

~~Circuit arrangement comprising an amplifier with bipolar transistors~~ amplifier

The invention relates to a circuit arrangement with an amplifier which is fed by a signal source with a complex internal resistance, which in series with a reactance network is arranged in parallel with the amplifier input for the purpose of noise reduction, the series arrangement having a series resonance frequency in the signal frequency range, with a negative feedback path from the output of the amplifier. Such a circuit arrangement is essentially known from "Proceedings of the IEEE", Volume 69, No. 6, "The Design of Low-Noise Amplifiers".

Said document states that in the case of signal sources with a complex or reactive internal resistance noise reduction is possible by the addition of a suitable reactance of a kind which depends on the nature of the signal source and the dominant noise source. In the case of a capacitive signal source the noise can be influenced in a different way by a series-parallel arrangement of an inductance. Parallel arrangement influences voltage noise and series arrangement influences current noise. This influence is maximal at resonance. The publication further states that the amplifier may also comprise bipolar transistors; however, this publication does not state which of the possibilities mentioned (parallel or series arrangement of a reactance) is to be preferred for an amplifier with bipolar transistors.

The publication further teaches that these noise reduction measures may give rise to signal distortions, which can be eliminated by a comparatively complex signal restoration network. How such a network is constructed is not indicated.

Moreover, it is stated that the amplifier may have parallel or series feedback. However, this influences the signal source in the same way as the noise source, so that compensation is not possible.

It is an object of the present invention to construct a circuit arrangement of the type defined in the opening paragraph having an amplifier with bipolar transistors in such a way that in the signal transmission range the noise at the output is reduced without the signal transmission being affected significantly and without the stability being affected. This object is achieved by means of the steps defined in the main Claim.

In a transistor amplifier the noise of the input transistor generally has the greatest influence on the overall noise of the amplifier, whilst current noise is generally predominant in the case of bipolar transistors. The influence of this current noise on the output signal is reduced by the series resonance. The circuit arrangement in accordance
5 with the invention can therefore be used advantageously as a low-noise broadband input stage for sources having an inductive or a capacitive source impedance.

The invention will now be described in greater detail with reference to the drawings. In the drawings:

Fig. 1 is the basic circuit diagram of a circuit arrangement in accordance
10 with the invention,

Fig. 2 shows a first embodiment,

Fig. 3 shows the use of a circuit arrangement as shown in Fig. 2 in a medium-wave receiver,

Figs. 4a to 4c show the waveforms of different, noise-essential parameters
15 as a function of the frequency in a circuit arrangement as shown in Fig. 2, and

Fig. 5 shows another embodiment of the invention.

In Fig. 1 a noisy amplifier is represented by an equivalent circuit comprising a noise-free amplifier 1, a noise voltage source u operating in series with the (inverting) input of the amplifier, and a noise current source i connected to this
20 input. The voltages and currents supplied by the noise sources u and i , respectively, are generally statistically independent, non-correlated quantities. The amplifier 1, whose structure is not further shown, comprises bipolar transistors for which the influence of current noise is generally predominant if the source impedance is sufficiently large.

The amplifier output from which the output voltage U can be taken is
25 connected to the amplifier input *via* a d.c. negative feedback path. The d.c. negative feedback path includes an impedance 2, generally a high-ohmic resistor, the noise component produced thereby being included in the noise current source i .

A further negative feedback branch is provided, which connects the output to a signal generator having a complex generator resistance *via* an impedance Z_a . The
30 generator is shown in Fig. 1 as an equivalent circuit with a signal current source and a complex resistance Z_g connected parallel thereto. The ohmic component of this generator resistance should be as small as possible within the signal frequency range as compared with its capacitive or inductive reactive component in order to ensure that the

influence of the noise produced thereby remains small.

The node between the signal source I , Z_g and the feedback impedance Z_a is connected to the input of the amplifier 1 *via* a reactance network 3. If this reactance network were absent the amplifier would have the same transmission characteristics for the signal current I and the noise current i . The reactance network 3 decouples the signal source from the noise source in such a way that the noise at the output is reduced without the signal transmission in the signal transmission range being significantly affected and without the stability being affected. For this purpose the reactance network 3 in combination with the feedback impedance Z_a is dimensioned in such a manner for a given source impedance that series resonance is produced in the signal frequency range, which resonance substantially short-circuits the noise current i and thereby reduces the influence of this noise current on the amplifier output signal. Since the signal transmission remains substantially unaffected by the negative feedback *via* the impedance Z_a , an improvement of the signal-to-noise ratio is obtained.

This principle will be explained in greater detail below with reference to two concrete examples shown in Figs. 2 and 5, in which similar parts bear the same reference symbols.

Fig. 2 shows a broadband input stage of a medium wave receiver with an inductive generator impedance in the form of a medium wave aerial. The generator impedance is shown in Fig. 2 as an equivalent circuit comprising an inductance of 0.5 mH and a resistor R of approximately 500 kohms arranged parallel thereto. The impedance Z_a is formed by a capacitor C_a of 5 pF, whilst the reactance network 3 is constituted by a capacitor C_p arranged in parallel with L and R and a capacitor C_s of 60 pF arranged between the generator and the amplifier input. The amplifier has an input resistance of 22 kohms and a gain of 38 dB at 1 MHz, which rolls off with 20 dB/decade in the medium wave range.

For the noise current source i the arrangement shown in Fig. 2 operates as a filter which has a transmission minimum (series resonance) at the resonance frequency of the inductance L with the sum of C_a , C_s and C_p , the frequency for this minimum decreases as the capacitance of capacitor C_p increases.

For the voltage noise another minimum is obtained, but this occurs for resonance of the inductance L with the sum of C_p and C_a (which means that this minimum is independent of the capacitance of capacitor C_s). Accordingly, the minimum

for voltage noise is higher than the minimum for current noise (for the same capacitance C_p).

The frequency dependence of the transmission of the voltage and current noise results in an overall noise at the output, whose minimum is situated between the
5 minima for current and for voltage noise. Said minimum can be transferred to a desired position in the transmission band by a suitable choice of the capacitance of capacitor C_p .

In contrast, the signal transmission for the generator current I is hardly influenced by the capacitance C_p owing to the negative feedback *via* the capacitor C_a ,
10 and it is not even influenced if this capacitance is chosen in such a manner that together with the inductance L it exhibits a resonance in the transmission range. In this case the loop gain increases to such an extent that no resonance step-up can occur at the output of the amplifier. In the case of a constant generator current I the output voltage in the medium wave range, *i.e.* from 535 to 1605 kHz, decreases approximately linearly by
15 approximately 10 dB. This decrease is caused by the negative feedback *via* the capacitor C_a , which increases as the frequency increases.

In Fig. 4a the transmission factor for the noise current i (*i.e.* the voltage produced by the noise current at the output of the amplifier 1, divided by the noise current i) is shown on a logarithmic scale as a function of the frequency (likewise on a
20 logarithmic scale), for different capacitances of C_p . The curve a is obtained for $C_p = 2$ pF, the curve b for $C_p = 30$ pF and the curve c for $C_p = 60$ pF. The current noise minimum is thus shifted towards low frequencies for an increasing capacitance.

Likewise, Fig. 4b shows the transmission factor for the voltage noise u as a function of the frequency for the same capacitances. As already stated, the voltage
25 noise minimum is higher than the current noise minimum, the minimum for $C_p = 2$ pF (curve a) being situated outside the transmission range.

Fig. 4c shows the overall noise, *i.e.* the equivalent input noise current parallel to the signal current which at the output of an identical but noise-free arrangement would produce the same noise as in the present circuit arrangement, as a
30 function of the frequency and also with C_p as a parameter. Relatively broad noise minima occur but these only cover a part of the medium wave range.

As already stated, the gain of the useful signal also depends on the frequency in the circuit arrangement shown in Fig. 2. To eliminate this frequency

dependence, the circuit arrangement in accordance with the invention is followed by a compensation stage 4 having an inverted frequency response, so that the output signal of this stage is essentially frequency-independent - in the case of a constant aerial signal.

This stage may comprise, for example, a bipolar transistor 41 whose
5 emitter resistor 42 is shunted by the series arrangement of a capacitor 43 of 150 pF and a resistor 45 of 500 ohms for the medium-wave frequencies. This results in a capacitive emitter impedance with an ohmic component. The base of the transistor 41 is connected to the output of the amplifier 1 and the emitter of the transistor 41 is connected to the capacitor Ca and the d.c. resistance 2. The resistance 2 may, however, alternatively be
10 connected directly to the output of amplifier 1. The collector is connected to a supply voltage *via* a resistor 46 with which a parallel resonant circuit 47 tuned to approximately 2 MHz is arranged in parallel. As a result of this, the collector impedance becomes inductive with an ohmic component. In this circuit arrangement a substantially frequency-independent output signal is obtained at the collector, which
15 constitutes the output 44 of the circuit arrangement.

Fig. 3 shows a medium wave receiver constructed in accordance with the principle shown in Fig. 2. The receiver section 6 comprises the compensation circuit 4, the part 5 of the circuit arrangement in accordance with the invention shown in broken lines in Fig. 2, and further signal processing components. The series arrangement of a
20 first capacitor Cp1 and a first switch S1 as well as the series arrangement of a second capacitor Cp2 and a second switch S2 are arranged in parallel with the aerial input 7. The capacitor Cp3 in parallel with the aerial input represents the winding capacitance of the aerial. If Cp1 and Cp2 are each approximately 30 pF the capacitance acting at the aerial input will be 2 pF, 32 pF or 62 pF depending on the positions of the switches S1
25 and S2.

* The switches S1 and S2 are operated by a logic circuit 9, which is controlled by the tuner 8 of the receiver 6, which tuner also determines the tuning frequency of the receiver 6. The logic circuit 9 derives the switching signals for the switches S1 and S2 from the tuning data of the tuner 8, for example, the frequency
30 division factors for a PLL circuit in the receiver section 6. The circuit 9 is constructed in such a way that the two switches are closed at low medium-wave frequencies up to approximately the frequency f1 (cf. Fig. 4c), so that up to this frequency the noise varies in accordance with the curve c. Between the reception frequencies f1 and f2 one

of the two switches S1, S2 is open and the other is closed. This results in a capacitance of approximately 32 pF at the input with a noise in accordance with the curve b, which in this frequency range is smaller than the noise in accordance with the curve c or a.

Accordingly, the two switches S1 and S2 are opened above the frequency f2 at which the curves a and b intersect each other, so that only the capacitance Cp3 of 2 pF is active at the aerial input. The noise then varies in accordance with the curve a in Fig. 4c. Due to this changeover it is achieved that always the capacitance combination producing the lowest noise is active at the input.

For the purpose of comparison Fig. 4c shows the broken-line curve d for the overall noise which would result if the capacitor Cs were absent but the switches S1 and S2 were switched in dependence upon the tuning frequency in such a manner that a noise minimum would be obtained. The improvement provided by the invention is clearly visible.

As already stated, the parallel resonance determined by the capacitor Cp in conjunction with the inductive impedance L of the generator cannot lead to resonance step-ups owing to the negative feedback via Ca. Consequently, the currents through the switches S1 and S2 always remain comparatively small in the circuit arrangement shown in Fig. 3, so that (particularly when formed as semiconductor switches) their finite resistance leads to signal losses, but these are not significant. Moreover, the changeover ensures that the parallel resonant circuit consisting of the inductance L and the capacitance Cp parallel thereto is always operated below its resonance frequency, which also precludes resonance effects.

The reduction of the noise in the medium wave receiver achieved by means of the invention is not as large as it would be in a receiver in which the aerial input would always be tuned to the reception frequency. Such a receiver would, however, either require a relatively expensive variable capacitor or a capacitance diode, which requires comparatively large tuning voltages. Moreover, such a receiver would require an exact alignment between the oscillator and the input circuit. Conversely, the invention can also be utilized - particularly as an integrated circuit - in receivers having a low supply voltage (for example 3 V). Alignment is not required.

Although the circuit arrangement in Fig. 2 has been explained in connection with a medium wave receiver, it may also be used as a broadband input stage in other cases if the signal generator has an essentially inductive generator

resistance, as for example the reproducing head of a magnetic tape apparatus. In this case the dimensioning of the reactance network C_s , C_p (and of the feedback capacitor C_a) should be adapted to the requirements imposed by such a circuit arrangement.

Fig. 5 illustrates the invention by means of an example relating to a
5 broadband input stage for capacitive signal generators such as, for example, a capacitive aerial. In this case the signal source is shown as an equivalent circuit comprising the series arrangement of a signal voltage generator 8 and a capacitor 9. The signal source is connected to the input of a first amplifier 1 (whose input noise sources are not separately shown) *via* a first inductance LS_1 . The output of this amplifier is connected
10 to the node between the generator 8, 9 and the first inductance LS_1 *via* a capacitor C_a . The inductance LS_1 is dimensioned in such a way that a series resonance is produced in the signal transmission range, which reduces the noise caused by the noise current source (not shown) at the output 11 of the circuit arrangement.

A parallel resonance is not obtained in the circuit arrangement shown in
15 Fig. 5, so that the voltage noise is hardly influenced. Since the current noise in an amplifier with bipolar transistors is predominant anyway in the case of a sufficiently large generator impedance, this is not an essential drawback. Instead, the circuit arrangement is frequency-independent owing to the capacitive negative feedback in conjunction with the capacitive generator.

20 In the same way as in the circuit arrangement of Fig. 1, the noise is only influenced in a given frequency range around the resonance point. In order to suppress the noise in a broader frequency range in a receiver circuit, the reactance network in the circuit arrangement shown in Fig. 5 should be rearranged in a similar way as in Fig. 3. For this purpose a second inductance LS_2 has one end connected to the input of the first
25 amplifier 1 and its other end to the inverting input of a further amplifier 1' having the same characteristics as the amplifier 1. The output of this amplifier is connected to the output of the amplifier 1. The power supply terminals of the amplifiers 1, 1' are connected to a power supply source *via* a change-over switch, so that always only one of the two amplifiers is operative.

30 When tuning to a lower frequency range, the change-over switch 10 is connected to the power supply terminal of the amplifier 1', the reactance network being formed by the series arrangement of the two inductances LS_1 and LS_2 . This reduces the noise in the lower frequency range. When tuning to a higher frequency range, the

change-over switch 10 is switched to the switch position shown in Fig. 5 by a control signal *s* (which can be generated in a manner similar to the switching signals for the switches *S*1, *S*2 in the circuit arrangement shown in Fig. 3). In this case only the inductance *LS*1 is active.

- 5 Again the signal transmission is hardly influenced by the inductances *LS*1 and *LS*2 owing to the negative feedback from the output 11 to the signal source *via* *Ca*.

 The embodiment shown in Fig. 5 is neither limited to receiver circuits having a capacitive aerial. It can be used in all those cases in which a generator having an essentially capacitive generator resistance is provided, for example, a capacitor
10 microphone.

CLAIMS

1. A circuit arrangement comprising an amplifier (1) with bipolar transistors (1), a signal source (I) with a complex internal resistance (Z_g), the signal source (I) being connected to a first terminal of a reactance network (3), which has a second terminal connected to the amplifier input,
- 5 a first signal negative feedback path (Z_a) leading from the output of the amplifier (1) to the first terminal of the reactance network, and
a second signal negative feedback path (2), which transmits direct current, leading from the output of the amplifier (1) to the second terminal of the reactance network (3),
the combination of the signal source (I) with the reactance network (3) and the signal
10 negative feedback path (Z_a) having a series resonance in the signal frequency range, which substantially short-circuits the noise current caused by the one input transistor of the amplifier.
2. A circuit arrangement as claimed in Claim 1, in which the signal source has an inductive internal resistance,
- 15 characterised in that the reactance network comprises a first capacitor (C_s) arranged between the signal source (I) and the amplifier input.
3. A circuit arrangement as claimed in Claim 2,
characterised in that a second capacitor (C_p) is arranged in parallel with the signal source.
- 20 4. A circuit arrangement as claimed in Claim 1, in which the signal source has a capacitive resistance,
characterised in that the reactance network comprises an inductance (LS_1 , LS_2) arranged between the signal source and the amplifier input.
5. A circuit arrangement as claimed in any one of Claims 1 to 4,
- 25 characterised in that a capacitor (C_a) is arranged in first the signal negative feedback path.
6. A circuit arrangement as claimed in Claim 3, for a tunable receiver,
characterised in that a switch which can be activated in dependence upon the tuning



frequency is arranged in series with the second capacitor.

7. A circuit arrangement as claimed in Claim 6,
characterised in that at least a further series arrangement comprising a capacitor in series with a switch is arranged in parallel with the second capacitor and the switch.

5 8. A circuit arrangement as claimed in Claim 4 for a tunable receiver,
characterised in that the inductance comprises a plurality of series-connected coils (LS1, LS2), the nodes between the coils and their terminals remote from the signal source are connected to the respective input of an amplifier (1, 1'), the power supply voltage of each one of the amplifiers being disconnectable in dependence upon the tuning
10 frequency.

9. A circuit arrangement as claimed in Claims 2 and 5,
characterised in that the circuit arrangement is followed by a compensation stage (4) having a frequency response which is inverted relative to that of the circuit arrangement.

15 10. A circuit arrangement as claimed in Claim 9,
characterised in that the compensation stage comprises a transistor (41) with a capacitive emitter impedance (42, 43, 45) and an inductive collector impedance (46, 47), in that the base of the transistor is connected to the output of the amplifier (1), in that the negative feedback capacitor (Ca) is connected to the emitter, and in that the collector of
20 the transistor (41) constitutes the output (44) of the compensation stage.