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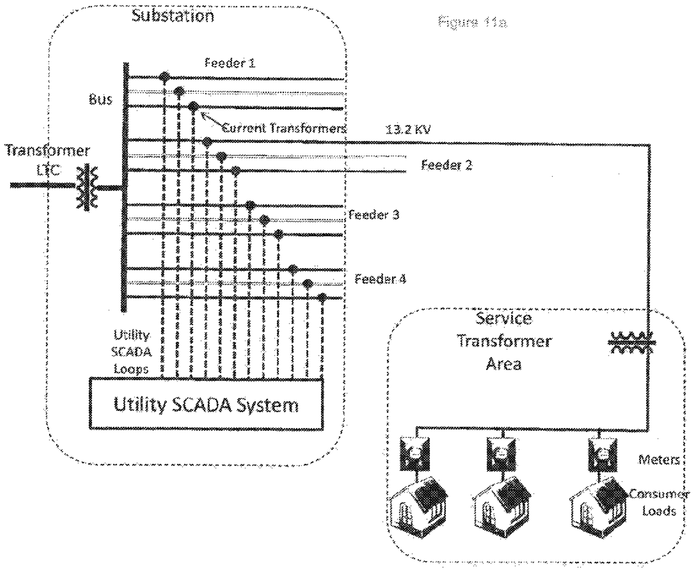
(54) **Title**: INFERRING FEEDER AND PHASE POWERING A TRANSMITTER



(57) **Abstract**: A system and method for inferring the feeder and phase of a transmitter on a plurality of electrical distribution lines. The system may include a low-voltage electrical distribution grid having one or more phases and one or more lines, a mechanism for transmitting a measuring data, a mechanism for receiving the measuring data, and a mechanism that analyzes the transmitted data to infer the phase and feed on which the transmission is injected.

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INFERRING FEEDER AND PHASE POWERING A TRANSMITTER

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. provisional patent application No. 61/834,573, filed June 13, 2013, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention is directed toward the use of signals on the electrical distribution grid to infer the feeder and phase powering an on-grid transmitter, and specifically for identifying the path of electricity flow from a substation to a metered load point or other monitored point.

SUMMARY

[0003] Electrical Distribution Substations contain one or more Substation Transformers, which step down the voltage from high transmission line levels (typically 130kV to 700kV) to the medium voltage levels (typically from 4kV to about 35kV, although higher voltages are possible) at which power is distributed to consumers within a distribution service area. At the edge of the Distribution Grid are a number of Service Transformers, which transform the medium voltage of the distribution grid to the low voltages (in the US, typically 120, 208, 240, 277, or 480) required for commercial, industrial, and residential consumers. Other voltages in addition to some of these can be used elsewhere in the world. Each Service Transformer powers one or more metered loads. A metered load can be a dwelling, a commercial or industrial building, an element of municipal infrastructure such as a series of street lamps, agricultural apparatus such as irrigation systems, or any other metered construct which can draw power from the distribution grid, or combinations of these.

[0004] The power grid is generally considered to be composed of two logical regions, the

Transmission Grid(s) and the Distribution Grid(s). The Transmission Grid originates at large generation points such as hydroelectric dams, nuclear reactors, wind farms, and coal-fired or gas-fired power plants. Power from the generation point is transmitted as high-voltage alternating current (AC) over a loosely connected network of long, high-voltage lines to points where demand for power exists, such as factories, farms, and population centers. At the edges of the Transmission Grid there is a collection of Distribution Substations. Distribution Substations contain one or more Substation Transformers, which step down the voltage from high transmission line levels (typically 130kV to 700kV) to the medium voltage levels (typically from 4kV to about 35kV, although higher voltages are possible) at which power is distributed to consumers within a distribution service area. At the edge of the Distribution Grid are a number of Service Transformers, which transform the medium voltage of the distribution grid to the low voltages (in the US, typically 120V, 208V, 240V, 277V, or 480V). Other voltages in addition to some of these can be used elsewhere in the world. In some cases, a tier of one or more transformers, called stepdown transformers, lying schematically between the Substation Transformers and the Service Transformers, create intermediate voltage reductions between the Substation and the Service Transformers. Each Service Transformer powers one or more metered loads. A load can be a dwelling, a commercial or industrial building, an element of municipal infrastructure such as a series of street lamps, or agricultural apparatus such as irrigation systems. A typical distribution grid includes other elements used to balance and regulate the flow of power. Examples of such elements are capacitor banks, voltage regulators, switches, and reclosers. Figure 10 illustrates a typical segment of the power grid.

[0005] Distribution grids have been designed and deployed in a variety of topological configurations. In the United States, distribution grid types are typically characterized as radial, loop, or networked. Other emerging cases are the campus grid and the microgrid. Additional topologies, not described, are used elsewhere in the world.

[0006] Figure 11a is a topological schematic of a typical radial grid. In a radial grid, a substation has one or more substation transformers. Each substation transformer has one or more substation busses. One or more three-phase feeders "radiate" outward from each substation bus, with single-phase, double-phase, or three-phase lateral lines branching off from the feeders, and tap-off points (or simply "taps") in turn, branching from the laterals. Radial grids are inexpensive to design and build because they are simple, but they are most vulnerable to outages because they typically lack redundant power paths, so that any break causes at least one load to lose power.

[0007] Figure 11b is a topological schematic of a typical loop distribution grid. In a loop grid, each end of select feeders is attached to a power source such as a bus of a substation transformer. If the loop is undamaged, then power is available at all loads if either substation transformer is operational. If there is a break in the loop, then power is available at all loads assuming that both transformers are operational. In normal circumstances, a system of switches is used to ensure that only one substation transformer at a time is delivering power to each segment of the grid.

[0008] Figure 11c is a topological schematic of a typical networked grid. This topology has maximum redundancy. In addition to employing multiple power sources, all the service transformers are linked to one another on the secondary side in a mesh arrangement. Multiple breaks in connectivity are required to cause a power outage at any point. Networked grids are most expensive to build and maintain, and are typically used in major urban areas such as Manhattan or Washington, DC where high-value, high criticality loads are concentrated together.

[0009] Figure 11d shows a microgrid or campus network. Microgrids are not traditional in electrical distribution technology, but are emerging as a response to increased focus on energy conservation and on distributed generation of energy from renewable sources. Many variations are possible. This type of grid is typically attached to, but severable from, a wider distribution grid, and may contain its own power sources such as windmills, solar panels, or rechargeable storage batteries as well as loads. The entire network may employ low-voltage lines.

[0010] A distribution substation receives high-voltage power from the transmission grid into one or more large power transformers. A distribution transformer may incorporate a type of regulator called a load-tap changer, which alters the voltage the transformer delivers to a power distribution bus (the substation bus) by including or excluding some turns of the secondary winding circuit of the transformer, thereby changing the ratio of input to output voltage. One or more feeders depend from the substation bus. If too many feeders are required, additional transformers and busses are used.

[0011] In order to monitor and control the components of the grid, current transformers (CTs) or other current sensors such as Hall-effect sensors are attached to power-bearing conductors within the substation. The CTs output a low current on a looped conductor which is accurately proportional to the current delivered at the high voltage conductor being monitored. These low-current outputs are suitable for connecting to data acquisition subsystems associated with Supervisory Control and Data Acquisition (SCADA) systems in the substation. Primary monitoring CTs are designed and built into the substation, because changing or adding CTs to the high-voltage components is impossible or dangerous while current is flowing. On the other hand, additional CTs may be safely added to the low-current SCADA loops as needed without impacting power delivery.

[0012] In addition to the power lines themselves, the distribution grid contains numerous other devices intended to regulate, isolate, stabilize, and divert the flow of power. These devices include switches, reclosers, capacitor banks (usually for power factor correction), and secondary voltage regulators. All these devices affect the behavior of the distribution grid when considered as a data-bearing network, as do the various loads and secondary power sources on the grid. Devices that have abrupt state changes will introduce impulse noise on the grid, as can loads turning on and off. Some devices, such as transformers and capacitor banks, filter and attenuate signals at certain frequencies. Other than the wires connecting a consumer load and the associated meter to a service transformer, the service transformer is typically the outermost element of the distribution grid before the power is actually delivered to a consumer. A meter is typically attached at the point where the power from the service transformer is delivered to the consumer. Service transformers can be three-phase, or single phase, as can meters.

[0013] Traditionally, reading meters was one of the largest operational costs incurred by electrical utilities. Originally, electric meters were analog devices with an optical read-out that had to be manually examined monthly to drive the utility billing process. Beginning in the 1970s, mechanisms for digitizing meter data and automating its collection began to be deployed. These mechanisms evolved from walk-by or drive-by systems where the meter would broadcast its current reading using a short-range radio signal, which was received by a device carried by the meter reader. These early systems were known as Automated Meter Reading systems or AMRs. Later, a variety of purpose-built data collection networks, commonly employing a combination of short-range RF repeaters in a mesh configuration with collection points equipped with broadband backhaul means for transporting aggregated readings began to be deployed.

[0014] These networks were capable of two-way communication between the "metering headend" at a utility service center and the meters at the edge of this data collection network, and are generally called an Advanced Metering Infrastructure or AMI. AMIs can collect and store readings frequently, typically as often as every 15 minutes, and can report them nearly that often. They can read any meter on demand provided that this feature is used sparingly, and can connect or disconnect any meter on demand as well. AMI meters can pass signals to consumer devices for the purpose of energy conservation, demand management, and variable-rate billing. Because the AMI network is separate from the power distribution grid except for the intersection at the meters, AMI meters are neither aware of nor sensitive to changes in the grid topology or certain conditions on the grid. Nonetheless, the introduction of AMI is often the first step in the direction of a true Smart Grid implementation.

[0015] AMI networks generally do not have all the capabilities required to support Smart Grid applications over and above meter reading and demand management. Significantly, the AMI network usually does not use the electrical grid as a transmission medium. It monitors only the metered load points, and hence does not detect electrical changes and conditions elsewhere on the distribution grid. Further, data-carrying capacity from the edge to the central concentrators is typically adequate for meter data and little more.

[0016] Sophisticated Smart Grid applications for energy conservation, asset protection, non-technical loss detection, load balancing, fault isolation, and recovery management require accurate information about the schematic relationship of grid assets, load and conditions on the several segments of the grid, and the current state of bi-modal and multi-modal assets. This information, together with the geospatial locations of the same assets, is called a grid map and is typically stored in a database. In general, AMI networks do not have the sensor mechanisms, monitoring capability, or the bandwidth to provide these types of information, with the result that present-day grid map databases are seldom updated in real time.

[0017] Utilities typically maintain two maps or models of the distribution grid. A Physical Network Model (PNM) aggregates the geospatial location of the assets on the grid. PNMs, thanks to modern GPS technology, are reasonably accurate with respect to point assets such as substations, capacitor banks, transformers, and even individual meters, although the accuracy of this information typically diminishes the further out on the distribution grid the assets are located, or diminishes inversely as a function of the value of the asset, or diminishes directly as a function of the frequency a given asset is accessed. Inaccuracies stem from failure to update the maps when repairs or changes are made, and includes both intentional and unintentional changes. For example, a service transformer may move from one side of a street to the other as a result of street widening. Such a move may additionally result in a change in the partitioning of metered loads among the service transformers in an area.

[0018] Longitudinal assets, especially buried cables, are less well represented in the PNM. The PNM can contain as-designed data regarding the location of the longitudinal assets, but since in many places the cable was laid before global positioning technology had matured, the designs were based on ground-level survey, and the original maps may or may not have been updated to reflect changes. Therefore, the location from the as-designed data may be inaccurate, and subsequent surface changes complicate the problem of verifying the geographic path taken by medium-voltage and low-voltage distribution lines.

[0019] The second model is the Logical Network Model, or LNM. LNMs describe how grid components are connected, without reference to their geospatial location. The LNM changes frequently. During the course of repairs, the way transformers attach to taps and laterals, and the way meters attach to transformers, may be altered. Such changes may affect both the LNM and the PNM. In many utilities, such intentional changes are recorded manually by field agents. The manual reports may or may not be updated in the LNM and PNM, and when updates are made the time lag between maintenance occurring and its being recorded could be significant. The problem is exacerbated by unintentional changes implemented automatically by automated but non-monitored switching elements and devices such as reclosers.

[0020] The fundamental problem of grid schematic mapping therefore involves determining what substation, bus, feeder, and phase powers a particular meter or other monitoring point.

[0021] While the aforementioned issues are themselves complex, the wiring at the periphery of the electrical distribution grid (i.e., the wiring from the service transformer to an electrical meter or meters) significantly adds to the difficulty of effecting grid schematic mapping. This wiring can have a radial topology, as is common in the US, or it can have a linear or "bus" topology, as is more common in Europe. Elsewhere in the world one can find both radial and bus topologies. In locales where transformers are mounted on poles and tap lines are above ground, one might think this wiring would be obvious. However, in those locales, it is very easy after an outage caused by a storm, a traffic accident, or scheduled construction, for repairs to be made in such a way as to change the transformer to which a meter is attached. In dense neighborhoods it is not always apparent how bundled and criss-crossing power lines connect buildings to transformers, especially when multiple transformers are attached to one pole.

[0022] In cases where transformers are pad-mounted or underground, and taps run underground, the construction may pre-date grid mapping. In that case, the only data that may be available are schematic designs made by survey. In general, no reliable record exists of whether this wiring was built strictly according to specification, or what has been the effect of subsequent modifications.

[0023] Practical benefits of having accurate distribution circuit maps include, but are not limited to, reductions in losses in the grid, load and phase balancing, reduced outage time, improved reliability, improved safety, asset protection, trend determination, and theft detection. It would be desirable to have a system that can provide real-time or near-real-time information that allows utilities to accurately determine distribution schematic information.

[0024] US Patent Application No. 13/871,944, titled "A System and Method for Inferring Schematic and Topological Properties of an Electrical Distribution Grid" and incorporated herein by reference in its entirety, teaches an on-grid transmitter which may transmit a Probe Transmission consisting of a sequence of pure tones of different frequencies or one or more sequential groups of a combination of two or more pure tones transmitted simultaneously. The transmission is made by injecting current onto a low-voltage power line at an electrical meter or other low-voltage access point. The application further teaches an on-grid receiver located at an electrical distribution substation or other medium-voltage access point, the receiver being configured to monitor all three phases of one or more medium voltage feeders. The receiver continuously digitizes and records the signal on all monitored power lines, sampling the recorded signal attempting to recognize a probe transmission. Because of the physical characteristics of the electrical grid, a Probe Transmission which was injected on exactly one phase of one feeder may be detected and recognized on one or more of the monitored power lines. The receiver knows a priori the phase of each monitored line and the schematic identity of the feeder to which it belongs. The receiver also knows the frequency, grouping, and duration of the tones in a Probe Transmission. The transmitter is not aware of its feeder-phase identity. One task of the receiver is to infer the phase and feeder on which the transmitter injected the Probe Transmission, regardless of the number of monitored lines on which the transmission was recognized.

[0025] If a Probe Transmission is detected on only one monitored line, then that line may be assumed to reflect the feeder and phase of the transmitter. However, if a Probe transmission is detected on more than one monitored line, then it cannot be assumed that the lines reflect the feeder and phase of the transmitter. Therefore, it would be desirable to be able to determine feeder and phase of a Probe Transmission in more than one monitored line.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] The accompanying drawings, which are incorporated in and form part of the specification, illustrate embodiments of the invention and, together with the description, serve to explain the principles of the invention. In the drawings:

[0027] Figure 1 is a view of an exemplary structure of a single on-grid transmission.

[0028] Figure 2 is a view of another exemplary structure of a single on-grid transmission.

[0029] Figure 3 is a graph (not to scale) of a snapshot of the AC waveforms on a distribution grid at a substation. The power fundamental and its odd harmonics are highlighted.

[0030] Figure 4 is an exemplary view of a check on the voting process and shows a probe transmission beginning on the phase-specific zero crossing point of power fundamental.

[0031] Figure 5 is a graph depicting the difficulty of inferring the grid location of a low-voltage transformer by detecting the signal injected by the transmitter at a substation. The graph shown in Figure 5 was created by injecting a low-voltage signal on one phase of one feeder of an electrical distribution substation having a total of five feeders.

[0032] Figure 6 is another exemplary method of applying a voting method.

[0033] Figure 7 is an example of a tone group providing idle frequencies while another tone group is being transmitted.

[0034] Figure 8 is another example of a tone group providing idle frequencies while another tone group is being transmitted.

[0035] Figure 9 is a view of yet another exemplary structure of a single on-grid transmission.

[0036] Figure 10 is a simplified illustration of the power path from a generation point to a distribution substation to a consumer, showing the high voltage, medium voltage, and low voltage regions of the distribution grid and depicting some of the major features of an electrical distribution grid.

[0037] Figure 11a is a simplified fragment of a radial-architecture distribution grid showing the lack of cycles in the grid topology.

[0038] Figure 11b is a simplified fragment of a looped-architecture distribution grid depicting two substations each able to deliver power to the service transformer delivering low-voltage power to the group of residences shown. The substation at left is currently powering the residential group.

[0039] Figure 11c is a simplified fragment of a networked architecture distribution grid. The four feeders shown could originate at a single substation (typical) or at multiple substations. The rectangular grid connects service transformers peer-to-peer on the low voltage side so that all feeders deliver power to the loads below the substations concurrently.

[0040] Figure 11d is an exemplary simplified fragment of a campus network. A three -phase transform powers a 480 volt bus from which depend a number three-phase laterals which run through the campus powering individual electrical outlets. Adding low-voltage generation points to the bus and providing means to isolate the bus from the distribution line converts the campus network into a self sufficient microgrid.

DETAILED DESCRIPTION OF THE INVENTION

[0041] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration specific exemplary embodiments of the invention. These embodiments are described in sufficient detail to enable those of ordinary skill in the art to make and use the invention, and it is to be understood that structural, logical, or other changes may be made to the specific embodiments disclosed without departing from the spirit and scope of the present invention.

[0042] The present invention discloses a method of inferring a feeder and phase of a transmitter when a Probe Transmission is detected on two or more monitored lines.

[0043] Figure 5 illustrates the difficulty of inferring the grid location of a low-voltage transformer by detecting the signal injected by the transmitter at a substation. The graph shown in Figure 5 was created by injecting a low-voltage signal on one phase of one feeder of an electrical distribution substation having a total of five feeders. The signal was a "sweep," increasing continuously in frequency from 1 KHz to 4 KHz. A receiver at the substation monitored all fifteen power lines (three phases each of five feeders) to record the Received Signal Strength (RSSI) of the sweep frequencies. Data set 502 represents the RSSI of the sweep on the feeder-phase of the transmitter. Data sets 503 represent the RSSIs of the sweep as received on all fourteen of the other feeder-phase lines at the substation. The sweep was detectable on all fifteen lines. Although described with respect to a sweep, the invention is not so limited. This phenomenon is called crosstalk or crossover. As expected, the signal on the line of injection was stronger than the other signal over most of the frequency band of interest 501. Note, however, that the signal strength of the crossover received signals does not diminish smoothly as frequency increases, and that at some frequencies the crossover signals are actually stronger than the signal on the line of injection. Repeated measurements show that the amplified frequencies do not remain consistent on the same distribution grid over time, nor is the behavior of every distribution grid the same. Thus, identifying the line of injection when it is not known becomes a non-trivial problem.

[0044] Figures 1 and 2 illustrate two examples of a number of possible patterns (as disclosed in U.S. Application No. 13/871,944) of an on-grid transmission in a grid-location aware ("GLA") network. Figure 1 shows an exemplary data-bearing transmission, comprising a preamble 102, a probe transmission 103, and a data segment 104. The message is preceded and followed by timing guard bands 101 and 105, respectively, in which not only does this on-grid transmitter refrain from transmitting, but in which, in a preferred approach, no on-grid transmitter powered by the same substation or substations is permitted to transmit. The probe transmission 103 is, in an approach, the GLA portion of the transmission. Figure 2 shows an exemplary on-grid transmission that includes a probe transmission 203 made only for the purpose of inferring the grid location of the transmitter. In the structure of Figure 2, the probe transmission 203 is, in an approach, the GLA portion of the transmission. Similarly, one or more idle sampling periods such as 201,202, 204, and 205 may precede and follow the GLA portion of the transmission. Although only two on-grid transmissions are shown, the invention is not so limited and there can be many different on-grid transmissions applied to carry-out the invention.

[0045] To infer the grid location of a transmitter, a receiver located at a substation or other junction point on the distribution grid, monitors all phases of at least one feeder whereon knowing the grid location of the transmitters is required. In a preferred approach, a transmitter is a special or general purpose computer having at least a processor and a computer readable memory. A transmitter also includes appropriate circuitry for transmitting signals and a receiver includes appropriate circuitry for receiving signals. A transmitter is typically an End-Point transmitter. In a preferred approach, a receiver or sensor is a special or general purpose computer having at least a processor and a computer readable memory. A receiver is typically a substation receiver. It is preferable but not required that all feeders of a particular substation transformer are monitored. The receiver digitizes and records the waveforms on each monitored power line (i.e., a phase of a feeder), recording both transmissions and idle periods. In an exemplary situation where a transmission like the structure of Figure 1 is applied, the receiver records sections 101, 102, 103, 104, and 105, although other approaches to recording the transmission can be applied. In an exemplary situation where a transmission like the structure of Figure 2 is applied, the receiver might record sections 201, 202, 203, 204, and 205. In an approach, the receiver records continuously. In another approach, the receiver records using policy information at its disposal to record only around intervals where transmissions are expected.

[0046] In one embodiment of the invention, the receiver samples each line as it records, attempting to recognize a Preamble 102 or a Probe Transmission (103, 203). When a transmission is recognized by means of a Preamble or a Probe Transmission being identified, recording continues at least until sufficient idle time has been collected. The receiver then extracts significant frequency/amplitude samples from the recording and conducts a "voting" process as follows. The significant frequencies are called tone frequencies, because each such frequency is transmitted as a pure tone in the Probe Transmission. The amplitude (or RSSI) at each tone frequency reflects the energy of the received signal.

[0047] In an exemplary voting process when a Figure 2 structure is being transmitted:

[0048] 1. Each section of the recording (e.g. 201,202,203,204,205) is processed to determine the energy at each tone frequency that is seen in each section. The number and duration of idle samples that may be recorded is variable; there is at least one.

[0049] 2. For each tone frequency, an average of the energy of the idle samples is subtracted from the energy in the Probe Transmission 203.

[0050] 3. The magnitude of the energy at each frequency is compared across all monitored feeder-phase lines.

[0051] 4. The monitored line (feeder-phase) with the most tone frequencies with the maximum energy is termed the device's grid location.

[0052] 5. In the case of a tie in the number of maximum energy levels, the sum of the magnitudes of the energy seen at the frequencies which were highest on each tied line is computed. Recall that the number of addends will be the same for each tied line, because that is the definition of a tie. The line with the highest summed energy is then determined to be the device's grid location.

[0053] In a preferred approach, data-bearing sections of the transmission, such as preamble 102 and data 104, are not included in the measurement, because in these sections, energy may be injected by the transmitter, but not in a consistent or predictable way. Hence, these sections are less useful for determining the "background" energy of the line. Note also that tone frequencies are selected so as to avoid the harmonics of the power fundamental.

[0054] In a preferred approach, if a transmitter is capable of always beginning to transmit at the zero-crossing of the power fundamental at the point of transmission, then a check on the method described above is possible.

[0055] Figure 3 illustrates both the characteristics of the low end of the frequency spectrum on a feeder-phase line of a typical distribution grid. Important characteristics of the spectrum are the 50Hz or 60Hz power fundamental 301, its harmonics 302, and the noise floor 303. It should be noted that from time to time a spike of impulse noise may exceed the usual noise floor. The defined channel or channels for modulated signals transmitted by an Edge Transmitter occupy a broad candidate spectrum lying between the 50 or 60 Hz power fundamental and the low-pass threshold of the service transmitters on the host power grid. The candidate spectrum for a particular substation is determined by measurement and set by policy and subject to regulatory constraints. Measurements determine which band or bands of the candidate spectrum are reliably received at each substation transformer. If a usable band is wider than the bandwidth needed for a reliable transmission, then the channel band may be defined to be variable. In such cases, the Remote Hub conducts measurements, described herein below, prior to transmitting to determine at present conditions which part of the wider channel is currently most favorable for transmitting. Conversely, at a Receiver located at a substation, the preamble detector samples the entire wide usable band, determining the actual band used by the transmitter based on where the preamble was detected. The location of a receiver can provide significant information about the circuitry providing the power flow.

[0056] Refer to Figure 4, which shows an exemplary check on a voting process, and includes probe transmission 401 beginning on the phase-specific zero crossing point 402 of power fundamental 403. Since the three phases of a feeder are 120 degrees out of phase, it is possible to determine the phase location of the transmitter based on the timing relation of its transmission with the feeder/phase line that is measured at the receiver. If two or more lines are tied with respect to the energy-based method, then the tied line which is in phase with the transmission is selected as the device's grid location. The phase of a transmission may be determined exclusively by the latter method, but without measurements of the RSSI there is no indication of the feeder of transmission.

[0057] Another check on the voting algorithms disclosed above may be the burst demodulation performance across all feeder-phases. For example, the data segment of a message, such as 104, may contain forward error correction ("FEC") or cyclic redundancy check ("CRC") information. When the most energetic received message, or one of the most energetic in case of a tie, has bit errors in the data segment of the message, or in the preamble, then it is possible that the energy "vote" has been distorted by impulse noise on one of the tone frequencies.

[0058] Additionally, in an approach, a data-bearing message may contain other information related to the grid location of the transmitter. Specifically, the data section may contain the identity of the transmitter. If the receiver has access to a stored grid-map database, then a current inferred grid location of a transmitter may be compared with a previous inferred or known grid location of the same transmitter, and this may be used to inform the decision about the outcome of the inference. Grid locations of devices at the edge of the grid do change from time to time, because of repairs, additions to the grid, changes in the switch states of features of the distribution grid, and the like. However, it may be possible to determine the likelihood of such a change having occurred from the grid map, or the inconsistency may become input to a situational analysis process.

[0059] Refer now to Figure 6, which illustrates a more compact method of implementing the voting method disclosed above. In this method, the Probe Transmission contains at least two tone groups, which are transmitted one group after another in sequence. The sequence may repeat. The sequence, in a preferred approach as always, is known to the receiver. Suppose that a Probe Transmission consists of two frequency tone groups, 601 and 602, which are transmitted in sequence. Instead of measuring one or more idle sections, as disclosed above, the receiver monitors only the probe frequencies. While tone group 601 is present, the frequencies of tone group 602 are also measured and used in lieu of an idle section. While tone group 602 is present, the frequencies of tone group 601 are also measured and used in lieu of an idle section. The algorithm then proceeds as described herein above.

[0060] Figures 7 and 8 illustrates how the frequencies of one tone group provide idle frequencies while the frequencies of the other tone group are transmitted. Figures 7 and 8 are graphs of the frequency spectrum, e.g., from 60 hertz to 3800 hertz, where data points are plotted against loudness, e.g., from -60 dB to +50 dB. In Figure 7, the heavy bars connected to lead lines 701 represent a set of tones (black tones), e.g., one tone group. The other plotted data points (blue tones) on the figure represent noise, e.g., background noise on the system. The tone group is compared to the background noise. In Figure 8, the heavy bars connected to lead lines 802 represent a set of tones (blue tones), e.g., one tone group, where this tone group is different than the tone group of Figure 7. The other plotted data points (black tones) on the figure represent noise, e.g., background noise on the system. The second tone group is compared to the background noise.

[0061] Also consider an exemplary message format of Figure 9 which includes timing guard bands 901 and 904, a combined preamble and probe section 902, and a data section 903. In this embodiment, the message preamble and the probe transmission are one and the same. Pure tones occur in the preamble, but a modulated identifier of known pattern may be superimposed. The compact voting method of Figures 6,7, and 8 may or may not be applicable depending on whether the pattern provides sufficient idle samples. The method of using the timing guard bands (901,904) to provide the idle samples will be applicable.

[0062] While the invention has been described and illustrated with reference to specific exemplary embodiments, it should be understood that many modifications, combinations, and substitutions can be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be considered as limited by the foregoing description but is only limited by the scope of the claims.

CLAIMS

What is claimed as new and desired to be protected by Letters Patent of the United States is:

1. A system for determining circuit topography, on an electrical distribution grid having more than one candidate feeder and phase, to which a transmitting device is connected, comprising:

at least one on-grid transmitting device coupled to a power line capable of injecting at least one signal onto said power line from which it is getting power; and

at least on-grid sensor device coupled at a substation coupled to at least said power line.

2. The system of claim 1, further comprising:

said sensor device being coupled at said substation being coupled to at least said power line to each feeder and phase that is a candidate supplier of the power for the transmitting device

3. The system of claim 1 wherein the on-grid transmitting device is a unit comprising at least a processor and computer-readable memory.

4. The system of claim 1 wherein the sensor device is a unit comprising at least a processor and computer-readable memory.

5. A system for inferring grid location of a transmitter, comprising:

a transmitter coupled to a distribution grid associated with a low-voltage transformer, and

a receiver located at a junction point of a distribution grid, said receiver coupled to receive a plurality of phases of at least one feeder of said distribution grid.

6. The system of claim 5 wherein transmitter comprises at least a computer processor and computer-readable memory.

7. The system of claim 6, wherein said transmitter is configured to provide a plurality of structures of probe transmission signals.

8. A method for determining circuit topography, on an electrical distribution grid having more than one candidate feeder and phase, comprising:

transmitting a using at least one on-grid transmitting device coupled to a power line capable of injecting at least one signal onto said power line from which it is getting power;

receiving signals on said power line using at least one on-grid sensor device coupled at a substation coupled to at least said power line; and

analyzing said receiving signals to determine which feeder is associated with said transmitting device.

9. The method of claim 8 wherein said one signal is a data bearing signal.

10. The method of claim 9 wherein said one signal includes a data bearing signal that includes a probe transmission.

11. The method of claim 9 wherein said one signal includes a data bearing signal that includes a preamble, a probe transmission, and a data segment.

12. The method of claim 8, further comprising the step of substantially continuously recording said received signals.

13. The method of claim 8, further comprising the step of substantially recording said received signals based on a recording policy.

14. The method of claim 8, wherein said analyzing further comprises the step of applying a voting policy to analyze the data.

15. The method of claim 8, wherein said analyzing further comprises the step of applying a check policy to analyze the data.

16. The method of claim 8, wherein said transmitting further comprises one of the steps of transmitting: one or more signals either individually, in combination, or in sequence.

17. The method of claim 8, wherein said receiving further comprises one of the steps of transmitting: one or more signals either individually, in combination, or in sequence.

18. A method of analyzing the signals of claim 5 from more than one feeder and phase wherein a determination is made as to which feeder and phase an End-point transmitter is connected and transmitting.

19. The method of claim 8, wherein said analyzing further comprises the step of analyzing the signals more than one feeder and phase on more than one substation wherein a determination is made as to which substation and feeder and phase is connected and transmitting.

20. The method of claim 8, wherein said transmitting further comprises of transmitting with a fixed timing relationship to the zero crossing point of the line voltage to which it is connected.

FIGURE 1

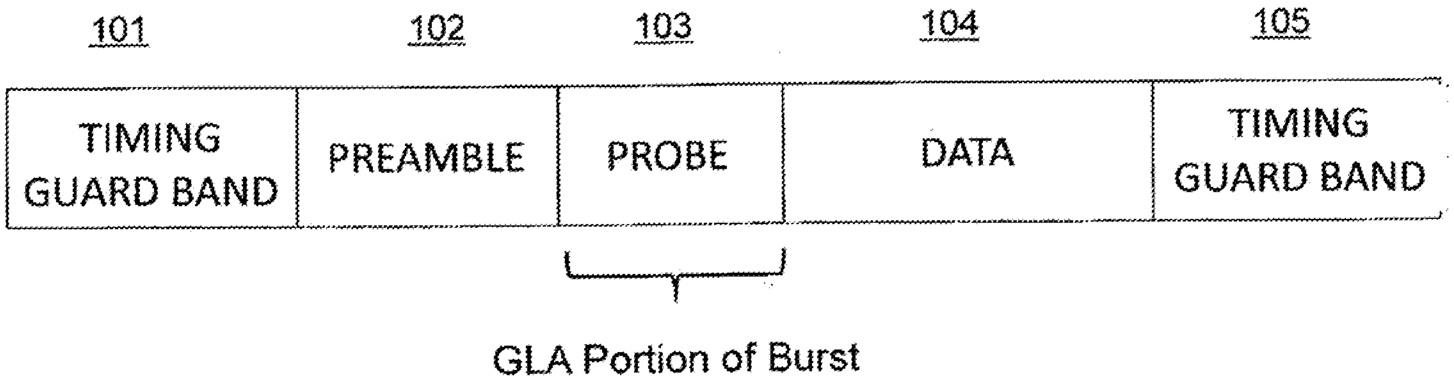

101
102
103
104
105
TIMING GUARD BAND
PREAMBLE
PROBE
DATA
TIMING GUARD BAND
GLA Portion of Burst

FIGURE 2

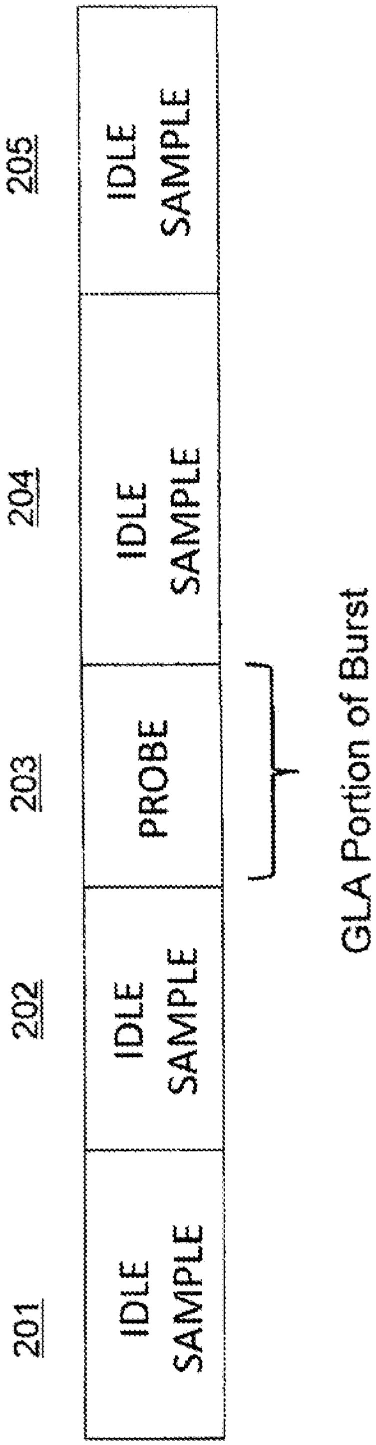

201
IDLE SAMPLE
202
IDLE SAMPLE
203
PROBE
204
IDLE SAMPLE
205
IDLE SAMPLE
GLA Portion of Burst

FIGURE 3

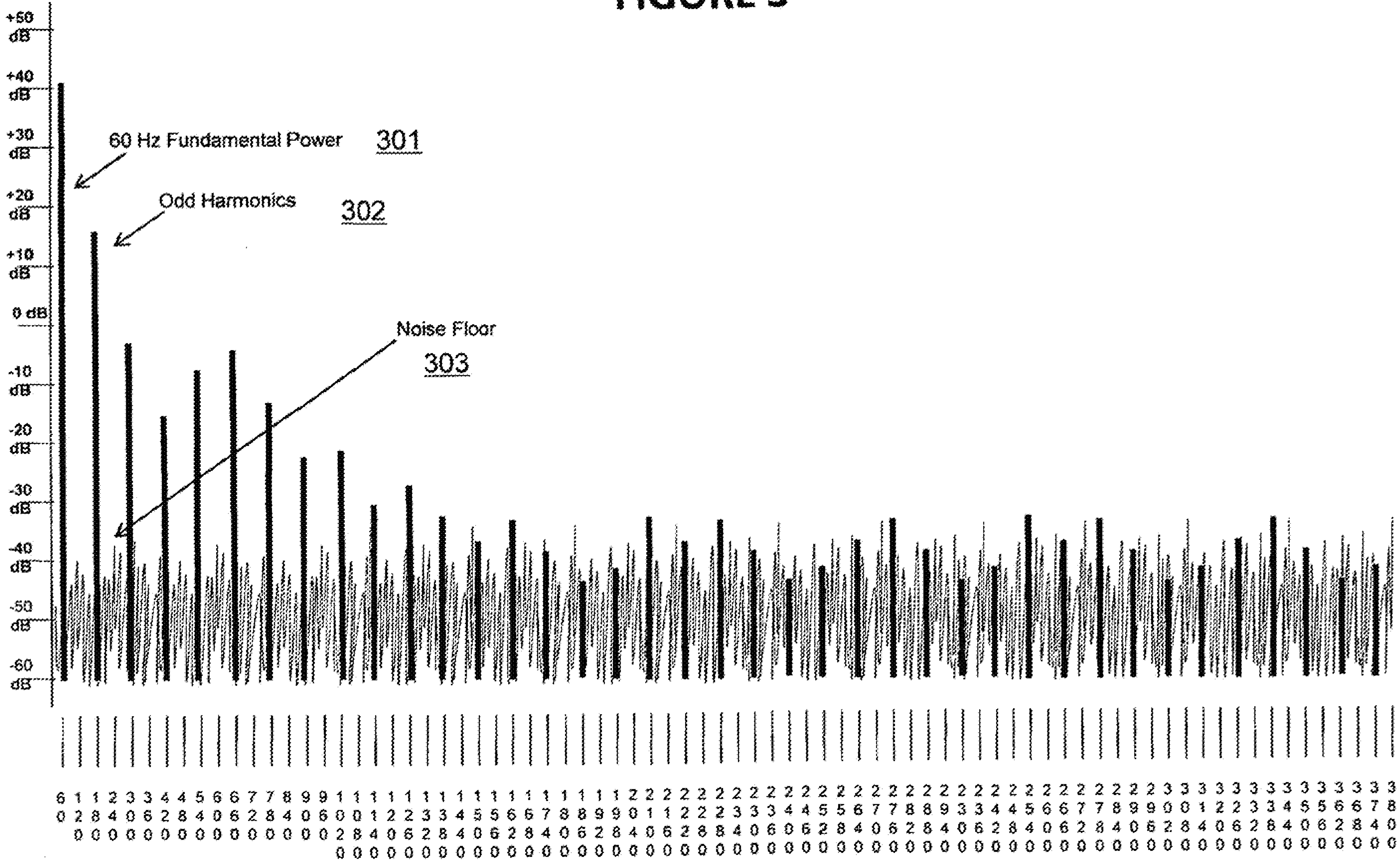

+50 dB
+40 dB
+30 dB
+20 dB
+10 dB
0 dB
-10 dB
-20 dB
-30 dB
-40 dB
-50 dB
-60 dB
60 Hz Fundamental Power
301
Odd Harmonics
302
Noise Floor
303
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1020
1080
1140
1200
1260
1320
1380
1440
1500
1560
1620
1680
1740
1800
1860
1920
1980
2040
2100
2160
2220
2280
2280
2340
2300
2360
2400
2460
2520
2580
2640
2700
2760
2820
2880
2940
2300
2360
2420
2480
2540
2600
2660
2720
2780
2840
2900
2960
3020
3080
3140
3200
3260
3320
3380
3440
3500
3560
3620
3680
3740
3800

FIGURE 4

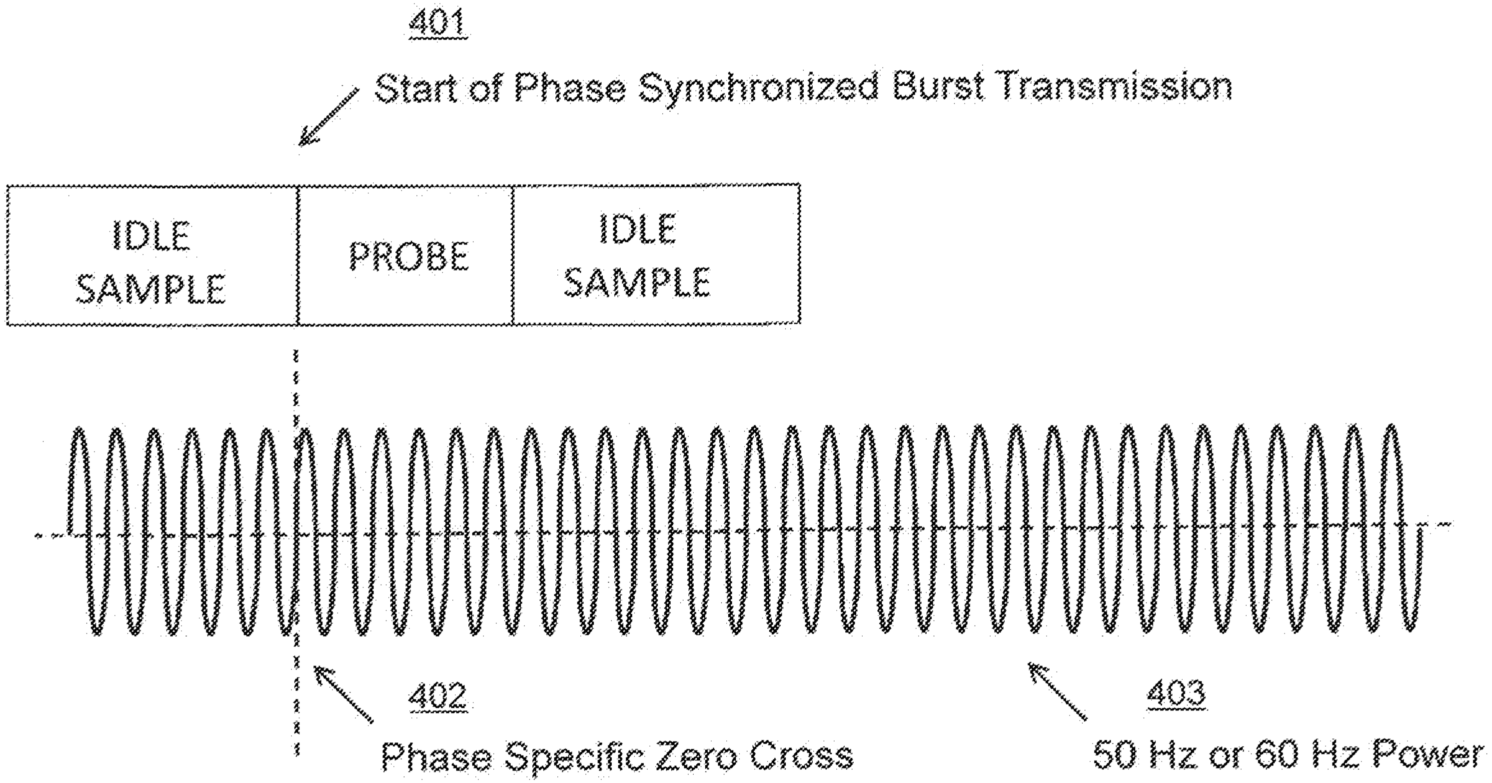

401
Start of Phase Synchronized Burst Transmission
IDLE SAMPLE
PROBE
IDLE SAMPLE
402
Phase Specific Zero Cross
403
50 Hz or 60 Hz Power

FIGURE 5

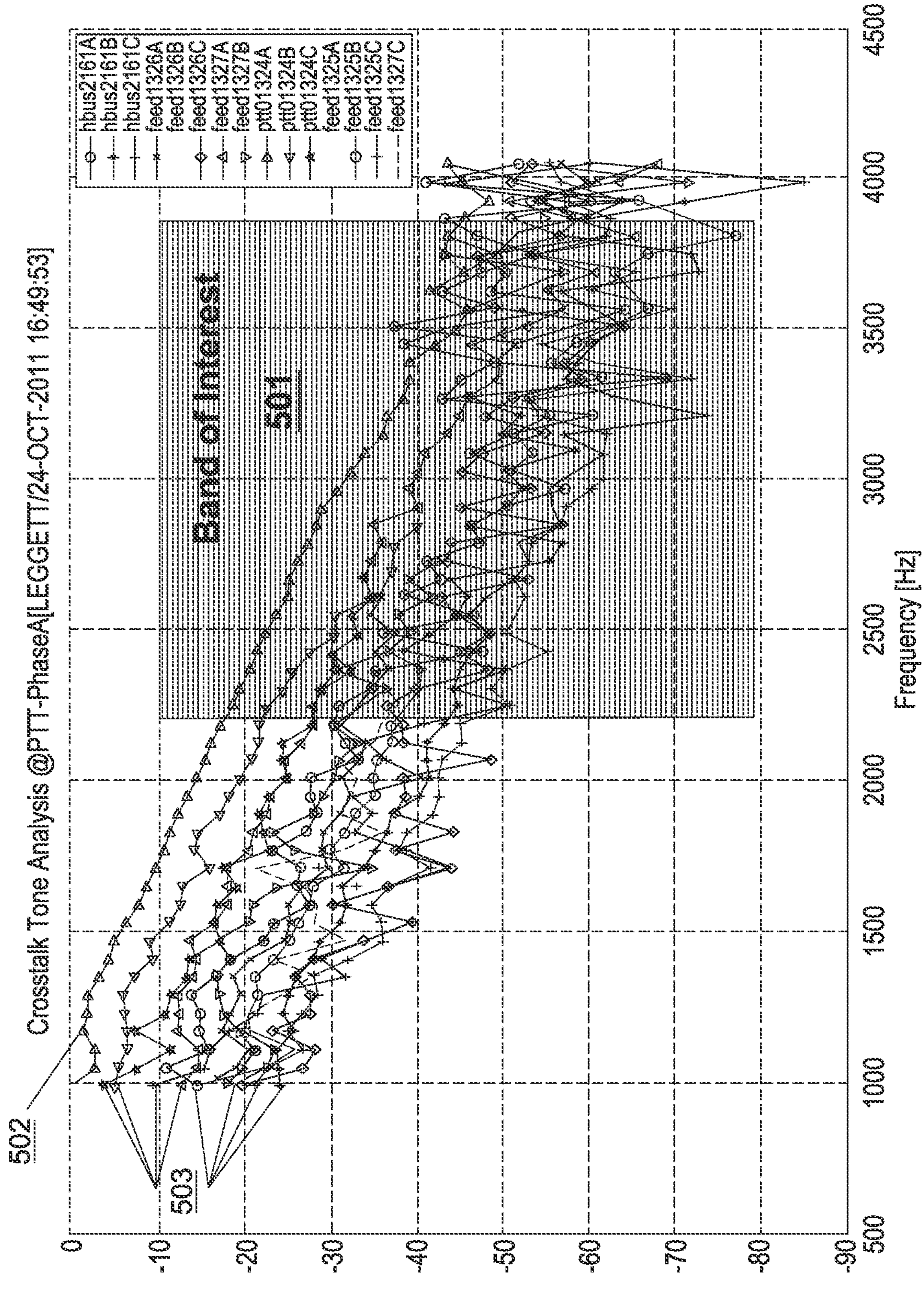

Crosstalk Tone Analysis @PTT-PhaseA[LEGGETT/24-OCT-2011 16:49:53]
502
503
Band of Interest
501
hbus2161A
hbus2161B
hbus2161C
feed1326A
feed1326B
feed1326C
feed1327A
feed1327B
ptt01324A
ptt01324B
ptt01324C
feed1325A
feed1325B
feed1325C
feed1327C
RSSI [dB]
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
Frequency [Hz]
500
1000
1500
2000
2500
3000
3500
4000
4500

FIGURE 6

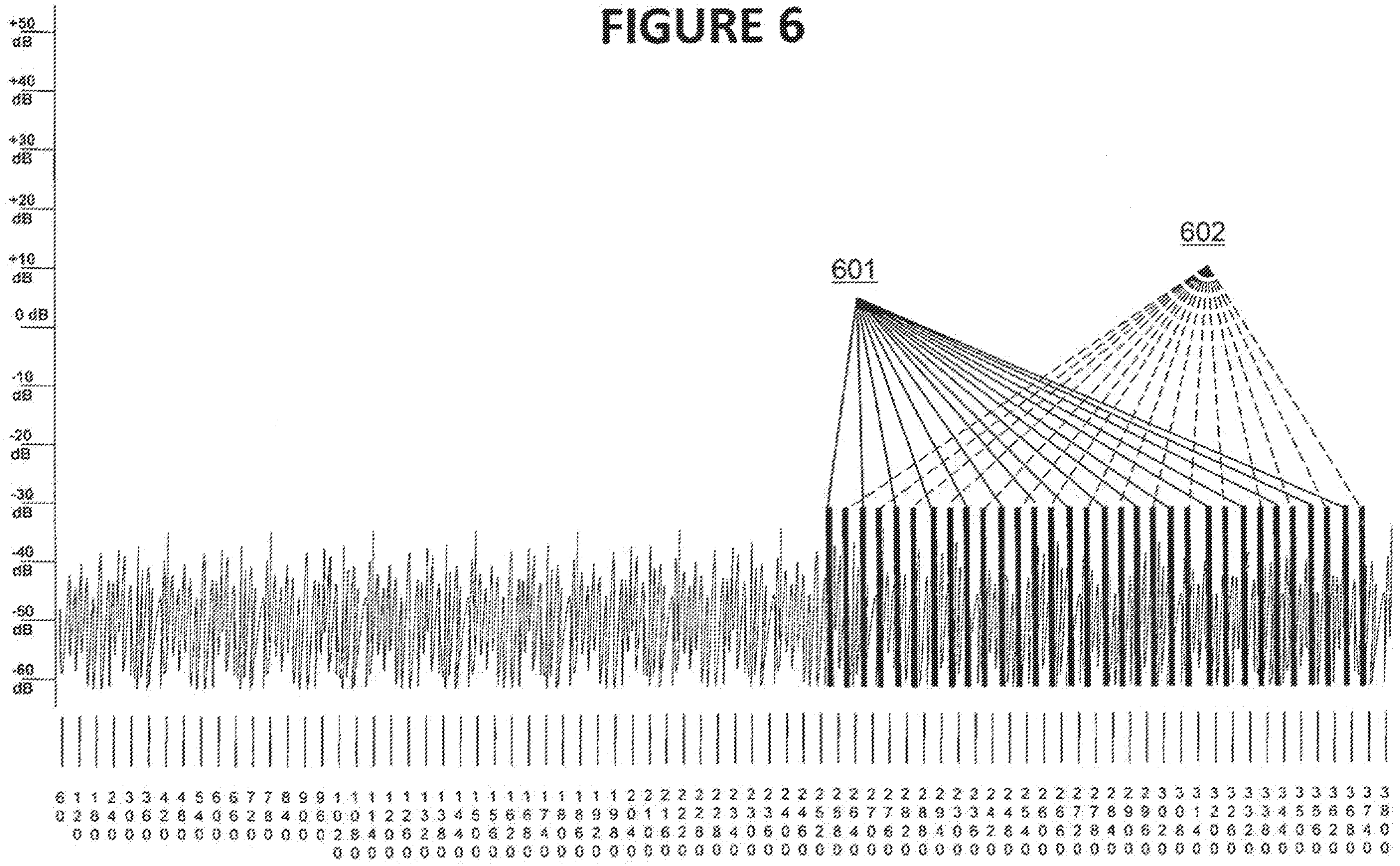
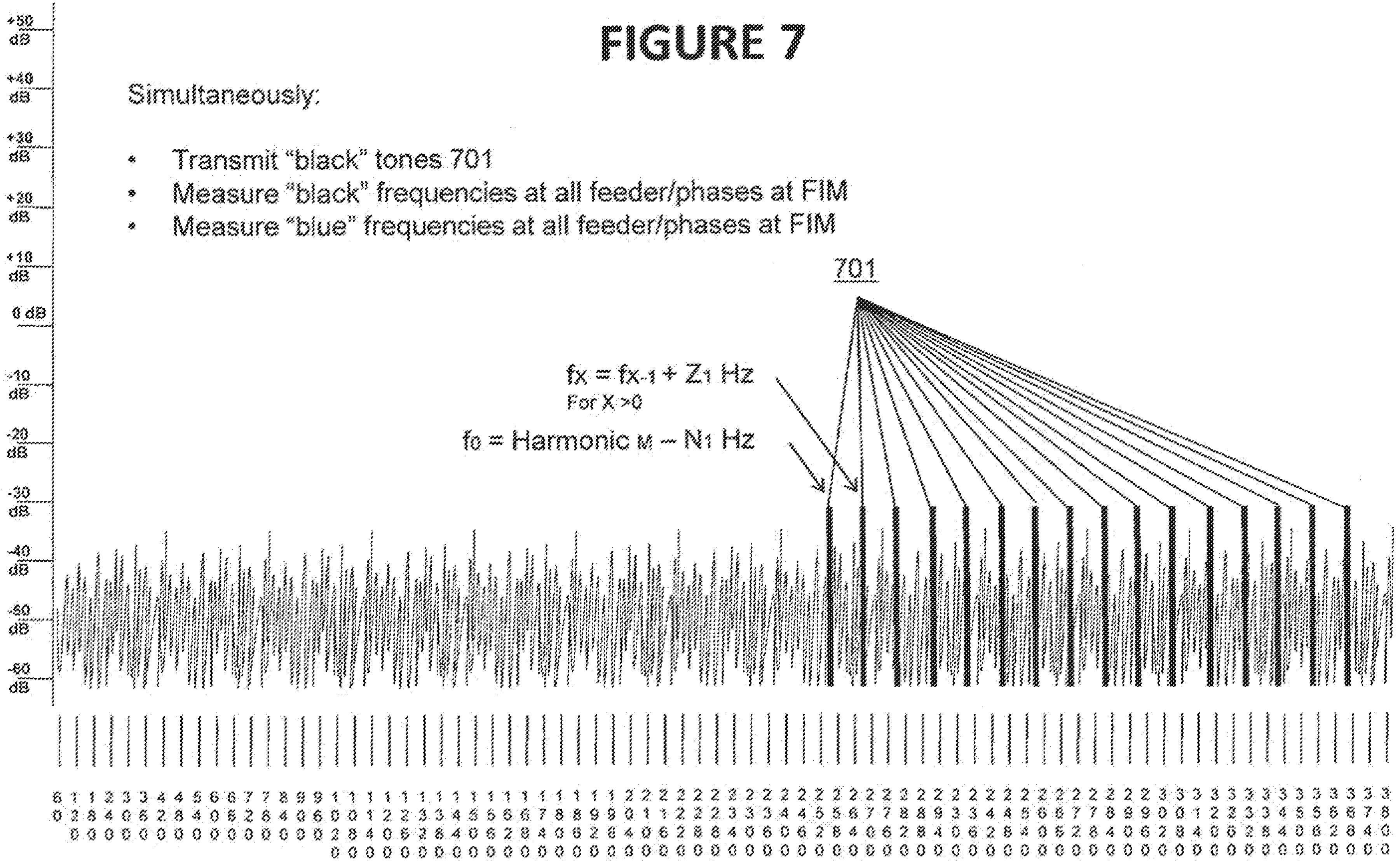

601
602
+50 dB
+40 dB
+30 dB
+20 dB
+10 dB
0 dB
-10 dB
-20 dB
-30 dB
-40 dB
-50 dB
-60 dB
60
120
180
240
300
360
420
480
540
600
660
720
780
840
900
960
1020
1080
1140
1200
1260
1320
1380
1440
1500
1560
1620
1680
1740
1800
1860
1920
1980
2040
2100
2160
2220
2280
2380
2340
2300
2360
2400
2460
2520
2580
2640
2700
2760
2820
2880
2940
2300
2360
2420
2460
2540
2600
2660
2720
2780
2840
2900
2960
3020
3080
3140
3200
3260
3320
3380
3440
3500
3560
3620
3680
3740
3800

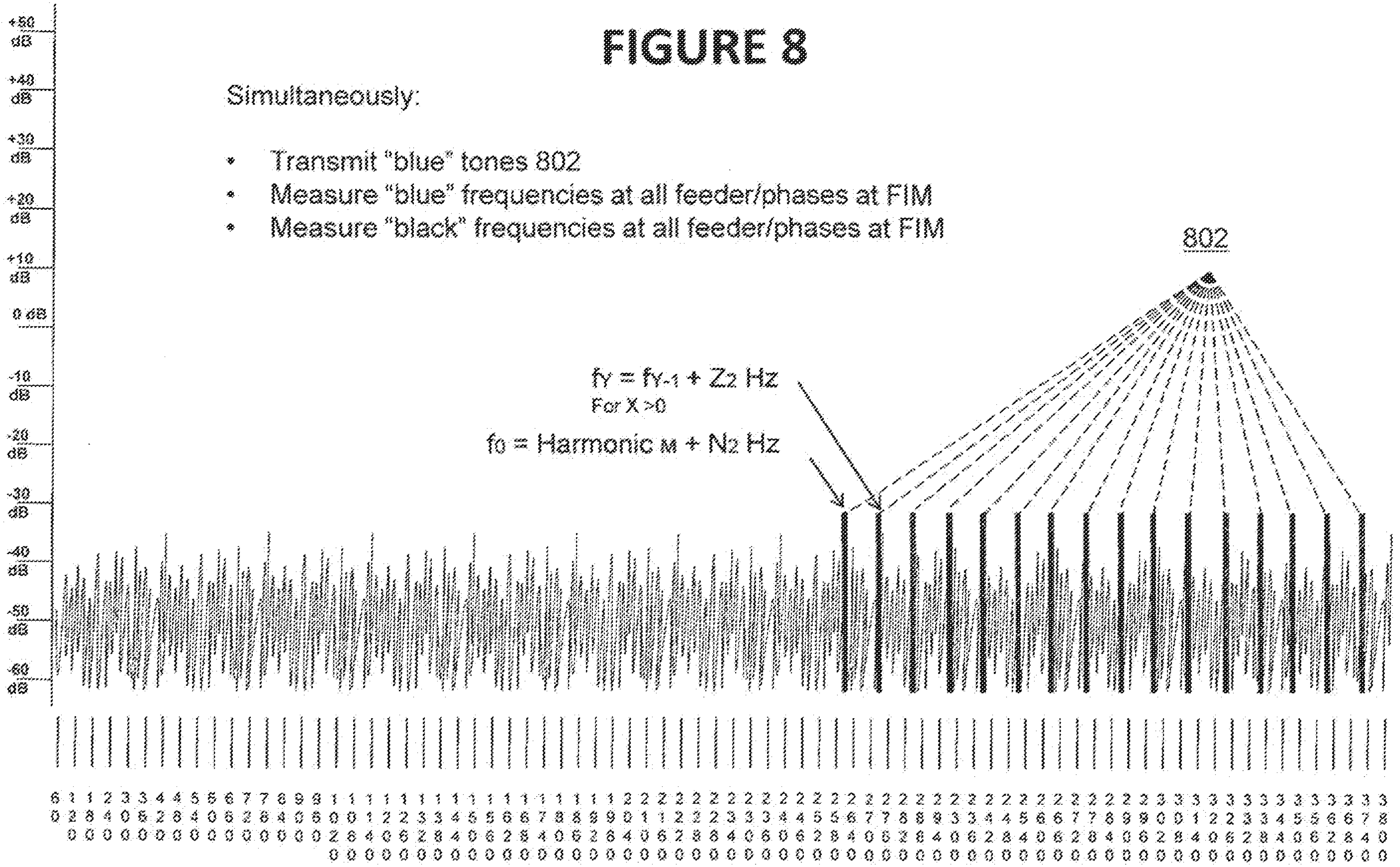
FIGURE 7



Simultaneously:

- Transmit "black" tones 701
- Measure "black" frequencies at all feeder/phases at FIM
- Measure "blue" frequencies at all feeder/phases at FIM

FIGURE 8



Simultaneously:

- Transmit "blue" tones 802
- Measure "blue" frequencies at all feeder/phases at FIM
- Measure "black" frequencies at all feeder/phases at FIM

FIGURE 9

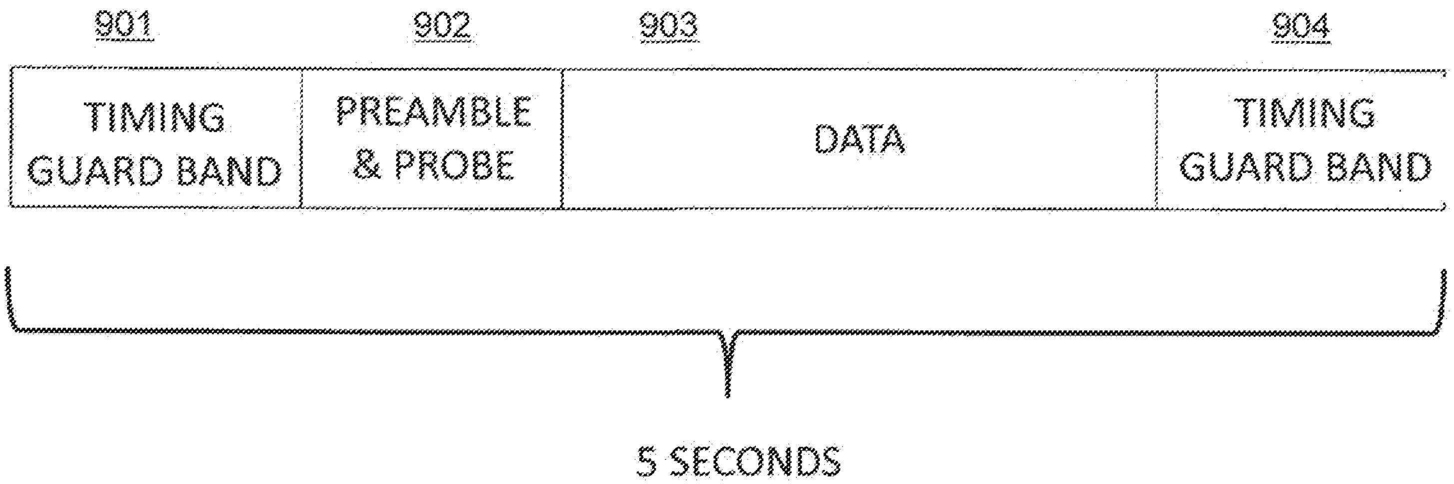
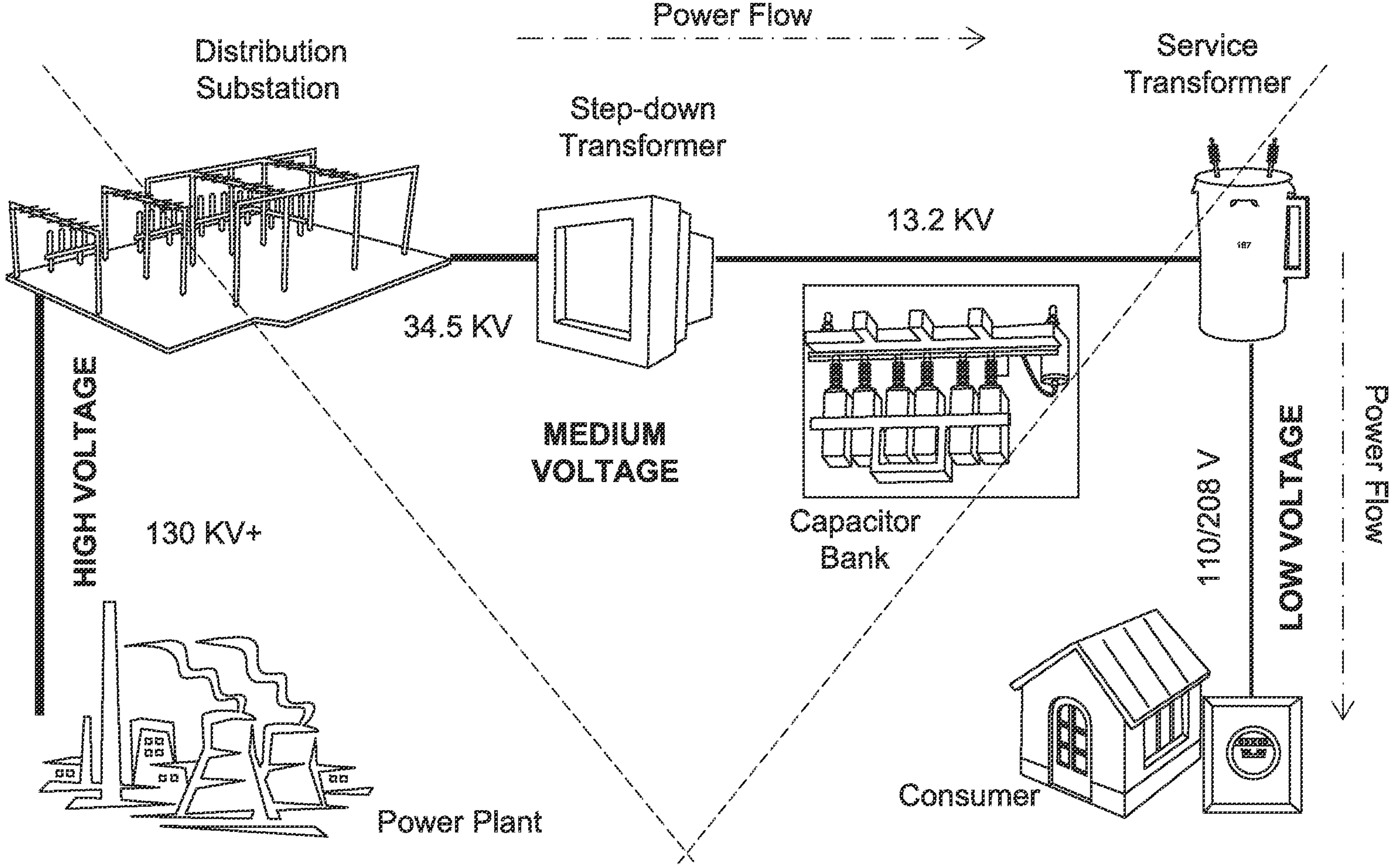

901
902
903
904
TIMING GUARD BAND
PREAMBLE & PROBE
DATA
TIMING GUARD BAND
5 SECONDS

FIGURE 10


Power Flow
Distribution
Substation
Step-down
Transformer
Service
Transformer
13.2 KV
34.5 KV
MEDIUM
VOLTAGE
HIGH VOLTAGE
130 KV+
Capacitor
Bank
110/208 V
LOW VOLTAGE
Power Flow
Power Plant
Consumer

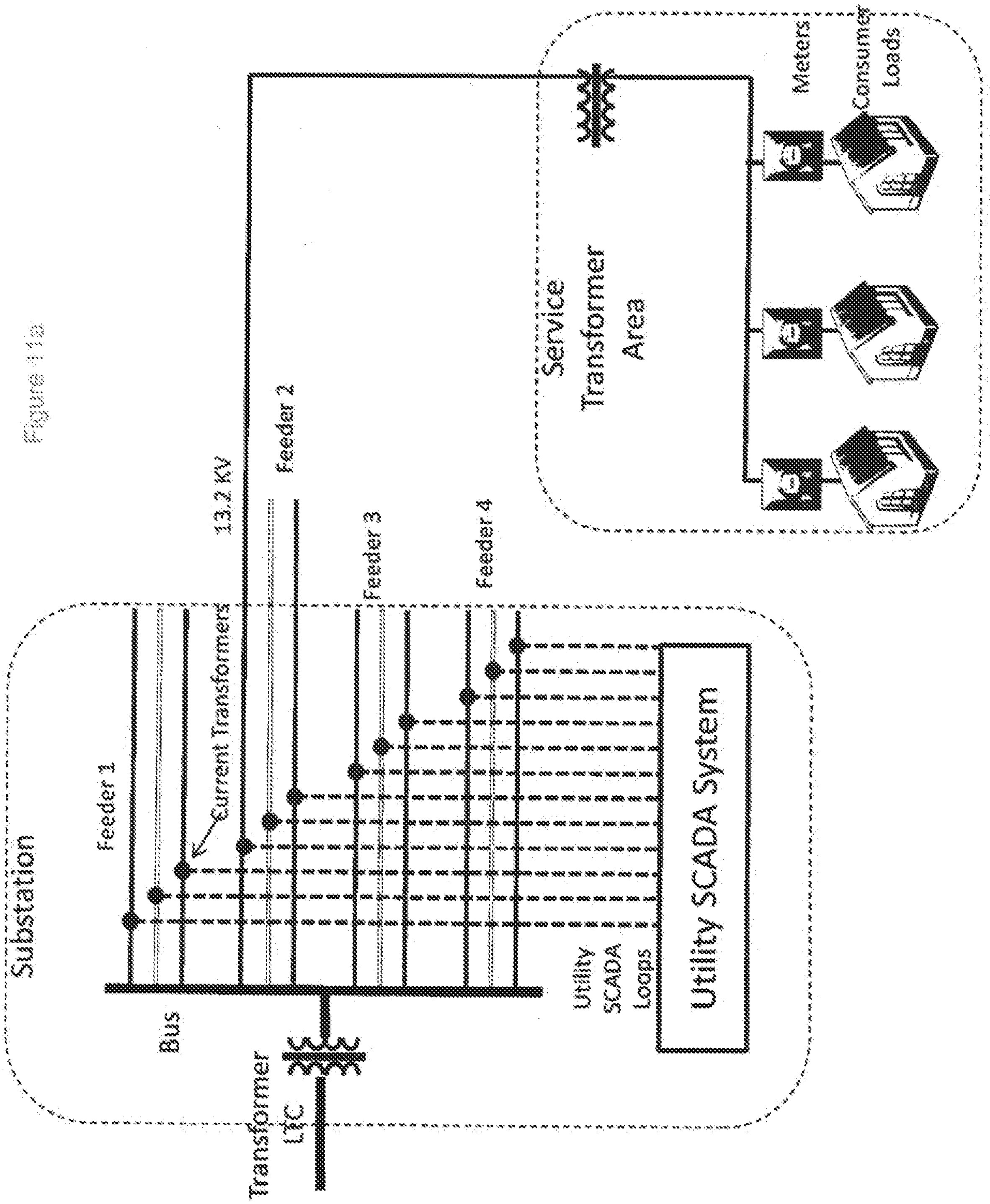

Substation
Feeder 1
Current Transformers
13.2 KV
Feeder 2
Feeder 3
Feeder 4
Bus
Transformer
LTC
Utility
SCADA
Loops
Utility SCADA System
Service
Transformer
Area
Meters
Consumer
Loads

Figure 11a

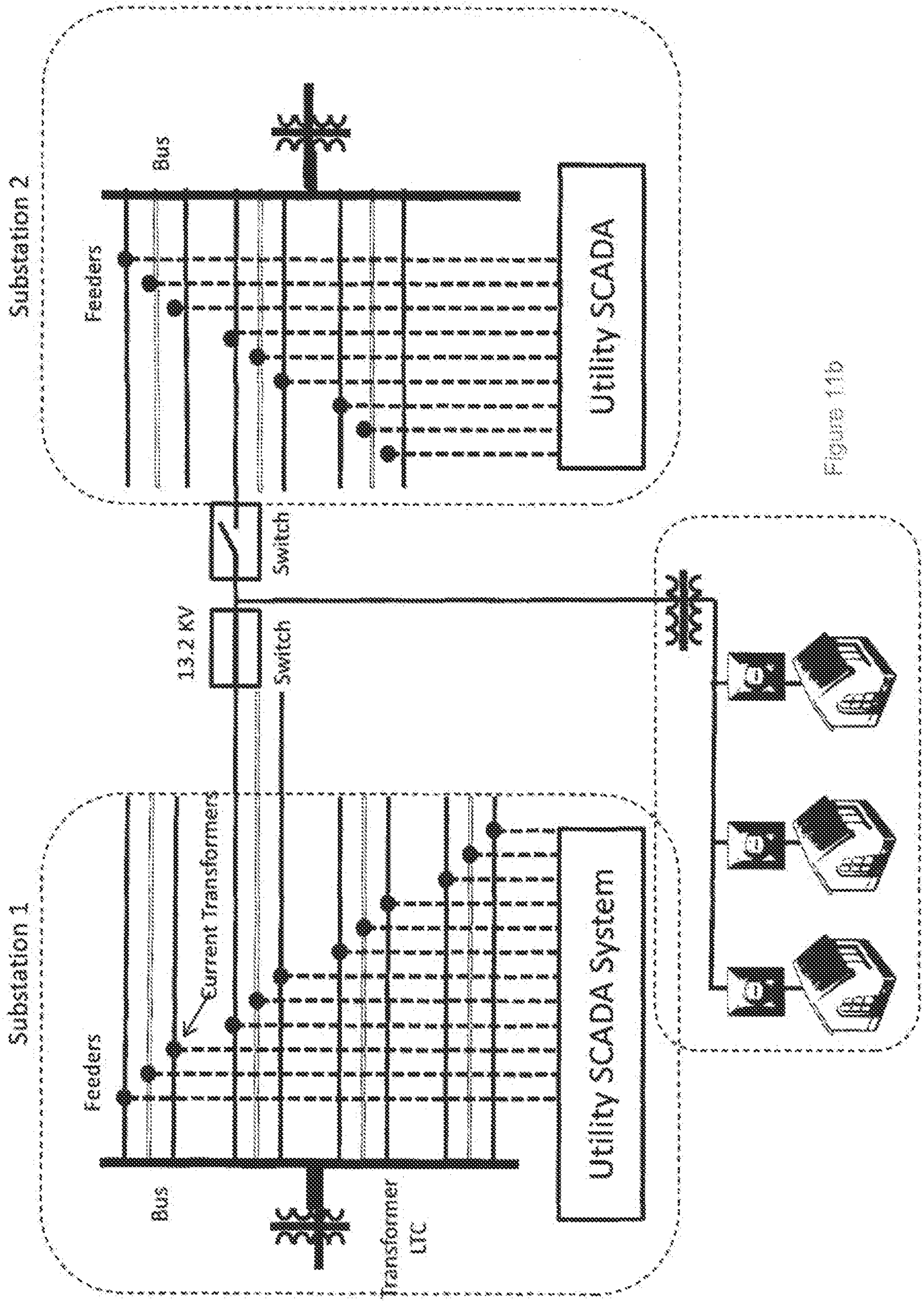

Substation 2
Bus
Feeders
Utility SCADA
Switch
13.2 KV
Switch
Substation 1
Feeders
Current Transformers
Bus
Transformer LTC
Utility SCADA System

Figure 11b

Figure 11c

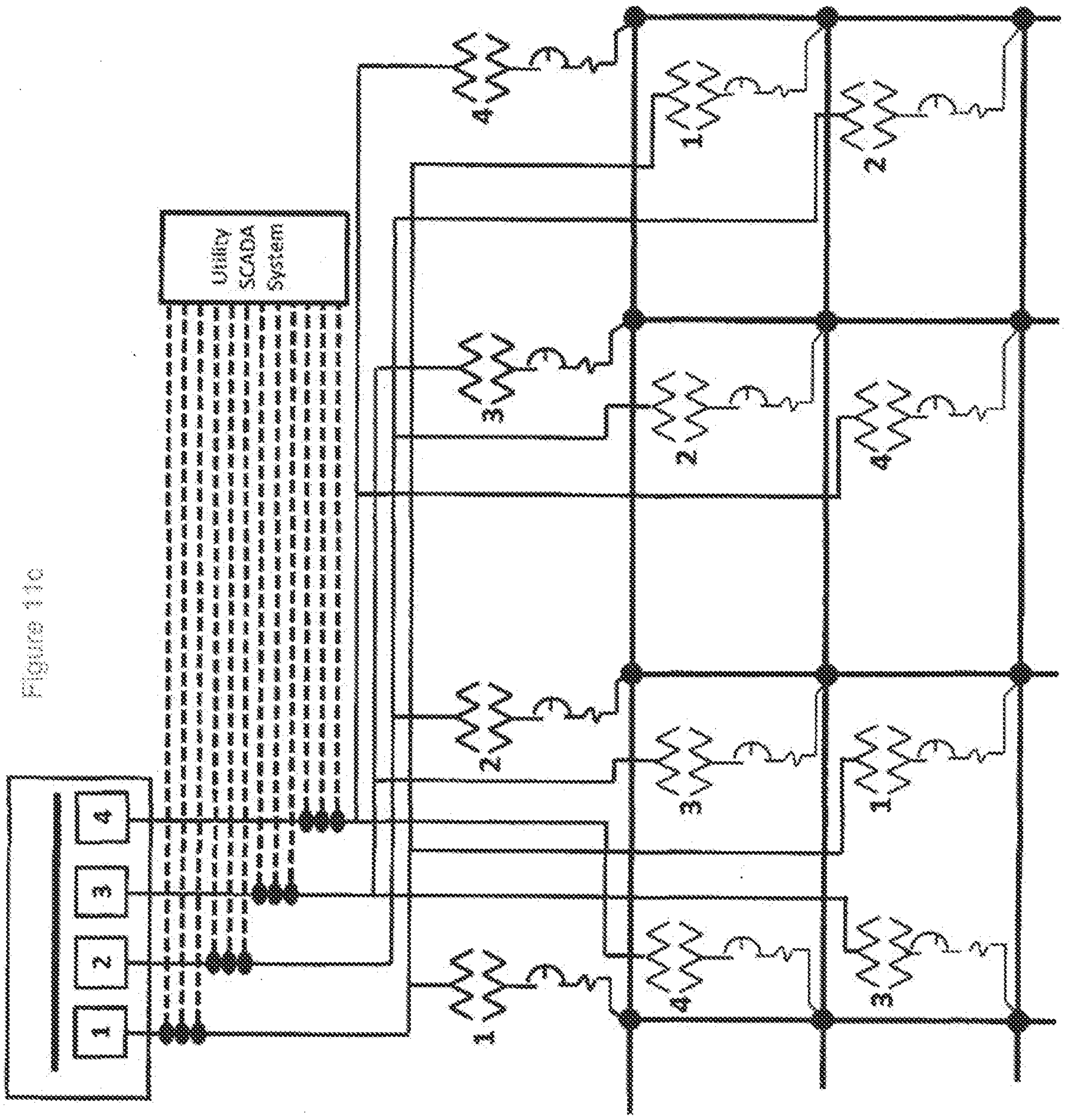
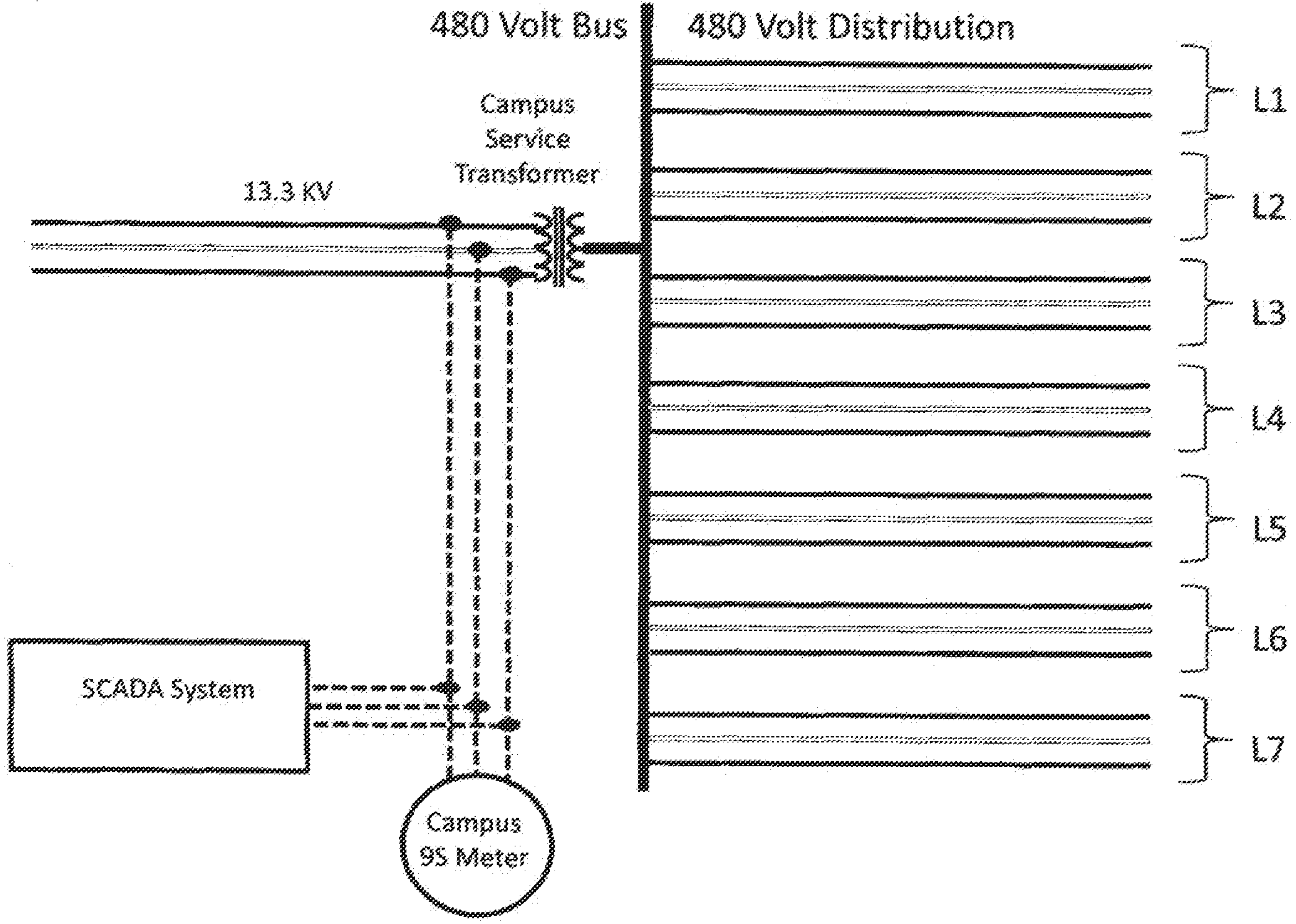


Figure 11d


480 Volt Bus
480 Volt Distribution
Campus Service Transformer
13.3 KV
L1
L2
L3
L4
L5
L6
L7
SCADA System
Campus 9S Meter

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US14/42393

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H04B 3/54, 3/06, 3/46 (2014.01)
CPC - H04B 3/54, 3/46; H04L 1/0023

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8): H04B 3/54, 3/06, 3/46 (2014.01)
CPC: H04B 3/54, 3/46; H04L 1/0023, 1/0001, 1/0002, 1/0004

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); Google Patent; Google Scholar; IEEE; Proquest; Total Patent; Korean Patent; Espacenet
Search terms used: circuit, topology, grid, power, feeder, phase, line, sensor, substation, transmit, policy, vote, signal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2012/0314868 A1 (BERNHEIM, H.) December 13, 2012; abstract, figure 1, paragraphs [0027]-[0030]	1, 5, 8, 9, 15-19 --- 2-4, 6, 7, 10-14, 20
Y	US 2012/0155557 A1 (BUSH, S. et al.) June 21, 2012; paragraph [0017]	2
Y	US 2010/0010857 A1 (FADELL, A.) January 14, 2010; paragraphs [0024], [0027]	3, 4, 6, 7
Y	US 7,701,330 B2 (IWAMURA, R.) April 20, 2010; column 16, lines 38-67	7, 10, 11
Y	US 7,571,028 B2 (LAPINSKI, S. et al.) August 04, 2009; column 4, lines 47-67, column 5, lines 1-8	12, 13
Y	US 7,069,117 B2 (WILSON, T. et al.) June 27, 2006; column 5, lines 28-39	14
Y	US 6,366,062 B2 (BARETICH, D. et al.) April 02, 2002; column 16, lines 65-67, column 17, lines 1-13	20
E, X	US 2014/0233662 A1 (HANSELL, J. et al.) August 21, 2014; abstract, figure 4, paragraphs [0072]-[0074]	1, 5, 8

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 24 September 2014 (24.09.2014)	Date of mailing of the international search report 20 OCT 2014
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Shane Thomas PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774