

- 1 -

Safety Isolating Transformer



166166

The present invention relates to a miniature safety isolating transformer, and in particular to a telephone
5 line matching transformer suitable for bi-directional data transfer up to at least 56 kbps.

Telephone line matching transformers, such as those used in modems, are currently wound with 1:1 turns ratio. If
10 wound side-by-side on a bobbin having walls defining two winding slots, each winding is identical and has the same dc resistance. Alternatively, if wound concentrically, the secondary winding (which would then be the last one applied) will have a slightly higher dc resistance than
15 the primary winding as the mean length of each turn is greater, assuming the same gauge of wire is used for both windings. If different gauges are used, this imbalance may be mitigated.

20 In the case of side-by-side construction, conventional bobbins have equal size winding slots, so both windings are identical. The bobbin walls and potting insulation together form a contiguous insulation with no gaps, referred to herein as "solid insulating means" that
25 insulates each winding from the other, and from the core. The core is normally a laminated stack formed from E-cores with three arms inwardly facing to form a magnetic circuit around both windings.

30 Examples of solid insulating material include encapsulating resins, plastics materials from which the winding bobbin is made, and any other solid material, not necessarily homogeneous but integrally bonded or cemented with adjacent material.

35

In a miniature isolating encapsulated transformer meeting international safety standards, such as IEC 950



G00002

- 2 -

(equivalent to EN60950, CSA 950 and UL 1950) for supplementary and reinforced insulation, the minimum distance through the solid insulation between primary and secondary is defined as being 0.4 mm.

5

As required by the standards, if there is conductive material insulated from each winding, no path between a winding and this conductive material less than 0.4 mm contributes as acceptable solid insulation. In other words, a separation of 0.2 mm between the core and each winding, making a total separation of 0.4 mm via the conductive material of the core only counts as 0.2 mm insulation, which is not acceptable.

15 Because of the symmetry of the side-by-side construction, therefore, in order to ensure that the path from, say, primary to lamination stack equals or exceeds 0.4 mm, the distance from lamination to secondary will also equal or exceed 0.4 mm. Therefore, with a symmetric construction, it is conventional to make all insulation distances between the windings and between each winding and the core the same and equal to at least the minimum specified separation of 0.4 mm. Minimizing the separation in this way allows more winding area to be employed which is generally desirable.

Isolating transformers in telephone matching applications have a turns ratio of 1:1, and this provides a number of known advantages. Together with the symmetrical construction mentioned above, this provides the benefit that a device could be mounted either way in a circuit. Also, the voltage gain is the same in both directions, and there is some convenience in having the load and line impedances the same. Although non-unity signal transformers are, per se, known, they are used in other applications, for example, when it is necessary to match a

- 3 -

relatively low voltage output from an integrated circuit to that on a line.

An example of such a miniature isolating transformer for use as a telephone line matching transformer is that sold by Electronic Techniques (Anglia) Limited as part number P3081. This transformer is 9 x 12.6 mm in extent and 7 mm high, and it is therefore small enough to be provided in a surface mount package. Whilst such miniature isolating line matching transformers provide good performance for modem data rates up to 33.6 kbps, none is satisfactory at the higher data rate of 56 kbps now becoming commonplace.

For good performance at higher data rates, it has been necessary to use larger isolating line matching transformers which are typically at least 18 mm on a side, and through-pin mounted. In the context of the present invention, such devices are not considered to be "miniature". Apart from the significantly greater circuit board area and volume consumed by such non-miniature devices, the use of through-pin mounting adds manufacturing cost as compared with a surface mount only circuit board. The larger size also has a significant impact on the manufacturing cost of the isolating line matching transformer, owing to the larger amount of magnetic core material. For example, the cost of permalloy core material (80% Ni) for a non-miniature transformer is about 20 pence, typically at least four times more than for a miniature transformer.

Despite the above well known advantages of miniature isolating transformers in terms of size and cost, it has hitherto not been possible to improve the performance to that needed for higher data rates. The fundamental problem is that even though the miniature transformers are not operated near saturation, there is still some third harmonic distortion. The requirements for third harmonic

- 4 -

distortion are more onerous for transformers operating at 56 kbps than at 33.6 kbps, owing to the requirement for a better signal-to-noise ratio and the use of higher frequencies. Prior art miniature safety isolating transformers cannot achieve this low level of distortion, with the result that the bit error rate of the transformer limits the overall bit error rate of the communication channel.

Conventional approaches to improving the third harmonic distortion cannot readily be applied to improve existing performance. For example, increasing the number of turns n would lower the flux density in the core, thereby improving distortion. However, this would necessitate the use of finer wire, and the dc resistance of the winding increases with n^2 . However, lower dc resistance is generally desirable, and the dc resistance of existing miniature devices is already near the limit of what is acceptable.

20

It is an object of the present invention to provide an improved miniature safety isolating transformer.

According to the invention, there is provided a miniature safety isolating transformer, comprising a magnetic core and a first winding and a second winding separated and electrically insulated by solid insulating means from each other and the core, characterised in that a minimum of a separation between the windings and a separation from the first winding to the core defines a safety isolating distance, the separation from the second winding to the core being less than said safety isolating distance.

This arrangement permits an increase in the overall winding area for either the second winding alone, or for both windings taken together, or for the first winding. At the same time, the safety isolating performance of the

- 5 -

device is maintained by the safety isolating distance associated with the first winding.

5 The increase in available winding area allows an increase in performance, for example a lowering in winding resistance with the use of larger gauge wire, or a decrease in flux density owing to a greater number of turns, or a combination of these. It is therefore also possible to decrease the distortion.

10

Surprisingly, it has been found that in many applications in which there has been a bias towards a unity turns ratio, a non-unity turns ratio can provide significant benefits. It is therefore not necessary for the winding areas to be equal, as in prior art miniature safety isolating transformers for use in telephone line matching.

15 In a preferred embodiment of the invention, the first and second windings share a common axis and are side-by-side on the magnetic core. The core then may have arms which define a magnetic circuit encompassing both of the windings. In this case, the outermost wraps of the second winding may be separated from an arm of the core by a distance less than the safety isolating distance, thereby
25 further increasing the available winding space.

The windings may be wound on one or more bobbins with walls that define a winding space for the windings, the walls then constituting at least some of the solid insulating means. The solid insulating means may include,
30 for example, an epoxy potting compound.

The innermost windings of the second winding may be separated from the core by one or more walls that have a
35 thickness less than the safety isolating distance. In general, the first and second windings are separated from

- 6 -

each other by a middle wall on the bobbin or bobbins that has a thickness of the safety isolating distance.

5 The bobbin may have a symmetric and conventional construction, but in one embodiment of the invention, the middle wall is not central on the bobbin.

10 Preferably, in order to increase winding space, use is made of the space above the outermost wraps of the second winding. Therefore, the outermost wraps of the second winding may be separated from the core by distance less than the safety isolating distance.

15 According to a second aspect of the invention, there is provided a telephone line matching circuit, comprising a small signal transformer with a magnetic core, a first winding, and a second winding, in which: the windings are inductively coupled through the core; the first winding is connected to terminals for connection to a telephone line;
20 the second winding is connected to the transmit output of a telephony device, characterised in that the turns ratio of the first winding to the second winding is between about 1:1.05 and 1:1.45.

25 The telephony device may be any type of terminal equipment adapted for bi-directional communication with a telephone network.

30 The matching circuit may be adapted for use in a variety of devices, and particularly in a modem.

The term "small", as used herein includes both miniature devices, for example those suitable for surface mounting, and also larger devices with dimensions of up to about
35 25 mm, more suited to through-pin mounting on a printed circuit board.

- 7 -

Preferably, the turns ratio of the first winding to the second winding is between about 1:1.1 and 1:1.2.

5 The small signal transformer may be a safety isolating transformer, in which case the first winding and the second winding will be separated and electrically insulated by solid insulating means from each other and the core.

10 In the case where the small transformer is a safety isolating transformer, a minimum of a separation between the windings and a separation from the first winding to the core defines a safety isolating distance, the separation from the second winding to the core then
15 preferably being less than said safety isolating distance.

The invention will now be described by way of example, with reference to the accompanying drawings, in which:

20 Figure 1A is an exploded perspective view of a miniature safety isolating transformer according to the prior art, having a pair of side by side windings on a bobbin and with a laminated E-core;

25 Figure 1B is a perspective view of the transformer of Figure 1A shown assembled within a casing;

Figure 2A is a schematic plan view of the transformer windings and core of Figure 1A and 1B

30 Figure 2B is a cross-section through the transformer of Figure 1, taken through line II-II;

35 Figure 3 is a cross-section at right angles to that of Figure 2B, taken through a safety isolating transformer according to a first aspect of the invention;

- 8 -

Figure 4 is a circuit diagram of a conventional circuit arrangement used in a modem for telephone line matching, showing the relationship between circuit elements and the safety isolating transformer of Figures 1A, 1B, 2A, 2B, or Figure 3, which may be a non-unitary turns ratio miniature safety isolating transformer according to a second aspect of the invention;

Figures 5, 6 and 7 show circuit diagrams of telephone line matching circuits, similar to that of Figure 4, but explaining how it is possible to eliminate a matching network of resistors R_1 and R_2 used in Figure 4 to suppress a modem transmit output at the receive input; and

Figure 8 shows an alternative way to eliminate a matching network of resistors R_1 and R_2 used in Figure 4 to suppress a modem transmit output at the receive input.

Figures 1A and 1B show in perspective, and Figure 2A and 2B show schematically, a conventional miniature safety isolating transformer 1, commercially available from Electronic Techniques (Anglia) Limited as part number P3081. The transformer 1 has a core in the form of a planar lamination stack 2 formed from a fully interleaved assembly of E-cores, each with three inwardly directed parallel arms 3,4,5. The core is formed from permalloy (80% Ni) and has outer dimensions of 8 mm x 11 mm.

A bobbin 6, integrally formed in an insulating plastics material, surrounds the middle of the arms 4, and has three square-section parallel walls 7,9,11 extending outwards from a pair of similar central square-section walls 8,10. Together, one set of walls 9,10,11 define a

- 9 -

winding space for a first winding 12 for connection to a telephone line, and another set of walls 7,8,9 defines another identical winding space for a second identical winding 14 for connection to the transmit output of a telephony device. The windings 12,14 therefore share a common axis 16 side-by-side on the central core arm 4, and are electrically isolated from each other.

The turns ratio is 1:1, and the number of turns n for each winding 12,14 is 642, with $43\text{ }\mu\text{m}$ diameter enamelled copper wire ($36\text{ }\mu\text{m}$ conductor). Each winding has a dc resistance of $170\text{ }\Omega$, making a total resistance of $340\text{ }\Omega$. If finer wire were used, such as the next size down of $39\text{ }\mu\text{m}$ diameter enamelled wire ($34\text{ }\mu\text{m}$ conductor), then it would be possible to achieve $n = 800$ turns. With this number of turns, however, the dc resistance of each winding would be excessive for telephone line matching applications, at about $230\text{ }\Omega$ each, or $460\text{ }\Omega$ in total.

As is well known to those skilled in the art, electrical contacts 17-22 extend to the windings 12,14, with the winding assembly being held in a plastic casing 23. An insulating epoxy compound (not shown) surrounds a space inside the casing 23 about the core 2, bobbin 6 and windings 12,14. The size of the casing (width x length x height) is $7\text{ mm} \times 9\text{ mm} \times 12.6\text{ mm}$. The epoxy compound and bobbin 6 form "solid insulating means" between the windings 12,14 and the core 2.

As shown schematically in Figures 2A and 2B, in order to meet the standard IEC 950 (or equivalent) for electrical isolation, a minimum gap 13 of 0.4 mm is provided between the windings, with the same gap 17,18 being provided between the outside of the windings 12,14 and the inside edges of the outer core arms 3,5, and also 19,24 between the inside of the windings 12,14 and the outer edges of the central core arm 4. Because of the well-known

- 10 -

advantages of a symmetric construction, the designers of all prior art miniature safety isolating transformers have striven to achieve the same gap at all points (whether 0.4 mm, or some other gap according to the necessary degree of electrical isolation), to maximize winding area, and achieve a reasonable dc resistance, and thereby improve transformer performance.

In practice, maintaining these gaps of 0.4 mm is wasteful of winding space which, in a miniature component, is at a premium. However, if it is possible that adequate or good performance can be achieved with non-symmetrical windings, then a whole range of possibilities opens up.

In fact, it is still possible to meet the minimum distances through solid insulation as required by the standard IEC 950 if the one or more walls on one, but not both, of the windings are thinned down, as long as the partition wall 9 between the windings remains at the minimum required for isolation. Additionally or alternatively, the standard may still be met if the same winding, but not both of the windings, is wound higher on the bobbin so the gap between the outside of the winding and inside edge of the core outer arms is reduced.

25

For example, the P3081 telephone line matching transformer mentioned above has a winding area of 1.3 mm^2 per slot. Figure 3, shows a miniature safety isolating transformer 30 similar to the P3081, but with an asymmetric bobbin 39 that has reduced gaps 31,32,33 to the core 2 on all three sides of one winding 35, referred to herein as the "second" winding, the other winding 34 being referred to herein as the "first" winding. The first and second windings 34,35 share a common axis 26. The core 2 extends along the common axis 26 with arms 27 that define a magnetic circuit that encompasses both the windings 34,35.

- 11 -

The bobbin 39 and windings 34,35 are surrounded by solid insulation 29 such as an epoxy potting compound. The epoxy compound 29 and bobbin 39 form "solid insulating means" between the windings 34,35 and the core 2.

5

The reduced gaps 31,32,33 are 0.2 mm and this increases the winding area to around 2.3 mm², which is a significant improvement. Of course, the bobbin walls need not be thinned down - simply winding "higher" achieves a useful improvement.

10

Gaps 36,37 between the first winding 34 and the core 2, and a gap 38 between the windings 34,35 remain unchanged at 0.4 mm, thereby maintaining the required safety isolation.

15

With an imbalance in the winding areas, several routes can be taken:

20 a) Keep the wire gauge constant: the second winding will then have more turns than the first winding, so the second winding will have a higher dc resistance and the turns ratio no longer will be 1:1. For example, the turns ratio may be as high as 1:1.5.

25

b) Keep the turns ratio constant: the transformer remains at a 1:1 ratio, but it is then possible to use larger diameter wire on the second winding to reduce the dc resistance of the second winding, which is usually beneficial.

30

c) Keep the dc resistances constant: more turns of thicker wire are used but not as high a turns ratio as (a) nor a drop in dc resistance as (b).

35

- 12 -

d) There are intermediate possibilities, for example varying the turns ratio away from 1:1, whilst reducing dc resistance.

5 One other possibility is to move the central barrier wall
9. Moving this to sacrifice the first winding space improves the overall winding area of the bobbin as the rate of increase in available second winding area is faster than the loss of first winding area. This may be
10 highly desirable in some applications (though, not particularly in a 600 Ω line matching application).

If the barrier is moved in the other direction i.e. reducing the second winding area, a point is reached where
15 the first and second areas are equalized. Using a common wire gauge a 1:1 transformer can then be produced with overall dc resistance less than the prior art (e.g. both winding areas increase from 1.3 to 1.6 mm²), or for similar overall dc resistance to the prior art the number
20 of turns can be increased per winding.

Note that there will in general still be some dc resistance imbalance as the mean length of the first and second windings will differ somewhat.
25

To see some of the effects of these variations it is necessary to derive two expressions and consider a simplified model of a telephone line and transformer. The expressions and the accompanying description are generally
30 applicable to various types of transformer, including both side-by-side and concentric arrangements, and whether or not the transformer is a miniature device or a safety isolating device.

35 The following description is generally applicable to transformers, for example whether small, miniature, side-

- 13 -

by-side or concentric, and with or without solid isolating means.

Reference is now made to Figure 4, which shows a typical circuit layout of a telephone line matching circuit 40 for telephone line matching applications with a transformer 41 which may be either the prior art transformer 1 or a transformer 30 according to the invention. The telephone line matching circuit 40 may be connected to a telephone line 100 with a source (line) impedance 15 is R (a typical value would be $.600 \Omega$), and the transformer 41 is assumed to be ideal except for winding resistances 42,43 R_{DC1} and R_{DC2} (i.e. we ignore leakage inductance and core losses, and assume the permeability of magnetic material is infinite). We also consider the case of a differential TX low impedance drive 44 from the modem, and a single-ended RX input 45 (high impedance) - these are typical - and the use of two resistors 46,47 R_1 and R_2 provides nearly total suppression of TX signals 44 at the RX input 45.

In Figure 4, V_{RX} is the signal received at the receiver 45 from connections 48 to the telephone line 100, V_{TX} is the signal at the connections 48 from the TX output V_D , $2V_S$ is the source signal 25 (with perfect match V_S appears across the line terminals), and V_D is the transmit drive signal.

As stated, assuming R_1 and R_2 are selected for optimum suppression of V_D at RX, that R_1 and $R_2 \gg$ other resistances in circuit, we have

$$\frac{V_{RX}}{V_S} = \frac{NR_L[1 + R_L/[R_{DC2} + N^2(R + R_{DC1})]]}{R_L + R_{DC2} + N^2(R_{DC1} + R)}$$

- 14 -

where $N = N_1/N_2$ and N_1 and N_2 are respectively the number of turns on the first winding 12,34 and second winding 14,35.

5 Receive signal loss = $20\log_{10}(V_{RX}/V_S)$ dB

$$V_{TX}/V_D = R / \{N[R_{DC1} + R + (R_{DC2} + R_L)/N^2]\}$$

Transmit signal loss = $20\log_{10}(V_{TX}/V_D)$ dB

10

As this is to be a matching application, return loss is important, so the load resistance R_L cannot be chosen without reference to the match. So in practice,

15 $R_L \approx N^2(R - R_{DC1}) - R_{DC2}$

(R_L may be a little higher than given by equality by trading off return loss in the interests of improved received signal loss.)

20

Taking a practical example, the surface mount part P3081 has a recommended match of $R = 600 \Omega$, $R_L = 330 \Omega$ and R_{DC1} and R_{DC2} are both about 170Ω , so that the sum of the winding resistances $R_{DC1} + R_{DC2}$ is 340Ω . Then,

25

RX loss ≈ -9.1 dB

TX loss ≈ -6.5 dB

30

It is always possible to compensate for the TX loss (6 dB would be expected in the ideal case) by adjusting the drive level V_D on the drive chip. However, the signal from the line is a 'given' and cannot be increased without insertion of an amplifier.

- 15 -

The combined resistances of R_{DC1} and R_{DC2} of 340Ω is near the upper limit of what is acceptable for a conventional 1:1 (first winding : second winding) turns ratio miniature safety isolating transformer.

5

Exploring the possibilities of modified winding spaces:-

e) Retain a 1:1 turns ratio, decrease the primary dc resistance: $R_{DC1} = 170 \Omega$, $R_{DC2} = 100 \Omega$, $R_L = 400 \Omega$. Then,

10

RX loss ≈ -6.8 dB

TX loss ≈ -6.5 dB (i.e. no change)

f) Increase the turns ratio to 1:1.2 and decrease primary dc resistance: $R_{DC1} = 170 \Omega$, $R_{DC2} = 144 \Omega$, $R_L = 576 \Omega$. Then,

15

RX loss ≈ -5.2 dB

TX loss ≈ -8.1 dB

20

g) Increase turns ratio to 1:1.1 and decrease primary dc resistance: $R_{DC1} = 170 \Omega$, $R_{DC2} = 121 \Omega$, $R_L = 484 \Omega$. Then,

RX loss ≈ -5.8 dB

25 TX loss ≈ -7.3 dB

Option (g) is an attractive combination as it gives a significant boost to RX signals without a sharp loss in TX signal; a small drop in TX signal can, in any case, be mitigated by local adjustment to V_D .

30

The problem with a high RX loss is that modem datapumps run into dynamic range problems. They perform A/D conversion at the RX input, so there is a fixed level of quantization noise so that, neglecting other sources of

35

- 16 -

noise, signal to noise is reduced if RX signals are attenuated. Furthermore, suppression of local TX signals is always imperfect, and RX signals have to be recovered from this background 'noise'.

5

The prior art P3081 miniature isolating transformer has a total winding resistance $R_{DC1} + R_{DC2} = 340 \Omega$, which on the limit of acceptability.

10 Ordinarily, a datapump would "expect" to connect to a 1:1 turns ratio transformer having a lower typical resistance of around 100Ω per winding. In this case: $R_{DC1} = 100 \Omega$, $R_{DC2} = 100 \Omega$, $R_L = 400 \Omega$. Then,

15 RX loss ≈ -6.0 dB

TX loss ≈ -6.0 dB

So a loss of around 6 dB is expected by design. With the P3081, RX loss drops below this by over 3 dB, but we note
20 that a 1:1.1 turns ratio modification which exploits the invention restores RX loss to about -5.8 dB at the expense of some correctable loss in the TX path.

If lower distortion is needed (and this is generally
25 desirable), it would be tempting to apply more turns than in P3081, but using prior art methods this runs into serious difficulties, in particular unacceptably high winding resistance.

30 Say, for example turns are increased (but still utilizing only 1.3 mm^2 per winding); then the dc resistance must rise. Because dc resistance rises, R_L reduces and there is severe RX signal loss particularly as R_1 and R_2 must adjust in an unfavourable direction.

35

- 17 -

With the prior art method, if we assume that $R_{DC1} = R_{DC2} = 200 \Omega$, then $R_L = 200 \Omega$ and, therefore:

RX loss ≈ -14 dB (which is wholly unacceptable)

5

Increasing R_L to 270Ω by trading match results in,

RX loss ≈ -11.4 dB (which is still unacceptable)

10 Therefore, in a conventional 1:1 turns ratio miniature safety isolating transformer, a winding resistance combined sum $R_{DC1} + R_{DC2} = 400 \Omega$ is unacceptable.

But if we leave R_{DC1} at 200Ω and introduce a 1:1.1 turns ratio by winding more turns on primary whilst reducing the dc resistance (using the present invention) we have:

15

$R_{DC1} = 200 \Omega$, $R_{DC2} = 150 \Omega$, $R_L = 430 \Omega$. Then,

RX loss ≈ -7.5 dB (which is an improvement)

20

TX loss ≈ -7.4 dB

This combination of RX loss and TX loss is reasonable.

Therefore, in a 1:1.1 turns ratio device, the invention allows a combined winding resistance $R_{DC1} + R_{DC2} = 350 \Omega$, which would have been unacceptable in a prior art device.

25

Alternatively, for a 1:1.2 turns ratio: $R_{DC1} = 200 \Omega$, $R_{DC2} = 180 \Omega$, $R_{DC1} + R_{DC2} = 380 \Omega$, $R_L = 510 \Omega$. Then,

30

RX loss ≈ -6.8 dB

TX loss ≈ -8.2 dB (which can be compensated for)

- 18 -

Practically, it will not do to keep increasing the turns ratio to improve RX loss because:

(i) to overcome the increasing TX loss, drive signal V_D must increase and the drive chip may run out of available gain/drive capability; and

(ii) as V_D increases, the signal leaking back to RX input (due to imperfect balance and the imbalancing effect of real lines) increases. Distortion products from the transformer may also increase, and these then become counterproductive tendencies.

The range of about 1:1.1 to about 1:1.2 is believed to optimal for this type of application, though a significantly useful benefit may still be obtained over a wider range, of between approximately 1:1.05 to 1:1.45.

Note that with protocols such as V.90 (56 kbps) and possibly some DSL technologies (Digital Subscriber Line), the data rate is asymmetric, that is, the data rate from the telephone exchange or central office to the user is higher than from the user to the central office. In these conditions the incoming signal-to-noise ratio (SNR) for the user may well be more important than the outgoing SNR, so the relatively small change to the turns ratio which improves the RX loss at the expense of the TX loss may be most desirable. Note that this effect is just as effective on a concentrically wound transformer.

30

One inconvenience with the circuit arrangement of Figure 4 is that the circuit designer must determine the appropriate values for R_1 and R_2 . If the transformer were ideal no resistor divider or tap would be required. The person building the circuit must follow these instructions and of course space must be provided on the circuit board. Although the cost of resistors and their placement during

35

- 19 -

manufacture is relatively small, any reduction in cost can become significant in a product destined for high volume production, such as a modem for use with a personal computer.

5

Figures 5 to 7 show with circuit diagrams 50,60,70 of telephone line matching circuits how a tapped winding may be used to overcome this inconvenience. Rather than using a resistor divider 46,47 R_1 , R_2 to optimize loss, a tapped winding can achieve the same effect in place of the resistors 46,47.

As shown in Figure 5, with an ideal transformer 51, infinite return loss (optimum match) is achieved with a load resistance 59 $R_L = 600 \Omega$. Then the RX signal 55 can be picked off directly at R_L as, at this point, the V_D signal 44 is completely suppressed.

As shown in Figure 6, with a non-ideal transformer 61 there are winding resistances 62,63 R_{DC1} and R_{DC2} . Consider case where $R_{DC1} = R_{DC2} = 100 \Omega$ and otherwise the transformer 61 is ideal 1:1.

In this case the best value for a load resistance 69 for an optimum match is $R_L = 400 \Omega$.

Under these conditions, the apparent load seen by the 400Ω V_D source 44 is 800Ω and the signal developed at point A with respect to 0 V is $0.167 V_D$. This signal can be reduced to zero at the RX input 65 between series resistors 66,67 R_1 and R_2 , by making $R_1 = 10 \text{ k}\Omega$, $R_2 = 30 \text{ k}\Omega$. Unfortunately R_1 and R_2 attenuate the receive signal at point A by a further 2.5 dB over any losses due to the winding resistance. Interestingly, as illustrated in Figure 7, the same result can be obtained by using a

- 20 -

tap 74 one-quarter way along the length of a primary winding 73, as illustrated in Figure 7.

5 With the use of the tap, the RX Signal 75 is still subject to the 2.5 dB extra loss. It does, however, do away with the need for the transformer manufacturer or user to have to determine the correct values of R_1 and R_2 .

10 The correct location of the tap 74 for suppression of the TX signal at the receive input 75 can be determined as follows. The expression relating R_1 and R_2 to R_L , R_{DC1} and R_{DC2} , for a line impedance of 600 Ω , is:

$$R_1/R_2 = 1 - 2R_L/\{R_L + R_{DC2} + N^2 \cdot (600 + R_{DC1})\}$$

15

where $N = N_1/N_2$.

20 If the line impedance were some other value, the numerical value 600 in this equation would be replaced by the particular value of the impedance.

In fact, the above expressions for V_{RX}/V_S , R_1/R_2 and V_{TX}/V_D are not exact because of an approximation resulting from the requirement that R_1 , R_2 are much greater than the
25 other resistances. For suitable values of R_1 , R_2 , these are good approximations.

30 Eliminating the resistances R_1 , R_2 , then in order to achieve the same suppression with a tap, the number of turns X and Y on opposite sides of the tap will be substantially the same as the ratio R_1/R_2 , i.e.:

$$X/Y \approx 1 - 2R_L/\{R_L + R_{DC2} + N^2 \cdot (600 + R_{DC1})\},$$

- 21 -

- where $X + Y = N_2$, R_{DC2} is the sum of the dc resistances R_X , R_Y of the two parts of the second winding either side of the tap. Often X/Y is very nearly equal to R_X/R_Y , though usually this will be only approximate. For example, say $X = 200$ turns and $Y = 600$ turns. Then $X/Y = 1/3$. But if X turns are applied first, and then Y turns are applied over the top of these, then Y turns will have a somewhat longer mean turn length, so $R_X/R_Y < 1/3$.
- Because of this effect, X/Y will not quite be the same as R_1/R_2 , but the error will be a small one. For most practical purposes, the relationship will be very close such that X/Y is substantially the same as R_1/R_2 .
- Figure 8 shows, as an alternative to the use of the tap, a telephone line matching circuit 80 in which the 2.5 dB loss mentioned above could be recovered if the chip drive could be adjusted so that, rather than two signals in anti-phase of $V_D/2$, the signals 84 were $V_D/3$ and $2V_D/3$.
- In practice, it is conventional that a proportion of V_D signal 44 is internally added in a chip to the RX signal to effect cancellation, so that R_1 and R_2 can be selected to yield adequate suppression (not complete suppression) without introducing the full amount of RX signal loss; so, for example, a suppression of 14 dB may be tolerated in the external circuit, for an improvement in loss to, say, 1.5 dB.
- From a purely signal point of view, there is no real benefit to using the tap 73 as opposed to R_1 , R_2 . The advantages come from the saving in material cost and placement cost of R_1 , R_2 , and the reduction in the area consumed by these resistors on the printed circuit board. These savings are partly offset by the small extra cost of providing a tapped winding 73. There is, however, the

- 22 -

advantage that the circuit designer need not have to determine the values of R_1 and R_2 which gives best overall performance if the transformer supplier has already done the work.

5

In summary, the invention provides a number of possibilities, which can assist in a more efficient/higher performance design of safety isolating transformer.

10 1. Side-by-side wound transformers:-

1.1. Wind more turns on the second winding, decreasing the gap from winding to lamination stack to less than 0.4 mm (or whatever minimum distance is specified by a standard) and maintaining this gap on the first winding (this will produce a non-unity ratio)

1.2. Utilize more winding space on the second winding, reducing distance from second winding to stack to less than 0.4 mm, and maintaining this gap on the first winding. If a common wire gauge is used for coil windings, non-unity turns ratio will result, as in 1.1 above. Otherwise, a unity ratio could be achieved with a lower dc resistance on the second winding, or a common dc resistance for both windings.

1.3. Thin down one or more bobbin wall sections between the second winding and the core resulting in increased winding area, allowing possibilities as 1.1 and 1.2 above.

1.4. Moving of central barrier away from a symmetric central position enables, for example (and combined with 1.1 to 1.3 above):

- 23 -

(i) Unity turns ratio with similar dc resistance per winding, but with more turns per winding than usual, and common wire gauge.

5 (ii) Non-unity turns ratio, but common wire gauge and lower overall dc resistance.

10 (iii) Generally speaking, a move towards equalizing the winding areas will be beneficial in overall performance terms.

2. Side-by-side or concentric constructions:-

15 2.1 Use of non-unity ratio transformers can improve overall performance in specific applications designed to be used with 1:1 transformers, particularly where a transformer has relatively high dc resistance per winding. A useful range in applications expected to receive a 1:1 transformer is 1:1.05 to 1:1.45. For
20 example, at a ratio 1:1.414 i.e. $1:\sqrt{2}$, the impedance ratio is then 1:2 exactly.

25 2.2 Use of a tapped winding in place of external bridge components performs the same function as in the case where the bridge components are pure resistances.

3. Side-by-side construction:-

30 3.1 Using existing bobbins (with a central divider and no thin walls) in order to avoid the cost of retooling, also provides benefits. The generation of a 1:1.1 or 1:1.2 turns ratio transformer using common wire gauge on each winding is then possible. On a
35 miniature transformer, the second winding can have outer windings closer to the core, for example < 0.4 mm as in 1.1 above. The first winding would be

- 24 -

fully wound but not encroaching on the 0.4 mm distance, and the second winding would have 10% to 20% more turns and reduce the distance. Here, the desire to utilize more winding space and achieve a 1:1.1 turns ratio and use a common wire gauge combine.

Using the invention, it has proved possible to modify the prior art P3081 miniature transformer, using an unmodified bobbin. The winding turns have been increased from 642:642 to 800:880 turns, using a wire gauge of 39 μm diameter (34 μm conductor) for both windings and with a turns ratio of 1:1.1. The 800 turn first winding fills the winding space to the fullest extent normally acceptable and the 880 turn second winding invades the 0.4 mm gap as described above. In this device, the sum of the winding resistances $R_{DC1} + R_{DC2} = 480 \Omega$ approximately.

As described, above, the invention provides a useful device with a sum of the winding resistances of 350 Ω and above, in excess of the prior art, which is limited to about 340 Ω . It is believed that a useful device could have a sum of winding resistances of up to about 600 Ω . Comparing the impedance of a typical telephone line 100 of about 600 Ω to the sum of the resistances of the windings, it can be seen that the invention permits the ratio of the sum of the DC resistances of the first and second windings to the telephone line matching impedance to be between about 7:12 to 1:1.

Using the conventional understandings and biases found in the prior art, an 800:800 turns device would have excessive dc resistance $R_{DC1} + R_{DC2} = 460 \Omega$ for normal application as a miniature telephone line matching and safety isolation transformer. However, the 800:880 turns device according to the invention is fully functional at

- 25 -

56 kbps, has a sum of dc winding resistances of 460 Ω , and fits in a tiny surface mount package having an extent of 9 mm x 12.6 mm by 7 mm high.

- 5 The general principles of the invention are, of course, not limited to side-by-side construction, but apply also to concentric construction of a miniature safety isolating transformer.
- 10 The various aspects of the invention may also be employed individually, or in combinations in which various synergistic benefits can be obtained by the interaction of effects, as described in detail above.

- 26 -

Claims

1. A miniature safety isolating transformer (30), comprising a magnetic core (2) and a first winding (34) and a second winding (35) separated and electrically insulated by solid insulating means (29,39) from each other and the core (2), characterised in that a minimum of a separation (38) between the windings and a separation (28,36) from the first winding (34) to the core (2) defines a safety isolating distance (28,36,38), the separation (31,32,33) from the second winding to the core (2) being less than said safety isolating distance (28,36,37,38).
2. A miniature safety isolating transformer (30) as claimed in Claim 1, in which the first and second windings (34,35) share a common axis (26) and are side-by-side on the magnetic core (2).
3. A miniature safety isolating transformer (30) as claimed in Claim 2, in which the core (2) has arms (27) which define a magnetic circuit encompassing both of the windings (34,35).
4. A miniature safety isolating transformer (30) as claimed in Claim 3, in which the outermost wraps of the second winding (35) are separated from an arm (27) of the core (2) by a distance (31) less than the safety isolating distance (28,36,37,38).
5. A miniature safety isolating transformer (30) as claimed in any of Claims 2 to 4, comprising one or more bobbins (39) with walls that define a winding space for the windings (34,35), the walls constituting at least some of the solid insulating means (29,39).

- 27 -

6. A miniature safety isolating transformer (30) as claimed in Claim 5, in which the innermost wraps of the second winding (35) are separated from the core (2) by one or more walls that have a thickness (33) less than the safety isolating distance (28,36,37,38).

7. A miniature safety isolating transformer (30) as claimed in Claim 5 or Claim 6, in which the first and second windings (34,35) are separated from each other by a middle wall (9) that has a thickness of the safety isolating distance (28,36,37,38).

8. A miniature safety isolating transformer (30) as claimed in Claim 7, in which the middle wall (9) is not central on the bobbin (39).

9. A miniature safety isolating transformer (30) as claimed in Claim 7, in which the bobbin (39) is symmetric.

10. A miniature safety isolating transformer (30) as claimed in any preceding claim, in which the turns ratio of the first winding (34) to the second winding (35) is between about 1:1.05 and 1:1.45.

11. A miniature safety isolating transformer (30) as claimed in Claim 10, in which the turns ratio of the first winding (34) to the second winding (35) is between about 1:1.1 and 1:1.2.

12. A telephone line matching circuit (40) comprising a miniature safety isolating transformer, the transformer (30) being as claimed in any preceding claim.

13. A telephone line matching circuit (40), comprising a small signal transformer (1,30) with a magnetic core (2), a first winding (12,34), and a second winding (14,35), in which: the windings (12,34;14,35) are inductively coupled

- 28 -

through the core (2); the first winding (12,34) is connected to terminals (20-22) for connection to a telephone line (100); the second winding (14,35) is connected to the transmit output (44) of a telephony device, characterised in that the turns ratio of the first winding (12,34) to the second winding (14,35) is between about 1:1.05 and 1:1.45.

14. A telephone line matching circuit (40) as claimed in Claim 13, in which the turns ratio of the first winding (12,34) to the second winding (14,35) is between about 1:1.1 and 1:1.2.

15. A telephone line matching circuit (40) as claimed in Claim 13 or Claim 14, in which the signal transformer is a miniature device (1,30).

16. A telephone line matching circuit (40) as claimed in any of Claims 13 to Claim 15, in which the signal transformer is a safety isolating transformer (1,30), the first winding (12,34) and the second winding (14,35) being separated and electrically insulated by solid insulating means (29,39) from each other and the core (2).

17. A telephone line matching circuit (40) as claimed in any of Claims 13 to 16, in which a minimum of a separation (38) between the windings (12,34;14,35) and a separation (28,36) from the first winding (12,34) to the core (2) defines a safety isolating distance (28,36,38), the separation (31,32,33) from the second winding (14,35) to the core (2) being less than said safety isolating distance (28,36,38).

18. A telephone line matching circuit (40) as claimed in any of Claims 13 to 17, in which the transformer windings are concentric.

- 29 -

19. A telephone line matching circuit as claimed in any of Claims 13 to 17, in which the transformer windings (12,34;14,35) are side-by-side.

5 20. A modem comprising a telephone line matching circuit (40), the circuit being as claimed in any of Claims 12 to Claim 19.

10 21. A telephone line matching circuit (40) as claimed in any of Claims 12 to 20, in which the sum of the DC resistances of the first and second windings (34,35) is between about 350 Ω and 600 Ω .

15 22. A telephone circuit, comprising a telephone line (100) connected to a telephone line matching circuit, the telephone line matching circuit (40) being as claimed in any of Claims 12 to 21, in which the ratio of the sum of the DC resistances of the first and second windings (34,35) to the telephone line matching impedance (15) is
20 between about 7:12 to 1:1.