

FILTERING

The present invention is concerned with filtering arrangements for use with telephone lines.

5 One situation in which such filtering is required is that of asymmetric digital subscriber line (ADSL) technology. This is a means of providing broadband digital services at rates of typically 1.5 to 6Mbit/s over local loop lines; this high transmission rate being provided in one direction only
10 (exchange to customer).

In order to maintain the attractiveness of this proposal it is important that ADSL is multiplexed on top of ordinary telephone services (POTS). This multiplexing is achieved by frequency division, using cross-over filters
15 which have become known as ADSL/POTS separation filters. Similar filters are required at both the local exchange and customer ends of the line. In principle identical filters may be used but the requirements at the exchange end are somewhat relaxed so an optimised design may use slightly
20 different filters. This document concentrates on the customer end filter which has the most challenging requirements, but the same problems are encountered with both filters.

Two particular aspects of telephone transmission
25 systems require careful attention. One of these is the generation of massive transients, due to such activities as on/off hook switching, loop disconnect dialling, ring cadencing and ring trip. Of these probably the worst is ring trip which can generate transient peak voltages of some 100V.
30 The second is the question of impedance balance.

In the UK (in common with many other parts of the world) non resistive frequency dependent impedances are used. The existing telephony access network infrastructure consists largely of twisted pairs of copper wires with polyethylene
35 insulation, running from the local exchange to the customer's premises. The characteristic impedance Z_0 of such transmission lines is given by

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$$Z_0 = \sqrt{((R + j\omega L)/(G + j\omega C))}$$

where R, L, G and C are the series resistance, inductance, shunt conductance and capacitance per unit length of the line, ω is the angular frequency and $j^2 = -1$.

Polyethylene is such a good insulator that G can be treated as zero whilst L (typically about 600 μ H/km) is, at telephony frequencies up to 4kHz, also negligible. Thus Z_0 can be approximated by

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$$Z_0 \approx \sqrt{(R/j\omega C)} = (1 - j)\sqrt{(R/\omega C)}$$

Typical values for R and C are 170 Ω /km and 50 nF/km so that at 1kHz Z_0 is approximately 520 - j520 ohm.

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In the access network telephony transmission is 2-wire, bidirectional, with separation of signals travelling in the two directions being achieved by bridges in the telephone and at the exchange. This situation is shown diagrammatically in Figure 1. In a telephone 1, a microphone 2 is coupled via an amplifier 3 and an impedance 4 (Z_c ohms) to a balun transformer 5 and hence the twisted-pair transmission line 6. The impedance 4 and the line impedance form 1 arm of the bridge, the other being formed by further impedances 7 and 8 of Z_c and Z_{0e} respectively. A differential amplifier 9 is connected across the bridge circuit and feeds an earpiece 10. Similarly at the exchange, the bridge comprises impedances 14, 17, 18, balun 15 and amplifiers 13, 19, the input impedance being Z_i and the impedance of the lower arm of the bridge Z_{0e} .

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It is apparent that the line 6 must present to the telephone 1 an impedance of Z_{0e} in order to balance the bridge in the telephone and prevent the user from hearing his own voice ("sidetone"). On a short line, Z_i needs to equal Z_{0e} to achieve balance, and similarly Z_c and Z_{0e} need to be equal for balance at the exchange.

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For longer lines, the impedance presented by the line will remain unchanged only if $Z_i = Z_c = Z_0$ and thus to keep

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both bridges balanced independent of line length ideally Z_c
= Z_{s0} = Z_i = Z_j = Z_{p0} .

For various reasons (such as historical precedent,
compromise across a variety of pair types and the convenience
5 of a resistive reference impedance) few if any operators have
ended up with such a network strategy. Sometimes Z_c and Z_i
are resistive (600, 900 or even 1200 Ohm) and Z_j , Z_{s0} chosen
by compromise. In the UK all four impedances are different,
frequency dependent and can be closely approximated by simple
10 RC networks. A good compromise between these 4 impedances
which can be used as the basis of ADSL/POTS separation filter
design is given in Figure 2, and in this document it is
called Z_m .

The present invention provides a telecommunications
15 station comprising

a line port connected to a transmission path having a
frequency dependent characteristic impedance;

a high-pass filter connected between the line port and
means for transmitting and/or receiving signals in an upper
20 frequency band;

a low-pass filter arrangement connected between the
line port and telephony apparatus for communication in a
lower frequency band;

wherein the low-pass filter arrangement comprises a
25 passive filter and impedance conversion arrangement connected
between the filter and the transmission path;

each impedance conversion arrangement being
substantially transparent to dc and to components exceeding
a predetermined amplitude.

30 In another aspect the invention provides an impedance
converter having first and second ports, an amplifier for
receiving the voltage at the first port and a transformer
coupling the output of the amplifier between the ports such
that the voltage at the second port is a predetermined
35 function of that at the first, and the current at the two
ports is the same.



In a further aspect the invention provides an impedance converter having first and second ports, a current transformer connected between the ports, an amplifier for receiving current from the transformer, and to draw or deliver current to one of the ports as a function of the received current, such that the current at the second port is a predetermined function of that at the first port and the voltage at the two ports is the same.

Some embodiments of the invention will now be described by way of example with reference to the accompanying drawings.

Figure 3 shows the basic structure of separation filtering at the customer premises. A twisted pair line 100 from the local exchange (not shown) is connected to a line termination point 101. Two filters are connected in parallel to this point, namely a low-pass filter 102, connected via a telephone port 103, to a conventional telephone 104, and a high-pass filter 105 connected to an ADSL port 106 and hence to ADSL equipment 107.

The two filters have non-overlapping pass-bands so that, on the path from the telephone 104 to the ADSL equipment 107, transient energy from the telephone is attenuated at all frequencies from DC up to the region of 1MHz. Ideally, each filter is nearly lossless in its passband, with a high degree of rejection (typically 100dB or more) in the stopband. As they are connected in parallel, the filters need to have a high impedance (open circuit) at stopband frequencies. (An alternative configuration is a series connection, requiring low impedance in the stopband).

The lowpass filter needs a passband from d.c. to about 4kHz, and is subject to two particular sets of requirements. Firstly it needs to be transparent to passage of ringing and line power from the line 100 to the telephone 104. As discussed earlier, it needs to be able to handle high-voltage transients without difficulty. (Also it should have virtually no impact on the operation of conventional line systems, thus requiring low leakage and low capacitance).



Secondly the filter impedance characteristics need to be such that bridge balance of (unmodified) telephones and exchange equipment is unaffected. Ideally this means that the characteristic impedance is the same as that of the line 100
5 - i.e. Z_m .

The characteristic impedance of a filter is that value of load impedance to the filter which minimises the frequency dependence of the impedance looking into the filter input. For a ripple-free (i.e. lossless) filter this is the same as
10 defining the characteristic impedance so that load impedance which results in the same value of impedance looking into the filter input (as with a transmission line).

These two requirements are mutually conflicting; the first requirement is difficult to meet using active filters,
15 because of the problem of passing dc and the presence of large voltages such as ringing current and power feeding. It is undesirable to process these signals using operational amplifier circuits because of the large voltages involved. Also there is a need to maintain dielectric isolation between
20 the wires of the pair and between each wire and ground both for safety reasons and to minimise problems with network test equipment which might otherwise report a fault on the line. Further there is a need to maintain very good linearity in the circuit because distortion, particularly of the ADSL
25 signal, would seriously compromise system performance.

The second requirement cannot be met with passive filters since these have a real (resistive) characteristic impedance whilst the characteristic impedance of the transmission line 100 is - as discussed in the introduction -
30 strongly frequency dependent.

Figure 4 shows one example of a filter arrangement as envisaged by the invention. It comprises a passive filter 200, shown here as a simple pi filter with an inductor 201 and capacitors 202, 203, although a higher order filter would
35 be needed (as discussed below) to attain the sort of rejection levels discussed earlier. The passive filter provides the desired performance for large signals but does



not meet the impedance requirement. However both the input and output of the filter 200 are connected inside back-to-back pair of Generalised Immittance Converters (GIC), 300, 400. (The terms "input" and "output" are used here for
5 convenience, but of course the filter arrangement passes signals in both directions).

The GIC is a two port device which acts to transform the impedance between the filter and the external circuitry connected to it. It behaves rather like a transformer but
10 instead of multiplying the impedance by a real factor it changes it by any desired transfer function $h(s)$.

There are a number of different designs of GIC; in particular the voltage GIC modifies the voltage between the two ports whilst leaving the current unchanged, whilst in a
15 current GIC the reverse is true. The GIC 300 used in figure 4 is a voltage GIC of unconventional construction in which a high-gain inverting amplifier 301 receives (via a dc blocking capacitor 302 and resistor (value R) 303 the voltage at the
right-hand port. The amplifier has a negative feedback path
20 of impedance $R(h(s) - 1)$ and its output is connected via a transformer 303 between left and right-hand ports.

The impedance seen looking into the left-hand port of the GIC 300 is $h(s)$ times the impedance seen looking into the left-hand side of the filter 200. Thus if (for example) the
25 filter 200 has a characteristic impedance $Z_0 = 320 \Omega$ and is to be matched to the reference impedance Z_m , then $h(s)$ needs to be chosen such that $Z_m = 320 h(s)$. Thus $h(s) - 1 = (Z_m - 320)/320$. Reference to Figure 2 shows that $Z_m - 320$ is just a parallel RC circuit and thus the feedback impedance in
30 Figure 4 is too, viz a resistor 304 and capacitor 305. The GIC 400 is identical to the GIC 300. This is however not always essential; indeed in a situation where the telephone is not well matched to the transmission line the balance may be improved by deliberately providing different GIC's so that
35 the GIC 300 provides good matching between the telephone and the filter and the GIC 400 provides a good match between the filter and the line.



It is observed that this particular construction of the GIC, with the transformer 303 and the blocking capacitor 302, is such that dc components are unaffected by it; in particular line power and ringing current can pass unimpeded.

5 Large transients can pass, simply causing saturation of the amplifier (the input and/or output of the amplifier can be provided with clamping diodes if necessary).

In an alternative arrangement, a current GIC would employ a current transformer to sense the line current, and

10 an amplifier (with the desired transfer function) having a current (i. e. high impedance) output to drive a corresponding current into/from the line.

For clarity, the filter arrangement of Figure 4 is ground referenced, but a balanced filter can be readily

15 constructed, as will shortly be described. First, however, an unbalanced 7th order passive filter is shown for reference in Figure 5. It is a modified elliptic filter with only two pairs of transmission zeros. It has inductors L4, L5, (with capacitors C5, C7) L8, and shunt capacitors C4, C6, C8 and

20 C11. Note that the inductor L8 has no capacitor in parallel, to prevent loading of the high-pass filter in the low-pass filter stopband.

Figure 6 shows a practical, balanced, embodiment. The line 100 and line port 101 are again shown, as are the

25 telephone port 102, high-pass filter 105 and ADSL port 106. Firstly it should be noted that a common-mode filtering choke T2 and associated resistors R1A, R1B between the telephone port 103 and the low-pass filter 102, and a second common mode filtering choke T6 with resistors R3A, R3B play no part-

30 in the filtering (note that the phasing of the windings of these differs from that of the remaining transformers with the low-pass filter 102).

The capacitors C4, C6 and C8 of Figure 5 are replaced by centre-tapped series pairs C4A, C4B etc; similarly C5 and

35 C7 are replaced by pairs C5A, C5B, C7A, C7B. The functions of inductors L4, L5 are performed by transformers T4, T5 in a balanced arrangement.



As before there are two generalised immittance converters, the first, 300' receives balanced signals from C4A, C4B via dc blocking capacitors C2A, C2B. One signal is inverted by an amplifier IC1 with resistors R5A, R6, and the two signals summed via R5B, R7 into the input of a second amplifier IC2 whose $h(s) - 1$ negative feed back path is provided by C3, R8 and R9. The transformer 303 is represented by transformer T3 with three windings phased as shown. The GIC 400' is identical to the GIC 300'.

10 The inductor L8 is represented by two transformers T8 and T9, the former with parallel resistors R4A, R4B outside the GIC's. This could be between the GIC's as a single transformer without resistance, but is placed outside to reduce the amount of high frequency ADSL signal received by the GIC itself. T8, T9, R4A and R4B represent an appropriately transformed version of the required inductance. The capacitor C11 is replaced by capacitor C11A, C11B in series (transformer C10 of the high-pass filter representing a short circuit at telephony frequencies). This capacitor is also outside the GIC's. Properly C11 should also undergo a transformation but this is not done for two reasons. C11 is also part of the high-pass filter and so cannot be transformed without side effects but the main problem is that the direct transformation of a capacitor requires an
25 Frequency Dependent Negative Resistor (FDNR) which is unrealisable without further active elements. As this would be too exposed to the ADSL signal, and would cause linearity and noise problems, it is not done.

Resistors R2A, R2B (though not part of the phototype filter of Figure 5) are included to damp the parallel resonance of T4 and C5. This damping ensures stability of the active filter in the stopband when the filter is adversely terminated (including short and open-circuits).

Other sources of in-band loss are the resistances of the wound components and the failure to provide the correct
35 transformation of the capacitor C11.

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The high-pass filter 105 shares the capacitors C11A, C11B and also has a balun transformer T10 which also forms the first shunt inductor of the high-pass filter, which additionally includes further series capacitors C12, C13 and 5 shunt inductors L10, L20.

Figure 7 shows a current GIC; here the current i_1 at the right-hand port is sensed by a current transformer 501. This is converted into a current $(h(s)-1)$ times as large by an amplifier 502 with a feedback resistor 503 of resistance 10 R and a complex load impedance 504 of impedance $R/(h(s)-1)$. The resulting current $i_1(h(s)-1)$ is coupled into the left-hand port by coupling the power rail of the amplifier 502 to it in a d.c. blocking capacitor 505, so that the total current at the left-hand port is $i_1 h(s)$. The power rail of the 15 amplifier is fed with power via a choke 506.

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CLAIMS

1. A telecommunications station comprising
a line port connected to a transmission line having a
5 frequency dependent characteristic impedance;
a high-pass filter connected between the line port and
means for transmitting and/or receiving signals in an upper
frequency band;
a low-pass filter arrangement connected between the
10 line port and telephony apparatus for communication in a
lower frequency band;
wherein the low-pass filter arrangement comprises a
passive filter and an impedance conversion arrangement
connected between the filter and the transmission path; -
15 the impedance conversion arrangement being
substantially transparent to dc and to components exceeding
a predetermined amplitude.
2. A telecommunications station according to claim 1, in
20 which the transfer function of the impedance converter is
such that the characteristic impedance of the filter is at
least approximately matched to the characteristic impedance
of the transmission line.
- 25 3. A telecommunications station according to Claim 1 or
2 including a second impedance conversion arrangement
connected between the filter and the telephony apparatus.
4. A telecommunications station according to claim 1, 2
30 or 3, in which the transmission line is a twisted-pair line.
5. An impedance converter having first and second ports,
an amplifier for receiving the voltage at the first port and
a transformer coupling the output of the amplifier between
35 the ports such that the voltage at the second port is a
predetermined function of that at the first, and the current
at the two ports is the same.



6. An impedance converter according to claim 5, in which the amplifier has a frequency-dependent transfer function.
7. An impedance converter according to claim 5 or 6 for connection to a balanced line, in which first and second terminals of the first port are connected by first and second transformer secondary windings to first and second terminals of the second port.
- 10 8. An impedance converter according to claim 7, having a single transformer with the said first and second secondary windings and a primary winding connected to the output of the amplifier.
- 15 9. An impedance converter having first and second ports, a current transformer connected between the ports, an amplifier for receiving current from the transformer, and to draw or deliver current to one of the ports as a function of the received current, such that the current at the second
20 port is a predetermined function of that at the first port and the voltage at the two ports is the same.
10. A filter for connection to a source or load having a frequency-dependent impedance, comprising a passive filter
25 and an impedance convertor according to any one of claims 5 to 9.
11. A telecommunications station according to claim 1, 2, 3 or 4 in which the impedance convertors are each according
30 to claim 5, 6, 7, 8 or 9.



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