Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2688059 A1 2010/06/18

(21) 2 688 059

(12) DEMANDE DE BREVET CANADIEN CANADIAN PATENT APPLICATION

(13) A1

(22) **Date de dépôt/Filing Date:** 2009/12/03

(41) **Mise à la disp. pub./Open to Public Insp.:** 2010/06/18

(30) **Priorités/Priorities:** 2008/12/18 (US61/138,694);
2009/06/05 (US12/478,908)

(51) **Cl.Int./Int.Cl.** *H04M 3/30* (2006.01)

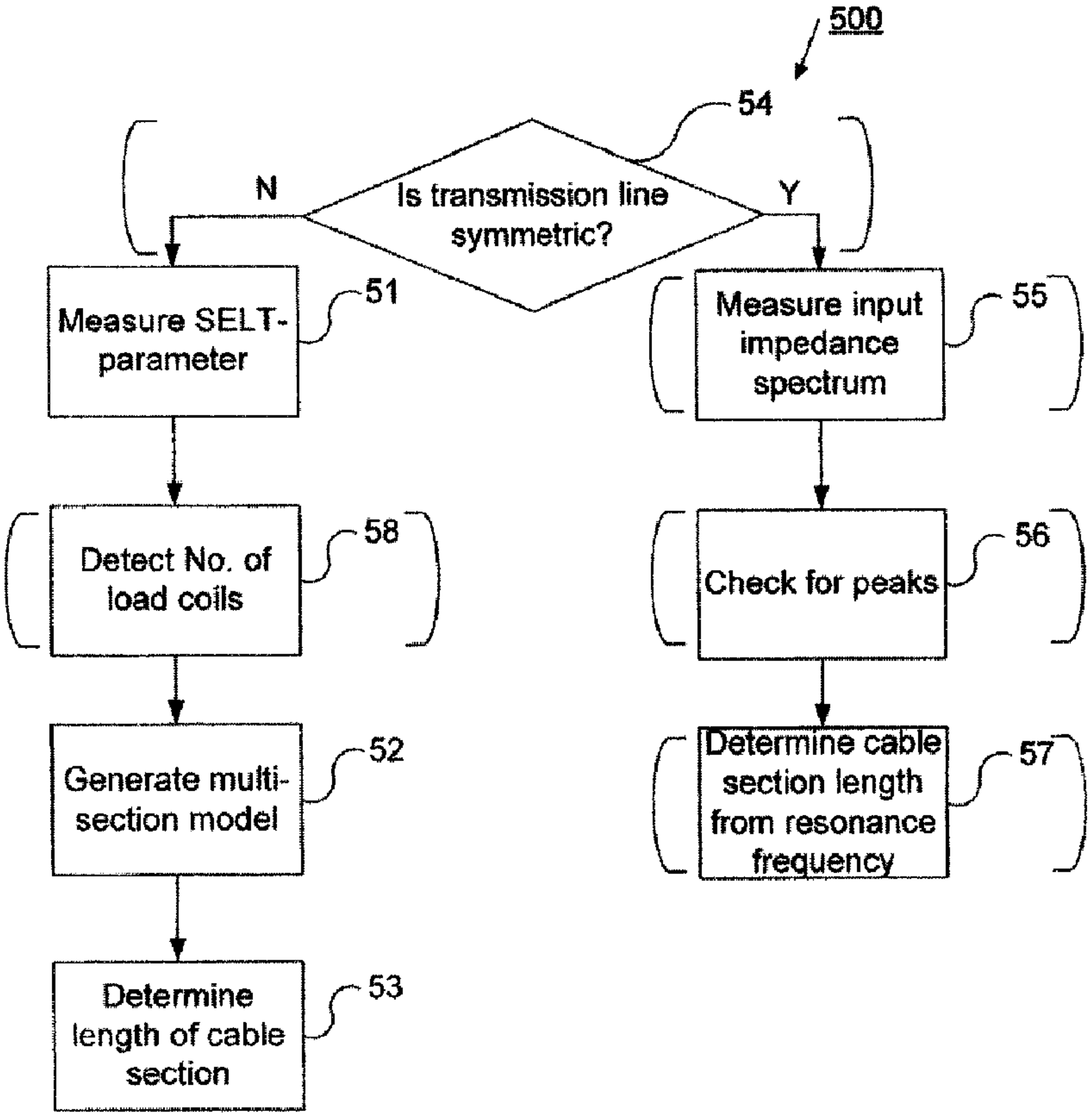
(71) **Demandeur/Applicant:**
TELEFONAKTIEBOLAGET L M ERICSSON (PUBL), SE

(72) **Inventeurs/Inventors:**
LINDQVIST, FREDRIK, SE;
FERTNER, ANTONI, SE

(74) **Agent:** NICOLAESCU, SAWYER

(54) Titre : METHODE ET LOCALISATEUR DE DETECTION ET DE LOCALISATION DE BOBINES DE CHARGE DANS UNE LIGNE DE TRANSMISSION

(54) Title: METHOD AND LOCALIZATION UNIT FOR DETECTING AND LOCATING LOAD COILS IN A TRANSMISSION LINE



(57) Abrégé/Abstract:

The present invention relates to a method and unit for load coil localization within a transmission line. The load coil localization is achieved using a model of the transmission line. The model is based on a parameter vector θ including parameters describing the

(57) Abrégé(suite)/Abstract(continued):

transmission properties of each load coil and cable section, and the length of a plurality of individual cable sections as unknown independent parameters. Using this model an approximation of a SELT (Single-ended line testing) parameter can be obtained. The location of at least one load coil is determined by substantially minimizing a criterion function that represents a deviation between a measurement of a SELT parameter and an approximation of the SELT parameter obtained from the model. The load coil localization method and unit can be used for both symmetric and non-symmetric transmission lines.

ABSTRACT

The present invention relates to a method and unit for load coil localization within a transmission line. The load coil localization is achieved using a model of the transmission line. The model is based on a parameter vector θ including parameters describing the transmission properties of each load coil and cable section, and the length of a plurality of individual cable sections as unknown independent parameters. Using this model an approximation of a SELT (Single-ended line testing) parameter can be obtained. The location of at least one load coil is determined by substantially minimizing a criterion function that represents a deviation between a measurement of a SELT parameter and an approximation of the SELT parameter obtained from the model. The load coil localization method and unit can be used for both symmetric and non-symmetric transmission lines.

P27996CA1

METHOD AND LOCALIZATION UNIT FOR DETECTING AND LOCATING LOAD COILS IN A TRANSMISSION LINE

CLAIMING BENEFIT OF PRIOR FILED PROVISIONAL APPLICATION

This application claims the benefit of U.S. Provisional Application Serial No. 61/138,694 filed on December 12, 2008 and entitled "Method for Detecting and Locating Load Coils" the contents of which are incorporated by reference herein.

TECHNICAL FIELD

The present invention relates in general to the field of transmission line analysis and more particularly to a method and device for locating one or several load coils within a transmission line.

BACKGROUND

Many copper-access network operators still have a considerable amount of customers subscribing only on telephony, i.e. the plain old telephone service (POTS). Consequently, there is a great interest in estimating the suitability of the twisted-pair copper lines for broadband services, provided by state-of-the-art digital subscriber line (DSL) technologies as ADSL2+and VDSL2. Common impairments that hinder or reduce the full potential of broadband access over these lines are e.g. crosstalk ingress due to line impedance unbalance, bridged-taps, and load coils. The far most severe impairment of these is the load coils, which are found on numerous lines in some countries.

The load coil is an inductive device that works like an impedance matching transformer. Telecom operators used to install load coils in order to provide telephony to customers located far from the Central Office (CO). However, at the same time as the load coil reduces the line attenuation at the voice frequencies, it drastically increases the attenuation at higher frequencies. Thus, the load coils must be removed before the line can be deployed for broadband services using the higher frequencies.

The operator has few options to pre-qualify the lines before investing in, and installing, broadband equipment. Essentially the options involve sending a technician into the field to conduct (expensive) manual testing, or to estimate the transmission line capacity from e.g. a database. However, since the original lines were installed decades ago, with various kinds of modifications made through out the years, databases of the access lines are often non-existing or inaccurate. Hence, a more attractive option for the operator is to employ automated one-port measurements from the CO, referred to as single-ended line testing (SELT).

The existing POTS transceivers have been designed to monitor and diagnose the narrow voice-band (0-4kHz) by measuring elementary parameters such as DC/AC voltage, the resistance/capacitance at frequency zero between the wires of the line and between each wire and ground. These types of traditional measurements normally require metallic access to the line, which is commonly provided by expensive bypass-relays. Even so, far from all POTS transceivers are able to detect and locate load coils. Moreover, conventional DSL modems, with a built-in SELT function, are not designed to detect the load coils since the access to the lower voice frequencies is normally blocked by the splitter filter, required by the co-existence of POTS and DSL transmission. Pre-qualification with DSL modems typically fails to distinguish the load coil from a cable-break or the far-end line termination. Consequently, there is a substantial benefit in performing these measurements via the already installed (narrow band) transceivers carrying POTS, i.e. via the telephone line cards.

There are several prior art methods oriented towards the detection of load coils while the localization has got less attention. The U.S. patent No. 4,620,068, the U.S. patent No.5,404,388 and the U.S. patent No. 6,668,041 all describe methods that determines whether a line is equipped with load coil(s) or not, i.e., loaded or not, by detecting characteristics in the magnitude or the phase of the measured line. However, localization of the load coil(s) is not addressed.

In a co-assigned PCT patent application WO 2007/072191 filed on December 20, 2006 and entitled "Load Coil Detection and Localization" both load coil detection and localization are considered. The contents of this application are incorporated by reference herein. However, in cases where the transmission line is not symmetric the methods and devices disclosed in this application may fail to provide an accurate enough load coil localization.

In the article entitled "Automated Loaded Transmission-Line Testing Using Pattern Recognition Techniques" by William T. Bisignani, published in IEEE Transaction On Instrumentation And Measurement, IM-24, No.1, 1975 automated testing of loaded lines is proposed. The method addresses load coil detection and localization by comparing the line under test with a pre-defined set of classes that represent possible line configurations. A decision space consisting of 20 regions (clusters) are utilized, each corresponding to one class. The number of pre-defined classes is kept low by assuming small deviation from the original load coil deployment rules. However, this assumption is not always valid due to changes of the access network by e.g. reconfigurations, displacement of the CO:s and introduction of transceiver-cabinets closer to the customer. Thus the topology of the loaded transmission line may be more irregular than what the original load coil deployment rules dictate, which would require a vast number of line-classes to accurately predict the location of the load coils.

A problem with prior art methods for load coil localization is therefore that they may be impractical or fail to provide accurate enough results in case of non-symmetric loaded transmission lines. A reliable and practical method for load coil localization is desirable to an operator since the operator may be interested in removing the load coil(s) so that the transmission line can support a DSL service. Without a reliable and practical load coil localization method the removal of load coils may be a cumbersome and expensive operation.

SUMMARY

An object of the present invention is to provide alternative methods and arrangements for load coil localization that allow for localization of load coils even if the transmission line is non-symmetric.

A first embodiment of the present invention provides a method for localization of load coils within a multi-section transmission line between two endpoints. A section of the transmission line is either a load coil or a cable section of a specific cable type. The method comprises performing a measurement of a SELT (Single-ended line testing) parameter at one of the two endpoints. This measurement provides a measurement of the characteristics of the transmission line at a number of frequencies. The method also comprises generating a model of the multi-section transmission line by means of which an approximation of the measured SELT parameter can be obtained. The model is based on a parameter vector θ including parameters describing the transmission properties of each section, and the length of a plurality of individual cable sections as unknown independent parameters. The method further comprises determining the length of one or several cable sections to thereby localize one or several load coils within the multi-section transmission line. This length determination is performed by substantially minimizing a criterion function that represents a deviation between the measurement of the SELT parameter and an approximation of the SELT parameter obtained from the model.

A second embodiment of the present invention provides a load coil localization unit for localization of load coils within a multi-section transmission line between two endpoints. A section of the transmission line is either a load coil or a cable section of a specific cable type. The load coil localization unit comprises an input unit. The input unit is adapted to receive a measurement of a SELT (Single-ended line testing) parameter at one of the two endpoints. This measurement provides a measurement of the characteristics of the transmission line at a number of frequencies. The load coil localization unit also comprises a model generator. The model generator is adapted to generate a model of the multi-section transmission line by means of which an approximation of the measured SELT parameter can be obtained. The model is based on a parameter vector θ including parameters describing the transmission properties of each section, and the length of a plurality of individual cable sections as unknown independent parameters. The load coil localization unit further comprises a processing unit. The processing unit is adapted to determine the length of one or several cable sections to thereby localize one or several load coils within the multi-section transmission line. The processing unit performs this length determination by substantially minimizing a criterion function that represents a deviation between the measurement of the SELT parameter and an approximation of the SELT parameter obtained from the model.

An advantage of embodiments of the present invention is that it can be implemented in existing telecommunications equipment without changing the hardware. It is for instance possible to implement the present invention in existing POTS and/or DSL transceivers without changing their hardware. An alternative is to implement the invention in a network management system that receives measurements on the transmission line from already existing transceivers. Thus implementation of the present invention may be achieved by a simple update of existing POTS and/or DSL networks.

Another advantage of embodiments of the present invention is that it does not rely on an assumption of line symmetry for accurate performance. Thus the present invention allows for accurate localization of load coils in case of non-symmetric transmission lines as well as symmetric transmission lines. Many transmission lines that previously were symmetric are now non-symmetric due to reconfigurations involving e.g. move of a Central Office or removal of a load coil. Furthermore the present invention is not restricted to a set of pre-determined and calibrated reference lines as on some prior art methods. Hence embodiments of the present invention are suited and robust for load coil localization of the transmission lines found in the copper access networks of today and provide an attractive alternative to manual in-field testing.

Further advantages and features of embodiments of the present invention will become apparent when reading the following detailed description in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic block diagram illustrating telecommunications network provided with a load coil localization unit in accordance with an example embodiment of the present invention.

Fig. 2 is a schematic block diagram illustrating a symmetric loaded transmission line.

Fig. 3 is a schematic block diagram illustrating a non-symmetric loaded transmission line.

Fig. 4 is a schematic block diagram illustrating an approximation of a symmetric loaded transmission line.

Fig. 5 is a flowchart illustrating an embodiment of a method according to the present invention.

Fig. 6 is a graph which is used to illustrate a comparison of input impedance peaks of symmetric transmission lines and non-symmetric transmission lines.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which preferred embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. In the drawings, like reference signs refer to like elements.

Referring to Fig. 1, there is shown a simplified block diagram of a telecommunications network 100 which is used to help explain a method 500 and a load coil localization unit 101 in accordance with example embodiments of the present invention. The telecommunications network 100 has a central office (CO) 102 at which there is terminated one end of a series of transmission lines 104. And, the other end of the transmission lines 104 terminate at customer premises sites 106 (one shown). Inside, the central office 102 there is a series of line cards 108 each of which is connected to one end of the transmission lines 104. The CO 102 also has a workstation 110 (copper plant manager 110) which interfaces with the line cards 108 so it can conduct a single-ended line testing (SELT) measurement in accordance with the method 500. Single-ended line testing is performed by sending a measurement signal $MS_{in}(t)$ on to the transmission line 104 and receiving a return signal $MS_{out}(t)$ from which it is possible to determine measurements of a number of different SELT-parameters representing the characteristics of the transmission line 104. The transmission lines 104 may be equipped with a number of load coils 114. The workstation 110 includes the load coil localization unit 101, which will be explained in greater detail below and which may be used to determine the location of one or several load coils 114 within a particular transmission line 104. The ability to locate the load coil(s) 114 is important because if there is a load coil 114 located within the transmission line 104 then that would disqualify the transmission line 104 from supporting a DSL service unless the load coil is removed. So, if an operator of the network 100 is able to find the load coil 114 then that load coil can be removed from the transmission line 104 so that it is able to support a DSL service. A detailed discussion about how the load coil 114 can be localized in accordance with example embodiments is provided following a brief discussion about why load coil(s) 114 were installed on the transmission line 104 in the first place.

Historically, the load coils 114 were installed on the transmission lines 104 to reduce attenuation in the POTS band (but at the cost of increased attenuation at higher frequencies which are now used by the DSL services). And, the common practice was that transmission lines 104 longer than 18 kft (5.5 km) were equipped with load coils 114, whereupon the transmission lines were called loaded lines. The load coils 114 were typically placed on the transmission lines 104 at regular intervals of either 6 or 4.5 kft (1.8 or 1.4 km). These intervals were denoted by letters H and D, respectively. The first load coil 114 appeared about half of this distance from the CO 102 and the last load coil was typically placed about 3 kft (1 km) from the customer premises (CP) sites 106. However, the distance from the last load coil 114 to the customer premises 106 may be in some cases up to 10 kft. The load coils 114 were typically 88 or 66 mH inductors, but some were 44 mH inductors. The typical identification schemes were H88 and D66. The subscribers (and bridged taps) were typically never placed between two loading coils 114. However, because of loop reconfigurations, installations on new COs 102 etc. there were left a number of shorter transmission lines 104 which had one or two load coils 114. And since, the records of the copper plant changes are often inaccurate and/or insufficient, nobody can be sure which transmission lines 104 still contain load coils 114 or where they are located. As a result, there can be numerous transmission lines 104, which could qualify to DSL service only if the load coils 114 could be localized and removed. Therefore, it is essential to localize these load coils 114.

Different methods for load coil localization can be used depending on whether the transmission line has a symmetric line topology or a non-symmetric line topology. Fig. 2 is a schematic illustration of a symmetric loaded transmission line. The distance d between two successive load coils 114 is equal and the distance from the CO, and from the customer premises site 106, to the nearest load coil is half the length between two successive load coils. Due to the symmetry, the transmission line 104 in Fig. 2 can be seen as a series of cascaded identical two-port cells where each cell consists of a load coil with two line-sections of length d/2 connected at each side.

For the POTS band frequencies the input impedance of the symmetric loaded line in Fig. 2 containing N load coils can be approximated by a continued fraction expansion (CFE). Subsequently, the symmetric loaded line can be viewed as a series of repeated cells of impedances, as illustrated in Fig. 4. In Fig. 4, Z_h denotes the first and last shunt impedance of each cell-circuit. The shunt impedance corresponds to the first and last line section of length d/2. Using the approximation of the symmetric loaded transmission line of Fig. 4 a method for detecting and locating load coils 114 within the transmission line can be derived as explained in the above mentioned co-assigned PCT patent application WO 2007/072191.

However, if the loaded transmission line 104 is non-symmetric, the method based on the approximation of Fig. 4 may not be able to provide an accurate enough load coil localization. Fig. 3 is a schematic illustration of a non-symmetric loaded transmission line 104. For simplicity, three load coils 114 are illustrated in Fig. 3, but it is to be understood that the transmission line 104 can contain any number of load coils. In Fig. 3 the distance between two successive load coils 114 may not be equal and the distance from the CO, and from the customer premises site 106, to the nearest load coil may differ and may be independent of the distance between two successive load coils. Even though most transmission lines were symmetric or close to symmetric at some point in time, it is today common that transmission lines have become non-symmetric due to reconfigurations made since the installation of the transmission line. It is for instance common that the CO 102 has been moved closer to the customer premises site 106. It is also possible that some but not all load coils within the transmission line has been removed which will have resulted in irregular intervals between successive load coils. Furthermore, the lack of symmetry of the transmission line may appear not only in terms various lengths of individual sections between the CO and the customer premises site 106. It is also likely that the transmission line includes different types of cable with different transmission characteristics, which also results in non-symmetry. There is therefore a need for a load coil localization method that is able to provide accurate results for non-symmetric transmission lines. Such a method is provided according to an example embodiment as will be explained in further detail below.

The load coil localization method according to an example embodiment uses model-based optimization. The non-symmetric transmission line 104 of Fig. 3 can be viewed as a multi-section transmission line comprising a number of load coils 114 and a number of cable sections 105 of lengths represented by independent length parameters $d_1, d_2, ...d_n$, where n is the number of cable sections of the transmission line. A cable section 105 is a continuous piece of cable of a specific cable type. Thus, if two successive load coils are connected by means of several interconnected pieces of cable of different cable types, then there will be several cable sections 105 between the two successive load coils. Bridged-taps are normally not found in loaded lines, and are therefore not considered herein, but can be handled in an analogous way. The load coil localization method according to the example embodiment comprises generating a model of the multi-section transmission line by means of which an approximation of a SELT parameter can be obtained. The model is based on a parameter vector θ including parameters describing the transmission properties of each section, i.e. of each load coil and each cable section. Furthermore, the lengths of a plurality of individual cable sections $d_1, d_2, ...d_n$ are unknown independent parameters in the model. For the most accurate results it is preferable that the length of each individual cable section is an independent parameter in the model, but depending on e.g. a-priori knowledge about the transmission line it may be possible to use the same length parameter for a couple of cable sections. For instance if it is known that the distance between the CO, and between the customer premises site, and the nearest load coil is the same then the same length parameter may be used to represent those distances. The method also comprises performing a measurement of the same SELT parameter that the model approximates at one of the two endpoints of the transmission line (normally from the CO side) to obtain a measurement of the characteristics of the transmission line at a number of frequencies. Then a value for one or several of the length unknown parameters $d_1, d_2, ...d_n$ is/are determined by substantially minimizing a criterion function that represents a deviation between the measurement of the SELT parameter and the approximation of the SELT parameter obtained from the model. This method is more complex than the method disclosed in the above mentioned co-assigned PCT patent application WO 2007/072191 but is more general and able to provide accurate load coil localization for both non-symmetric and symmetric loaded transmission lines. There are however several ways of reducing the complexity of the method as will become apparent from the detailed description of an example of a preferred embodiment of the present invention.

According to this example embodiment the SELT parameter that is measured is a line input impedance $Z_{in}(f)$ of the transmission line (f denotes frequency) and the model will in this case be a model $Z_{model}(f,\theta)$ of the line input impedance. The model $Z_{model}(f,\theta)$ depends on a parameter vector θ, with parameters that represent transmission line properties such as the number of line sections, the lengths of cable sections and the cable types. The lengths of the cable sections are determined by minimizing a criterion function J(θ) that represents the deviation between the measured line input impedance $Z_{in}(f)$ and the model $Z_{model}(f,\theta)$. This criterion function can be expressed as

$$J(\theta) = \sum_{f=flow}^{fhigh} \left| Z_{in}(f) - Z_{\mathrm{mod}\,el}(f,\theta) \right|^{p} \qquad \text{EQ.1}$$

where fhigh is the highest frequency considered, flow is the lowest frequency considered and p is an integer greater than zero, i.e. p=1, 2, 3,... . For the special case where p=2 the criterion function J(θ) corresponds to the sum of least-squares, often referred to as the least-squares (LS) error. It will naturally be possible to obtain a more accurate result if many frequencies are considered. The parameter vector θ that minimizes the value of J(θ) is denoted

$$\theta_{LS} = \arg\min_{\theta} J(\theta) \qquad \text{EQ.2}$$

and the values for the cable section length parameters d_1, d_2, ...d_n of θ_{LS} are chosen as estimates for the cable section lengths. Estimating the lengths of the cable sections 105 means also that the locations of the load coils114 are estimated.

For the model $Z_{model}(f,\theta)$ the two-port theory is used. The multi-section transmission line 104 is represented by cascaded two-port networks. A section, i.e. a load coil 114 or a cable section 105 is modelled by a frequency-dependent chain matrix (also referred to as ABCD-matrix or transmission matrix). A section s is represented by a chain matrix

$$M^s = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \qquad \text{EQ.3}$$

For a cable section this matrix is modeled by a matrix

$$M^{cable} = \begin{bmatrix} \cosh(\gamma d_s) & Z_0 \sinh(\gamma d_s) \\ \dfrac{\sinh(\gamma d_s)}{Z_0} & \cosh(\gamma d_s) \end{bmatrix}, \qquad \text{EQ.4}$$

while a load coil is modeled by a matrix

$$M^{loadcoil} = \begin{bmatrix} 1 & j2\pi f L_C \\ 0 & 1 \end{bmatrix}. \qquad \text{EQ.5}$$

In equation EQ. 4 d_s denotes the length of the section s, γ is propagation constant, and Z_0 is characteristic impedance. In equation EQ.5 L_C is load coil inductance and $2\pi f$ is angular frequency in unit rad/s. Note that the frequency dependence of γ and Z_0 is omitted for simplicity. The complexity of the minimization problem may be reduced by inserting numerical values for γ and Z_0 using e.g. a cable database as will be discussed further below.

The total transmission matrix M for the multi-section transmission line 104 is given by

$$M = M^1 \times M^2 \ldots \times M^{ns}, \qquad \text{EQ.6}$$

where ns is the number of sections of the multi-section transmission line and where a section s is represented by a transmission matrix M^s. The input impedance of the modelled transmission line, associated with the parameter vector θ, can be expressed as

$$Z_{\text{model}}(f,\theta) = \frac{A(f,\theta)Z_T(f) + B(f,\theta)}{C(f,\theta)Z_T(f) + D(f,\theta)} \qquad \text{EQ.7}$$

where A, B, C and D are the chain matrix elements of matrix M in equation EQ.6. These four elements depend, as explicitly stated, on the frequency f and on the parameter vector θ. In equation EQ.7 $Z_T(f)$ denotes far-end termination impedance of the multi-section transmission line. In many cases it can be assumed that the termination is an on-hook POTS phone with approximately infinite impedance, leading to a simplified model for the line input impedance derived from EQ.7, i.e.

$$Z_{\text{model}}(f,\theta)=\frac{A(f,\theta)}{C(f,\theta)} \qquad \text{EQ.8} \ .$$

Having defined a model for $Z_{in}(f)$ by equation EQ.8, we now return to the minimization in equation EQ.2.

Given a loaded transmission line with ns number of sections, it follows from equations EQ.3-EQ.6 that substitution of equation EQ.8 in equation EQ.1 leads to a non-linear LS minimization problem in equation EQ.2, since the model in equation EQ.8 is not linear in the unknown parameters of θ. This problem may e.g. be solved by means of stochastic optimization according to a method that is known to the person skilled in the art. However the minimization poses a challenge due to the multi-dimensional criterion function with multiple local optima. The success of the solution of this problem depends on several factors as e.g. choice of optimization algorithm, number of unknown parameters (dimension), boundary constraints, and amount of available a priori information. A number of strategies that may be used to lower the complexity of the problem according to different example embodiments will be explained below.

As mentioned above a load coil detection method and a load coil localization method particularly suitable for symmetric loaded transmission lines is disclosed in the herein incorporated by reference co-assigned PCT patent application WO 2007/072191. This load coil detection method is based on measuring the line input impedance of the transmission line and checking if there are peaks in the impedance function. A peak in the impedance function indicates presence of a load coil. Thus the number of present load coils is determined by counting the number of peaks. For a symmetric transmission line it is then possible to determine the location of the load coil(s), and thus the length of the cable sections, from the highest measured resonant frequency as explained in the above mentioned PCT patent application (this load coil localization method is hereinafter referred to as a load coil localization method for symmetric lines). However, there will be a frequency-shift of the resonant peak(s) of the impedance function for a non-symmetric transmission line relative to a symmetric transmission line which means that the load coil localization method for symmetric lines decreases in accuracy if the transmission line is non-symmetric. The frequency-shift of resonant peaks is illustrated in Fig. 6, which is a plot showing input impedances Z_{in} of non-symmetric loaded transmission lines (see lines 3 and 4, where S-L denotes that a load coil is preceded by a short cable section and followed by a long cable section, while L-S denotes the opposite relationship of cable section lengths) compared to the input impedances for Z_{in} of symmetric loaded transmission lines (see lines 1 and 2). The peaks of Z_{in} are shifted towards lower frequencies when the cable length of a section increases or some additional cable is connected to the transmission line 104. But a symmetric and a non-symmetric loaded transmission cable with the same number of load coils present will have the same number of peaks in the impedance function even if these peaks are located at different frequencies. Therefore the load coil detection method, in which it is determined that the number of load coils present is equal to the number of peaks in the impedance function, can be used to lower the complexity of the minimization problem above according to an embodiment of the present invention.

By first detecting the number of load coils using e.g. the load coil detection method discussed above (or another load coil detection method according to prior art) the structure of the line topology of the multi-section transmission line 104 is known prior to the minimization in equation EQ.2. It thus remains to estimate the lengths of the cable sections 105 and the parameters that are related to the transmission characteristics of the cable sections that depend on cable type. However, the number of unknown parameters may be further reduced to one integer-value per cable type and one length-parameter per cable section if estimates or known values from a cable data base are used. The cable database may list numeric estimates or known values that represent the transmission properties of different cable types. It is also possible to use a cable database that specify cable models with inherent electromagnetic and geometric parameters that characterize cable insulation material, resistivity, wire diameter etc. of different cable types but then the complexity will be higher than the case when each cable type is represented by a single numeric value. If it is known a priori that there is a single cable-type line (i.e. only one type of cable) between two successive load coils and the inductance of the load coils is known to be e.g. 88mH or 66mH then there are $2(N+1)$ parameters in the parameter vector θ to be optimized for N number of load coils.

In the above described example embodiment the SELT parameter that was measured and modelled was the input impedance $Z_{in}(f)$. However it is also possible to measure and model another type of SELT-parameter according to alternative embodiments. An example of another type of SELT-parameter that may be used is a one-port scattering parameter, referred to as S_{11}. Load coil localization could then be achieved by substantially minimizing the deviation between a measurement of S_{11} and an approximation of S_{11} obtained from a model.

A flow diagram of an example embodiment of the load coil localization method 500 according to the present invention is illustrated in Fig. 5. The method 500 comprises a step 51 in which a chosen SELT-parameter is measured. In a step 52 a model of the multi-section transmission line 104 is generated. The model is generated such that an approximation of the SELT-parameter that was measured in step 51 can be obtained from the model. Furthermore the model is based on the parameter vector θ including parameters that described the transmission properties of each section. The lengths of a plurality of individual cable sections are also unknown independent parameters in the model. The length of one or several cable sections are then determined in a step 53, which also means that one or several load coils are localized. This determination of cable section length(s) is performed by substantially minimizing a criterion function that represents a deviation between the measurement of the SELT-parameter and the approximation of the SELT-parameter obtained from the model generated in step 52.

As explained above, it is optional in the method 500 to substitute at least some of the parameters in the vector θ with known values or a limited number of possible numeric estimates in order to simplify the determination of cable section lengths in step 53 by reducing the number of unknown parameters.

Although it is shown in Fig. 5 that step 51 is performed prior to step 52, it is possible to change the order of these two steps.

As mentioned above, an optional step 58 in which the number of load coils within the transmission line is detected may also be performed prior to generating the model of the multi-section transmission line 104. There are a number of different load coil detection methods according to prior art. By first detecting the number of load coils using one of those methods it is possible to use this knowledge when generating the model in step 52. Thus the number of unknown parameters in the model may be reduced and the problem that needs to be solved in step 53 becomes simpler.

The method provided by steps 51-53 (and optional step 58) is general and can be used for load coil localization within both symmetric and non-symmetric transmission lines. However, since this method is more complex than the above mentioned load coil localization method for symmetric lines, it would be beneficial to use the more complex method for non-symmetric transmission lines and the less complex method for symmetric transmission lines. Therefore, as an option, the method 500 may include an initial step 54 in which it is determined if the multi-section transmission line is symmetric. If it is found in step 54 that the transmission line is symmetric, the load coil localization may be performed in accordance with the load coil localization method for symmetric lines. This implies that the input impedance spectrum of the transmission line would be measured, optional step 55 and that impedance function is examined to check for peaks, optional step 56. The length of a cable section can then be determined form the highest resonance frequency as disclosed in the PCT patent application WO 2007/072191, optional step 57. If it in step 54 is found that the transmission line is non-symmetric, the load coil localization may be performed according to steps 51-53 (and possibly also step 58) as explained above.

One way of determining if a transmission line is to be determined as symmetric or non-symmetric in step 54 is to compare an estimation of the total line length obtained by means of the load coil localization method for symmetric lines with an independent estimate of the total line length, which is not based on an assumption of line symmetry. In case the two estimates differ significantly, it is likely that the transmission line is non-symmetric and that the load coil localization method according to steps 51-54 should be used. The limits for when the two estimates are considered to differ significantly or are considered to be substantially equal is an implementation choice and depends on the desired accuracy in the load coil localization. It is for instance possible determine that the transmission line is symmetric if an absolute difference between the two estimates is below a predetermined threshold value ε. The threshold value ε may e.g. be chosen to be 100 meters, but other values are also possible depending on the desired accuracy of the load coil localization. Another example is that the transmission line is considered to be symmetric if the two estimates differ by less than e.g. 10% or 20%.

An estimate of the total line length $\hat{d}_{totSYM}$ is obtained from the load coil localization method for symmetric lines by multiplying the number of detected load coils $\hat{N}$ with the distance $\hat{d}$ between two neighbouring load coils as determined by the load coil localization method for symmetric lines, i.e.

$$\hat{d}_{totSYM} = \hat{N}\hat{d} \qquad \text{EQ.9}$$

An independent estimate $\hat{d}_{tot}$ of the total line length may be obtained if the measured line input impedance is approximated with a capacitance, i.e.

$$Z_{in}(f) \approx \frac{1}{j2\pi f C_{km} d_{tot}}. \qquad \text{EQ.10}$$

The approximation in equation EQ.10 is only valid for low frequencies. It thus follows from equation EQ.10 that the total line length can be estimated by

$$\hat{d}_{tot} = \frac{-1}{\Im\{Z_{in}(f_{low})2\pi f_{low}C_{km}\}}, \qquad \text{EQ.11}$$

where f_{low} is the lowest available measured frequency in Hz and $\Im\{.\}$ denotes the imaginary part. Thus it would be determined in step 54 that the transmission line under text is symmetric if $\hat{d}_{totSYM} \approx \hat{d}_{tot}$.

It can be noted that if step 54 is performed by determining if $\hat{d}_{totSYM} \approx \hat{d}_{tot}$ then this would imply that step 55-57 in Fig. 5 actually would have been performed prior to step 54 in order to determine $\hat{d}_{totSYM}$. Thus, if it is decided in step 54 that the transmission line is to be considered as symmetric then there is no need to repeat steps 55-57. Step 54 would then serve as a confirmation that the previously made cable section length determination is valid for load coil localization.

The cable section length determination that is performed in step 53 is made by means of substantially minimizing the criterion function that represents the deviation between the measured SELT parameter and the approximation of the SELT parameter obtained from the model as mentioned above. This could involve setting up an optimization criterion such as equation EQ.2 according to the above described embodiment and possibly also boundary constraints and substitution of possible parameter values depending on the amount of available a priori information regarding the transmission line under test. To provide a specific example of an embodiment, the minimization may be performed using stochastic optimization with Gaussian adaptation. A cable data base consisting of e.g. ETSI 0.4 mm, ETSI 0.5 mm and ETSI 0.63 mm, which defines the set of γ and Z_0 in equation EQ.8. Optional step 58 may be performed to determine the number of load coils in the model. Optimization constraints may be applied that define acceptable length intervals for the first and the last cable sections, as well as inter-load coil spacing, e.g. 0.3-3.0 km for the first cable section, 0.3-3.5 km for the last cable section and 1.5-3.8 km for intermediate cable sections.

Accordingly, there are many different techniques available for solving this optimization problem, both numeric and analytical depending on the dimension of the problem. The present invention is however not limited to any specific type of technique for solving this optimization problem. Furthermore, depending on the desired accuracy of the load coil localization it is not necessary to find exactly the optimal solution, i.e. the solution that minimizes the deviation between the measurement of the SELT-parameter and the approximation from the model. It may be considered sufficient to find a near optimal solution that e.g. determines the section lengths within a relative error of 10% or within 100 meters from the true length.

The method according to the present invention may be performed using a load coil localization unit 101. The load coil localization unit could for instance be integrated in a CO workstation 110 as shown in Fig. 1, but integration in other network equipment or implementation as a separate unit is also feasible. It is possible to implement the load coil localization unit using already existing hardware in telecommunications networks and to utilize already installed transceivers for one-port measurements. It is for instance possible to integrate the load coil localization unit in existing POTS and/or DSL transceivers without changing their hardware. An alternative is to integrate the load coil localization unit with a network management system that receives measurements on the transmission line from already existing transceivers. Thus, implementation of the load coil localization unit according to the present invention may involve provisioning of new software only, although implementations requiring new hardware, firmware or combinations thereof are also feasible as will be understood by the person skilled in the art from this description.

The example load coil localization unit 101 in Fig. 1 comprises an input unit 112 which is adapted to receive the measurement of the SELT parameter. A model generator 113 is adapted to generate the model by which the approximation of the measured SELT parameter can be obtained. The load coil localization unit 101 also includes a processing unit 200 that is adapted to perform the cable section length determination according to step 53. The load coil localization unit may optionally also include a load coil detector unit 201 adapted to perform load coil detection in accordance with step 58.

In the drawings and specification, there have been disclosed typical preferred embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims.

CLAIMS

1. A method for localization of load coils within a multi-section transmission line between two endpoints, wherein a section of the transmission line is defined as a load coil or a cable section of a specific cable type, said method comprising:

performing a measurement of a SELT (Single-ended line testing) parameter at one of the two endpoints, which provides a measurement of the characteristics of the transmission line at a number of frequencies,

generating a model of the multi-section transmission line by means of which an approximation of said measured SELT parameter can be obtained, which model is based on a parameter vector θ including parameters describing the transmission properties of each section, and the length of a plurality of individual cable sections as unknown independent parameters,

determining the length of at least one cable section to th\\\ereby localize at least one load coil within the multi-section transmission line by substantially minimizing a criterion function that represents a deviation between the measurement of the SELT parameter and an approximation of the SELT parameter obtained from the model.

2. The method according to claim 1, wherein said substantial minimization of the criterion function is derived with respect to a plurality of said number of frequencies.

3. The method according to claim 1, further comprising:

a step of detecting the number of load coils within the multi-section transmission line by means of a load coil detection method, and

a step of inserting the number of detected load coils in said model to reduce the number of unknown parameters in the model.

4. The method according to claim 3, wherein said load coil detection method includes

performing a measurement of the line input impedance spectrum of the multi-section transmission line at one of the two endpoints,

determining the number of amplitude peaks of the measured line input impedance spectrum, and

setting the number of detected load coils to equal the number of determined amplitude peaks.

5. The method according to claim 1, wherein a limited number of possible numeric estimates or known values of the parameter vector θ, or a subset of the parameter vector θ, is derived from a cable database, listing estimates or known values representing the transmission properties of specific cable types, to reduce the number of unknown parameters in the model.

6. The method according to claim 1, wherein said measured SELT parameter is a one-port scattering parameter S_{11}.

7. The method according to claim 1, wherein said measured SELT parameter is the line input impedance.

8. The method according to claim 7, wherein said model is based on the approximation that the far end termination impedance of the multi-section transmission line is a frequency dependent parameter $Z_T(f)$.

9. The method according to claim 7, wherein said model is a model of the line input impedance and is given by:

$$Z_{\text{model}}(f,\theta) = \frac{A(f,\theta)Z_T(f) + B(f,\theta)}{C(f,\theta)Z_T(f) + D(f,\theta)},$$

where θ is said parameter vector, f denotes frequency and A, B, C and D are chain matrix elements of a matrix $M = M^1 \times M^2 ... \times M^{ns} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$, where ns is the number of sections of the multi-section transmission line and where a section s is represented by a transmission matrix M^s.

10. The method according to claim 7, wherein said model is based on the approximation that the far end termination impedance of the multi-section transmission line is infinite.

11. The method according to claim 10, wherein said model is a model of the line input impedance and is given by:

$$Z_{\text{model}}(f,\theta) = \frac{A(f,\theta)}{C(f,\theta)},$$

where θ is said parameter vector, f denotes frequency and A and C are chain matrix elements of a matrix $M = M^1 \times M^2 ... \times M^{ns} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$, where ns is the number of sections of the multi-section transmission line and where a section s is represented by a transmission matrix M^s.

12. The method according to claim 1, wherein said method further comprises an initial step of determining if the multi-section transmission line is substantially symmetric, and wherein the length of at least one cable section is determined by means of a load coil localization method for symmetric lines if the multi-section transmission line is determined to be substantially symmetric, instead of performing said steps of generating the model and determining the length of the least one cable section using the model.

15. The load coil localization unit according to claim 14, wherein said substantial minimization of the criterion function is derived with respect to a plurality of said number of frequencies.

16. The load coil localization unit according to claim 14, further comprising a load coil detector unit adapted to detect the number of load coils within the multi-section transmission line by means of a load coil detection method, and wherein said model generator is adapted to insert the number of detected load coils in said model to reduce the number of unknown parameters in the model.

17. The load coil localization unit according to claim 16, wherein said load coil detection unit comprises

an input unit adapted to receive a measurement of the line input impedance spectrum of the multi-section transmission line at one of the two endpoints, and

a processing unit adapted to determine the number of amplitude peaks of the measured line input impedance spectrum, and to set the number of detected load coils to equal the number of determined amplitude peaks.

18. The load coil localization unit according to claim 14, wherein said model generator is adapted to use a limited number of possible numeric estimates or known values of the parameter vector θ, or a subset of the parameter vector θ, from a cable database, listing estimates or known values representing the transmission properties of specific cable types, to reduce the number of unknown parameters in the model.

19. The load coil localization unit according to claim 14, wherein said measured SELT parameter is a one-port scattering parameter S_{11}.

20. The load coil localization unit according to claim 14, wherein said measured SELT parameter is the line input impedance.

21. The load coil localization unit according to claim 20, wherein said model is based on the approximation that the far end termination impedance of the multi-section transmission line is a frequency dependent parameter $Z_T(f)$.

22. The load coil localization unit according to claim 21, wherein said model is a model of the line input impedance and is given by:

$$Z_{\text{model}}(f,\theta) = \frac{A(f,\theta)Z_T(f) + B(f,\theta)}{C(f,\theta)Z_T(f) + D(f,\theta)},$$

where θ is said parameter vector, f denotes frequency and A, B, C and D are chain matrix elements of a matrix $M = M^1 \times M^2 ... \times M^{ns} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$, where ns is the number of sections of the multi-section transmission line and where a section s is represented by a transmission matrix M^s.

23. The load coil localization unit according to claim 20, wherein said model is based on the approximation that the far end termination impedance of the multi-section transmission line is infinite.

24. The load coil localization unit according to claim 23, wherein said model is a model of the line input impedance and is given by:

$$Z_{\text{model}}(f,\theta) = \frac{A(f,\theta)}{C(f,\theta)},$$

where θ is said parameter vector, f denotes frequency and A and C are chain matrix elements of a matrix $M = M^1 \times M^2 ... \times M^{ns} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$, where ns is the number of sections of the multi-section transmission line and where a section s is represented by a transmission matrix M^s.

25. The load coil localization unit according to claim 14, wherein said processing unit is further adapted to determine if the multi-section transmission line is substantially symmetric, and to determine the length of at least one cable section by means of a load coil localization method for symmetric lines if the multi-section transmission line is determined to be substantially symmetric, instead of by means of said model generated by the model generator.

26. The load coil localization unit according to claim 25, wherein said processing unit is adapted to determine if the multi-section transmission line is substantially symmetric by:

computing a first estimate $\hat{d}_{totSYM}$ of the total line length of the multi-section transmission line by means of a load coil localization method for symmetric lines,

deriving a second estimate $\hat{d}_{tot}$, independent of the first estimate, of the total line length of the multi-section transmission cable,

comparing said first and second estimates, and

determining that the multi-section transmission line is substantially symmetric if an absolute difference between the first and second estimate is below a predetermined threshold value ε.

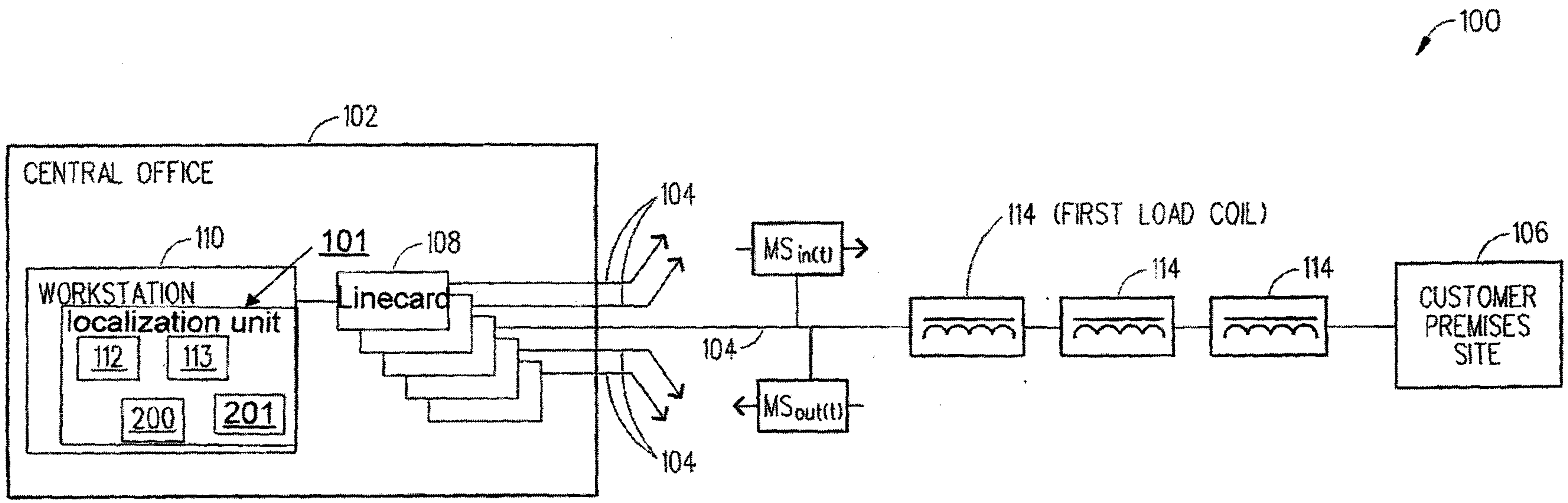

100
102
CENTRAL OFFICE
110
WORKSTATION
101
localization unit
112
113
200
201
108
Linecard
104
104
104
$MS_{in(t)}$
$MS_{out(t)}$
114 (FIRST LOAD COIL)
114
114
106
CUSTOMER PREMISES SITE

Fig. 1

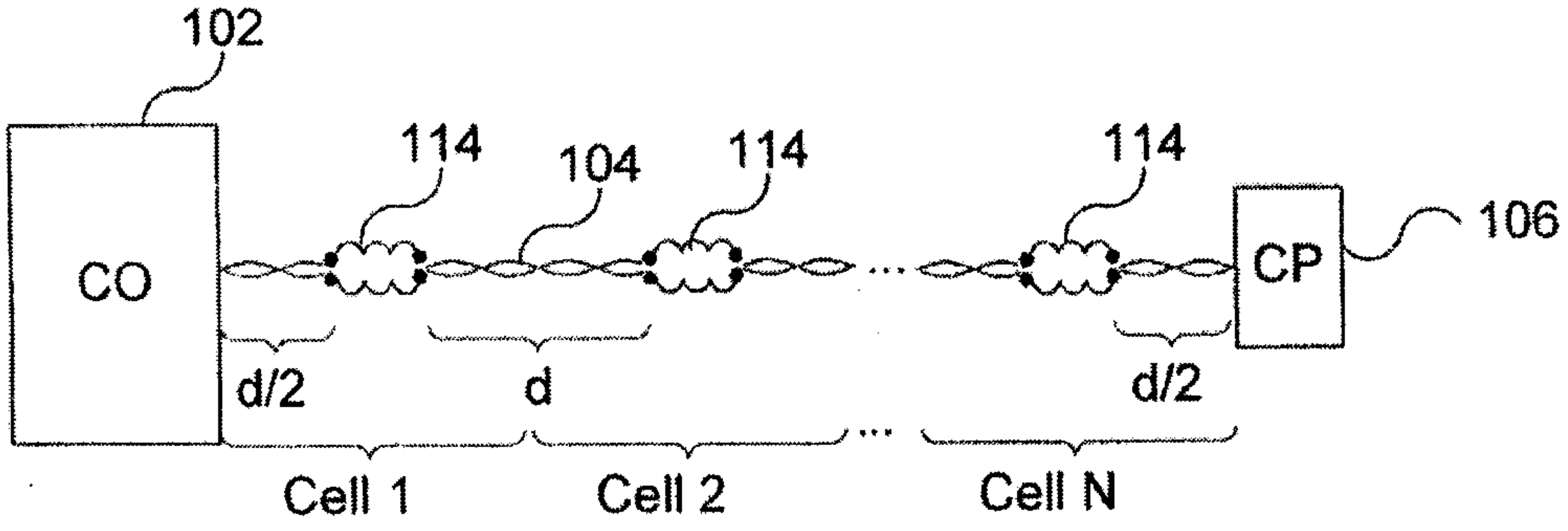


Fig. 2

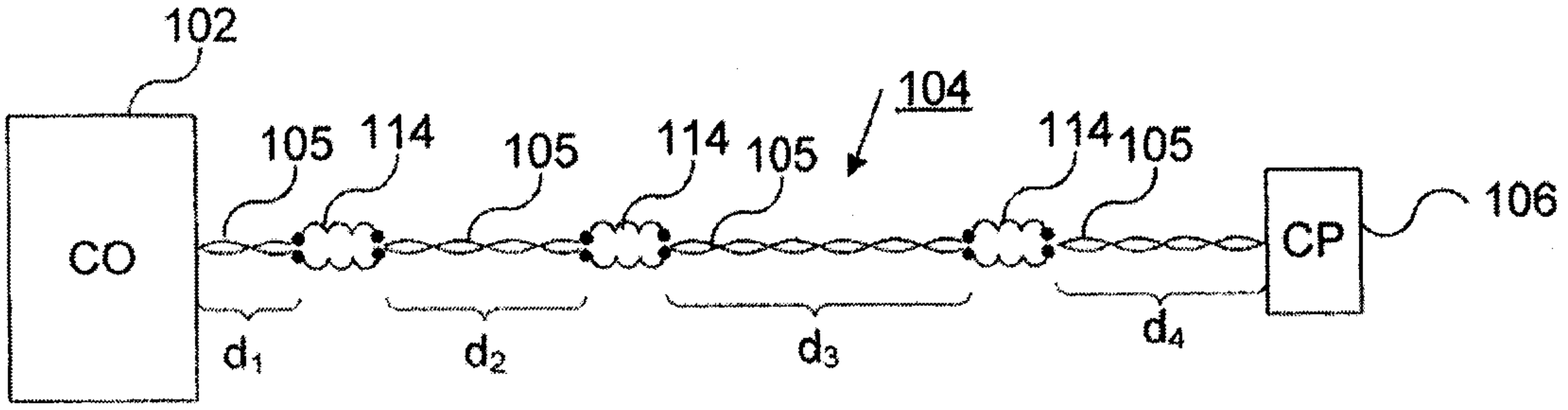


Fig. 3

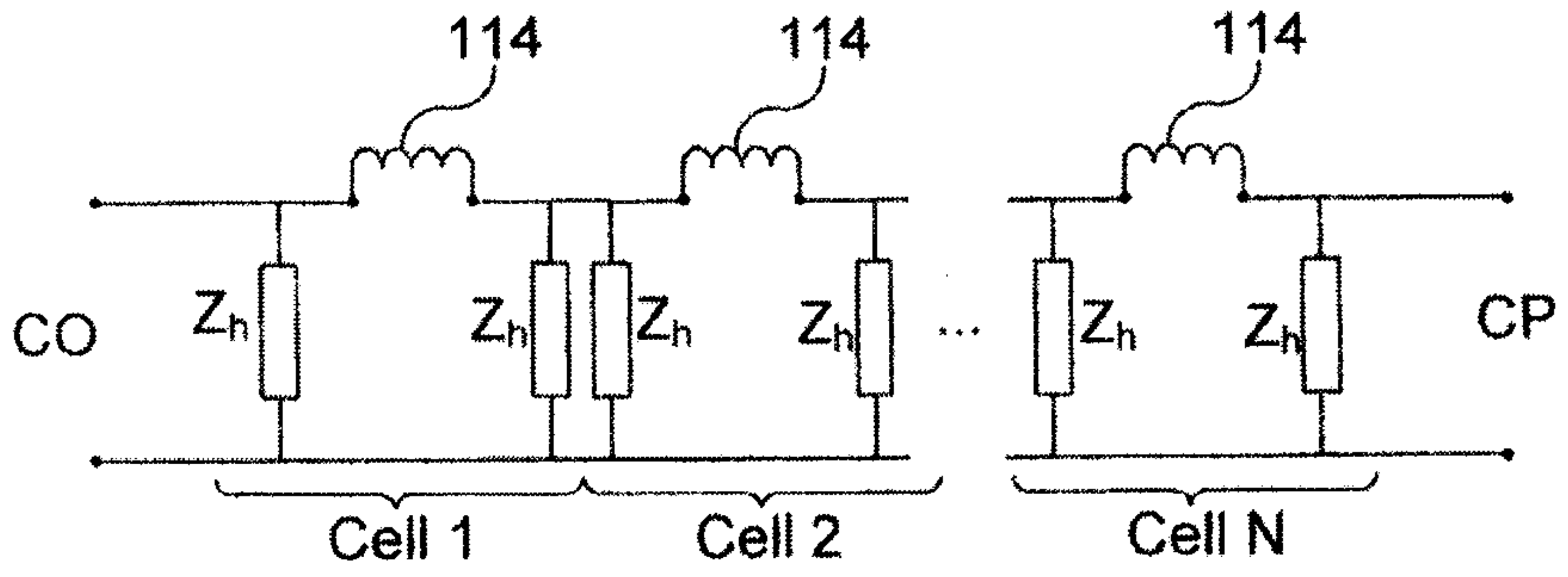


Fig. 4

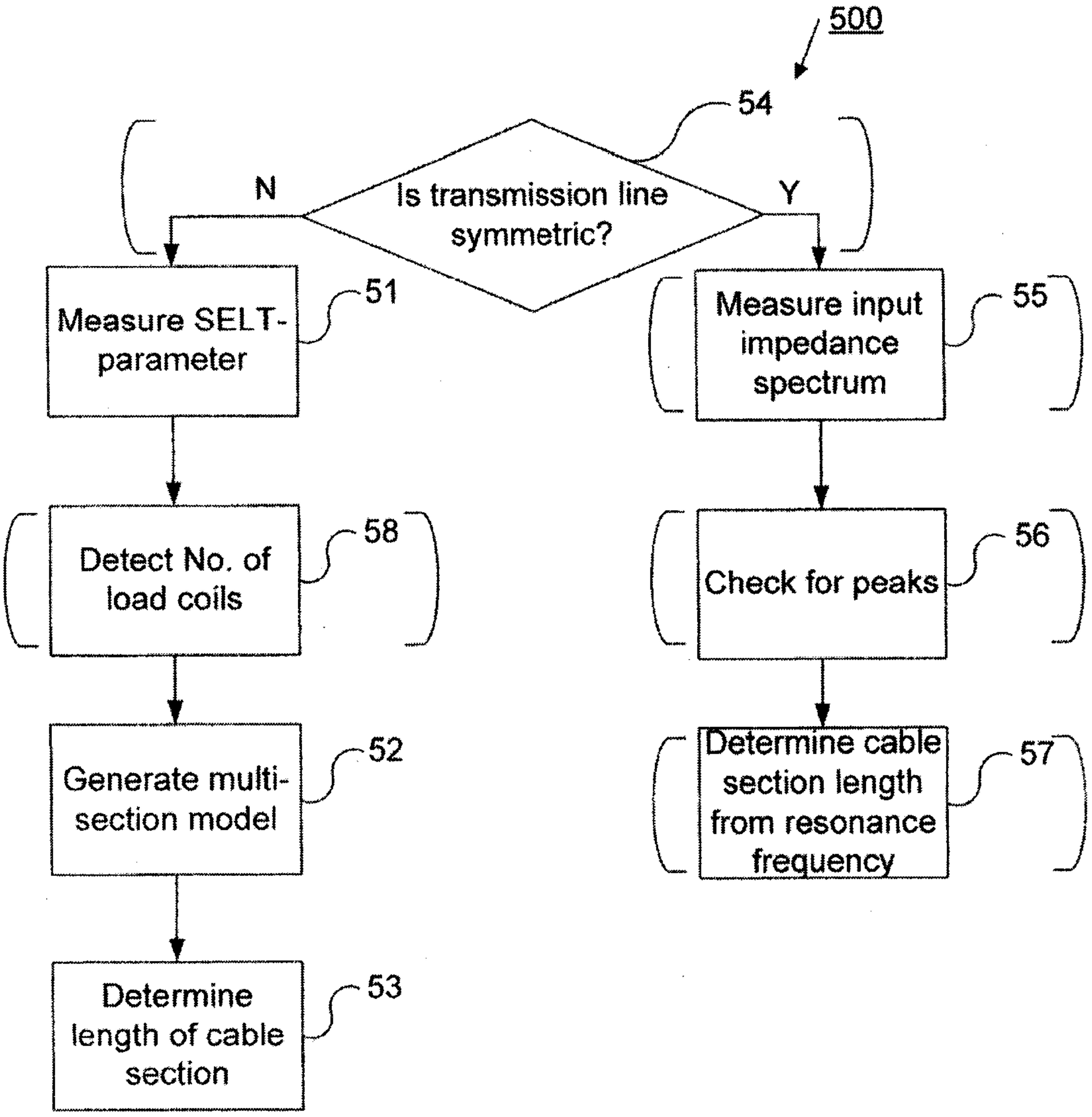

500
54
Is transmission line symmetric?
N
Y
Measure SELT-parameter
51
Detect No. of load coils
58
Generate multi-section model
52
Determine length of cable section
53
Measure input impedance spectrum
55
Check for peaks
56
Determine cable section length from resonance frequency
57

Fig. 5

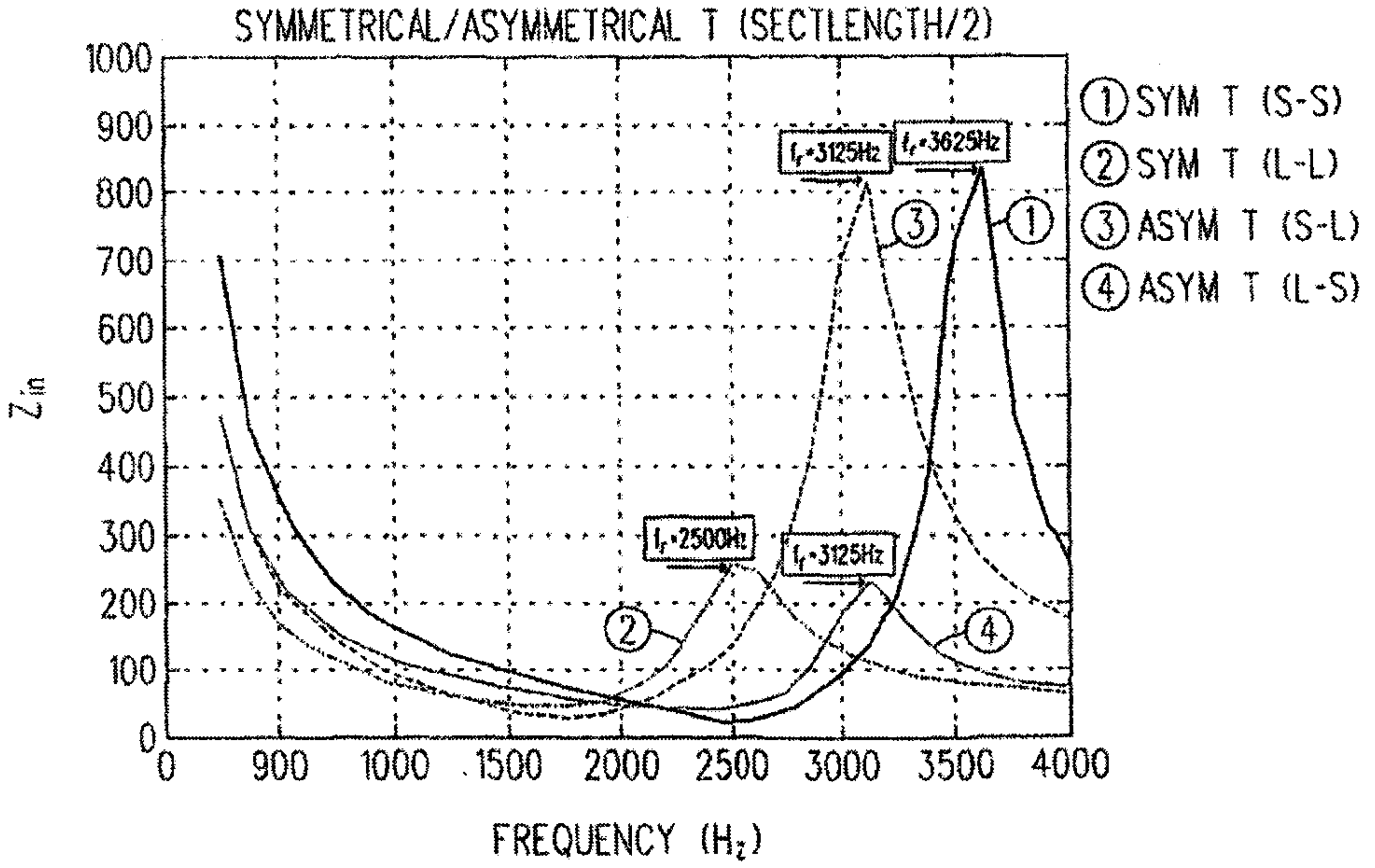
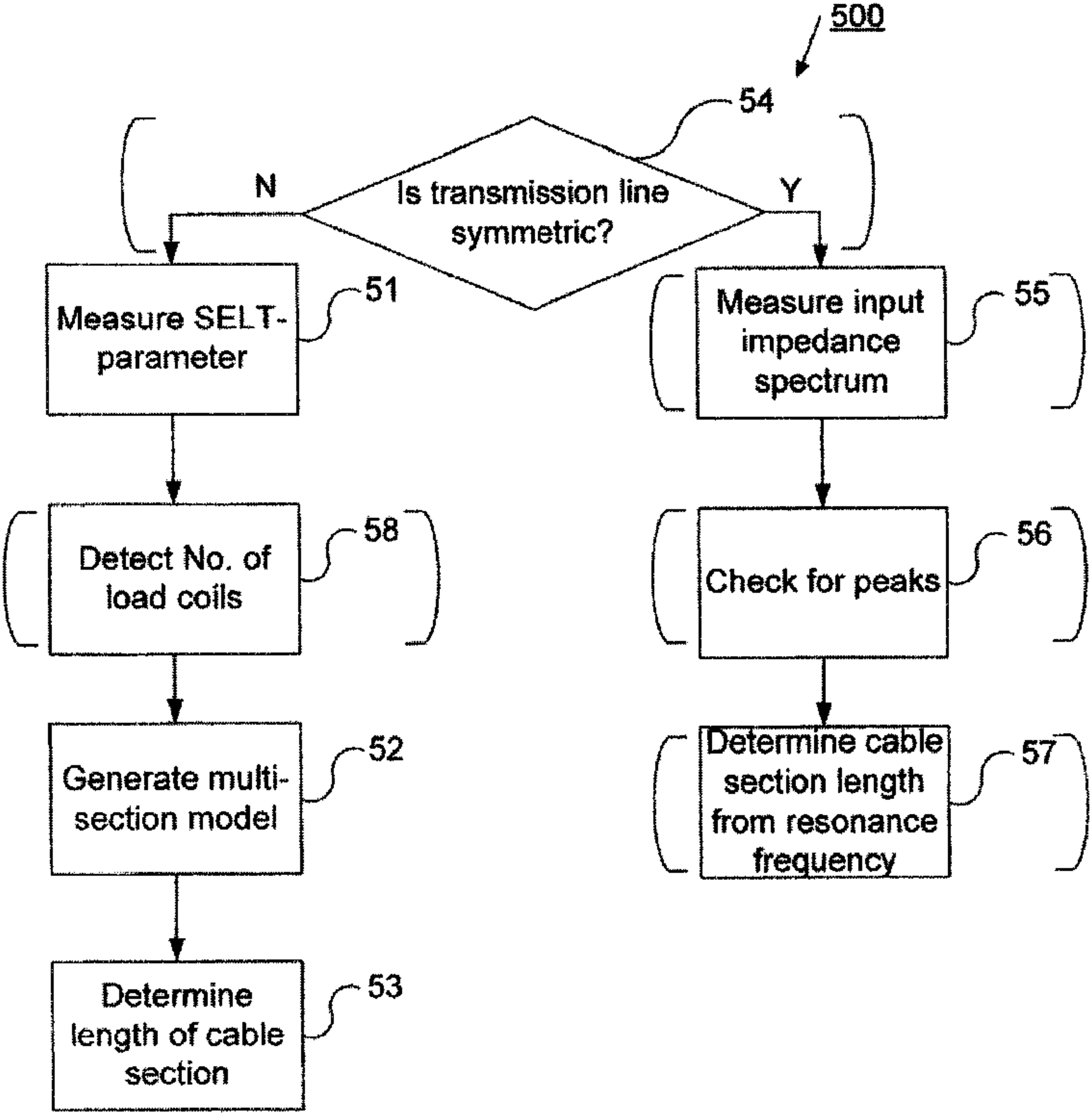

SYMMETRICAL/ASYMMETRICAL T (SECTLENGTH/2)
1000
900
800
700
600
500
400
300
200
100
0
Z_{in}
0
900
1000
1500
2000
2500
3000
3500
4000
FREQUENCY (H_z)
f_r=3125Hz
f_r=3625Hz
f_r=2500Hz
f_r=3125Hz
①
②
③
④
① SYM T (S-S)
② SYM T (L-L)
③ ASYM T (S-L)
④ ASYM T (L-S)

Fig. 6


500
54
Is transmission line symmetric?
N
Y
Measure SELT-parameter
51
Measure input impedance spectrum
55
Detect No. of load coils
58
Check for peaks
56
Generate multi-section model
52
Determine cable section length from resonance frequency
57
Determine length of cable section
53