

**Coupling of Telecommunications Signals to a Balanced
Power Distribution Network**

This invention relates to a method of signal injection,
5 transmission, interconnection (termination) and detection,
and to a power transmission network, ie. a mains
electricity distribution and/or transmission network, and
a filter therefor. In particular it relates to the use of
overhead mains electricity networks and/or lines for
10 telecommunications transmission (e.g. voice, data, image
and/or video).

In the UK, it is conventional to describe a power network
for 33kV and above as a "transmission network", and one
15 for less than 33kV as a "distribution network". In this
specification the term "electricity distribution and/or
power transmission network" (EDN) is normally used, but
general references to power networks and to transmission
of signals are to be construed as applying to all such
20 networks.

Traditionally telecommunications signals have been
transmitted on independent networks e.g. telephone lines.
More recently, in order to simplify and increase
25 efficiency of telecommunications services to domestic or
industrial premises, there have been investigations into
using existing electricity transmission and distribution
networks to carry telecommunications services.

30 It has been known to utilise above ground (overhead) (OH)
power lines for the transmission of additional control,
speech and data signals. However, with such
transmissions, in the past the frequency spectrum has been
allocated for and restricted to particular applications in
35 order to avoid interference with other telecommunications

services. In addition, the strength of signals which could be transmitted was generally thought to be limited since the amount of radiation produced by the transmission is related to the strength of the signal and this
5 radiation must be kept to a minimum.

Such transmission signals have therefore been of low power and confined within a specific frequency band allocated by international agreement for such purposes, so this
10 mechanism has been thought to be unsuitable for large scale voice and/or data transmission where signals extend well into the radio spectrum (e.g. 150 kHz and above).

Furthermore, if signals are to be transmitted on overhead
15 power networks then other problems need to be overcome, such as the problems of noise on the networks, varying customer loads attached to the network, and impedance matching between communications equipment attached to the network and the network itself.

20

It has been known to use spread spectrum techniques to transmit data at carrier frequencies of between 6kHz and 148kHz on underground (UG) and overhead (OH) EDN's. Again, in this allocated frequency band such transmissions
25 suffer from low data rates and low traffic capacities due to power line noise characteristics. Due to the limited spectrum available and high noise levels encountered wideband telecommunications signals have not been sent.

30 Although papers such as that by J.R. Formby and R.N. Adams, ("The mains network as a high frequency signalling medium", The Electricity Council, January 1970) suggested a communications potential for the low and medium voltage networks, no further work was undertaken. Even today,
35 with the prospect of remote meter reading and selective

load control, solutions tend to employ techniques such as telephony and radio communications, thus avoiding the mains network where possible.

- 5 Ideas have been put forward but few have proceeded past the theoretical stage, due to the hostile environment presented by the mains network. The problems to be overcome include electrical noise, (both constant background noise and transient spikes) and high
10 attenuation of high frequency signals due to skin and proximity effects.

Messrs Formby and Adams suggested using frequencies in the range of 80 to 100 kHz. 100 kHz was recommended as a
15 maximum because theory suggested that higher frequencies would suffer from excessive attenuation. Other papers recommend a maximum of 150 kHz due to the fact that radiated signals higher than 150 kHz would interfere with broadcast radio signals.

20

A further situation where power lines are also used for the transmission of speech and data signals is on the electricity wiring inside buildings. In such configurations the internal 240V mains wiring is used for
25 the transmission of data, with appropriate filtering being provided to add and separate the data signals from the power signals. Additionally a filter, such as the Emlux filter described in European Patent Application 141673, may be provided to prevent data signals leaving the
30 building and entering the power supply network external to the building. The Emlux filter described consists of a tuned ferrite ring which acts effectively as a band stop filter. In order to be effective the band stop filter must be of narrow bandwidth and therefore is not suitable
35 for use with high speed data communications, since a large

number of such band stop filters would be required.

As described above, in general there are two basic EDN architectures namely underground (UG) and overhead (OH).

5

Underground networks are generally composed of a number of different types of "pseudo-coaxial" cables which are screened types of cables providing for propagation of high frequency (HF) communications signals between the inner
10 conductor(s) and outer conductor sheath(s) in an unbalanced mode. Typical values of characteristic impedance for which UG cables may range from 10 to 75 ohms. In particular, transmission of telecommunications signals on such networks is described in the applicant's
15 prior PCT application, published as WO 94/09572, the disclosure of which is incorporated herein by reference. In order to provide maximum power transfer and good impedance matching between the EDN and a HF coaxial termination point, a prior art unbalanced conditioning
20 unit design is utilised as shown in figure 9.

The application of a conditioning device to all the termination points of an underground (UG) EDN will result in the EDN being optimised for the propagation of HF
25 communications signals without any impairment of the EDN's capacity to efficiently deliver electrical energy at ultra low frequencies (ULFs), i.e. 50 to 60 Hz.

As described in WO 94/09572, such an enclosed and
30 conditioned EDN will preferably have HF characteristics, above 1 MHz, which includes:-

1. A minimal HF noise floor.
2. Immunity to variable loads at ULFs, i.e. 50 to 60 Hz.
- 35 3. A safe point of interconnection for low amplitude HF

communication signals.

4. Directional propagation of HF communication signals.
5. Suitable network service termination points for electricity distribution and telecommunications service provision.

Overhead (OH) Networks are generally composed of open wire feeders which are flown on wooden poles or metal towers. The conductors generally run parallel in either horizontal, vertical or triangular configurations and, as such, are similar to open wire transmission lines which are commonly used for propagating HF communications signals, say between a high power HF broadcast transmitter and a remotely located HF aerial array.

Typical conductor spacing on such OH EDN support structures is approximately 1 metre, with relatively small conductor diameters. As a result the characteristic impedance of such networks is high in relation to similar UG networks. Typical values of characteristic impedance for OH networks extend from 300 to 1000 ohms.

Typical OH EDNs have power factor correction capacitors fitted at regular intervals to compensate for the net effect of inductive power loads at 50/60 Hz. These capacitor banks usually consist of one capacitor per phase conductor connected between the phase conductor and the network neutral and/or earth conductor. The capacitors produce relatively high reactive currents at power frequencies of 50 to 60 Hz which advance the current phasors closer to the voltage phasors thus improving the efficiency of the EDN at power frequencies.

The effect of such capacitors at the traditional mains signalling frequencies of 3kHz to 148.5kHz is to severely

attenuate the power line carrier signals, often to such a low level as to render the systems inoperative.

It may be thought that this problem would be overcome
5 simply by raising the communications signals above 1 MHz,
as the effect of the capacitors becomes insignificant due
to the inductive reactance of the interconnecting (jumper)
leads and the internal construction of the capacitors.
The overall reactance of the capacitors appears inductive
10 at frequencies above 1 MHz and as a result their shunt
impedance becomes greater than the characteristic
impedance of the OH lines resulting in minimal loading and
hence minimal line loss at HF.

15 However, one resulting problem is that at such frequencies
the power transformers appear as a high impedance,
inductive, loads above 1MHz and their resultant impedance
becomes much greater than the characteristic impedance of
the OH lines.

20 Thus, by utilising frequencies above 1MHz the power
transformer does not significantly reduce the
communications signal level or provide HF by-pass between
the primary and secondary windings of the power
25 transformer. Power transformers may be considered as low
pass filters with cut off frequencies well below 1 MHz.

Another problem with some sections of OH EDNs is that they
may have single phase sections fed off the main polyphase
30 network. This may result in an unbalancing of the network
creating impedance miss-match and subsequent radiation of
the HF signal(s) from the network. This makes the network
very lossy and reduces propagation of the
telecommunications signals.

35

A coupling unit ("conditioning unit") is disclosed in WO 94/09572 for coupling high frequency signals to an EDN. However, such a conditioning unit is not particularly well suited to either coupling HF communications signals across
5 power transformers in an OH EDN as described above or to decoupling any single phase sections fed off the main polyphase network.

The present invention aims to provide a method and
10 apparatus for telecommunications transmission on a power network which alleviates some or all of the above problems.

Accordingly, in a first aspect, the present invention
15 provides a balanced electricity distribution and/or power transmission network, the network including input means for the input onto the network of a telecommunications signal having a carrier frequency greater than approximately 1MHz from an unbalanced source and output
20 means for removing said telecommunications signal from the network wherein said input means and said output means provide impedance matching between said network and said source.

25 Thus, propagation of HF communication signals over such networks is optimised, and the input and output means ("conditioning units") provide for interconnection between a source e.g. a relatively low impedance unbalanced HF (possibly coaxial) termination, and a high impedance
30 balanced OH EDN, and provide efficient unbalanced to balanced impedance transformation and termination.

In this way both speech and data signals can be transmitted at carrier frequencies of greater than
35 approximately 1MHz, allowing for a larger available

spectrum and greater transmission capacity. The carrier frequency may in fact be less than 1MHz ie. 800KHz or even as low as 600KHz, but as it is reduced so is the bandwidth.

5

A plurality of telecommunications signals may be provided, each having different carrier frequencies. The term "carrier frequency" refers to the unmodulated frequency of the carrier signal, and not to the frequency of the

10 telecommunications signal once modulated.

On, for example, a 400V network the carrier frequency may preferably be between 1-10MHz, and on, eg., a 11kV network may be between e.g. 1-20MHz, or possibly 5-60MHz. However

15 the frequency may be up to 100's of MHz depending on the network and the application. For example, over short distances (10-20m) a frequency range of e.g. 1-600MHz or 1-800MHz may be used.

20 The power network may include one or more phases..

Preferably the network is a polyphase network including e.g. any one or more of 2, 3, 4, 5, 6, 7 etc phases.

Different sections of the network may include different numbers of phases.

25

The network may typically be a trunk and branch multipoint (or multipoint to point) electricity distribution and/or power transmission network.

30 Preferably the network is balanced i.e. provides balanced transmission characteristics. The network may be an "overhead" network i.e. the cable(s) of the network may lie above ground e.g. flown or strung between pylons.

35 Preferably at least part (or all) of the transmission

network is external to any building or premises such as an office or house and the signal(s) is/are transmissible along said external part. Inside such buildings, transmission distances are typically short and therefore
5 attenuation losses relatively unimportant.

Preferably the power network is a major (e.g. overground) power network including e.g. any or all of 132kV, 33kV, 11kV, 415V and 240V sections. The telecommunications
10 signals may be transmitted over any or all of the sections of the power network by suitable detection, amplification and/or regeneration and reintroduction as and when necessary.

15 Preferably the network includes connection means located at at least one, and preferably all, of the interconnection points between the OH EDN and any interconnecting UG EDNs. The connection means provide impedance matched HF connection between the OH and UG EDNs
20 to permit efficient propagation of HF communication signals between the OH and UG network sections. This helps to ensure that the HF communication signal power may be kept to a minimum in order to reduce the level of radiation from any unscreened OH EDN sections.

25 In order to overcome the problem of coupling HF communications signals across transformers at various voltage levels a HF by-pass unit is preferably provided which can either provide for balanced to balanced or
30 balanced to unbalanced by-pass in either direction, i.e. primary to secondary or secondary to primary sides of the power transformer.

The by-pass unit may utilise any or all of: fuse
35 protection, capacitive coupling, dust iron or ferrite

transformer impedance matching and balanced or unbalanced termination capability. The frequency response of the ferrite materials at 50 to 60 Hz is negligible and by suitable centre tapping of the primary and/or secondary
5 windings together with adequate insulation of the core materials good flashover protection may be provided.

It should be noted that by utilising HF communications signals above 1 MHz together with inductor core materials
10 such as dust iron and ferrite, it becomes possible to fabricate both high voltage capacitors and high impedance inductive elements which are sufficiently small in physical size to be retro fitted to existing OH EDN support structures and in many cases may simply replace
15 existing jumper wires.

In a preferred embodiment, full duplex facilities are provided by utilising, for example, frequency (FDD), time (TDD) and/or code division multiplexing and/or multiple
20 access (CDMA) techniques, i.e. signals may be transmitted and/or received in all directions simultaneously.

A network according to the present invention may be used for many speech and/or data transmission purposes, such as
25 remote reading of electricity meters, remote banking and shopping, energy management systems, telephony (voice), switched telephony, security systems and/or interactive data services, multimedia services and television.

30 A wide range of different transmission techniques are available for use with electricity power line communications, each using various modulation methods including frequency, time and code division multiplexing. It has been determined that the spread spectrum method
35 offers inherent security and good interference rejection

characteristics. These properties are achieved using a large bandwidth and hence requires the design of a specific filter.

- 5 Modulation methods include amplitude, frequency, phase; single, double and vestigial sideband, pulse position, width and amplitude; frequency shift keying (FSK), Gaussian filtered FSK (GFSK), Gaussian minimum shift keying (GMSK), Quaternary phase shift keying (QPSK),
- 10 Orthogonal quaternary phase shift keying (OQPSK), Quadrature amplitude modulation (QAM), $\text{Pi}/4$ QPSK etc.

A large number of standard cordless, mobile and cellular radio phone communication techniques may be suitable for

15 effecting signal transmission over a conditioned network.

According to a further aspect, the present invention provides a method of signal transmission including input of a telecommunications signal having a carrier frequency

20 of greater than approximately 1MHz from an unbalanced source onto a balanced electricity power distribution and/or transmission network and subsequent reception of the signal. Preferably, said signal is transmitted using frequency, time and/or code division multiplexing

25 techniques.

In a further aspect, the present invention provides a communications apparatus (known hereinafter as a "network conditioning unit") for use with a network according to

30 the first aspect of the present invention. The network conditioning unit includes a pair of balanced low pass filter portions for filtering out the low frequency high amplitude mains power signal i.e. separating it from the telecommunications signal(s) and allowing it to pass

35 through the conditioning unit. The unit also includes a

pair of balanced high pass coupling elements for input and removal of telecommunications signals from the network and, preferably, a terminating element of similar impedance to the characteristic impedance of the network
5 at that point.

The use of such a unit allows HF signals to be input onto the network and LF marks signals to pass through the unit.

- 10 Such a unit may also be used to ensure that the high frequency telecommunications signals may pass around transformers on the EDN and/or may or may not (as appropriate) be coupled to connecting UG EDN's.
- 15 Preferably, the variable electrical loading effects (i.e. the load impedances) of all items which are coupled onto the network from time to time and which utilise electrical energy (i.e. the electrical loads) are isolated from the communications signals by the action of low pass filter
20 element(s) of the conditioning unit(s).

Preferably the conditioning unit can be connected to the network in both a balanced and unbalanced configuration.

- 25 Preferably the network conditioning unit provides impedance matching between reception/transmission devices and the power network. Additionally the network conditioning unit may carry full load or fault current at power frequencies whilst still carrying the voice and data
30 signals.

In a third aspect, the present invention provides a method of signal transmission using a network as described herein.

Where signals are being transmitted along a polyphase (e.g. three phase) electricity power network, the signal propagation may be between any or all of the phases and ground. In preferred embodiments the signal is injected
5 between any two of the phases, or between one of the phases and a neutral conductor.

Where signals are being transmitted along a single phase electricity distribution service cable a pseudo-coaxial
10 effect may be obtained. Single phase cables may typically be either concentric or split-concentric. In the case of a split-concentric cable, means (such as a capacitive coupling between the parts of the split-concentric sheath) may be provided so that at the desired frequency
15 the cable behaves as a standard concentric cable. Thus a pseudo-coaxial effect is achievable and the cable provides an unbalanced transmission characteristic.

Preferably, any spurious self resonance in the inductive
20 or capacitive elements are avoided. As the lower cut off frequency of the conditioning unit is increased the minimum values of inductance and capacitance may be proportionally reduced.

25 In a further aspect, the present invention provides an overhead electricity distribution and/or power transmission network having a number of phases, said number being chosen from the list 1,2,3,4,5,6,7,8,9,n (where n is an integer greater than 9), but preferably
30 having 1, 2 or 3 phases, and including input means for the input of a telecommunications signal having a carrier frequency greater than approximately 1MHz onto at least one of the phase conductors of the network and output means for removing said telecommunications signal from at
35 least one other phase conductor of the network.

In a further aspect, the present invention provides a balanced electricity distribution and/or power transmission network, the network including input means for the input onto the network of a telecommunications signal having a carrier frequency greater than
5 approximately 1MHz and output means for removing said telecommunications signal from the network.

In a further aspect, the present invention provides a
10 method of signal transmission including input of a telecommunications signal having a carrier frequency of greater than approximately 1MHz onto at least one phase conductor of an overhead and/or balanced electricity power distribution and/or transmission network, and subsequent
15 reception of the signal from at least one other phase conductor of the network, said network having a number of phases, said number being chosen from the list
1,2,3,4,5,6,7,8,9,n (where n is an integer greater than 9), but preferably having 1, 2 or 3 phases.

20 Any or all of the above aspects may include features described elsewhere in this specification.

Embodiments of the present invention will now be described
25 with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a part of a network in which aspects of the present invention may be used;

30 Fig. 2 is a schematic diagram of a first transmission system for a network according to figure 1;

Fig. 3 is a schematic diagram of a second transmission system for a network according to figure 1;

Fig. 4 is a schematic diagram of a third transmission system for a network according to figure 1;

Fig. 5A is a cross section through a typical three phase
5 cable;

Fig. 5B is a section through a typical coaxial cable;

Fig. 6 is a first embodiment of a network conditioning
10 unit according to the present invention;

Fig. 7 is a second embodiment of part of a network conditioning unit according to the present invention;

15 Fig. 8 is a third embodiment of part of a network conditioning unit according to the present invention;

Fig. 9 is a schematic diagram of a prior art unbalanced conditioning unit.

20

Fig. 10 is a cross-sectional diagram of a floating neutral-type EDN cable.

Figs. 11A, 11B and 11C show sectional views through a
25 concentric, split-concentric and pseudo-concentric cable respectively;

Fig. 12 is a schematic diagram of a two-wire, balanced, power distribution and/or transmission network according
30 to an aspect of the present invention;

Fig. 13 is a schematic diagram showing a typical layout of signal transmission/reception components at a terminal pole of a power distribution and/or transmission network;

35

Fig. 14 is a schematic diagram of an embodiment of an interface for connecting telecoms apparatus to a high voltage network;

- 5 Fig. 15 is a schematic diagram of a circuit for providing an interface between overhead and underground power cables.

Fig. 1 shows generally a network 40. Mains electricity
10 enters the network from an 11kV transmission line 42 (e.g. an OH EDN), via a transformer 44 and onto a 400V three phase network 46. The 400V three phase network is supplied to a number of locations, such as buildings 48. Each of these buildings may receive only a single phase
15 electricity supply or alternatively may receive a three phase power supply.

Voice and data signals may be injected into the network (or alternatively received from the network) at a point
20 50, to be transmitted and/or received by users in the premises 48. In order to separate the voice and data communication signals from the low frequency high amplitude power signal each signal source and/or destination is provided with an unbalanced conditioning
25 unit 52 - shown in more detail in figure 9. This network conditioning unit includes a low pass filter for separating out the two signals.

The present invention is primarily concerned with the
30 propagation of HF signals on the OH EDN 42.

A further (high current) conditioning unit 51 may be fitted between the electricity distribution transformer 44 and the injection point 50 in order to further remove
35 transformer noise from the conditioned network 40. The

unit 51 is fitted with a high current inductor.

Fig. 2 shows a portion of an OH 11kv three phase network 42 into which and from which data signals may be transmitted and received using the network conditioning units 52. If the cable of the network 40 is underground, it is clad i.e. is surrounded by a sheath 41 e.g. along all or substantially all of its length. However, if the set of cables are overhead(as is the case with most embodiments of the present invention), such a sheath is omitted.

As an example, data signals could be transmitted onto the yellow phase of the network by network conditioning unit 52 i.e., the signal is applied between the yellow phase and earth/neutral as shown. The transmitted data may then be received by any or all of conditioning units 52B, 52C and 52D which are connected to the yellow, red and blue phases respectively. In other words transmitted data may be picked up on any phase of the cable, including the phases onto which the signals were not injected by the transmitting unit. As can be seen, data can be transmitted and received by each unit.

Each phase of the network 42 is shown to include a transformer 43. Typically this is effected by a single three phase transformer unit for all three phases, and not by three separate single phase transformers - although the latter may be possible.

30

Fig. 3 shows a portion of a three phase network 42 into which and from which data signals may be transmitted and received using four network conditioning units 52. As shown, the data signals are transmitted across two phases of the three phase network - in this case the red and blue

phases. This example could also apply to a balanced network, using balanced conditioning units 1301.

If one or more phases are not in use (e.g. the yellow phase in Fig. 3), the non-used phases(s) may be terminated to provide an appropriate impedance. This may be done using an "L" circuit i.e. a series inductor with a shunter capacitor on the transformer side. This provides an optimum impedance and ensures that an RF signal which is coupled between e.g. the red and yellow phases, is not shunted down by a low impedance transformer connection. This is particularly useful if there is insufficient inductive reactance at e.g. the yellow phase transformer connection point.

15

In Fig. 4 an alternative transmission system to Fig. 2 is shown, in which the data signals are transmitted across all three phases, i.e. blue, red and yellow, of the three phase network 40.

20

Fig. 5A shows a simplified cross section of a typical three phase underground power cable 54, including red phase 56, yellow phase 58, and blue phase 60. Data signals are transmitted between blue phase 60 and earth 62, and are injected into the network via network conditioning unit 52. At high frequencies, the mutual capacitance between the phases effectively produces a close coupling effect. Therefore, such a transmission system gives a pseudo-coaxial characteristic, roughly equivalent to the coaxial cable shown in Fig. 5B. The mutual capacitance between any two of the phases in the three phase cable is shown schematically as 64 in Fig. 5A - similar mutual capacitance exists between other parallel conductors within single construction multi-conductor cables. This is how the HF signals are propagated on UG

35

EDN's connected to an OH EDN.

Referring to Fig. 6, an embodiment of a balanced conditioning unit according to an aspect of the invention is indicated generally by the reference numeral 10. The conditioning unit 10 has dual high frequency signal connections balanced about 0v and/or earth.

The EDN connections are made via terminals 1 and 5 and may be for example 110v term 1, 0v term 3 and 110V term 5, or 230V term 1, 0v term 3 and neutral term 5. Fuses F1 and F4 protect capacitors C1 and C4 respectively in case of failure, having low frequency paths to 0v and/or earth via L1 and L4 respectively.

15

C1 together with L1, and C4 together with L4, form high pass filter elements permitting high frequency signals above 1 MHz to be applied at terminals 2 and/or 4, to couple via C1, F1 and C4, F2 to the EDN terminals at 1 and 5 respectively. Inductors L2 and L5, together with capacitors C2 and C5, provide low pass filter sections each having capacitor protection via fuses F2 and F5 respectively. Two similar filter units are cascaded and are formed similarly with L3 and L6 together with capacitors C3 and C6 with similar capacitor protection via fuses F3 and F4 respectively. These low pass filter units allow the ultra low frequency 50 to 60Hz power components to pass without distortion and to be connected to the customer wiring via pins 6 and 7.

30

The communications signals may be interconnected in a balanced mode via terminals 2 and 4 or split unbalanced modes between terminals 2 and 3 or 4 and 3 respectively.

35 The absolute values of the capacitive and inductive

components will depend upon the characteristic impedance of the EDN but typical values for a 50 ohm impedance EDN are $L2 = L3 = L5 = L6 = 16 \mu H$; $C2 = C3 = C4 = C5 = C6 = 0.01 \mu Fd$. $F1 = F2 = F3 = F4 = F5 = F6 = 500mA$; $L1 = L4 = 150 \mu H$; $C1 = C4 = 0.01 \mu Fd$.

In order to efficiently couple telecommunications transmissions lines (TTL) it is important to ensure:-

- 10 1. Correct impedance at the point of interface.
2. That the network propagation characteristics remain constant.

When utilising an EDN to carry high frequency communications signals efficiently interact between the TTL and the EDN is made via a conditioning unit. Provided that the TTL is unbalanced, i.e. coaxial or pseudo coaxial and the EDN is similarly coaxial or pseudo coaxial (e.g. a UG EDN), then efficient interface and communications signal cross propagation will result.

However, if it is required to interface between say an unbalanced coaxial or pseudo coaxial TTL, and say an open wire balanced overhead EDN or a floating neutral type EDN either overhead or underground (as is the case with the present invention), then a conditioning unit such as shown in fig. 6 is required to efficiently transform between the unbalanced and balanced network sections.

Figures 7 and 8 show embodiments of, respectively, low pass and high pass filter elements which could make up a conditioning unit according to the present invention.

Fig. 7 shows how inductors and capacitors may be combined to form low pass balanced filter elements and how they may

be cascaded to improve performance. For frequencies above 1 MHz the inductors and capacitors may be manufactured with sufficiently small physical dimensions so as to be included in overhead EDNs without the need for major restructuring of the existing pole or tower mounted components.

A typical value for a LPF inductor element, say L10 or L11, for an overhead EDN with a phase to phase line d impedance of say 600 ohms, is in the order of $50\mu\text{H}$. Such an inductor may be formed over a ferrite core to further reduce its physical size and provide for a LPF cut off frequency below 1 MHz. The inductive element is also designed to carry full EDN load and fault currents.

If the low cut off frequency of the filter is raised to say 5 MHz then the value of the inductor may be reduced proportionally to $10\mu\text{H}$ with further reduction in the physical size of the element. Two inductors of similar value should be utilised, shown in Figure 7 as L10 and L11, in order to maintain a balance of the lumped transmission line parameters.

Similarly, the LPF decoupling capacitors C10 and C11 have typical values between 0.01 and $0.001\mu\text{Fds}$. Capacitors of these values may be of relatively small physical size for working voltages up to 33kV and are easily mounted at the appropriate points on overhead EDN poles or towers without restructuring of the existing components.

Such LPF elements may form part of a balanced EDN conditioning unit design, as shown in fig. 6.

Fig. 8 shows how inductors and capacitors may be combined to form balanced, high pass filter (HPF) elements and how

they may be cascaded to improve performance. For frequencies above 1 MHz the inductors and capacitors may be manufactured with sufficiently small physical dimensions so as to be included in overhead EDNs without the need for major restructuring of the existing pole or tower mounted components.

A typical value for a HPF inductor element, say L13 or L14, for an overhead EDN with phase to phase line impedance of say 600 ohms is in the order of 250 μ H. Such an inductor may be formed over a ferrite core to further reduce its physical size and provide for a flat HF amplitude response above 1 MHz, with minimal attenuation, when combined with C13 and C14.

15

The prime objective of these shunt inductive elements is to provide low impedance paths to the earth and/or neutral of the EDN should a capacitive element fail. The resulting high current at 50/60Hz will then cause protective devices such as series line fuse links to blow and protect the EDN accordingly. The inductors also sharpen the frequency response of the HPF units.

20

A typical value for the HPF coupling capacitors C13 and C14 lies between 0.01 and 0.001 μ Fds. Capacitors of these values may be relatively small in physical size for working voltages up to 33kV and are easily mounted at the appropriate points on overhead EDN poles or towers without restructuring of the existing components.

30

The values given for these components are exemplary only, and different preferred values will be appropriate for other design frequencies.

35 Fig. 10 shows a cross section through an EDN cable 100

which is designed to provide a floating neutral. One of the conductors (101,102) carries the 50/60Hz phase voltage, the other carries the neutral or star/bye point potential. Each conductor is insulated by e.g.

- 5 impregnated paper or a polymer type medium 103 and the cable is covered in e.g. a lead, copper or aluminium sheath 104 which may be further protected by steel wire armour.
- 10 The lead sheath is normally at earth potential and in the UK is bonded to earth at the distribution transformer point. The conductors may be of copper or aluminium construction and under normal conditions the 50/60Hz phase and neutral currents should be equal in magnitude and
- 15 opposite in phase, i.e. balanced.

At high frequencies above 1 MHz the cable may be treated as a pseudo-screened cable with signal propagation between the earth sheath and phase conductor, the earth sheath and
20 neutral conductor or between the phase and neutral conductors.

In the UK, UG EDNs usually have the neutral bonded to earth at the transformer point, therefore the HF signals
25 would normally be propagated between the phase conductor and the earthed cable sheath. Then, when connecting to a conditioning unit as shown in Fig. 6, the earth cable sheath is attached to the conditioning unit at point 3, the phase conductor at, say, point 1 and the neutral
30 conductor at point 5; the HF communication signals being applied via point 2 and point 3 (earth).

All HF signal components on both the phase conductor and those capacitively induced onto the neutral conductor will
35 be attenuated by the low pass filter sections created by

L2 C2, L3 C3, L5 + C5 and L6 + C6 respectively.

Therefore, at point 6 only the required 50/60Hz phase voltage, with respect to neutral at point 7, is presented at the customer's electricity meter point.

5

Referring to Fig. 9, a prior art unbalanced conditioning unit - as shown in WO 94/09572 - is indicated generally by the reference numeral 10 and is connected between a mains electricity input 12 and a mains electricity output 14. A
10 signal input/output line 16 is also connected into the filter. The mains power line is a standard 50Hz mains electricity power supply providing a domestic electricity power source of 240v at a maximum current of 100 amps for normal usage.

15

The filter 10 is assembled into a metal box which prevents radiation of the communication signals to externally located appliances and which provides a connection 18 to earth for the signal input/output line 16. The filter 10
20 includes a first or main inductor 20 formed e.g. of 16mm² wire wound on a 10mm diameter, 200mm long ferrite rod with 30 turns of wire therearound. This provides an inductance of approximately 50μH. This may be a minimum for the signal characteristics utilised. The use of better
25 materials or a plurality of series inductors would increase the inductance of the inductor up to, for example, approximately 200μH.

Each end of the main inductor 20 is provided with a
30 connection to the signal input/output line 16. A first connection 22 between the mains electricity input 12 and signal input/output line 16 comprises a first or coupling capacitor 24 having a capacitance of between 0.01 and 0.50μF, and preferably around 0.1μF. This coupling
35 capacitor 24 is connected to a first fuse 26 which is

arranged to blow in the event of failure or a fault developing in capacitor 24.

A second connection 28 includes a second capacitor 30
5 having a capacitance of between 0.001 and 0.50 μ F,
preferably around 0.1 μ F. This capacitor provides further
attenuation of the communication signals by shorting to
the earth or ground 18. A second fuse 32 is provided to
blow if a fault develops in the second capacitor 30,
10 thereby preventing further unit damage.

The signal input/output line 16 is connected to a second
inductor 34 having an inductance of approximately 250 μ H
minimum. This inductor is provided as a damage limiter in
15 the event of failure of the coupling capacitor 24. In the
event of such a failure this inductor provides a path to
the ground 18 for the 50Hz mains electricity power
frequency, thereby blowing fuse 26. The inductor has no
effect on the communication frequency signals present on
20 the signal input/output line 16.

It is to be noted that the neutral conductor is not
filtered, and therefore if this unit was to be used with a
phase/neutral system, then unwanted signals could still
25 pass through.

Figs. 11A, 11B and 11C show sectional views through a
single phase concentric, split-concentric and "pseudo"-
concentric cables respectively. A typical concentric
30 single phase cable (as illustrated in Fig. 11A) consists
of a central metallic conductor core (typically aluminium)
110 surrounded by an insulating layer 112 (typically PVC).
Around the insulating layer 112 are laid a plurality of
metallic conductors 114 (typically copper) over which lies
35 an insulating and protective sheath 116 (typically PVC).

In use the neutral and earth are combined in the outer sheath of metallic conductors 114.

A split-concentric cable (as illustrated in Fig. 11B) is similar to the concentric cable except that the outer layer of metallic conductors 114 is split into two portions - e.g. an upper portion 115 and a lower portion 117. These portions are divided by insulators 118, 120 and in use the neutral and earth are split so that one portion of the outer metallic sheath carries only one of them.

In order to maintain a pseudo-coaxial effect in the split-concentric service cables at the desired transmission frequencies (e.g. above 1MHz) one or more capacitors 122 may be connected between the upper and lower portions 115, 117 of the outer metallic sheath 114. These capacitor(s) may be fitted e.g. at the termination and/or conditioning points of the cable.

20

Fig. 12 shows the HF conditioning concept according to the present invention applied to a section of, say, OH balanced EDN.

The conditioning unit shown comprises of a LP and a HP filter section (LPF and HPF respectively) connected so as to permit directional coupling of the HF communications signals to the conditioned network section 1201, i.e. the section of EDN between the two conditioning units.

30

F_1 and F_2 are typically protective line fuses providing interconnection to the HP filter unit which is in turn coupled to an isolation transformer 1202 consisting of, say, a ferrite core material so as to give good high frequency coupling, primary to secondary windings, between

35

say 1 and 30 MHz.

The transformer is in turn connected to a radio transmitter/receiver unit 1203 which transmits and
5 receives signals at HF modulating and demodulating the HF carrier signals as appropriate via a modem unit 1204 which inputs and outputs speech/data and/or image signals as appropriate. The speech signals may by-pass the modem and be interconnected directly to the TX/RX unit in an
10 analogue form if required. If the signals input to the modem are presented in a common digital format then they may be easily multiplexed or combined for transmission over the network. The transceivers may operate in simplex, duplex or half duplex as required.

15 With a conditioned section of balanced EDN as shown, the HF communications highway thus formed is immune to the effects of variable 50/60Hz loading i.e. HF noise components generated by certain types of 50/60 Hz
20 electrical loads. Directional coupling of HF communications signals above 1 MHz onto any section of balanced OH or UG EDN is thereby permitted.

It should be noted that by utilising high frequencies
25 above 1 MHz the HP and LP filter section components, which form the conditioning units, become sufficiently small, in physical size, to be mounted on e.g. the EDN OH wooden poles or steel pylons without major modification to existing EDN hardware. Similarly on UG EDNs the
30 conditioning unit components may be incorporated in cable joint housings, roadside pillars, street lighting columns and the like.

Fig. 13 illustrates the potential location points for the
35 various OH EDN HF conditioning components 1301 as applied

to a wooden support pole 1302.

The overhead conductors 1303, 1304 are connected to the head of the wooden pole 1302. A line trap or inductor 1305 may be included in the line of each of the conductors 1303, 1304, and a decoupling capacitor 1306 may connect each conductor to local earth 1307. A tap wire 1308 is taken from one or both of the conductors 1303, 1304 to the RF coupling unit 1301 which is mounted on the pole 1302. A coax feed 1309 then connects the RF coupling unit 1301 to TX/RX equipment 1310.

Fig. 14 illustrates a bi-directional, balanced, OH, EDN conditioning unit such as may be pole mounted as in Fig. 13. J_1 and J_2 connect onto two phase conductors of a polyphase OH EDN. Protection is afforded by fuse links F_1 and F_2 and HF coupling is provided by capacitors C_1 and C_2 .

HF electromagnetic coupling is then provided by T_1 which has typically a dust iron or ferrite core. The core has the appropriate turns ratio, primary to secondary, to provide the required impedance match between the EDN OH balanced phase conductors and the unbalanced coaxial cable 1401 which will interconnect via the safety box 1402 to the HG transmitter receiver unit(s).

The windings of T_1 may be bifilar or trifilar in order to provide the balanced to unbalanced termination requirements. The primary and secondary windings are bonded to earth to provide protection paths for F_1 and F_2 . Optional fuse links F_3 and F_4 may be included in the safety box.

Typical component values for a 25kV OH EDN bi-directional conditioning unit might be:-

$J_1 = J_2 =$ link wire

$F_1 = F_2 =$ GEC HRC fuse links type VTF 15/3

$C_1 = C_2 =$ HVC type TLC150AC - 102, $0.001/\mu F \pm 20\%$, 15kV RMS
@ 50/60Hz, 50kVdc between terminals.

5

$T_1 =$ 17 turns, with centre tap, primary : 5 turns
secondary, core type Hawnt Electronics 3C11.

RFC1 = RFC2 = 50 μH wound on ferrite core to sink

10 potential 50/60 Hz fault current and rupture HRC fuse
link(s) F3 and/or F4.

Fig. 15 shows a section of overhead (OH) polyphase (3
phase and earth) electricity distribution network (EDN)

15 1501. By suitable interfacing, a high frequency
communications signal above 1 MHz may be impressed on the
network e.g. between black and blue phase conductors.

In order to propagate HF signals efficiently between such
20 a section of OH EDN and a phase to neutral section of UG
network, a suitable HF coupling arrangement becomes
necessary to overcome the problems of impedance matching
and balanced to unbalanced network termination.

25 In order to provide HF coupling to the OH network,
interconnection via a high frequency ferrite transformer
element T1 is made via protective fuses F1, F2 and HF
coupling capacitors C1 and C2. HF transformer T1 is
typically designed to match from a 600 ohm impedance
30 balanced line to a 50 ohm impedance unbalanced UG cable
with coupling via HF coupling capacitor C3 and protective
fuse F3.

In order to prevent the unbalanced underground pseudo
35 coaxial conductor (UGC) from loading the balanced OH

network, a T filter comprising of L_1 , L_2 and C_7 is utilised where L_1 is typically $16.5 \mu\text{H}$, C_7 is typically $0.01 \mu\text{Fd}$ and L_2 is typically $50 \mu\text{H}$. These modifications provide HF conditioning of the EDN and permit the network to
5 efficiently and safely distribute both electrical energy at ultra low frequency, i.e. 50 to 60 Hz, and communications signals above 1 MHz.

Note that transformer T_1 has a centre tapped primary which
10 provides a ULF path for fuses F_1 and/or F_2 should capacitor C_1 and/or capacitor C_2 become short circuit.

The UG cable feeds a number of single phase ground mounted transformers each of which has an HF by-pass conditioning
15 unit fitted. The HF signals impressed on T_3 primary are coupled via safety fuse F_4 and capacitor C_6 onto the primary winding of HF transformer T_2 which has a ferrite core and is connected in series with earth (0v).

20 Thus the unbalanced HF signal present on the UG feeder and across T_3 primary is also impressed on T_2 primary. It should be noted that the primary impedance of power transformer T_3 is relatively high at HF. The turns ratio and windings of T_2 are such that the secondary winding
25 presents a balanced impedance transformer HF coupling via C_4 , C_5 and safety fuses F_5 and F_6 to the balanced centre tapped secondary of T_3 and onto the secondary mains cables off T_3 secondary to the customer premises together with the ULF high amplitude power components. It should be
30 noted that the secondary windings of T_3 represent a relatively ^{LOW}~~high~~ impedance at power frequencies, i.e. 50 to 60 Hz.

The invention is not confined to the foregoing details and
35 variations may be made thereto within the scope of the

invention.

THIS SHEET HAS BEEN
REPLACED

32



CLAIMS:

1. A balanced electricity distribution and/or power
5 transmission network, the network including input means
for the input onto the network of a telecommunications
signal having a carrier frequency greater than
approximately 1MHz from an unbalanced source and output
means for removing said telecommunications signal from the
10 network, wherein said input means and said output means
provide impedance matching between said network and said
source.
2. A network according to claim 1 wherein said input
15 means includes means for connecting to a source which is a
relatively low impedance unbalanced HF coaxial source.
3. A network according to claim 1 or claim 2 wherein
said network is an overhead network.
- 20 4. A network according to any one of the above claims
wherein at least part of the network is external to any
building and the signal is transmissible along said
external part.
- 25 5. A network according to any one of the above claims
wherein the network includes connection means located at
an interconnection point between the network and an
interconnecting unbalanced network, said connection means
30 providing an impedance matched HF connection between the
two networks to permit efficient propagation of HF
communication signals therebetween.
6. A network according to claim 5 wherein said
35 interconnecting unbalanced network is an underground power

This Sheet Has Been Replaced





network.

7. A network according to any one of the above claims including two sections of network separated by a power transformer, further including HF by-pass means for transmitting said signal from one of said network sections to the other, by-passing said transformer.
8. A network according to any one of the above claims wherein the carrier frequency is between approximately 1-60MHz.
9. A method of signal transmission including input of a telecommunications signal having a carrier frequency of greater than approximately 1MHz from an unbalanced source onto a balanced electricity power distribution and/or transmission network and subsequent reception of the signal, wherein said source and said network are coupled by coupling means which provide impedance matching therebetween.
10. Communications apparatus for use with a balanced electricity distribution and/or power transmission network, including a balanced low pass filter portion for allowing, in use, a low frequency high amplitude mains electricity power signal to pass through the apparatus, and a balanced high pass filter portion for coupling HF signals having a carrier frequency of greater than 1MHz onto the network.
11. Communications apparatus according to claim 10 including impedance matching means for impedance matching between reception/transmission devices and the electricity power distribution and/or transmission network.



12. Communications apparatus according to claim 10 or
claim 11 including means for connecting the apparatus to
both a balanced and an unbalanced electricity distribution
and/or transmission network, and allowing said low
5 frequency high amplitude mains electricity signal to pass
therebetween.
13. Communications apparatus according to any one of
claims 9-12 including means for connecting a balanced and
10 an unbalanced HF signal to the network.
14. Communications apparatus according to any one of
claims 10 to 13 connected to an electricity power
distribution and/or transmission network.
- 15 15. Communications apparatus according to claim 14
wherein said network is a network according to any one of
claims 1 to 8.
- 20 16. Use of a communications apparatus with a balanced
electricity distribution and/or power transmission
network, the apparatus including a balanced low pass
filter portion for allowing, in use, a low frequency high
amplitude mains electricity power signal to pass through
25 the apparatus and a balanced high pass filter portion for
coupling HF signals having a carrier frequency of greater
than 1MHz onto the network.
17. Use of telecommunications apparatus for transmission
30 or reception of a telecommunication signal having a
carrier frequency greater than approximately 1MHz on a
network according to any one of claims 1 to 8.
18. An electricity distribution and/or power transmission
35 network substantially as herein described with reference



* C L M S *

This Sheet Has Been Replaced

to figs. 1-8 and 10-15 of the accompanying drawings.

19. Communications apparatus substantially as herein described with reference to figs. 1-8 and 10-15 of the
5 accompanying drawings.

20. A method of signal transmission substantially as herein described with reference to figs. 1-8 and 10-15 of the accompanying drawings.



This Sheet Has Been Replaced

A barcode with vertical bars of varying widths, located below the text "This Sheet Has Been Replaced".