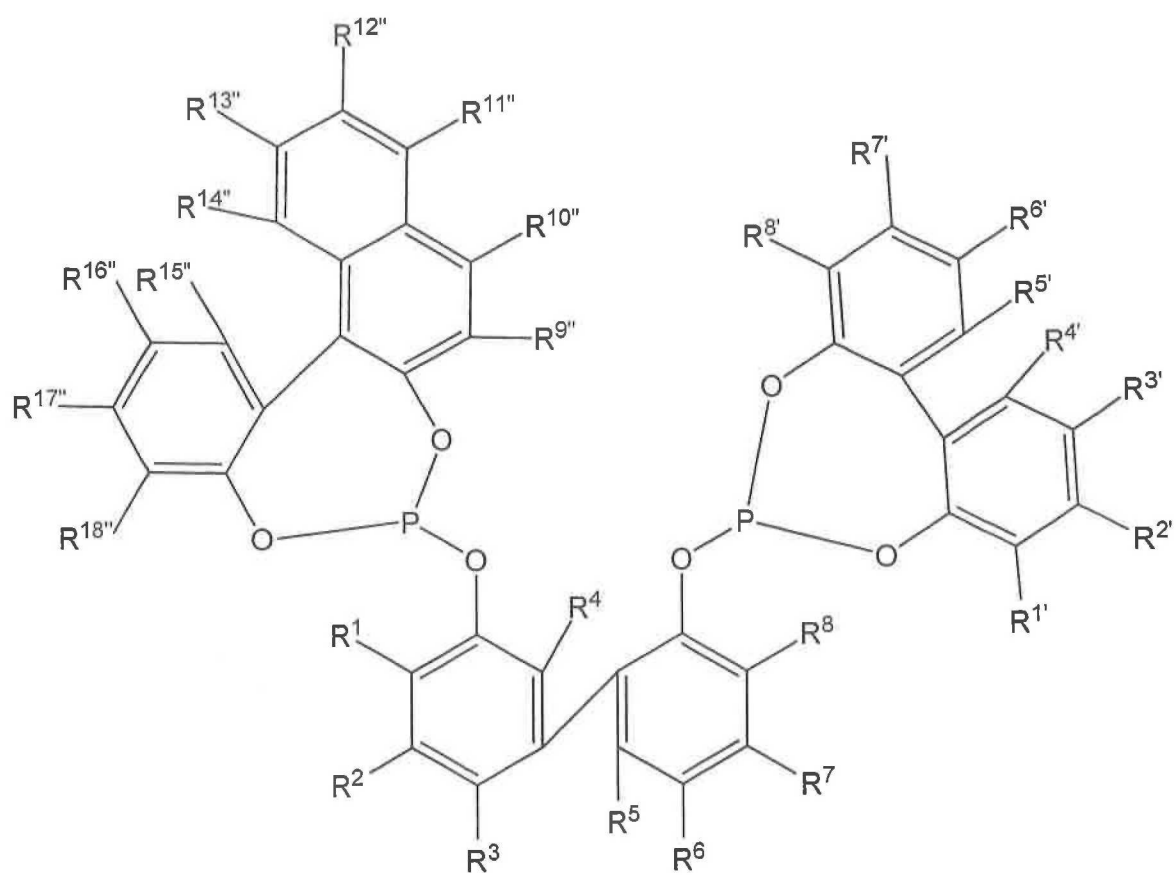
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The problem addressed by the invention was that of providing bisphosphites having a novel structure compared to the bisphosphites known in the literature.

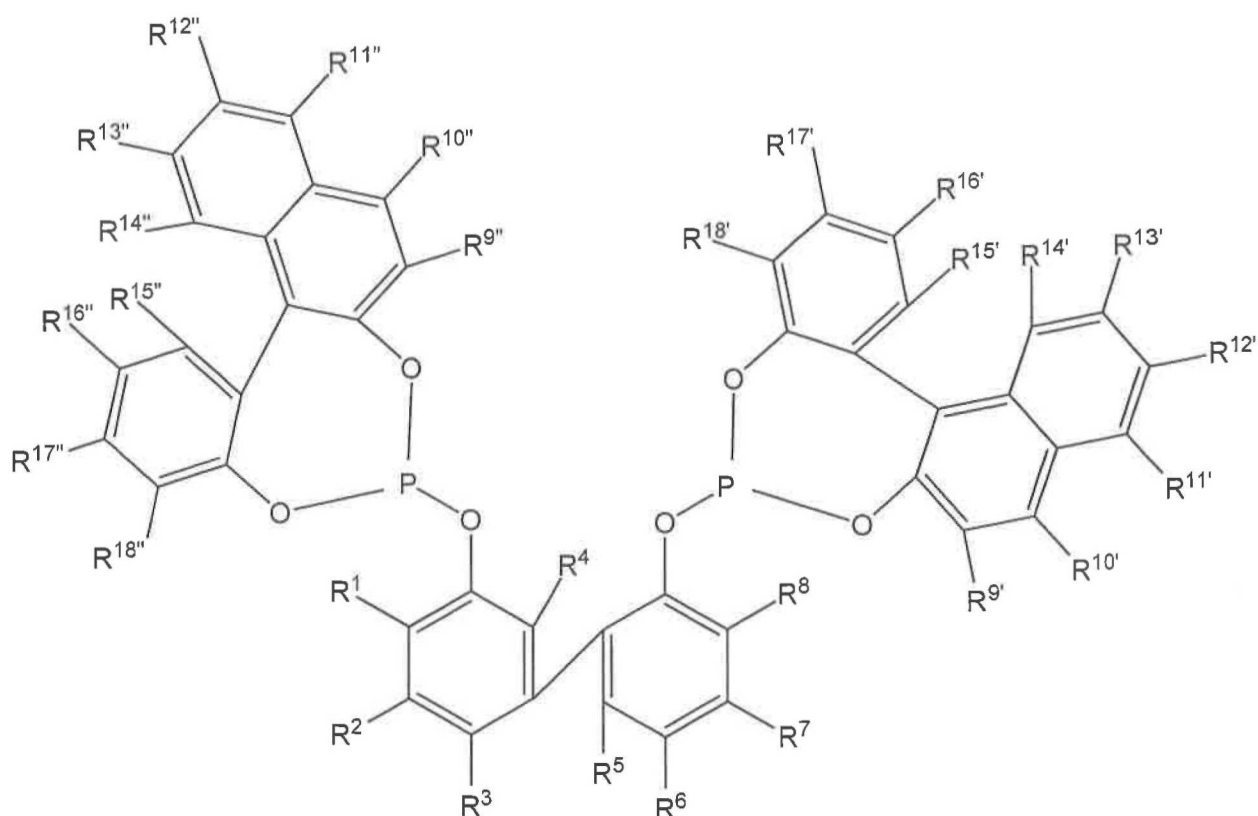
The object is achieved by a compound according to Claim 1.

Compound having one of the three general structures (I) to (III):





(II)



(III)

5

where

R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH,
 10 -SO₃H, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

R^{1'}, R^{2'}, R^{3'}, R^{4'}, R^{5'}, R^{6'}, R^{7'}, R^{8'}, R^{9'}, R^{10'}, R^{11'}, R^{12'}, R^{13'}, R^{14'}, R^{15'}, R^{16'}, R^{17'}, R^{18'} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH,
 15 -SO₃H, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

R^{1''}, R^{2''}, R^{3''}, R^{4''}, R^{5''}, R^{6''}, R^{7''}, R^{8''}, R^{9''}, R^{10''}, R^{11''}, R^{12''}, R^{13''}, R^{14''}, R^{15''}, R^{16''}, R^{17''}, R^{18''} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -OH, -SO₃H,
 20 -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

where the alkyl and aryl groups mentioned may be substituted.

5 $-(C_1-C_{12})$ -Alkyl and $-O-(C_1-C_{12})$ -alkyl may each be unsubstituted or substituted by one or more identical or different radicals selected from $-(C_3-C_{12})$ -cycloalkyl, $-(C_3-C_{12})$ -heterocycloalkyl, $-(C_6-C_{20})$ -aryl, fluorine, chlorine, cyano, formyl, acyl and alkoxycarbonyl.

$-(C_6-C_{20})$ -Aryl and $-(C_6-C_{20})$ -aryl- $-(C_6-C_{20})$ -aryl- may each be unsubstituted or substituted by one or more identical or different radicals selected from:

10 $-H$, $-(C_1-C_{12})$ -alkyl, $-O-(C_1-C_{12})$ -alkyl, $-O-(C_6-C_{20})$ -aryl, $-(C_6-C_{20})$ -aryl, -halogen (such as Cl, F, Br, I), $-COO-(C_1-C_{12})$ -alkyl, $-CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-CO-(C_1-C_{12})$ -alkyl, $-CO-(C_6-C_{20})$ -aryl, $-COOH$, $-OH$, $-SO_3H$, $-SO_3Na$, $-NO_2$, $-CN$, $-NH_2$, $-N[(C_1-C_{12})$ -alkyl] $_2$.

In the context of the invention, the expression " $-(C_1-C_{12})$ -alkyl" encompasses straight-chain and branched alkyl groups. Preferably, these groups are unsubstituted straight-chain or branched
15 $-(C_1-C_8)$ -alkyl groups and most preferably $-(C_1-C_6)$ -alkyl groups. Examples of $-(C_1-C_{12})$ -alkyl groups are especially methyl, ethyl, propyl, isopropyl, n-butyl, isobutyl, sec-butyl, tert-butyl, n-pentyl, 2-pentyl, 2-methylbutyl, 3-methylbutyl, 1,2-dimethylpropyl, 1,1-dimethylpropyl, 2,2-dimethylpropyl, 1-ethylpropyl, n-hexyl, 2-hexyl, 2-methylpentyl, 3-methylpentyl, 4-methylpentyl, 1,1-dimethylbutyl, 1,2-dimethylbutyl, 2,2-dimethylbutyl, 1,3-dimethylbutyl, 2,3-dimethylbutyl, 3,3-
20 dimethylbutyl, 1,1,2-trimethylpropyl, 1,2,2-trimethylpropyl, 1-ethylbutyl, 1-ethyl-2-methylpropyl, n-heptyl, 2-heptyl, 3-heptyl, 2-ethylpentyl, 1-propylbutyl, n-octyl, 2-ethylhexyl, 2-propylheptyl, nonyl, decyl.

The elucidations relating to the expression " $-(C_1-C_{12})$ -alkyl" also apply to the alkyl groups in $-O-$
25 $-(C_1-C_{12})$ -alkyl, i.e. in $-(C_1-C_{12})$ -alkoxy. Preferably, these groups are unsubstituted straight-chain or branched $-(C_1-C_6)$ -alkoxy groups.

Substituted $-(C_1-C_{12})$ -alkyl groups and substituted $-(C_1-C_{12})$ -alkoxy groups may have one or more substituents, depending on their chain length. The substituents are preferably each
30 independently selected from $-(C_3-C_{12})$ -cycloalkyl, $-(C_3-C_{12})$ -heterocycloalkyl, $-(C_6-C_{20})$ -aryl, fluorine, chlorine, cyano, formyl, acyl and alkoxycarbonyl.

The expression " $-(C_3-C_{12})$ -cycloalkyl", in the context of the present invention, encompasses mono-, bi- or tricyclic hydrocarbyl radicals having 3 to 12, especially 5 to 12, carbon atoms.

These include cyclopropyl, cyclobutyl, cyclopentyl, cyclohexyl, cycloheptyl, cyclooctyl, cyclododecyl, cyclopentadecyl, norbornyl and adamantyl. One example of a substituted cycloalkyl would be menthyl.

- 5 The expression " $-(C_3-C_{12})$ -heterocycloalkyl groups", in the context of the present invention, encompasses nonaromatic saturated or partly unsaturated cycloaliphatic groups having 3 to 12, especially 5 to 12, carbon atoms. The $-(C_3-C_{12})$ -heterocycloalkyl groups have preferably 3 to 8, more preferably 5 or 6, ring atoms. In the heterocycloalkyl groups, as opposed to the cycloalkyl groups, 1, 2, 3 or 4 of the ring carbon atoms are replaced by heteroatoms or heteroatom-
 10 containing groups. The heteroatoms or the heteroatom-containing groups are preferably selected from $-O-$, $-S-$, $-N-$, $-N(=O)-$, $-C(=O)-$ and $-S(=O)-$. Examples of $-(C_3-C_{12})$ -heterocycloalkyl groups are tetrahydrothiophenyl, tetrahydrofuryl, tetrahydropyranyl and dioxanyl.
- 15 In the context of the present invention, the expression " $-(C_6-C_{20})$ -aryl and $-(C_6-C_{20})$ -aryl- (C_6-C_{20}) -aryl-" encompasses mono- or polycyclic aromatic hydrocarbyl radicals. These have 6 to 20 ring atoms, more preferably 6 to 14 ring atoms, especially 6 to 10 ring atoms. Aryl is preferably $-(C_6-C_{10})$ -aryl and $-(C_6-C_{10})$ -aryl- (C_6-C_{10}) -aryl-. Aryl is especially phenyl, naphthyl, indenyl, fluorenyl, anthracenyl, phenanthrenyl, naphthacenyl, chrysenyl, pyrenyl, coronenyl. More particularly, aryl
 20 is phenyl, naphthyl and anthracenyl.

Substituted $-(C_6-C_{20})$ -aryl groups and $-(C_6-C_{20})$ -aryl- (C_6-C_{20}) -aryl groups may have one or more (e.g. 1, 2, 3, 4 or 5) substituents, depending on the ring size. These substituents are preferably each independently selected from $-H$, $-(C_1-C_{12})$ -alkyl, $-O-(C_1-C_{12})$ -alkyl, $-O-(C_6-C_{20})$ -aryl, $-(C_6-$
 25 $C_{20})$ -aryl, $-halogen$ (such as Cl, F, Br, I), $-COO-(C_1-C_{12})$ -alkyl, $-CONH-(C_1-C_{12})$ -alkyl, $-(C_6-C_{20})$ -aryl- $CON[(C_1-C_{12})$ -alkyl] $_2$, $-CO-(C_1-C_{12})$ -alkyl, $-CO-(C_6-C_{20})$ -aryl, $-COOH$, $-OH$, $-SO_3H$, $-SO_3Na$, $-NO_2$, $-CN$, $-NH_2$, $-N[(C_1-C_{12})$ -alkyl] $_2$.

Substituted $-(C_6-C_{20})$ -aryl groups and $-(C_6-C_{20})$ -aryl- (C_6-C_{20}) -aryl groups are preferably substituted $-(C_6-C_{10})$ -aryl groups and $-(C_6-C_{10})$ -aryl- (C_6-C_{10}) -aryl groups, especially substituted
 30 phenyl or substituted naphthyl or substituted anthracenyl. Substituted $-(C_6-C_{20})$ -aryl groups preferably bear one or more, for example 1, 2, 3, 4 or 5, substituents selected from $-(C_1-C_{12})$ -alkyl groups, $-(C_1-C_{12})$ -alkoxy groups.

In one embodiment, R^1 , R^2 , R^3 , R^4 , R^5 , R^6 , R^7 , R^8 are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

In one embodiment, R^{1'}, R^{2'}, R^{3'}, R^{4'}, R^{5'}, R^{6'}, R^{7'}, R^{8'} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

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In one embodiment, R^{1''}, R^{2''}, R^{3''}, R^{4''}, R^{5''}, R^{6''}, R^{7''}, R^{8''} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

10

In one embodiment, R^{9'}, R^{10'}, R^{11'}, R^{12'}, R^{13'}, R^{14'}, R^{15'}, R^{16'}, R^{17'}, R^{18'} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

In one embodiment, R^{9''}, R^{10''}, R^{11''}, R^{12''}, R^{13''}, R^{14''}, R^{15''}, R^{16''}, R^{17''}, R^{18''} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

15

In one embodiment, R¹, R², R³, R⁴, R⁵, R⁶, R⁷, R⁸ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl.

In one embodiment, R^{1'}, R^{2'}, R^{3'}, R^{4'}, R^{5'}, R^{6'}, R^{7'}, R^{8'} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl.

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In one embodiment, R^{1''}, R^{2''}, R^{3''}, R^{4''}, R^{5''}, R^{6''}, R^{7''}, R^{8''} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl.

In one embodiment, R^{9'}, R^{10'}, R^{11'}, R^{12'}, R^{13'}, R^{14'}, R^{15'}, R^{16'}, R^{17'}, R^{18'} are selected from:

25

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl.

In one embodiment, R^{9''}, R^{10''}, R^{11''}, R^{12''}, R^{13''}, R^{14''}, R^{15''}, R^{16''}, R^{17''}, R^{18''} are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl.

30

In one embodiment, the compound has the general structure (I).

In one embodiment, the compound has the general structure (II).

In one embodiment, the compound has the general structure (III).

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The invention is illustrated in detail hereinafter by working examples and a figure.

Figure 1 shows a reaction apparatus in which the coupling reaction to give the corresponding unsymmetric biaryls can be conducted. The apparatus comprises a nickel cathode (1) and an anode composed of boron-doped diamond (BDD) on silicon (5). The apparatus can be cooled with the aid of a cooling jacket (3). The arrows indicate the flow direction of the cooling water. The reaction space is sealed by a Teflon stopper (2). The reaction mixture is mixed by a magnetic stirrer bar (7). On the anodic side, the apparatus is sealed by screw clamps (4) and seals (6).

10 Analysis

Chromatography

The preparative liquid chromatography separations via flash chromatography were conducted with a maximum pressure of 1.6 bar on 60 M silica gel (0.040-0.063 mm) from Macherey-Nagel GmbH & Co, Düren. The unpressurized separations were conducted on Geduran Si 60 silica gel (0.063-0.200 mm) from Merck KGaA, Darmstadt. The solvents used as eluents (ethyl acetate (technical grade), cyclohexane (technical grade)) had been purified by distillation beforehand on a rotary evaporator.

For thin-film chromatography (TLC), ready-made PSC silica gel 60 F254 plates from Merck KGaA, Darmstadt were used. The R_f values are reported as a function of the eluent mixture used. The TLC plates were stained using a cerium/molybdatophosphoric acid solution as immersion reagent. Cerium/molybdatophosphoric acid reagent: 5.6 g of molybdatophosphoric acid, 2.2 g of cerium(IV) sulphate tetrahydrate and 13.3 g of concentrated sulphuric acid to 200 ml of water.

Gas chromatography (GC/GCMS)

The gas chromatography studies (GC) on product mixtures and pure substances were effected with the aid of the GC-2010 gas chromatograph from Shimadzu, Japan. Analysis is effected on an HP-5 quartz capillary column from Agilent Technologies, USA (length: 30 m; internal diameter: 0.25 mm; film thickness of the covalently bound stationary phase: 0.25 μ m; carrier gas: hydrogen; injector temperature: 250°C; detector temperature: 310°C; programme: "hard" method: start temperature 50°C for 1 min, heating rate: 15°C/min, end temperature 290°C for 8 min). Gas chromatography-mass spectrometry analyses (GC-MS) of product mixtures and pure substances were recorded with the aid of the GC-2010 gas chromatograph combined with

the GCMS-QP2010 mass detector from Shimadzu, Japan. Analysis is effected on an HP-1 quartz capillary column from Agilent Technologies, USA (length: 30 m; internal diameter: 0.25 mm; film thickness of the covalently bound stationary phase: 0.25 μ m; carrier gas: hydrogen; injector temperature: 250°C; detector temperature: 310°C; programme: "hard" method: start temperature 50°C for 1 min, heating rate: 15°C/min, end temperature 290°C for 8 min; GC-MS: ion source temperature: 200°C).

Melting points

Melting points were measured with the aid of the SG 2000 melting point determination instrument from HW5, Mainz, and are uncorrected.

Elemental analysis

The elemental analyses were conducted in the analytical division of the Organic Chemistry department of the Johannes Gutenberg University of Mainz on a Vario EL Cube from Foss-Heraeus, Hanau.

Mass spectrometry

All electrospray ionization analyses (ESI+) were conducted on a QToF Ultima 3 from Waters Micromasses, Milford, Massachusetts. EI mass spectra and the high-resolution EI spectra were analysed on an instrument of the MAT 95 XL sector field instrument type from ThermoFinnigan, Bremen.

NMR spectroscopy

The NMR spectroscopy studies were conducted on multi-nucleus resonance spectrometers of the AC 300 or AV II 400 type from Bruker, Analytische Messtechnik, Karlsruhe. The solvent used was CDCl₃. The ¹H and ¹³C spectra were calibrated according to the residual content of undeuterated solvent using the NMR Solvent Data Chart from Cambridge Isotopes Laboratories, USA. Some of the ¹H and ¹³C signals were assigned with the aid of H,H-COSY, H,H-NOESY, H,C-HSQC and H,C-HMBC spectra. The chemical shifts are reported as δ values in ppm. For the multiplicities of the NMR signals, the following abbreviations were used: s (singlet), bs (broad singlet), d (doublet), t (triplet), q (quartet), m (multiplet), dd (doublet of doublets), dt (doublet of triplets), tq (triplet of quartets). All coupling constants J were reported in hertz (Hz) together with the number of bonds covered. The numbering given in the assignment

of signals corresponds to the numbering shown in the formula schemes, which do not necessarily have to correspond to IUPAC nomenclature.

General operating procedures

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All the preparations which follow were carried out under protective gas using standard Schlenk techniques. The solvents were dried over suitable desiccants before use (Purification of Laboratory Chemicals, W. L. F. Armarego (Author), Christina Chai (Author), Butterworth Heinemann (Elsevier), 6th edition, Oxford 2009).

- 10 Phosphorus trichloride (Aldrich) was distilled under argon before use. All preparative operations were effected in baked-out vessels. The products were characterized by means of NMR spectroscopy. Chemical shifts (δ) are reported in ppm. The ^{31}P NMR signals were referenced according to: $\text{SR}_{31\text{P}} = \text{SR}_{1\text{H}} * (\text{BF}_{31\text{P}} / \text{BF}_{1\text{H}}) = \text{SR}_{1\text{H}} * 0.4048$. (Robin K. Harris, Edwin D. Becker, Sonia M. Cabral de Menezes, Robin Goodfellow, and Pierre Granger, Pure Appl. Chem., 2001, 73, 1795-1818; Robin K. Harris, Edwin D. Becker, Sonia M. Cabral de Menezes, Pierre Granger, Roy E. Hoffman and Kurt W. Zilm, Pure Appl. Chem., 2008, 80, 59-84).
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Synthesis of unsymmetric biaryls

- 20 The unsymmetric biaryls were prepared by an electrochemical method by coupling two phenols or one naphthol and one phenol which differ in terms of oxidation potential. In this regard, see also B. Elsler, D. Schollmeyer, K. M. Dyballa, R. Franke, S. R. Waldvogel, "Metall- und reagensfreie hochselektive anodische Kreuzkupplung von Phenolen" [Metal- and Reagent-Free High-Selectivity Anodic Cross-Coupling of Phenols], Angew. Chem., 2014, DOI: 10.1002/ange.201400627
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General procedure

The coupling reaction was conducted in an apparatus as shown in Figure 1.

- 30 5 mmol of the first phenol having an oxidation potential $E_{\text{ox}1}$ together with 15 mmol of the second phenol having an oxidation potential $E_{\text{ox}2}$ are dissolved in 1,1,1,3,3,3-hexafluoroisopropanol (HFIP) and MeOH or in formic acid and MeOH in the amounts specified in Table 1 below. The electrolysis is galvanostatic.

The outer shell of the electrolysis cell is kept at a controlled temperature of about 10°C by means of a thermostat, while the reaction mixture is stirred and heated to 50°C with the aid of a sand bath. After the electrolysis has ended, the cell contents are transferred together with toluene to a 50 ml round-bottom flask and the solvent is removed on a rotary evaporator at 50°C, 200-70 mbar, under reduced pressure. Unconverted reactant is recovered by means of short-path distillation (100°C, 10⁻³ mbar).

Electrode material

Anode: boron-doped diamond (BDD) on Si

10 Cathode: Ni mesh

Electrolysis conditions:

Temperature [T]: 50°C

Current [I]: 15 mA

15 Current density [j]: 2.8 mA/cm²

Charge [Q]: 2 F/mol of deficiency component

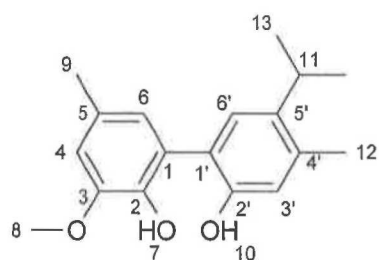
Terminal voltage [U_{max}]: 3-5 V

20 The biaryls were synthesized by the general method described above, and in a reaction apparatus as shown in Figure 1.

In the structures (I) and (II), each outer unit consists of a 2,2'-biphenol unit.

25 The synthesis of symmetrical 2,2'-biphenol units is sufficiently well known to a person skilled in the art and can be found in the standard technical literature.

2,2'-Dihydroxy-4',5-dimethyl-5'-(methylethyl)-3-methoxybiphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 2.28 g (15 mmol, 3.0 equiv.) of 3-methyl-4-(methylethyl)phenol were dissolved in 33 ml of HFIP, 0.68 g of methyltriethylammonium methylsulphate (MTES) were added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 9:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a colourless solid.

Yield: 716 mg (50%, 2.5 mmol)

10 GC (*hard* method, HP-5): $t_R = 14.87$ min

$R_f(\text{CH:EA} = 4:1) = 0.43$

$m_p = 126.8^\circ\text{C}$ (recrystallized from CH)

$^1\text{H NMR}$ (600 MHz, DMSO) $\delta = 1.17\text{--}1.12$ (m, 6H, 13-H), 2.24 (m, 6H, 9-H/12-H), 3.01 (dt, 1H, 11-H), 3.79 (s, 3H, 8-H), 6.55 (s, 1H, 6-H), 6.66 (d, 1H, 6'-H), 6.73 (d, 1H, 4-H), 6.96 (s, 1H, 3'-H), 8.16 (s, 1H, 7-H), 8.84 (s, 1H, 10-H);

Couplings: $^4J_{4\text{-H}, 6\text{-H}} = 2.2$ Hz, $^4J_{6'\text{-H}, 11\text{-H}} = 2.9$ Hz, $^3J_{11\text{-H}, 13\text{-H}} = 6.8$ Hz;

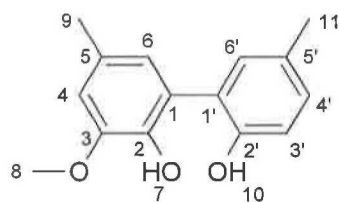
$^{13}\text{C NMR}$ (151 MHz, DMSO) $\delta = 18.73, 20.80$ (C-9/C-12), 23.54 (C-13), 28.10 (C-11), 55.78 (C-8), 111.23 (C-4), 117.34 (C-6'), 123.42 (C-1'), 123.49 (C-6), 126.43 (C-1), 127.36 (C-5), 127.49 (C-3'), 134.40 (C-5'), 136.62 (C-4'), 141.12 (C-2), 147.65 (C-3), 151.69 (C-2').

20 HRMS for $\text{C}_{18}\text{H}_{22}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc: 309.1467, found: 309.1457

MS (EI, GCMS): $m/z(\%)$: 286 (50) $[\text{M}]^+$, 271 (100) $[\text{M}-\text{CH}_3]^+$, 244 (22) $[\text{M}-\text{C}_3\text{H}_6]^+$.

Elemental analysis for $\text{C}_{18}\text{H}_{22}\text{O}_3$: calc: C: 75.50%, H: 7.74%, found: C: 75.01%, H: 7.70%.

25 2,2'-Dihydroxy-5,5'-dimethyl-3-methoxybiphenyl



1.66 g (12 mmol, 1.0 equiv.) of 4-methylguaiacol and 3.91 g (36 mmol, 3.0 equiv.) of 4-methylphenol were dissolved in 65 ml of HFIP and 14 ml of MeOH, 1.63 g of methyltriethylammonium methylsulphate (MTES) were added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash

chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a colourless solid.

Yield: 440 mg (36%, 1.8 mmol)

5 GC (*hard* method, HP-5): t_R = 13.56 min

$R_f(\text{CH:EA} = 4:1) = 0.38$

$m_p = 162.0^\circ\text{C}$ (recrystallized from CH)

$^1\text{H NMR}$ (400 MHz, DMSO) δ = 2.18 (s, 3H, 9-H/11-H), 2.21 (s, 3H, 9-H/11-H), 3.76 (s, 3H, 8-H), 6.53 (s, 1H, 6-H), 6.71 (s, 1H, 4-H), 6.75 (d, 1H, 3'-H), 6.86-6.94 (m, 2H, 4'-H/6'-H), 8.53 (bs, 1H, 7-H/12-H);

Couplings: $^3J_{3'-\text{H}, 4'-\text{H}} = 8.4 \text{ Hz}$;

$^{13}\text{C NMR}$ (101 MHz, DMSO) δ = 20.21, 20.77 (C-9/C-11), 55.79 (C-8), 111.36 (C-4), 115.69 (C-3'), 123.50 (C-6), 125.72 (C-1'), 126.16 (C-1), 127.20 (C-5), 127.30 (C-5'), 128.50 (C-6'), 131.83 (C-4'), 141.20 (C-2), 147.61 (C-3), 152.11 (C-2').

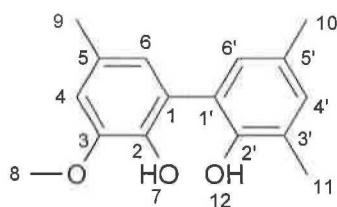
15 HRMS for $\text{C}_{15}\text{H}_{16}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc: 267.0997, found: 267.0999

MS (EI, GCMS): $m/z(\%)$: 244 (100) $[\text{M}]^+$, 229 (64) $[\text{M}-\text{CH}_3]^+$.

Elemental analysis for $\text{C}_{15}\text{H}_{16}\text{O}_3$: calc: C: 73.75%, H: 6.60%, found: C: 73.81%, H: 6.54%.

2,2'-Dihydroxy-3-methoxy-3',5,5'-trimethylbiphenyl

20



0.70 g (6 mmol, 1.0 equiv.) of 4-methylguaiaicol and 2.08 g (17 mmol, 3.0 equiv.) of 2,4-dimethylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 9:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a pale yellow solid.

Yield: 663 mg (45%, 2.5 mmol)

30

GC (*hard* method, HP-5): t_R = 13.97 min

$R_f(\text{CH:EA} = 4:1) = 0.29$

$m_p = 119.7^\circ\text{C}$ (recrystallized from DCM/CH)

$^1\text{H NMR}$ (400 MHz, CDCl_3) $\delta = 2.34$ (s, 3H, 10-H), 2.35 (s, 3H, 11-H), 2.38 (s, 3H, 9-H), 3.94 (s, 3H, 8-H), 6.16 (s, 1H, 12-H), 6.20 (s, 1H, 7-H), 6.76 (d, 1H, 4-H), 6.78 (d, 1H, 6-H), 6.98 (d, 1H, 6'-H), 7.03 (d, 1H, 4'-H);

Couplings: $^4J_{4\text{-H}, 6\text{-H}} = 1.7$ Hz, $^4J_{4'\text{-H}, 6'\text{-H}} = 2.1$ Hz;

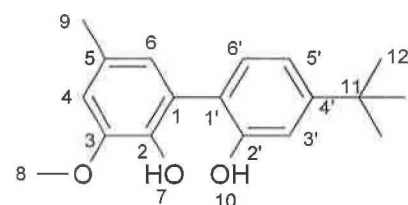
$^{13}\text{C NMR}$ (101 MHz, CDCl_3) $\delta = 16.51$ (C-9), 20.54 (C-10), 21.20 (C-11), 56.12 (C-8), 110.92 (C-4), 123.95 (C-6), 124.13 (C-1), 124.64 (C-1'), 126.18 (C-3'), 128.82 (C-6'), 129.59 (C-5'), 130.40 (C-5), 131.40 (C-4'), 139.46 (C-2), 146.35 (C-3), 149.42 (C-2').

10 HRMS for $\text{C}_{18}\text{H}_{16}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc: 281.1154, found: 281.1152

MS (EI, GCMS): $m/z(\%)$: 242 (100) $[\text{M}]^+$, 227 (38) $[\text{M}-\text{CH}_3]^+$.

Elemental analysis for $\text{C}_{16}\text{H}_{18}\text{O}_3$: calc: C: 68.31%, H: 6.45%, found: C: 68.29%, H: 6.40%.

2,2'-Dihydroxy-3-methoxy-5-methyl-4'-(dimethylethyl)biphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 2.25 g (15 mmol, 3.0 equiv.) of 3-tert-butylphenol were dissolved in 33 ml of HFIP, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell.

20 After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a colourless solid.

Yield: 808 mg (63%, 3.1 mmol)

25 GC (*hard* method, HP-5): $t_R = 13.97$ min

$R_f(\text{CH:EA} = 4:1) = 0.29$

$m_p = 160.3^\circ\text{C}$ (recrystallized from DCM/CH)

$^1\text{H NMR}$ (400 MHz, CDCl_3) $\delta = 1.37$ (s, 9H, 12-H), 2.36 (s, 3H, 9-H), 3.94 (s, 3H, 8-H), 6.25 (s, 1H, 7-H), 6.48 (s, 1H, 10-H), 6.75 (d, 1H, 6-H), 6.79 (d, 1H, 4-H), 7.08 (dd, 1H, 5'-H), 7.12 (d, 1H, 3'-H), 7.27 (d, 1H, 6'-H);

Couplings: $^4J_{4\text{-H}, 6\text{-H}} = 1.7$ Hz; $^3J_{5'\text{-H}, 6'\text{-H}} = 8.0$ Hz, $^4J_{3'\text{-H}, 5'\text{-H}} = 1.7$ Hz;

^{13}C NMR (101 MHz, CDCl_3) δ = 21.24 (C-9), 31.31 (C-12), 34.58 (C-11), 56.15 (C-8), 110.79 (C-4), 114.94 (C-3'), 118.30 (C-5'), 122.37 (C-1'), 123.88 (C-1), 123.94 (C-6), 130.45 (C-6'), 130.53 (C-4'), 139.24 (C-5), 146.32 (C-3), 152.91 (C-2'), 153.13 (C-2).

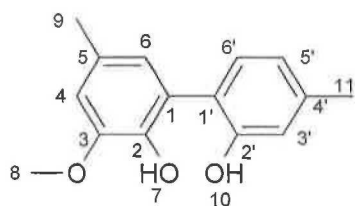
HRMS for $\text{C}_{15}\text{H}_{16}\text{O}_4$ (ESI+) $[\text{M}+\text{Na}]^+$: calc: 309.1467, found: 309.1466

5 MS (EI, GCMS): $m/z(\%)$: 242 (100) $[\text{M}]^+$, 227 (38) $[\text{M}-\text{CH}_3]^+$.

Elemental analysis for $\text{C}_{18}\text{H}_{22}\text{O}_3$: calc: 75.50%, H: 7.74%, found: C: 75.41%, H: 7.72%.

2,2'-Dihydroxy-4',5-dimethyl-3-methoxybiphenyl

- 10 0.70 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 1.65 g (15 mmol, 3.0 equiv.) of 3-methylphenol were dissolved in 33 ml of HFIP, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1
15 eluent (cyclohexane:ethyl acetate) and two cross-coupling products are obtained as colourless solids.



Yield: 266 mg (21%, 1.1 mmol)

20 GC (*hard* method, HP-5): t_R = 13.72 min

$R_f(\text{CH:EA} = 4:1) = 0.25$

m_p = 136.2°C (recrystallized from DCM/CH)

^1H NMR (400 MHz, CDCl_3) δ = 2.35 (s, 3H, 9-H/11-H), 2.37 (s, 3H, 9-H/11-H), 3.94 (s, 3H, 8-H), 6.17 (s, 1H, 10-H), 6.35 (s, 1H, 2-H), 6.74 (d, 1H, 4-H), 6.76 (s, 1H, 6-H), 6.88-6.83 (m, 1H, 5'-
25 H), 6.90 (d, 1H, 3'-H), 7.21 (d, 1H, 6'-H);

Couplings: $^4J_{4\text{-H}, 6\text{-H}} = 1.8$ Hz, $^3J_{5'\text{-H}, 6'\text{-H}} = 7.7$ Hz, $^4J_{3'\text{-H}, 5'\text{-H}} = 1.5$ Hz;

^{13}C NMR (101 MHz, CDCl_3) δ = 21.11, 21.20 (C-9/C-11), 56.13 (C-8), 110.81 (C-4), 118.25 (C-3'), 121.97 (C-5'), 122.39 (C-1), 123.77 (C-1'), 123.85 (C-6), 130.50 (C-5), 130.68 (C-6'), 139.30 (C-4'), 139.54 (C-2), 146.31 (C-3), 153.33 (C-2').

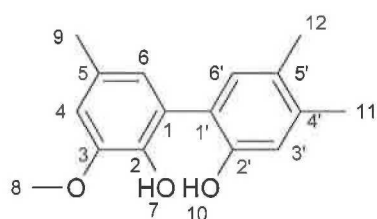
30 HRMS for $\text{C}_{15}\text{H}_{16}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}]^+$: calc: 267.0997, found: 267.1006

MS (EI, GCMS): $m/z(\%)$: 244 (100) $[\text{M}]^+$, 229 (18) $[\text{M}-\text{CH}_3]^+$.

Elemental analysis for $C_{15}H_{16}O_3$: calc: C: 73.75%, H: 6.60%, found: C: 73.70%, H: 6.68%.

5

2,2'-Dihydroxy-3-methoxy-4'-5,5'-trimethylbiphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 1.83 g (15 mmol, 3.0 equiv.) of 3,4-dimethylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 9:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a colourless solid.

Yield: 688 mg (52%, 2.6 mmol)

GC (*hard* method, HP-5): t_R = 14.52 min

R_f (CH:EA = 4:1) = 0.29

m_p = 152.3°C (recrystallized from DCM/CH)

1H NMR (400 MHz, $CDCl_3$) δ = 12.25 (s, 3H, 11-H), 2.28 (s, 3H, 12-H), 2.36 (s, 3H, 9-H), 3.93 (s, 3H, 8-H), 6.19 (s, 1H, 7-H), 6.25 (s, 1H, 10-H), 6.73 (d, 1H, 4-H), 6.76 (s, 1H, 6-H), 6.88 (s, 1H, 3'-H), 7.08 (s, 1H, 6'-H);

Couplings: $^4J_{4-H, 6-H}$ = 1.7 Hz;

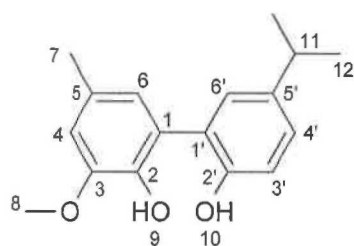
^{13}C NMR (101 MHz, $CDCl_3$) δ = 18.89 (C-11), 19.60 (C-12), 21.24 (C-9), 56.14 (C-8), 110.74 (C-4), 118.93 (C-3'), 122.54 (C-1), 123.82 (C-6), 123.97 (C-1'), 129.03 (C-5), 130.46 (C-4'), 131.69 (C-6'), 137.94 (C-5'), 139.26 (C-2), 146.31 (C-3), 151.36 (C-2').

HRMS for $C_{16}H_{18}O_3$ (ESI+) $[M+Na]^+$: calc: 281.1154, found: 281.1157

MS (EI, GCMS): m/z (%): 258 (100) $[M]^+$, 243 (10) $[M-CH_3]^+$.

Elemental analysis for $C_{16}H_{18}O_3$: calc: 74.39%, H: 7.02%, found: C: 74.32%, H: 7.20%.

5

2,2'-Dihydroxy-5'-isopropyl-3-methoxy-5-methylbiphenyl

0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 2.05 g (15 mmol, 3.0 equiv.) of 4-isopropylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a brownish oil.

Yield: 0.53 g (39 mmol; 1.9%).

GC (*hard* method, HP-5): $t_R = 14.23$ min

$R_f(\text{CH:EA} = 4:1) = 0.30$

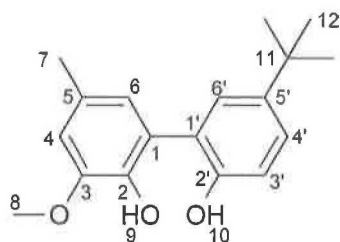
^1H NMR (400 MHz, CDCl_3) $\delta = 1.27$ (m, 6H), 2.36 (s, 3H), 2.91 (dt, $J = 13.8, 6.9, 6.9$ Hz, 1H), 3.94 (s, 3H), 6.13-6.27 (m, 2H), 6.82-6.65 (m, 1H), 6.25 (m, 2H), 6.75 (s, 1H), 6.77 (s, 1H), 6.99 (d, $J = 8.1$ Hz, 1H), 7.19-7.12 (m, 2H);

^{13}C NMR (101 MHz, CDCl_3) $\delta = 21.25, 24.27, 33.40, 56.18, 110.92, 117.60, 123.91, 124.23, 125.07, 127.29, 128.80, 130.57, 139.29, 141.42, 146.31, 151.51$.

HRMS for $\text{C}_{17}\text{H}_{20}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc: 295.1310, found: 295.1297

MS (EI, GCMS): $m/z(\%)$: 272 (80) $[\text{M}]^+$, 257 (100) $[\text{M}-\text{CH}_3]^+$.

2,2'-Dihydroxy-3-methoxy-5-methyl-5'-tert-butylbiphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 2.26 g (15 mmol, 3.0 equiv.) of 4-*tert*-butylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a yellowish oil.

Yield: 0.48 g (34%, 1.7 mmol)

GC (*hard* method, HP-5): $t_R = 14.52$ min

$R_f(\text{CH:EA} = 4:1) = 0.24$

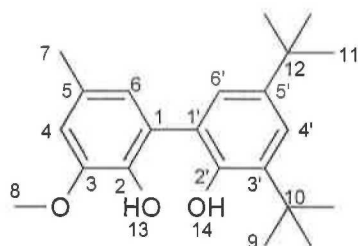
^1H NMR (400 MHz, CDCl_3) $\delta = 1.34$ (s, 9H), 2.37 (s, 3H), 3.94 (s, 3H), 6.17 (s, 1H), 6.24 (s, 1H), 6.75 (s, 1H), 6.77 (s, 1H), 6.99 (d, $J = 8.4$ Hz, 1H), 7.31-7.29 (m, 1H), 7.33 (dd, $J = 8.4, 2.5$ Hz, 1H).

^{13}C NMR (101 MHz, CDCl_3) $\delta = 21.28, 31.61, 34.20, 56.18, 110.91, 117.25, 123.92, 124.41, 124.63, 126.38, 127.78, 130.58, 139.32, 143.70, 146.32, 151.22$.

HRMS for $\text{C}_{18}\text{H}_{22}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc: 309.1467, found: 309.1476

MS (EI, GCMS): $m/z(\%)$: 286 (28) $[\text{M}]^+$, 271 (100) $[\text{M}-\text{CH}_3]^+$.

2,2'-Dihydroxy-3',5'-di-*tert*-butyl-5-methyl-3-methoxybiphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 3.12 g (15 mmol, 3.0 equiv.) of 2,4-di-*tert*-butylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant

are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 9:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a colourless solid.

Yield: 0.41 g (24%, 1.2 mmol)

5

GC (*hard* method, HP-5): $t_R = 15.15$ min

$R_f(\text{CH:EA} = 9:1) = 0.35$

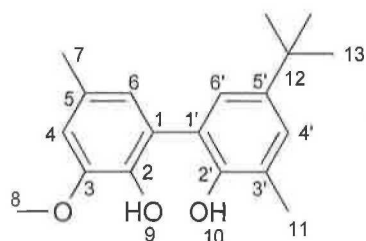
$m_p = 120.2$ °C (recrystallized in *n*-pentane)

$^1\text{H NMR}$ (400 MHz, CDCl_3) $\delta = 1.36$ (s, 9H), 1.50 (s, 9H), 2.38 (s, 3H), 3.96 (s, 3H), 6.00 (s, 1H),
10 6.05 (s, 1H), 6.77 (s, 1H), 7.16 (d, $J = 2.5$ Hz, 1H), 7.39 (d, $J = 2.5$ Hz, 1H).

$^{13}\text{C NMR}$ (101 MHz, CDCl_3) $\delta = 21.23, 29.88, 31.69, 34.40, 35.23, 56.17, 111.03, 123.96, 124.17, 125.09, 125.50, 130.42, 136.73, 139.72, 142.36, 146.45, 149.82$.

MS (EI, GCMS): $m/z(\%)$: 342 (22) $[\text{M}]^+$, 327 (100) $[\text{M}-\text{CH}_3]^+$.

15 2,2'-Dihydroxy-3',5-dimethyl-3-methoxy-5'-tert-butylbiphenyl



0.69 g (5 mmol, 1.0 equiv.) of 4-methylguaiacol and 2.47 g (15 mmol, 3.0 equiv.) of 2-methyl-4-*tert*-butylphenol were dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of
20 methyltriethylammonium methylsulphate (MTES) was added and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a yellowish oil.

25 Yield: 0.69 g (46%, 2.3 mmol)

GC (*hard* method, HP-5): $t_R = 14.79$ min

$R_f(\text{CH:EA} = 4:1) = 0.33$

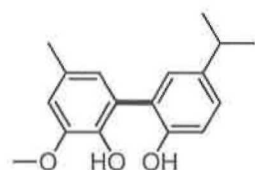
$^1\text{H NMR}$ (400 MHz, CDCl_3) $\delta = 1.37$ (s, 9H), 2.39 (d, $J = 2.4$ Hz, 6H), 3.94 (s, 3H), 6.15 (s, 1H),
30 6.17 (s, 1H), 6.77 (s, 1H), 6.79 (s, 1H), 7.17 (d, $J = 2.5$ Hz, 1H), 7.24 (d, $J = 2.4$ Hz, 1H);

^{13}C NMR (101 MHz, CDCl_3) δ = 16.90, 21.28, 31.67, 34.12, 56.16, 110.94, 124.02, 124.17, 124.59, 125.41, 125.65, 127.86, 130.47, 139.50, 143.07, 146.40, 149.41.

MS (EI, GCMS): $m/z(\%)$: 300 (18) $[\text{M}]^+$, 285 (100) $[\text{M}-\text{CH}_3]^+$.

5

10 2,2'-Dihydroxy-3-methoxy-5-methyl-5'-(1-methylethyl)biphenyl



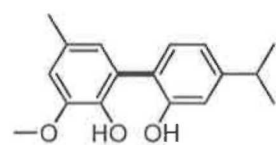
0.69 g (5 mmol, 1.0 eq.) of 4-methylguaiacol and 2.05 g (15 mmol, 3.0 eq.) of 4-isopropylphenol and 0.68 g of methyltriethylammonium methylsulphate (MTES) in 27 ml of HFIP + 6 ml of MeOH were added to methyltriethylammonium methylsulphate (MTES) and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a brownish oil.

20 Yield: 39 g (1.9 mmol; 18%).

R_f (cyclohexane:ethyl acetate = 4:1) = 0.30; ^1H NMR (400 MHz, CDCl_3) δ = 1.27 (m, 6H), 2.36 (s, 3H), 2.91 (sept, J = 6.9 Hz, 1H), 3.94 (s, 3H), 6.13-6.27 (m, 2H), 6.65-6.82 (m, 2H), 6.99 (d, J = 8.1 Hz, 1H), 7.12-7.19 (m, 2H); ^{13}C NMR (101 MHz, CDCl_3) δ = 21.37, 24.39, 33.53, 56.31, 111.04, 117.73, 124.04, 124.36, 125.20, 127.42, 128.93, 130.70, 139.42, 141.55, 146.44, 151.64. HRMS for $\text{C}_{17}\text{H}_{20}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}]^+$: calculated: 295.1310, found: 295.1297; MS (EI, GCMS): $m/z(\%)$: 272 (80) $[\text{M}]^+$, 257 (100) $[\text{M}-\text{CH}_3]^+$.

25

2,2'-Dihydroxy-3-methoxy-5-methyl-4'-(methylethyl)biphenyl



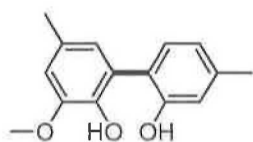
30 0.69 g (5 mmol, 1.0 eq.) of 4-methylguaiacol and 2.065 g (15 mmol, 3.0 eq.) of 3-isopropylphenol and 0.68 g of methyltriethylammonium methylsulphate (MTES) were dissolved

in 33 ml of HFIP and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a brownish oil (yield: 52%, 705 mg, 2.6 mmol).

R_f (cyclohexane:ethyl acetate = 4:1) = 0.29; ^1H NMR (400 MHz, CDCl_3) δ = 1.27 (s, 3H), 1.29 (s, 3H), 2.34 (s, 3H), 2.91 (sept, J = 7.0 Hz, 1H), 3.94 (s, 3H), 6.15 (s, 1H), 6.35 (s, 1H), 6.73 (d, J = 1.8 Hz, 1H), 6.75-6.77 (m, 1H), 6.90 (dd, J = 7.9 Hz, 1.8 Hz, 1H), 6.94 (d, J = 1.7 Hz, 1H), 7.23 (d, J = 7.8 Hz, 1H). ^{13}C NMR (101 MHz, CDCl_3) δ = 21.36, 24.02, 33.92, 56.30, 77.16, 110.91, 115.77, 119.56, 122.81, 124.00, 124.08, 130.65, 130.84, 139.38, 146.43, 150.72, 153.54. HRMS for $\text{C}_{17}\text{H}_{20}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calculated: 295.1310, found: 295.1305; MS (EI, GCMS): $m/z(\%)$: 272 (100) $[\text{M}]^+$, 257 (50) $[\text{M}-\text{CH}_3]^+$. Elemental analysis for $\text{C}_{17}\text{H}_{20}\text{O}_3$: calculated 74.97%, H: 7.40%, found: C: 75.05%, H: 7.36%.

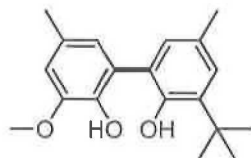
15 2,2'-Dihydroxy-4',5-dimethyl-3-methoxybiphenyl

0.28 g (2 mmol, 1.0 eq.) of 4-methylguaiacol, 1.22 g (6 mmol, 3.0 eq.) of 3-methylphenol and 0.77 g of MTBS were dissolved in 25 ml of HFIP and the electrolyte was transferred to the beaker-type electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and this led to the two cross-coupling products as a colourless and viscous oil.



Yield: 21%, 266 mg, 1.1 mmol; R_f (cyclohexane:ethyl acetate = 4:1) = 0.25; m_p = 136.2°C (crystallized from dichloromethane/cyclohexane); ^1H NMR (400 MHz, CDCl_3) δ = 2.35 (s, 3H), 2.37 (s, 3H), 3.94 (s, 3H), 6.17 (s, 1H), 6.35 (s, 1H), 6.74 (d, J = 1.8 Hz, 1H), 6.76 (s, 1H), 6.88-6.83 (m, 1H), 6.90 (d, 1H, J = 1.5 Hz), 7.21 (d, 1H, J = 7.7 Hz); ^{13}C NMR (101 MHz, CDCl_3) δ = 21.11, 21.20, 56.13, 110.81, 118.25, 121.97, 122.39, 123.77, 123.85, 130.50, 130.68, 139.30, 139.54, 146.31, 153.33. HRMS for $\text{C}_{15}\text{H}_{16}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calculated: 267.0997, found: 267.1006; MS (EI, GCMS): $m/z(\%)$: 244 (100) $[\text{M}]^+$, 229 (18) $[\text{M}-\text{CH}_3]^+$. Elemental analysis for $\text{C}_{15}\text{H}_{16}\text{O}_3$: calculated: C: 73.75%, H: 6.60%, found: C: 73.70%, H: 6.68%.

2,2'-Dihydroxy-5,5'-dimethyl-3'-(1,1-dimethylethyl)-3-methoxybiphenyl



5

0.69 g (5 mmol, 1.0 eq.) of 4-methylguaiacol, 2.47 g (15 mmol, 3.0 eq.) of 4-methyl-2-*tert*-butylphenol and 0.68 g of methyltriethylammonium methylsulphate (MTES) were dissolved in 27 ml of HFIP + 6 ml of MeOH and the electrolyte was transferred to the electrolysis cell. After the electrolysis, the solvent and unconverted amounts of reactant are removed under reduced
10 pressure, the crude product is purified by flash chromatography on silica gel 60 in a 4:1 eluent (cyclohexane:ethyl acetate) and the product is obtained as a yellow oil (yield: 36%, 545 mg, 1.8 mmol).

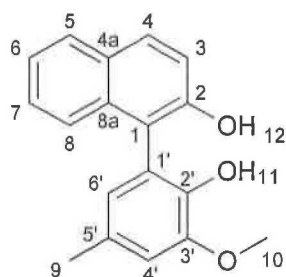
R_f (cyclohexane:ethyl acetate = 9:1) = 0.36; ^1H NMR (400 MHz, CDCl_3) δ = 1.46 (s, 9H), 2.34 (m, 6H), 3.93 (s, 3H), 5.99 (s, 1H), 6.01 (s, 1H), 6.74 (s, 2H), 6.96 (d, J = 1.9 Hz, 1H), 7.14 (d, J = 1.9
15 Hz, 1H); ^{13}C NMR (101 MHz, CDCl_3) δ = 21.05, 21.32, 29.96, 35.05, 56.30, 77.16, 111.21, 124.18, 124.24, 125.92, 127.67, 129.15, 129.22, 130.51, 137.57, 139.87, 146.57, 150.10. HRMS for $\text{C}_{22}\text{H}_{30}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calculated: 323.1623, found: 323.1618; MS (EI, GCMS): m/z (%): 300 (100) $[\text{M}]^+$, 285 (100) $[\text{M}-\text{CH}_3]^+$.

20 In structures (I) and (II), one outer portion in each case has a naphthyl-phenyl unit; in structure (III), both outer portions have a naphthyl-phenyl unit.

1-(2-Hydroxy-3-methoxy-5-methylphenyl)-2-naphthol

25 The electrolysis is conducted according to the general procedure in an undivided flange cell with a BDD anode. For this purpose, 0.78 g (5 mmol, 1.0 equiv.) of 2-naphthol and 2.18 g (15 mmol, 3.0 equiv.) of 4-methylguaiacol are dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) is added and the electrolyte is transferred into the electrolysis cell. The solvent and unconverted amounts of reactant are removed under
30 reduced pressure after the electrolysis, the crude product is purified on silica gel 60 in the form of "flash chromatography" in 4:1 eluent (CH:EA) and a product mixture is obtained. A second

“flash chromatography” in dichloromethane enables a separation of the two components as a pale red crystalline main product and a colourless crystalline by-product.



Yield: 899 mg (61%, 3.2 mmol)

5 GC (*hard* method, HP-5): t_R = 15.77 min

R_f (CH:EA = 4:1) = 0.36, R_f (DCM) = 0.36

m_p = 145.5 °C (recrystallized from DCM/CH)

^1H NMR (400 MHz, CDCl_3) δ = 2.39 (s, 3H, 9-H), 3.96 (s, 3H, 10-H), 5.47-5.52 (m, 1H, 12-H), 5.65-5.69 (m, 1H, 11-H), 6.75 (d, 1H, 6'-H), 6.85 (d, 1H, 4'-H), 7.32 (dd, 1H, 3-H), 7.34-7.43 (m, 2H, 6-H/7-H), 7.51 (d, 1H, 8-H), 7.83 (s, 1H, 5-H), 7.85 (d, 1H, 4-H);

Couplings: $^3J_{3\text{-H}, 4\text{-H}}$ = 9.0 Hz, $^3J_{7\text{-H}, 8\text{-H}}$ = 8.3 Hz, $^4J_{4'\text{-H}, 6'\text{-H}}$ = 1.8 Hz;

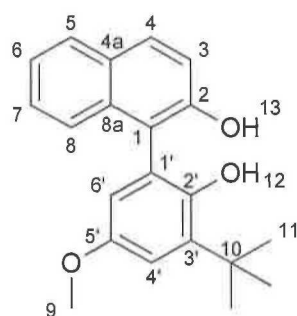
^{13}C NMR (101 MHz, CDCl_3) δ = 21.22 (C-9), 56.08 (C-10), 112.06 (C-4'), 116.62 (C-1), 117.81 (C-3), 119.33 (C-1'), 123.36 (C-6/C-7), 124.42 (C-6'), 124.86 (C-8), 126.48 (C-6/C-7), 128.15 (C-4), 129.18 (C-4a), 129.83 (C-5), 130.36 (C-5'), 133.16 (C-8a), 141.72 (C-2'), 147.24 (C-3'), 150.84 (C-2).

HRMS for $\text{C}_{18}\text{H}_{16}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}^+]$: calc.: 303.0997, found: 303.1003

MS (EI, GCMS): m/z (%): 280 (100) $[\text{M}]^+$, 265 (12) $[\text{M}-\text{CH}_3]^+$, 249 (12) $[\text{M}-\text{OCH}_3]^+$.

Elemental analysis for $\text{C}_{18}\text{H}_{16}\text{O}_3$: calc.: C: 77.12%, H: 5.75%, found: C: 76.96%, H: 5.82%.

20 1-(3-(Dimethylethyl)-2-hydroxy-5-methoxyphenyl)-2-naphthol



The electrolysis is conducted according to AAV1 in an undivided flange cell with a BDD anode. For this purpose, 0.72 g (5 mmol, 1.0 equiv.) of 2-naphthol and 2.77 g (15 mmol, 3.0 equiv.) of

2-(dimethylethyl)-4-methoxyphenol are dissolved in 27 ml of HFIP and 6 ml of MeOH, 0.68 g of methyltriethylammonium methylsulphate (MTES) is added and the electrolyte is transferred to the electrolysis cell. The solvent and unconverted amounts of reactant are removed under reduced pressure after the electrolysis, the crude product is purified on silica gel 60 in the form of a "flash chromatography" in 9:1 eluent (CH:EA) and the product is obtained as a colourless solid.

Yield: 1.05 g (63%, 3.2 mmol)

GC (*hard* method, HP-5): $t_R = 15.75$ min

$R_f(\text{CH:EA} = 4:1) = 0.43$

10 $m_p = 139.9$ °C (recrystallized from DCM/CH)

^1H NMR (400 MHz, CDCl_3) $\delta = 1.46$ (s, 9H, 11-H), 3.77 (s, 3H, 9-H), 4.72 (s, 1H, 2'-H), 5.36 (s, 1H, 2-H), 6.63 (d, 1H, 6'-H), 7.08 (d, 1H, 4'-H), 7.32 (d 1H, 3-H), 7.50-7.35 (m, 3H, 6-H/7-H/8-H), 7.87-7.83 (m, 1H, 5-H), 7.89 (d, 1H, 4-H);

Couplings: $^3J_{3\text{-H}, 4\text{-H}} = 8.9$ Hz; $^4J_{4'\text{-H}, 6'\text{-H}} = 3.1$ Hz;

15 ^{13}C NMR (101 MHz, CDCl_3) $\delta = 29.41$ (C-11), 35.19 (C-10), 55.68 (C-9), 111.95 (C-6'), 114.18 (C-1), 115.87 (C-4'), 117.63 (C-3), 119.16 (C-1'), 123.89, 124.15 (C-6/C-8), 127.38 (C-7), 128.31 (C-5), 129.19 (C-4a), 130.97 (C-4), 132.99 (C-8a), 139.05 (C-3'), 146.93 (C-2'), 151.94 (C-2), 153.41 (C-5').

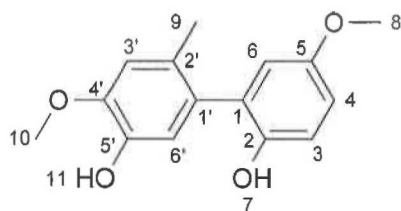
HRMS for $\text{C}_{21}\text{H}_{22}\text{O}_3$ (ESI+) $[\text{M}+\text{Na}]^+$: calc.: 345.1467, found: 345.1465

20 MS (EI, GCMS): $m/z(\%)$: 322 (100) $[\text{M}]^+$, 307 (38) $[\text{M}-\text{CH}_3]^+$.

Elemental analysis for $\text{C}_{21}\text{H}_{22}\text{O}_3$: calc.: 78.23%, H: 6.88%, found: C: 78.18%, H: 6.82%.

The central unit has a 2,3'-biphenol unit.

25 2,5'-Dihydroxy-4',5-dimethoxy-2'-methylbiphenyl



1.66 g (12 mmol, 1.0 equiv.) of 4-methylguaiacol and 4.49 g (36 mmol, 3.0 equiv.) of 4-methoxyphenol were dissolved in 80 ml of HFIP, 1.63 g of MTES were added and the electrolyte was transferred into the electrolysis cell. The solvent and unconverted amounts of reactant are removed under reduced pressure after the electrolysis, the crude product is purified

on silica gel 60 in the form of a "flash chromatography" in 4:1 eluent (cyclohexane: ethyl acetate) and the product is obtained as a colourless solid.

Yield: 2.05 g (66%, 7.9 mmol)

5 GC (*hard* method, HP-5): $t_R = 14.03$ min

$R_f(\text{CH:EA} = 4:1) = 0.33$

$m_p = 118.7$ °C (recrystallized from DCM/CH)

^1H NMR (600 MHz, DMSO) $\delta = 2.01$ (s, 3H, 9-H), 3.66 (s, 3H, 8-H), 3.77 (s, 3H, 10-H), 6.53 (d, 1H, 6-H), 6.55 (s, 1H, 6'-H), 6.72 (dd, 1H, 4-H), 6.77 (s, 1H, 3'-H), 6.79 (d, 1H, 3-H), 8.73 (s, 1H, 11-H), 8.75 (s, 1H, 7-H);

Couplings: $^3J_{3\text{-H}, 4\text{-H}} = 8.7$ Hz; $^4J_{4\text{-H}, 6\text{-H}} = 3.0$ Hz

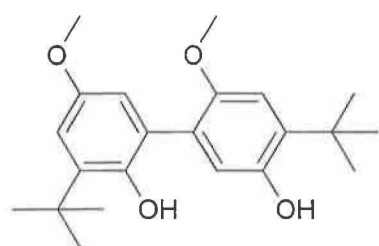
^{13}C NMR (151 MHz, DMSO) $\delta = 19.33$ (C-9), 55.32 (C-8), 55.73 (C-10), 113.24 (C-4), 113.75 (C-3'), 115.99 (C-3), 116.07 (C-6), 117.40 (C-6'), 126.56 (C-2'), 129.06 (C-1), 130.95 (C-1'), 143.80 (C-5'), 146.52 (C-4'), 148.29 (C-2), 151.81 (C-5).

15 HRMS for $\text{C}_{15}\text{H}_{16}\text{O}_4$ (ESI+) $[\text{M} + \text{Na}^+]$: calc.: 283.0946, found: 283.0942

MS (EI, GCMS): $m/z(\%)$: 260 (100) $[\text{M}]^+$, 245 (12) $[\text{M} - \text{CH}_3]^+$.

Elemental analysis for $\text{C}_{15}\text{H}_{16}\text{O}_4$: calc.: C: 69.22%, H: 6.20%, found: C: 69.02%, H: 6.34%.

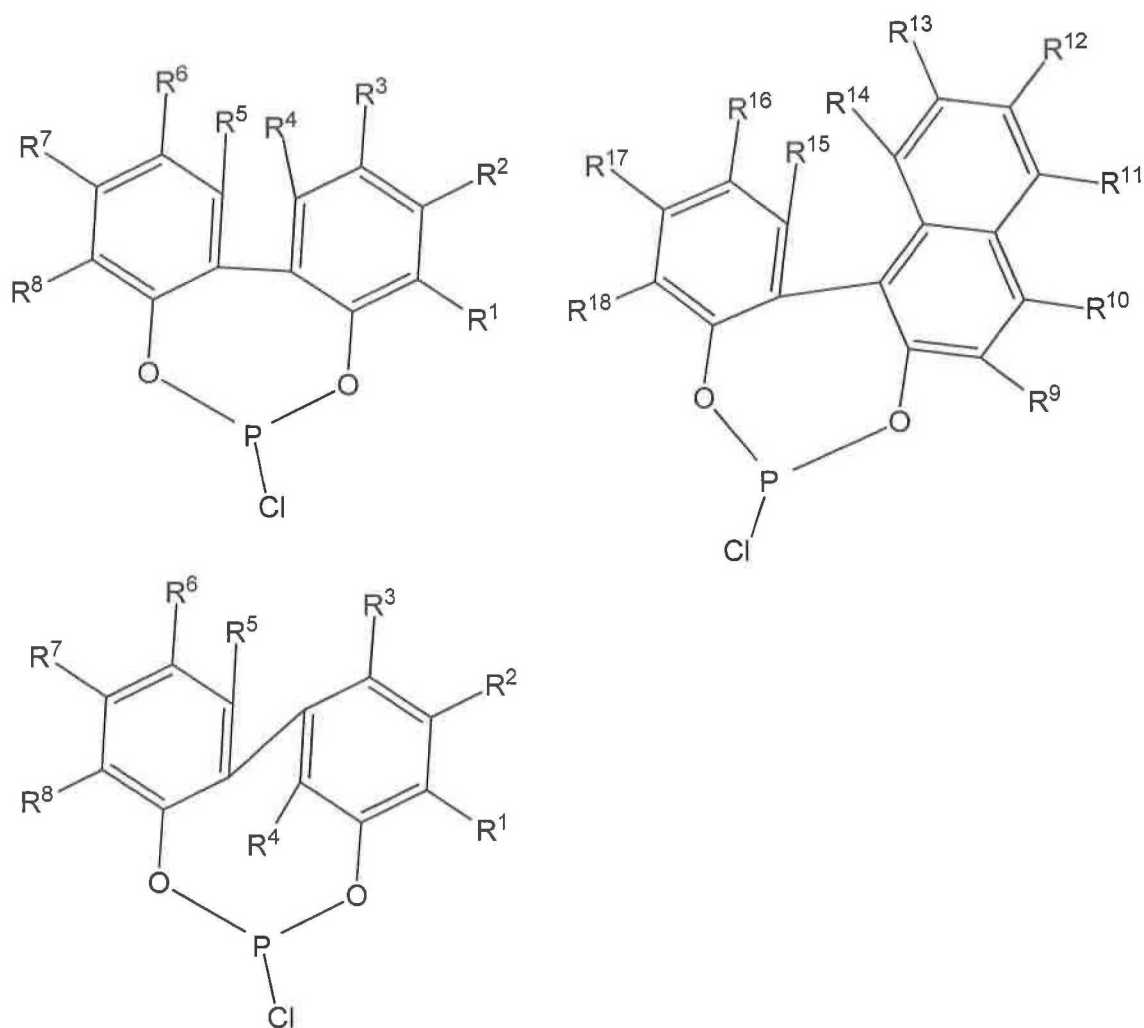
3,4'-di-tert-butyl-5,6'-dimethoxy-[1,1'-biphenyl]-2,3'-diol



The synthesis was effected according to the above general procedure. After purification by column chromatography, the product was obtained in a 15% yield.

25 For an alternative preparation route see: Anwar A. Hamama, Wassef W. Nawar Journal of Agricultural and Food Chemistry 1991, 36, 1063-1069.

Synthesis of the chlorophosphites



For the preparation of the inventive compounds, various chlorophosphites are required, specifically those having a biphenol unit on the one hand and those having a naphthyl-phenyl unit on the other hand.

Given here as an illustrative example is 6-chlorodibenzo[*d,f*][1,3,2]dioxaphosphepine, which can be prepared according to DE 10 2008 043 584. All other chlorophosphites can be prepared in an analogous manner, i.e. by addition of phosphorous trichloride in the presence of a base. In this regard, see also "Phosphorus(III) Ligands in Homogeneous Catalysis – Design and Synthesis" by Paul C.J. Kamer and Piet W.N.M. van Leeuwen; John Wiley and Sons, 2012; inter alia p. 94 ff. and the references cited therein.

Since chlorophosphites formed from binol (1,1'-binaphthol) are prepared in an analogous manner to those having a biphenol unit, those chlorophosphites having a naphthyl-phenyl unit are also synthesized in an analogous manner.

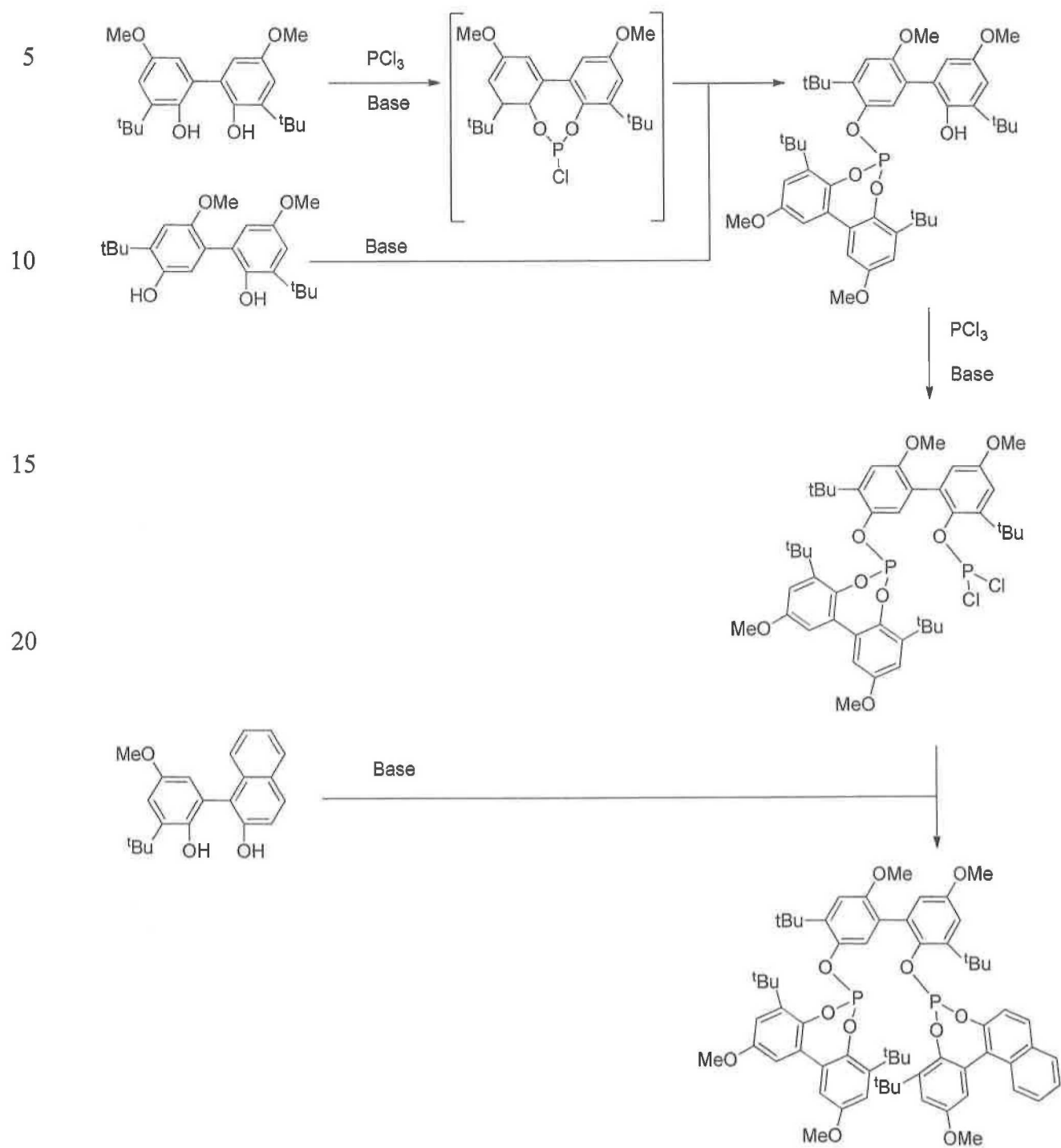
Synthesis of the inventive compounds

5 The inventive compounds can be prepared by various routes. Three possible routes are shown in the schemes below.

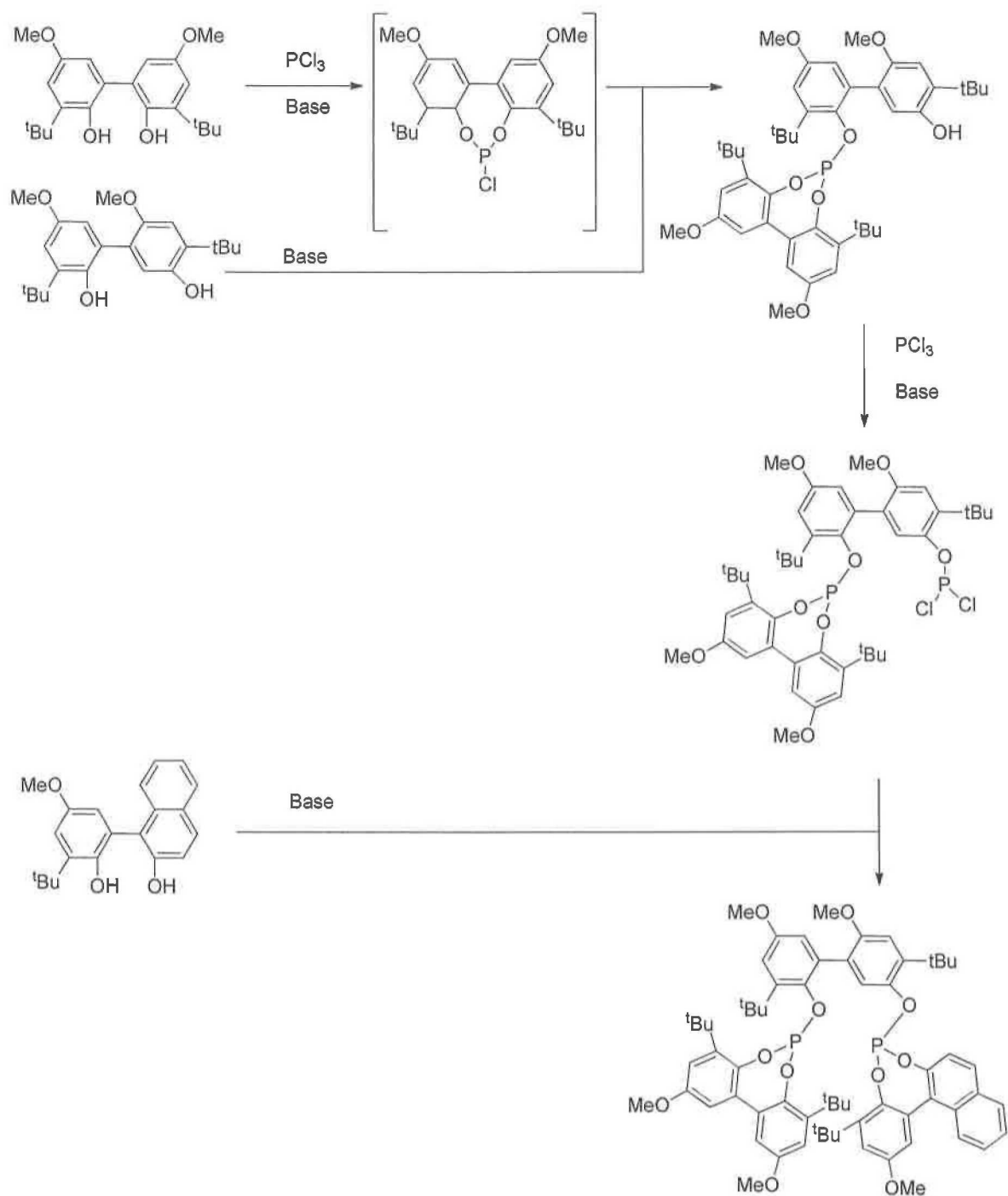
The reaction routes shown are shown merely for illustrative purposes and in a simplified form. Thus, if required, base or solvent may be used in addition in all steps. These are sufficiently well known to those skilled in the art and can be found in the technical literature, such as
10 "Phosphorus(III) Ligands in Homogeneous Catalysis – Design and Synthesis" by Paul C.J. Kamer and Piet W.N.M. van Leeuwen; John Wiley and Sons, 2012; inter alia p. 94 ff. and the references cited therein.

The reaction schemes shown below are suggestions. The sequence of the attachment of the individual units to the central unit may be varied, for example by first attaching the naphthyl-phenyl unit in the form of its chlorophosphite, then reacting the structures generated with
15 phosphorous trichloride and then attaching a biphenol. Such a procedure is sufficiently well-known to those skilled in the art and can be found in the technical literature.

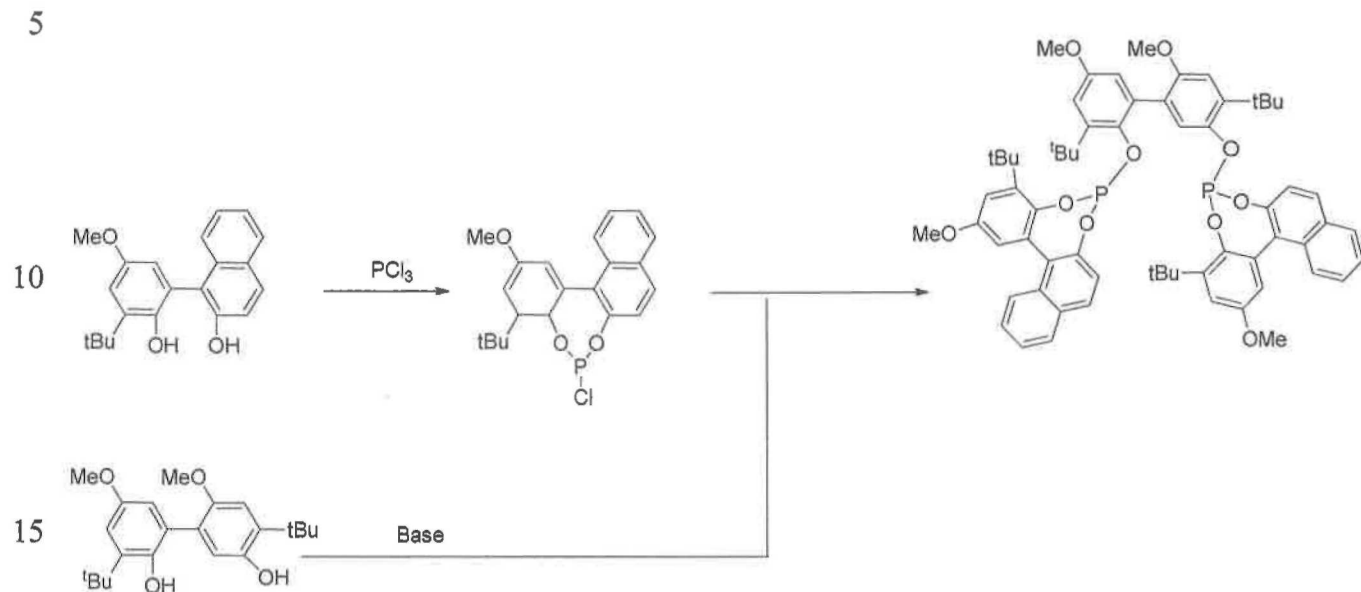
Reaction scheme for a compound of formula (I)



Reaction scheme for a compound of formula (II)



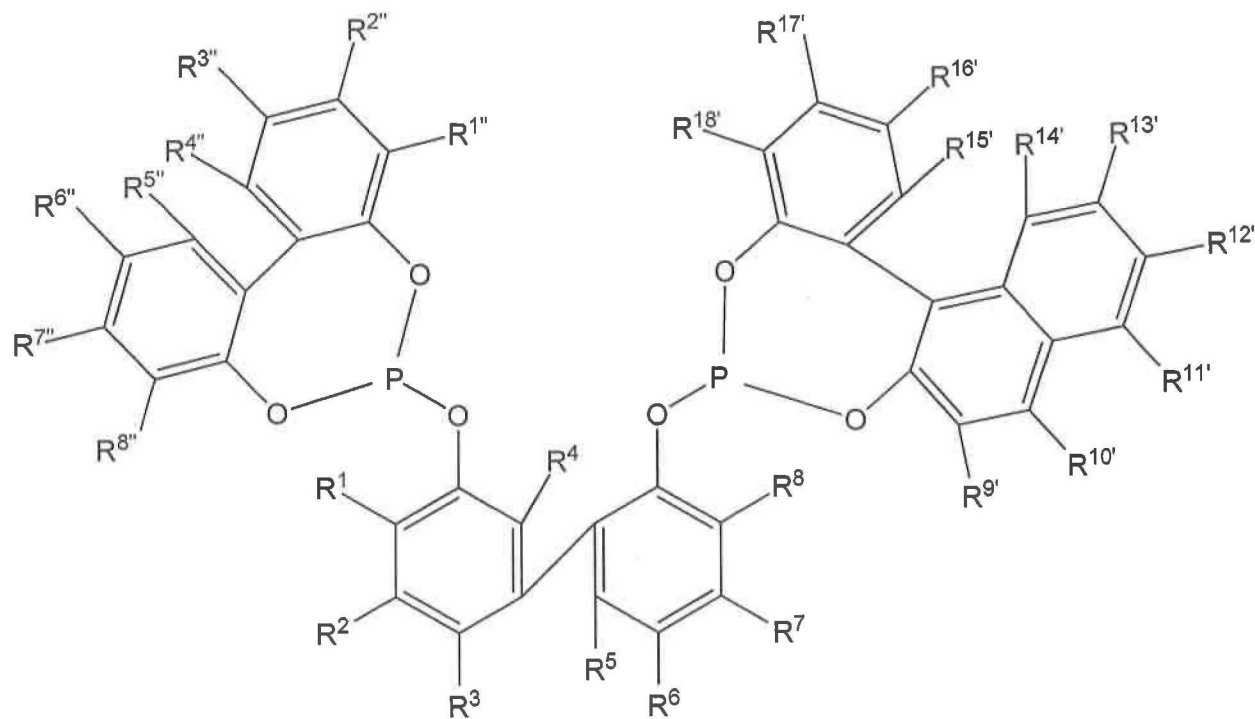
Reaction scheme for a compound of formula (III)



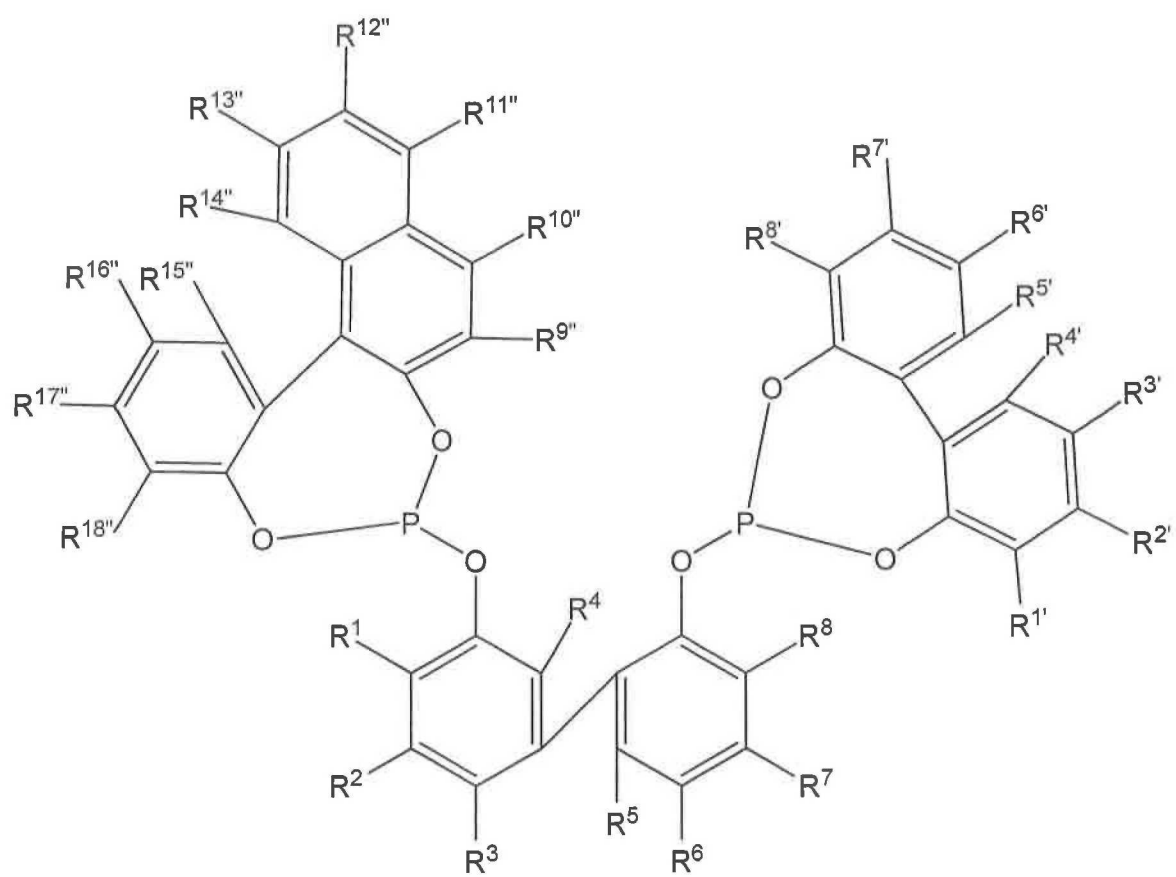
- 20 For the first time, a synthesis route by which the inventive compounds can be prepared by an efficient route has been illustrated. The bisphosphites obtained in this way fulfil the objective, since these, for the first time, have a naphthyl-phenyl unit as outer unit and a 2,3'-biphenol unit as central unit.

Claims

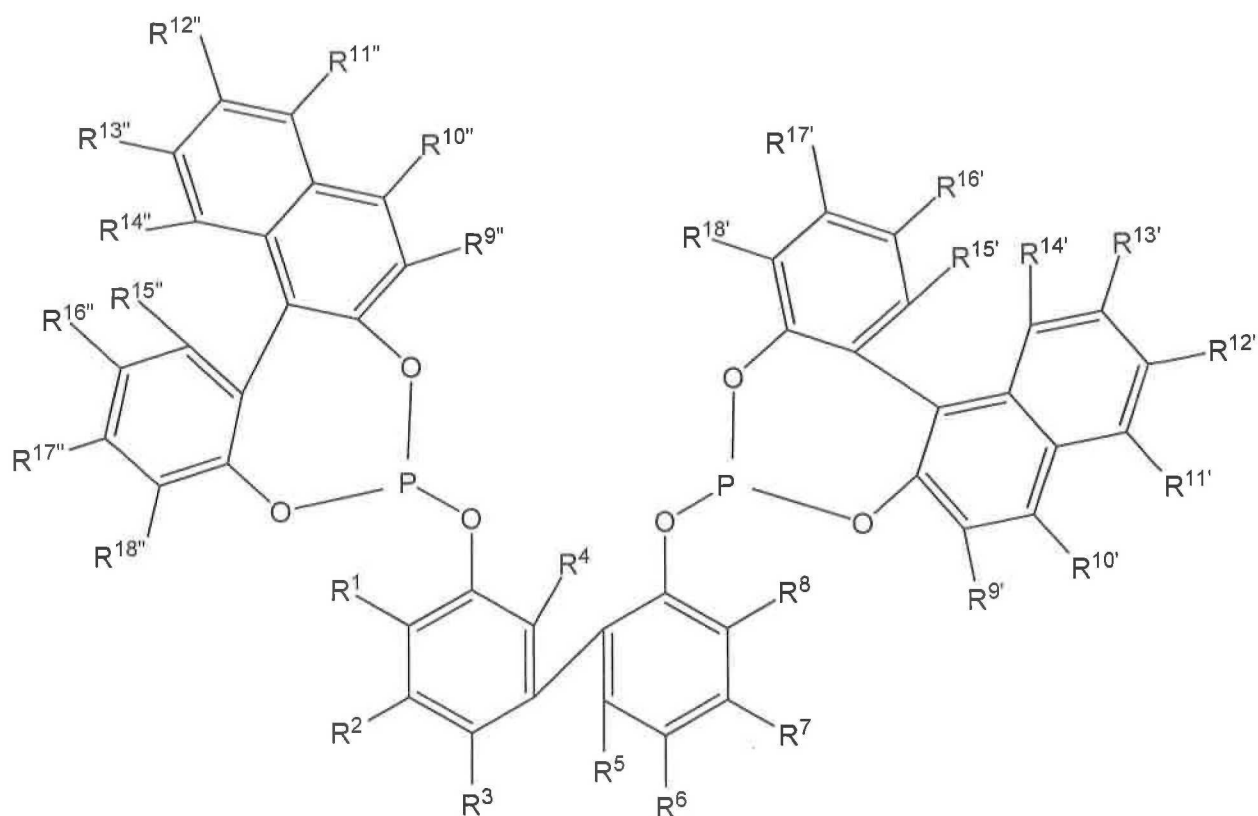
1. Compound having one of the three general structures (I) to (III):



(I)



(II)



(III)

5

where

 $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -CN, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

10 $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -COOH, -OH, -SO₃H, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

15 $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8, R^9, R^{10}, R^{11}, R^{12}, R^{13}, R^{14}, R^{15}, R^{16}, R^{17}, R^{18}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl, halogen, COO-(C₁-C₁₂)-alkyl, CONH-(C₁-C₁₂)-alkyl, -CO-(C₁-C₁₂)-alkyl, -CO-(C₆-C₂₀)-aryl, -OH, -SO₃H, -NH₂, -N[(C₁-C₁₂)-alkyl]₂;

20

where the alkyl and aryl groups mentioned may be substituted.

2. Compound according to Claim 1,

where $R^1, R^2, R^3, R^4, R^5, R^6, R^7, R^8$ are selected from:

5 -H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

3. Compound according to either of Claims 1 and 2,

where $R^{1'}, R^{2'}, R^{3'}, R^{4'}, R^{5'}, R^{6'}, R^{7'}, R^{8'}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

10

4. Compound according to any of Claims 1 to 3,

where $R^{1''}, R^{2''}, R^{3''}, R^{4''}, R^{5''}, R^{6''}, R^{7''}, R^{8''}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

15 5. Compound according to any of Claims 1 to 4,

where $R^{9'}, R^{10'}, R^{11'}, R^{12'}, R^{13'}, R^{14'}, R^{15'}, R^{16'}, R^{17'}, R^{18'}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

6. Compound according to any of Claims 1 to 5,

20 where $R^{9''}, R^{10''}, R^{11''}, R^{12''}, R^{13''}, R^{14''}, R^{15''}, R^{16''}, R^{17''}, R^{18''}$ are selected from:

-H, -(C₁-C₁₂)-alkyl, -O-(C₁-C₁₂)-alkyl, -O-(C₆-C₂₀)-aryl, -S-alkyl, -S-aryl.

7. Compound according to any of Claims 1 to 6,

where the compound has the general structure (I).

25

8. Compound according to any of Claims 1 to 6,

where the compound has the general structure (II).

9. Compound according to any of Claims 1 to 6,

30 where the compound has the general structure (III).