

Hybrid Circuit

5 The present invention relates to a hybrid circuit in accordance with the preamble of claim 1.

10 For conversion from two-wire circuits, on which signals are transmitted in accordance with the frequency duplex channel system in duplex operation, to four-wire circuits, on which signals are transmitted in simplex operation, separating filters or hybrid circuits are used, as are described, for example, in Steinbuch/Rupprecht, Nachrichtentechnik, Springer-Verlag, Heidelberg 1982, Third Edition, Volume 2, pages 46-52, or Herter/Lörcher, Nachrichtentechnik, Hanser Verlag, Munich 1994, Seventh Edition, page 72 and page 329. Hybrid circuits are used in such applications as amplifying
15 circuits, which are inserted between segments of two-wire circuits for the necessary boosting of the signal level of the bidirectionally transmitted signals. Furthermore, hybrid circuits are provided on the subscriber or transmitter side in order to feed the transmitted signals from a two-wire transmission line to a receiving amplifier and feed the signals to be transmitted from a transmitter amplifier to the transmission line (see, for example, L.W.
20 Couch, DIGITAL AND ANALOG COMMUNICATION SYSTEMS, Prentice-Hall Inc. 1997, pages 536 - 543 or). An important requirement for the hybrid circuit is that no component of the output signal of the transmitter amplifier may reach the input of the receiving amplifier.

25 Depicted in Figure 1 is a passive hybrid circuit, which is known from Siemens, IC's for Communications, ISDN Echocancellation Circuit, IEC-Q, PEB 2091 - Version 4.3,

User's Manual 02.95, Figure 83 (Hybrid Circuit), in which the outputs of a transmitter unit or a transmitter amplifier TX are each connected via a resistor Rqt or Rqr to the terminals of a transformer TF that connects the hybrid circuit with a transmission line having an impedance ZI, and the inputs of a receiving unit or a receiving amplifier RX that has an internal resistance Rr are each connected via a resistor R3t or R3r to the terminals of the transformer TF. To compensate for the transmission signal component (distortion component) feeding back from the transformer TF to the receiving amplifier RX, the receiving amplifier RX is supplied with a correspondingly inverted component (compensating component) of the transmitting signal from the terminals of the transmitter amplifier TX via resistors R1t and R2t or R1r and R2r. For complete compensation of the distortion signal, a point-symmetric design of the resistance bridge is provided with regard to the input of the receiving amplifier RX, where the resistors of the compensation path are weighted in accordance with the compensating component to be provided. One must take into account that the distortion component is influenced by the circuit impedance ZI. Thus, for compensation of the circuit impedance ZI, a balance impedance Zb corresponding thereto is provided in the compensation branch of the hybrid circuit. The resistors of the known circuit are chosen as follows: Rqr and Rqt = 24 ohm; R1t and R1r = 619 ohm, R2t, R2r, R3t, and R3r = 10 k ohm. The balance impedance Zb consists of a 681 ohm resistor, which is connected in series to the parallel circuit of a 3.01 k ohm resistor and a 6.8 nF capacitor. The compensation requirement of this bridge circuit with a transformation ratio of the transformer TF of 1 to 1 is as follows:

$$(R1t + R1r) : Zb = (Rqt + Rqr) : ZI$$

where R2t = R2r and R3t = R3r, or preferably, R2t = R2r = R3t = R3r.

With an input resistance Rr of the receiving unit, moreover, the following

condition must be satisfied:

$$R_r \gg (R_{2t}, R_{2r}, R_{3t}, R_{3r}) \gg R_{1t}, R_{1r}, R_{qt}, R_{q3}$$

5 A disadvantage of this circuit is that a relatively large number of resistors is required, the values of which must be chosen precisely. Furthermore, the balance impedance Z_b must be chosen in accordance with the transmission circuits employed and in accordance with the characteristic impedance Z_I of the transmission circuit.

10 Thus, the task that forms the basis of the present invention is to create a simplified hybrid circuit that requires no balance impedance Z_b .

This task is solved by the measures cited in the characterizing part of claim 1.
Advantageous embodiments of the invention are cited in further claims.

15 The hybrid circuit in accordance with the invention, which requires no balance impedance Z_b , has a simplified circuit design and can thus be produced cost-effectively. Since no balance impedance Z_b is required, the hybrid circuit can be connected to various transmission lines without adjustments. Elimination of any interference that may arise in
20 the low frequency range is achieved with a simple filter for all transmission circuits normally used. Thus, calibrations or adjustments of the hybrid circuit in accordance with the invention resulting from component tolerances or due to changes in the diameter of the transmission line are eliminated. Furthermore, the hybrid circuit in accordance with the invention is especially suitable for receiving units that have relatively low input resistance.

25 The invention is described in more detail below by way of example with the aid of

an illustration. Shown are:

- Figure 1 a hybrid circuit with a balance impedance,
- Figure 2 the typical resistance curve of a transmission line as a function of the frequency,
- Figure 3 the typical phase curve of a transmission line as a function of the frequency,
- Figure 4 a hybrid circuit in accordance with the invention,
- Figure 5 curves for the signal attenuation of transmission lines with different line diameters as a function of frequency,
- Figure 6 a hybrid circuit in accordance with the invention with a connected filter,
- Figure 7 a possible embodiment of the filter in accordance with Fig. 6
- Figure 8 a known hybrid circuit with active echo compensation, and
- Figure 9 the hybrid circuit in accordance with Figure 8 with passive echo compensation in accordance with the invention.

Figure 1 shows the hybrid circuit described at the outset, which has a balance impedance Z_b . It can be ascertained from Figure 2 that the amount of resistance $|Z_I|$ of a transmission circuit above 10,000 Hz - 20,000 Hz typically lies in the range of 135 ohms. The phase curve in this range moves in the region of 0° . Thus, compensation of the resistance and phase behavior of the transmission line for the cited frequency range can be omitted or an ohmic resistance can be used for Z_b , which is eliminated in accordance with the invention through the scaling of the resistance bridge, where the symmetry of the resistance bridge, however, must remain intact. This is achieved by scaling the resistance bridge in such a way that the value of the balance resistance Z_b to be adjusted approaches infinity so that the balance resistance Z_b loses its effect on the compensation component and is thus no longer necessary.

This is attained by the hybrid circuit in accordance with the invention depicted in Figure 4, in that the resistors R_{1t} , R_{2t} , as well as R_{3t} and, with symmetry, R_{1r} , R_{2r} , as well as R_{3r} are chosen to at least approach the same value R . The values of the resistors R_{qt} and R_{qr} (with symmetry, $R_{qt} = R_{qr}$) - taking into account the transformation ratios of the transformer TF and the parallel resistors R_{1t} , R_{1r} , R_{2t} , R_{2r} , R_{3t} , R_{3r} that are connected in series and the input resistance R_r of the receiving amplifier RX - are chosen such that the hybrid circuit is adapted to the characteristic impedance Z_I . The values of the resistors R_{1t} , R_{1r} , R_{2t} , R_{2r} , R_{3t} , and R_{3r} are furthermore chosen such that the signal transmitted by the corresponding voltage dividers reaches the input of the receiving amplifier RX without significant reduction. The value R of the resistors R_{1t} , R_{1r} , R_{2t} , R_{2r} , R_{3t} , R_{3r} must then be chosen approximately 10 to 100 times greater than the value of the resistors R_{qr} and R_{qt} , which corresponds approximately to the value $\frac{1}{2} |Z_I|$ for a transformation ratio of the transformer TF of 1:1.

In Figure 6, the resistors R_{1t} and R_{2t} or R_{1r} and R_{2r} are combined into a resistor R_{4t} or R_{4r} , which has the value $2R$. The circuit arrangement is thus further simplified in comparison to the hybrid circuit of Figure 4. In Figure 6, the hybrid circuit in accordance with the invention is furthermore advantageously connected to the receiving unit RX via a filter FR.

Taking full advantage of the capacities of copper cables, which still constitute the majority of exchange areas of Telecom networks, permits implementation of services with broad band data transmission over the existing cable network. Relatively large capital investments in the expansion of existing cable systems are thus eliminated, at least for the medium term. With HDSL technology (High bit rate Digital Subscriber Line in accordance with ETSI-Norm ETR 152), data rates of approximately 2 Mbit/s are realized in data transmission over copper wires (see, for example, COMTEC, Technische Mitteilungen der

CH-Telecom, 2/1997, page 29 or Siemens, telecom report CH Edition 3/95, page 11).

5 In individual cases, problems are noticed in designing HDSL transmission routes which make the use of newly developed HDSL components questionable or require adjustments within the transmission system. In particular, it was established that the construction of HDSL transmission routes with certain copper cables is not possible or is only possible with the use of selected components or the performance of expensive compensation procedures. Due to the expected future volume of HDSL technology usage in the exchange area of Telecom systems, such adjustments, which for the most part take up a lot of time, should definitely be avoided.

15 The invention thus has the task of specifying measures that make it possible to realize, without case-specific adjustments, transmission routes for high data transmission rates using copper cables as they are found in the exchange area of communication systems.

The solution of this task is achieved through the measures cited in the characterizing part of claim 1.

20 Copper cables of varying lengths and diameters, as they are found in the exchange area of communication systems, can be used for the design of HDSL transmission routes by implementing the measures in accordance with the invention, which can be achieved with low expenditure, and without requiring adjustments of further components of the transmission systems to the cable characteristics. In addition, the use of commercially available components of the transmission system (for example, commercially available HDSL components) becomes possible for practically all copper cables which, due to their

lengths and diameters, can be used for HDSL transmission routes.

The invention is described in more detail below by way of example with the aid of an illustration. Shown are:

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Figure 1 curves for the signal attenuation, as a function of frequency, of three copper cables with different lengths and line diameters

Figure 2 a possible embodiment of a filter provided for dynamic clipping,

Figure 3a the block diagram of a known HDSL-transmission route,

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Figure 3b the block diagram of an HDSL-transmission route in accordance with the invention for simplex operation,

Figure 3c the block diagram of an HDSL-transmission route in accordance with the invention for duplex operation, and

Figure 4 curves for the signal attenuation, as a function of frequency, of two copper cables of equal length and equal line diameter.

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In the exchange area of Telecom networks, there are copper cables which differ with respect to length, insulating materials, as well as the spacing and diameter of the wire pairs and thus have differing circuit characteristics (amount of resistance, inductance, capacitance, leakage per unit length, as well as characteristic impedance). Typically, copper cables with lengths of up to 7 km and diameters of approximately 0.4 mm to 1.4 mm are present in the exchange area of communication networks. Problems implementing HDSL transmission routes with standard components have been solved hitherto by case-by-case adjustments to match the copper lines to be used. In certain instances, a suitable line was selected from several lines after test trials.

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By means of an analysis of problems that had arisen, it was surprisingly determined that the origin of the problem generally is not the attenuation of a transmission circuit, but rather the attenuation distortion, which, astoundingly, is especially strong in copper cables with a relatively large line diameter (for example, 1.4 mm), which are used to realize relatively long HDSL transmission routes due to the lower amount of attenuation. For example, a copper line with a larger diameter and lower attenuation can cause problems compared to a copper line with a smaller diameter and greater attenuation. Specifically, it was determined through testing of copper cables of different diameters and lengths that copper cables with greater diameters and greater lengths have a greater attenuation distortion than copper cables with smaller diameters and approximately the same average attenuation.

Figure 1 shows the curve of the attenuation distortion (attenuation curve as a function of frequency) of copper cables SL1, SL2, and SL3 with diameters of 0.4 mm, 1.0 mm, and 1.4 mm, the lengths of which are selected such that they have the same attenuation at a frequency of about 220 kHz. It is natural, however, that when the lengths are equal, the 1.4 mm cable SL1 has a lower attenuation over the entire frequency range than the 0.4 mm cable SL3, as is depicted in Figure 4. It can be ascertained from the graph in Figure 1 that the 1.4 mm cable SL1 has a significantly lower attenuation in the low frequency range ($<10^4$ Hz) and a significantly higher attenuation in the high frequency range ($>10^5$ Hz) than the 0.4 mm cable SL3. In the region of 1000 Hz, the 0.4 mm cable SL3 has an attenuation that is about 10 dB greater than the 1.4 mm cable SL1. A signal transmitted over the 1.4 mm cable SL1 thus has a dynamic range that is about 10 dB greater (see $\text{dyn1} < \text{dyn2}$) than a signal that is transmitted over the 0.4 mm cable SL3. Even if the 1.4 mm cable SL1 were several hundred meters shorter and had a lower attenuation, this could lead to problems. Specifically, the differing attenuations of the

copper wires SL1, SL2, SL3 are generally compensated in the data sink of a transmission system by a gain control, which, however, does not alter the attenuation distortion. As a result, the line equipment or the components provided for digital signal processing must be suitable for processing signals with greater dynamic ranges when using copper cables with greater diameters. Known digital HDSL receiver components often fulfill these requirements only marginally so that problems can crop up on occasion. The required resolution for the digital section of the receiver circuit (digital/analog converter, equalizer) is determined by the dynamic range of transmitted signals and those to be processed. Thus, a significantly higher dynamic reserve is required for the signals that are transmitted from the 1.4 mm cables SL1, which corresponds to the zone z shown in Figure 1.

In accordance with the invention, therefore, a filter FR is provided for HDSL transmission routes, by which means the signal components in the low frequency range ($<10^4 \text{ Hz}$) can be decreased by about 10 dB. To this end, the filter FR, which corresponds for example to the RC Filter shown in Figure 2 that is designed in a known manner with capacitors C_f and resistors R_f , preferably has an attenuation curve as shown in Figure 1 (see the behavior of the line fkl). One can ascertain therefrom that the filter attenuates signals in the range of up to 1000 Hz by approximately 10 dB. As a result of using the filter FR, the dynamic range of the signals transmitted via the 1.4 mm cable SL1 adjusts to the dynamic range of the signals transmitted via the 0.4 mm cable SL3. However, insofar as a 0.4 mm cable SL3 is connected to the filter FR, the signal components in the low frequency range ($<10^4 \text{ Hz}$) are not decreased below the signal level of the signal components in the high frequency range ($10^4 \text{ Hz} - 10^5 \text{ Hz}$), which would result in a reduced signal-to-noise ratio. Hence, in the case of the line network copper cable with the smallest diameter, care should be taken when selecting the filter characteristic curve to ensure that the attenuation in the low frequency range does not exceed the maximum

attenuation occurring in the high frequency range. The circuit arrangement in accordance with the invention can thus be used for all laid copper cable SL1, ..., SL3, without unacceptably high attenuations arising in copper cables SL3 with thinner diameters.

5 Figure 3a shows the block diagram of the HDSL transmission route known from COMTEC, Technische Mitteilungen der CH-Telecom, 2/1997, page 28, which has a line termination HDSL/LT, that is connected by subscriber connection cables SL1, ..., SL3 to a network termination HDSL/NT, from which individual basic access lines are led out. Figure 3b shows the block diagram of an HDSL transmission route in accordance with the
10 invention for simplex operation. From line termination LTSX, data are sent from transmitter units TX in simplex operation via the subscriber connection cables SL1, ..., SL3 to network termination NTSX or to a filter FR for each one, designed for dynamic compensation, and onward to receiver units RX. In the block diagram in accordance with
15 Figure 3c, the data transmission proceeds between line and network terminations LTDX and NTDX in a known manner in duplex operation via the hybrid circuits GS, wherein a filter FR is provided for dynamic compensation between each hybrid circuit GS and the accompanying receiving unit RX.

20 Furthermore, the filter FR can also be advantageously used together with integrated receiving units RX, which may be part of a transceiver. Suited thereto are, for example, the components SK70704/SK70707 of the company LEVEL ONE, which are described in the associated data sheet "1168 kbps HDSL Data Pump Chip Set", of May 1996.

25 Figure 5 shows the attenuation curves as a function of frequency for cables with different diameters (0.4 mm; 1.0 mm and 1.4 mm). These typically are pure copper cables

as are laid in the majority of telephone networks. It can be seen from the graph that cables with larger diameters have a significantly lower attenuation in the low frequency range ($<10^4$ Hz) and a significantly higher attenuation in the high frequency range ($>10^5$ Hz) than cables with correspondingly smaller diameters. In the region of 1000 Hz, the 0.4 mm cable has an attenuation that is about 10 dB greater than the cable with a diameter of 1.4 mm. In the region of 100,000 Hz, the attenuations of these two cables are approximately identical. A signal transmitted over the 1.4 mm cable thus has a dynamic range that is about 10 dB greater (see $\text{dyn1} < \text{dyn2}$) than a signal that is transmitted over the 0.4 mm cable. However, the dynamic range of the signals that are transmitted and to be processed determines the resolution required for the analog-to-digital converter (see U. Tietze, Ch. Schenk, Halbleiterschaltungstechnik, Eighth Edition, Springer Verlag, Berlin 1986, page 765). Hence, a significantly more complex and thus costlier analog-to-digital converter is required for the signals transmitted over the 1.4 mm cables.

In accordance with the invention, therefore, a filter FR is provided in the circuit arrangements in accordance with Figure 6, Figure 7 and Figure 9, by means of which the signal components in the low frequency range ($<10^4$ Hz) are attenuated by approximately 10 dB. For this purpose, the filter FR, which corresponds to the filter shown in Figure 7 for example, preferably has an attenuation curve as is shown in Figure 5 (see the curve of the line fkl). It can be seen therefrom that signals in the range up to 1000 Hz are attenuated by approximately 10 dB by the filter FR.

Through the use of the filter FR, the dynamic range of the signals transmitted over the 1.4 mm cable is adapted to the dynamic range of the signals transmitted over the 0.4 mm cable. However, insofar as an 0.4 mm cable is connected to the hybrid circuit in accordance with Figure 6, Figure 7 or Figure 9, the signal components in the low

frequency range ($<10^4$ Hz) are not decreased below the signal level of the signal components in the high frequency range (10^4 Hz - 10^5 Hz), which would result in a reduced signal-to-noise ratio.

5 The circuit arrangement in accordance with the invention can thus be used for all laid copper cables, in which case the analog-to-digital converter need not have a greater resolution.

10 The circuit arrangement shown in Figure 8, which has an active hybrid circuit G1, is known from the data sheet of May 1996 of the company LEVEL ONE for the components SK70704/SK70707, which can be used as "1168 kbps HDSL Data Pump Chip Set" (see in particular page 8, Figure 3 and page 26, Figure 13 of the data sheet). In the circuit depicted, the signal to be transmitted is passed through a scrambler SCR, an encoder ENC, a filter TXF, an amplifier LD, and resistors Rqt and Rqr to the transformer TF. From the transformer TF, the transmitted signals are fed to an equalizer circuit ETR via resistors Rc and Rd, a first summing stage S1, a subsequent differential stage DIFF, an analog-to-digital converter ADC, and a third summing stage S3 connected to a digital echo compensator. For compensation of the component (distortion component) of the transmitted signal feeding back from the transformer TF to the receiving amplifier RX, the differential stage DIFF is fed a correspondingly inverted component (compensation component) of the transmitted signal from the output of the amplifier LD via resistors Ra and Rb, as well as a second summing stage S2. The distortion or echo component in the input signal is thus compensated. Complex resistances Za and Zb are provided in the receiving path and in the correction path for adaptation to the transmission line. In the case of a change in the diameter of the transmission line, the correction section achieves an insufficient compensation of the distortion or echo component to the extent that the

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complex resistances Z_a and A_b are not appropriately adjusted. Moreover, when transmission lines with large diameters (such as 1.4 mm) are chosen, signal distortions (clipping) can occur at the output of the analog-to-digital converter ADC to the extent that the latter does not have an adequately high resolution. Also shown in Figure 8 are the elements (see <-- IC) that are contained in the above-mentioned integrated circuits.

In Figure 9, the same integrated circuit is connected to the hybrid circuit g_2 shown in Figure 6, whose advantages are particularly clear in this case as well. The hybrid circuit G_2 in accordance with the invention in turn permits the connection of transmission lines with varying diameters without circuit adjustments. Moreover, the use of an analog-to-digital converter ADC with reduced resolution is permissible. Losses arising through passive echo compensation and filtering can easily be compensated with the aid of the integrated circuit IC, in that the output signal of the filter FR is fed uninverted to the first summing stage S1 and is fed inverted to the second summing stage S2. Thus, phase-correct addition of the signals present at the summing stages S1 and S2 takes place in the differential stage.

Furthermore, the invention can also be used for hybrid circuits without transformers TF.

**WHAT IS CLAIMED IS:**

1. A hybrid circuit to connect a transmitter unit (TX) and a receiver unit (RX) to a two-wire transmission line with a bridge circuit, which has four bridge arms, each of which has two resistors (R1t, R2t; R1r, R2r; R3r, Rqr; R3t, Rqt), which are specified in such a way and which connect the two outputs (txa1, txa2) of the transmitter unit (TX) and the two inputs (rxel, rxe2) of the receiver unit (RX) in such a way that the components of the transmitted signal appearing at the input of the receiving unit (RX) cancel each other out, where the transmission line is connected, possibly through an interposed transformer (TF), to the transmitter unit (TX) through the first resistors (Rqt and Rqr) of the third and fourth bridge arms (R3r, Rqr; R3t, Rqt), and to the receiver unit (RX) through the second resistors (R3t and R3r) of the third and fourth bridge arms (R3r, Rqr; R3t, Rqt) **wherein** the resistors (R1t, R2t, R3r, Rqr or R1r, R2r, R3t, Rqt) of the four bridge arms are chosen such that an impedance (Zb), to be provided per se for compensation of the impedance (Zl) of the transmission line, takes on a sufficiently high value that the provided error tolerance for the hybrid circuit is maintained even without the inclusion of this impedance (Zb).

2. A hybrid circuit in accordance with claim 1 or the preamble to claim 1 with a real or complex balance resistance (Zb) provided for compensation of the line impedance (Zl), **wherein** all bridge arms are connected to the input of the receiver unit (RX) through a filter (FR) which is chosen such that the signal components in the low frequency range are attenuated sufficiently that the dynamic ranges dyn1, dyn2 of signals transmitted over lines with different diameters are at least approximately equal.

3. A hybrid circuit in accordance with claim 1, **wherein** the resistors (R1t, R2t, R3t,



P16480.S02

R1r, R2r, R3r) of the bridge circuit - with the exception of the resistors (Rqt, Rqr), which connect the terminal of the transmitter (TX) with the transmission line - have the value R, which is at least five times greater than the value of the resistors (Rqt, Rqr).

- 5 4. A hybrid circuit in accordance with claim 1 or 3, **wherein** the resistors (R1t, R2t, R3r, Rqr or R1r, R2r, R3t, Rqt) of the four bridge arms are selected such that an impedance (Zb), which should always be provided to compensate for the impedance (ZI) of the transmission line, takes on a value that is greater than 10 R.
- 10 5. A hybrid circuit in accordance with claim 3 or 4, **wherein** the series-connected resistors (R1t, R2t; R1r, R2r) belonging to the first two bridge arms are each combined into a single resistor (R4t; R4r).
- 15 6. A hybrid circuit in accordance with claim 3, 4 or 5, **wherein** the resistors (R1t, R2t, R3t, R1r, R2r, R3r) of the bridge circuit - with the exception of the resistors (Rqt, Rqr), which connect the output of the transmitter unit (TX) with the transmission line - are chosen such that the signal level of the transmitted signals is reduced as little as possible.
- 20 7. A hybrid circuit in accordance with claim 3, 4, 5, or 6, **wherein** the resistors (Rqt, Rqr) of the bridge circuit, which connect the terminal of the transmitter unit (TX) with the transmission line, correspond to approximately one half of the value of the line impedance (ZI).
- 25 8. A hybrid circuit in accordance with one of claims 1 - 7, **wherein**, for a bandwidth of the transmission channel of several 100 kHz, the filter (FR) has an attenuation between



P16480.S02

5 dB and 15 dB in the region of the first 10 kHz.

5 9. A hybrid circuit in accordance with one of claims 1 - 8, **wherein** the receiver unit (RX) has two inputs that may be connected to a differential stage (DIFF) through input amplifiers, where the output signal of the filter (FR) is fed inverted to the first input and the output signal of the filter (FR) is fed uninverted to the second input.

10 10. A hybrid circuit in accordance with claim 9, **wherein** the hybrid circuit is connected to an integrated circuit of the type SK70704 from LEVEL ONE.