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(54) **CROSSTALK TEST UNIT AND METHOD OF CALIBRATION**

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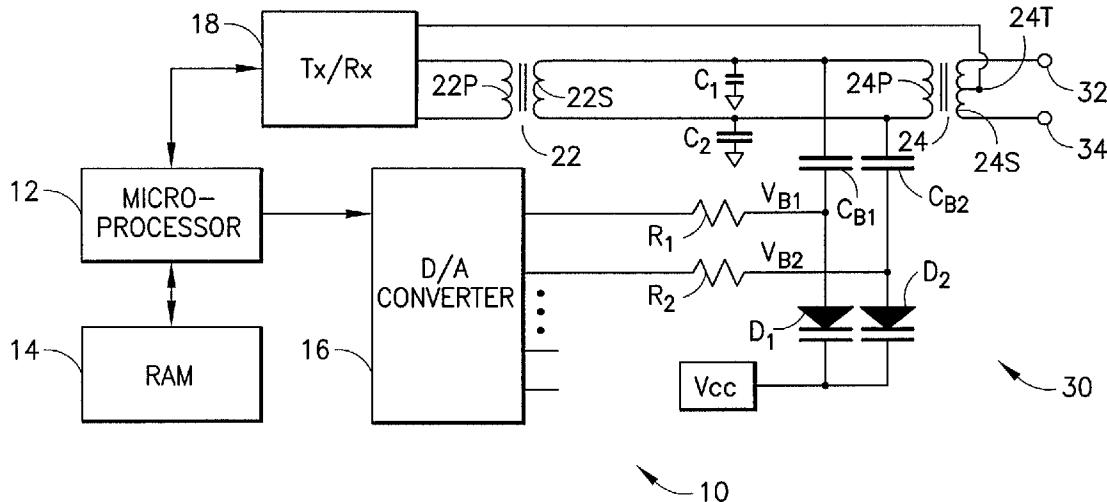
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**(57) ABSTRACT**

A test unit for measuring crosstalk in twisted pair cable. The test unit has an output signal balance (OSB) circuit that compensates for parasitic capacitance at its output terminals. The OSB circuit has a voltage controlled capacitance connected in circuit with each output terminal to control the effective capacitance between the output terminals and ground. The bias voltage for the variable capacitances is calibrated by a method in which the voltage for one of the variable capacitors is held constant while the voltage for the other capacitor is varied in voltage levels. A test signal frequency sweep is applied to the test unit output terminals. First and second voltage values are obtained and a final bias voltage value is calculated from using these two values.

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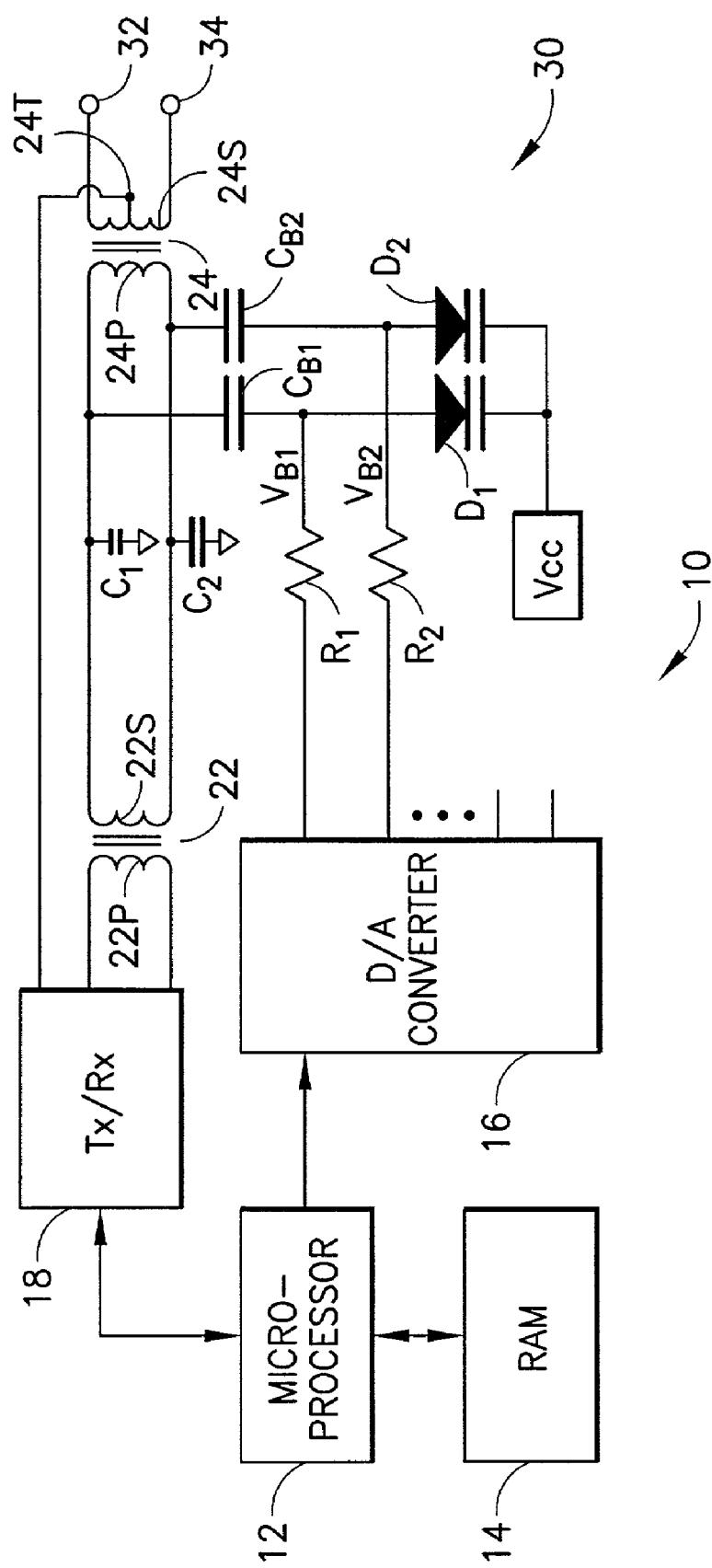


FIG. 1

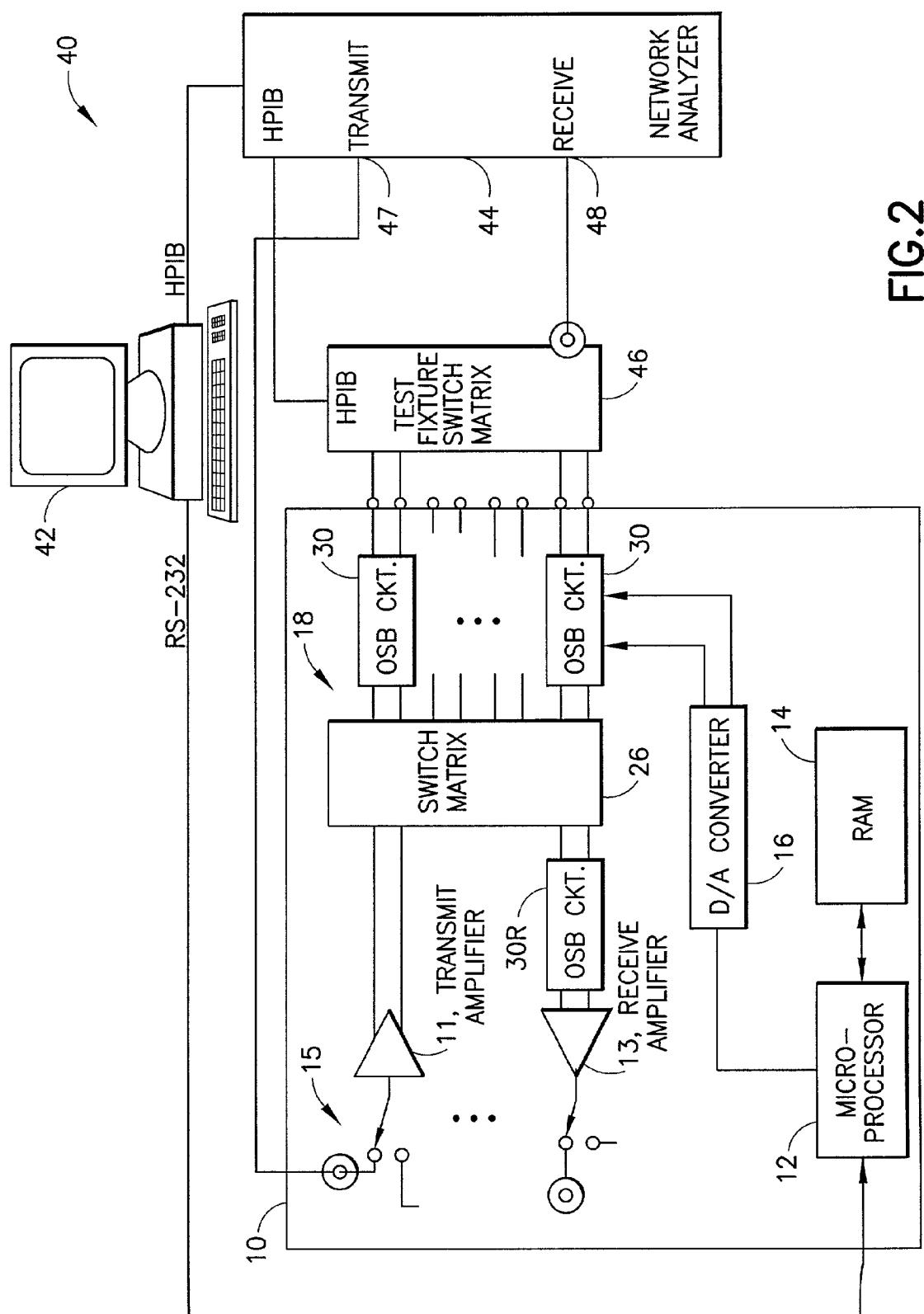


FIG. 2

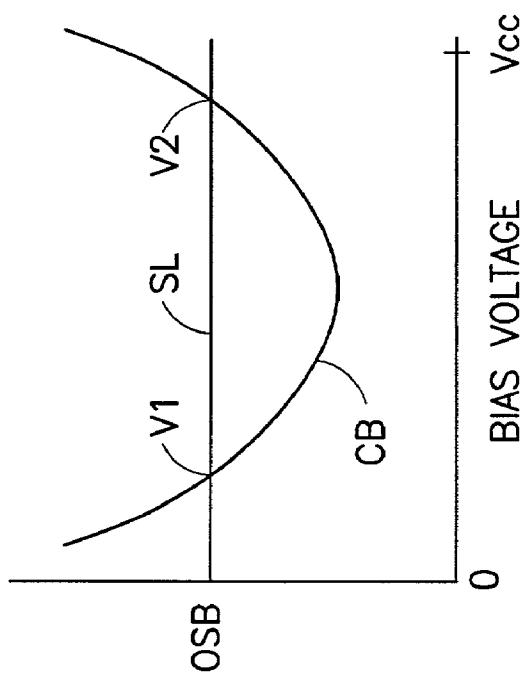


FIG. 4

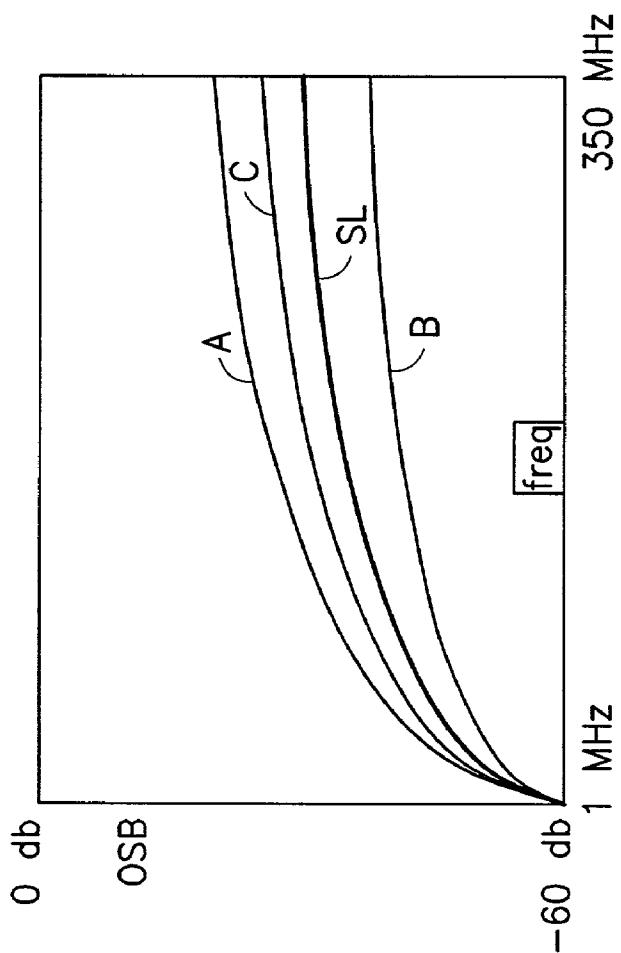


FIG. 3

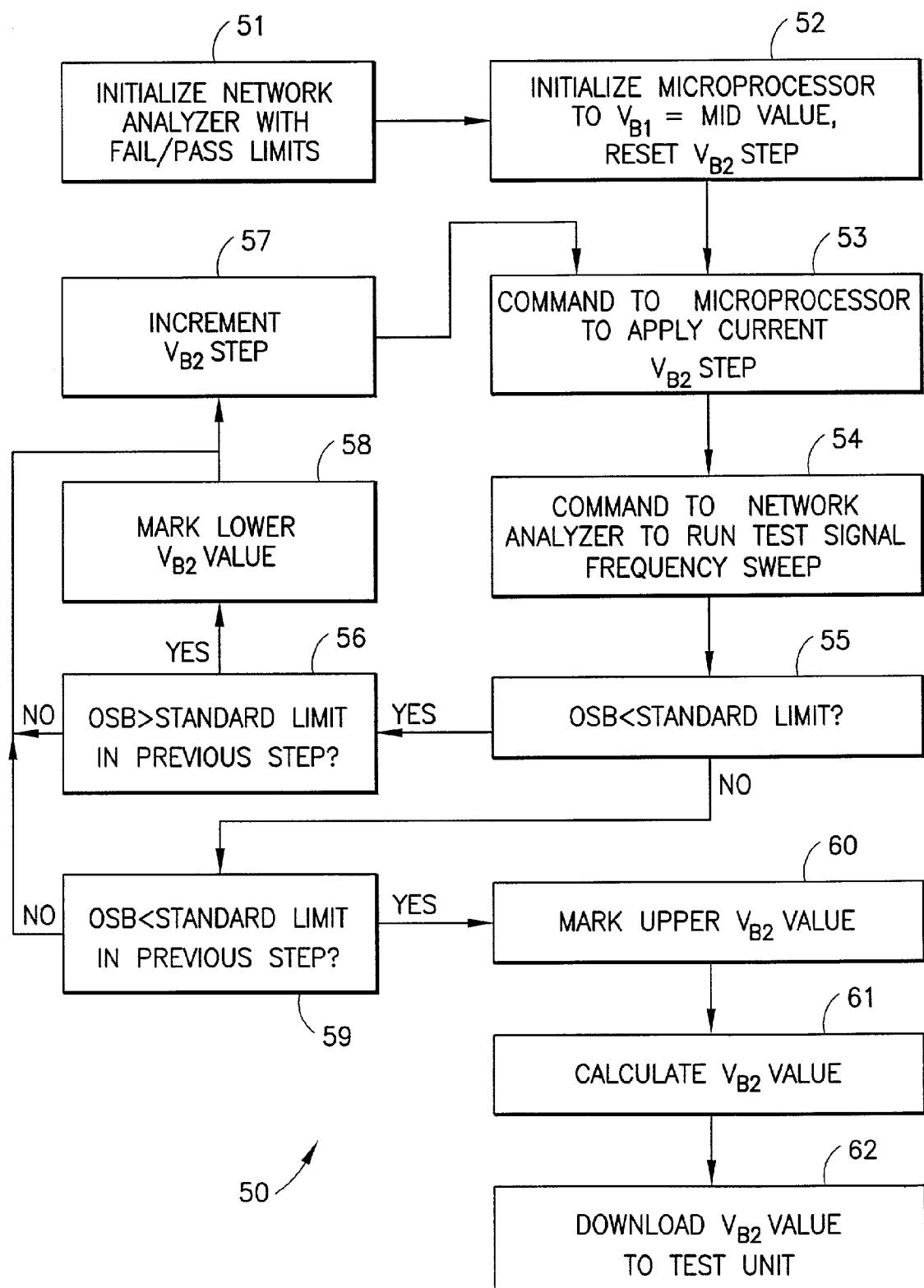


FIG.5

## CROSSTALK TEST UNIT AND METHOD OF CALIBRATION

### FIELD OF THE INVENTION

**[0001]** This invention relates to the measurement of crosstalk in a multi-pair cable. In particular, the invention relates to a test unit with minimized output signal imbalance and common mode susceptibility and to a method for calibrating the test unit.

### BACKGROUND OF THE ART

**[0002]** Crosstalk in a multi-pair cable is the unwanted coupling of signals from one wire pair to another. When crosstalk is measured at the same end of the cable where the crosstalk originates, the technique is called near end crosstalk (NEXT) measurement. Twisted pair LAN technologies, such as 10BASE-T, 100BASE-T, and Token Ring are primarily vulnerable to cable crosstalk problems that can be tested by measuring the NEXT of the installed cable.

**[0003]** When crosstalk is measured at the end of the cable opposite from where the crosstalk originates, the technique is called far end crosstalk (FEXT) measurement. FEXT is measured by applying a test signal to a wire pair at a far end of the cable and measuring the disturbance on the other wire pairs in the cable at the other or near end. It is relevant to specify the FEXT performance of cabling for network technologies, such as the new 1000BASE-T specification, that transmit simultaneously on multiple wire pairs in the same direction.

**[0004]** While it is easy to measure the FEXT performance of an installed multi-pair cable, it is difficult to specify certification limits for such measurements since FEXT varies with the cable length. The equal level far end crosstalk (ELFEXT) measurement technique was developed as a practical alternative for field certification. Generally, ELFEXT equals FEXT minus attenuation caused by the cable. ELFEXT measurements compensate for the effect of varying cable length so that all installed cable can be certified to the same limit.

**[0005]** Residual crosstalk is any signal that is due to the test instrument itself. Residual crosstalk error must be taken into account in crosstalk measurement analysis.

**[0006]** A test signal is generally applied to a wire pair in a differential mode. That is, the signals on the wires of a wire pair are ideally equal in amplitude and opposite in phase (180° out of phase). These conditions reflect an ideal output signal balance (OSB). A differential receiver, receiving a signal with common mode and differential mode components of the wires, will ideally reject the common mode component and respond only to the differential component. This characteristic reflects an ideal common mode rejection (CMR).

**[0007]** However, these conditions are hard to achieve due to imperfect components used to make the test unit and to asymmetries in layout. For example, the output terminals of a test unit can have unbalanced parasitic capacitances. In the past, such imbalance has been minimized by careful selection of components and layout or placement within the test unit assembly. This selection and placement process has been costly and time consuming.

**[0008]** Accordingly there is a need for a test instrument that minimizes deviation of OSB and CMR from the perfect or ideal conditions of equal amplitude and opposite phase. There is also a need for a method to calibrate such an instrument.

### SUMMARY OF THE INVENTION

**[0009]** A test unit for conducting crosstalk measurements of a cable under test according to the present invention has a plurality of pairs of output terminals. Each pair of output terminals has a first terminal and a second terminal that have first and second parasitic capacitances, respectively. A first variable capacitor is coupled to the first terminal to form a first effective capacitance value that includes the first parasitic capacitance. A second variable capacitor is coupled to the second terminal to form a second effective capacitance value that includes the second parasitic capacitance. A controller sets the first and second variable capacitors to a first predetermined value and a second predetermined value, respectively. The first predetermined value and the second predetermined value are selected such that the first effective capacitance value is substantially equal to the second effective capacitance value.

**[0010]** The variable capacitors are preferably varactors that exhibit a variable capacitance that is voltage controlled. The controller sets the first and second predetermined values by controlling a first bias voltage and a second bias voltage applied to the first and second varactors, respectively.

**[0011]** A method according to the present invention calibrates the output signal balance of the test unit by calibrating, the test unit when it is not connected to a cable. First the first bias voltage is set to a predetermined value. The second bias voltage is then sequentially set to n voltage values. A test signal frequency sweep is applied to the first and second output terminals for each of the n voltage values. An OSB response is measured during each test signal frequency sweep. A first voltage value is marked when the OSB response becomes lower than a predetermined limit. A second voltage value is marked when the OSB response subsequently becomes larger than the standard limit. A bias voltage value is then calculated using the first and second voltage values. The bias voltage is then downloaded to the test unit.

### BRIEF DESCRIPTION OF THE DRAWINGS

**[0012]** Other and further objects, advantages and features of the present invention will be understood by reference to the following specification in conjunction with the accompanying drawings, in which like reference characters denote like elements of structure and:

**[0013]** FIG. 1 is a circuit schematic diagram in part and a block diagram in part of a test unit according to the present invention;

**[0014]** FIG. 2 is a block diagram of a calibration system for calibrating the FIG. 1 test unit;

**[0015]** FIG. 3 is a graph of OSB versus frequency for optimized bias voltage values;

**[0016]** FIG. 4 is a graph of OSB versus bias voltage;

**[0017]** FIG. 5 is flow diagram of a calibration procedure performed by the computer and network analyzer of FIG. 2 for the test unit according to the invention.

## DESCRIPTION OF PREFERRED EMBODIMENT

[0019] With reference to **FIG. 1**, there is provided a test unit generally represented by numeral **10**. Test unit **10** has a microprocessor **12**, a random access memory (RAM) **14**, a digital to analog (D/A) converter **16**, a transmit/receive (Tx/Rx) measurement section **18**, a transformer **22**, a transformer **24** and an output signal balance circuit **30**.

[0020] Test unit **10** generally performs crosstalk measurements of a cable (not shown in **FIG. 1**) by way of a pair of output terminals **32** and **34**. The cable is a multi-pair cable that has a plurality of twisted wire pairs. For example, the cable may be of a type that is used in a local area network (LAN) for coupling computer terminals and servers in a network. When connected to test the cable, output terminals **32** and **34** are connected to one of the wire pairs of the cable.

[0021] Microprocessor **12** directs measurement procedures by means of operating Tx/Rx measurement section **18** to transmit, receive and process signals via output terminals **32** and **34** to the wire pair under test. The measurement procedures and test parameters are stored in RAM **14** and accessed by microprocessor **12**. RAM **14** may include non-volatile memory in whole or in part.

[0022] Test signals are translated between output terminals **32** and **34** and Tx/Rx measurement section **18** via transformer **22** and **24**. Transformer **22** is connected in series with transformer **24**. Transformer **22** has a primary winding **22P** connected with Tx/Rx measurement section **18** and a secondary winding connected with a primary winding **24P** of transformer **24**. Transformer **24** has a secondary winding **24S** that is connected to output terminals **32** and **34**. These connections permit the translation of test signals in a differential mode via output terminals **32** and **34** with the cable under test.

[0023] Secondary winding **24S** has a center tap **24T** that is connected with Tx/Rx measurement section **18**. This connection permits the translation of signals in a common mode via output terminals **32** and **34** with the cable under test. That is, the signals on the wires of a wire pair are ideally equal in amplitude and phase.

[0024] Output terminal **32** has a parasitic capacitance **C<sub>1</sub>**, shown as a shunt capacitor to circuit ground or other reference. Similarly, output terminal **34** has a parasitic capacitance **C<sub>2</sub>**, shown as a shunt capacitor to circuit ground. These parasitic capacitances **C<sub>1</sub>** and **C<sub>2</sub>** are shown as coupled to terminals **32** and **34** by transformer **24**. These parasitic capacitances **C<sub>1</sub>** and **C<sub>2</sub>** arise from the components used in test unit **10** as well as their layout in assembly. Parasitic capacitances **C<sub>1</sub>** and **C<sub>2</sub>** are generally unequal in value. This causes a deviation or variance from an ideal OSB and CMR.

[0025] In accordance with the present invention, OSB circuit **30** is provided to minimize any such deviation. OSB circuit **30** includes a first active device **D<sub>1</sub>** connected in parallel with parasitic capacitance **C<sub>1</sub>** and a second active device **D<sub>2</sub>** connected in parallel with parasitic capacitance **C<sub>2</sub>**. Active devices **D<sub>1</sub>** and **D<sub>2</sub>** have a capacitance that varies with an applied voltage. Active devices **D<sub>1</sub>** and **D<sub>2</sub>** may suitably be varactors that under normal operating conditions are in a reverse bias condition. Active devices **D<sub>1</sub>** and **D<sub>2</sub>** have their cathodes connected to a d. c. voltage source **VCC**. Active device **D<sub>1</sub>** has its anode connected via a resistor **R<sub>1</sub>** to D/A converter **16** and active device **D<sub>2</sub>** has its anode connected via a resistor **R<sub>2</sub>** to D/A converter **16**.

[0026] A d. c. blocking capacitor **C<sub>B1</sub>** is connected in series with active device **D<sub>1</sub>**. A d. c. blocking capacitor **C<sub>B2</sub>** is connected in series with active device **D<sub>2</sub>**.

[0027] Microprocessor **12** causes D/A converter **16** to apply predetermined bias voltages **VB<sub>1</sub>** and **VB<sub>2</sub>** to the anodes of active devices **D<sub>1</sub>** and **D<sub>2</sub>**, respectively. The values of **VB<sub>1</sub>** and **VB<sub>2</sub>** are selected to operate active devices **D<sub>1</sub>** and **D<sub>2</sub>** in a reverse bias condition and to yield a first effective capacitance between output terminal **32** and ground and a second effective capacitance between output terminal **34** and ground, the first and second effective capacitances being substantially equal. Microprocessor **12** accomplishes this by means of **VB<sub>1</sub>** and **VB<sub>2</sub>** parameters or values that are stored in RAM **14** and used to generate the **VB<sub>1</sub>** and **VB<sub>2</sub>** voltages.

[0028] Varactors **D<sub>1</sub>** and **D<sub>2</sub>** are preferably packaged in the same semiconductor assembly to achieve nearly identical varactors as well as common temperature compensation. For example, varactors **D<sub>1</sub>** and **D<sub>2</sub>** may suitably be M/A-COM part number MA4ST083CK.

[0029] Though OSB circuit **30** is shown as connected to the primary winding **24P** of transformer **24**, it could just as well be connected directly to terminals **32** and **34** or to the primary winding **22P** of transformer **22**.

[0030] Though test unit **10** is shown in **FIG. 1** with a single pair of output terminals, test unit **10** may have a plurality of pairs of output terminals with each having a separate OSB circuit. For example test unit **10** may have four pairs of output terminals for testing of a conventional cable that has four twisted wire pairs. D/A converter **16** is shown in **FIG. 1** to have additional pairs of output leads for the additional OSB circuits.

[0031] Referring to **FIG. 2**, there is shown a system **40** for the calibration of test unit **10** to set the **VB<sub>1</sub>** and **VB<sub>2</sub>** parameters for the frequency range of interest. Calibration system **40** includes a computer **42**, a network analyzer **44** and a switch matrix **46**. Computer **42** is connected with network analyzer via a standard test bus **HPIB** and to test unit **10** via a standard serial interface **RS-232**. Computer **42** may suitably be a personal computer that has a memory in which is stored calibration procedures for controlling network analyzer **44** and test unit **10**.

[0032] Tx/Rx measurement section **18** of test unit **10** includes a transmit amplifier **11**, a receive amplifier **13**, a calibration mode switch **15**, and a switch matrix **26**. Transformers, such as **22** and **24** of **FIG. 1** are not shown in **FIG. 2** to avoid clutter. Calibration switch **15** is shown in the calibration position in **FIG. 2** to allow test signals to be injected into amplifier **11** by network analyzer **44** or taken from receive amplifier **13** by network analyzer **44**. Test unit **10** also includes a separate OSB circuit **30** for each of four pairs of output terminals.

[0033] Network analyzer **44** is conventional. It has a transmit terminal **47** that is connected to transmit amplifier **11** for the purpose of injecting a test signal into test unit **10**. The injected test signal is applied via switch matrix **26** to a selected one of OSB circuits **20** as directed by microprocessor **12** under the control of computer **42**. Network ana-

lyzer has a receive terminal **48** that receives the injected test signal from the selected OSB circuit **20** via test switch matrix **46**.

[0034] Referring to FIG. 3, a set of curves A, B, C and SL illustrate that OSB by nature deteriorates as signal frequency increases. Curve SL is a standard limit, such as Telecommunications Industry Association level III OSB limit.

[0035] The calibration process involves injecting a test signal frequency sweep into transmit amplifier **11** for each of n step values of one of the bias voltages to find the bias voltage value that most nearly reflects the standard limit over the frequency range of interest.

[0036] Referring to FIG. 4, the standard limit at a particular frequency is shown as an OSB level SL. A curve CB represents for test unit **10** the values of OSB at this particular frequency as a function of bias voltage, and shows how the OSB varies above and below the standard limit.

[0037] According to the calibration method of the present invention, one of the bias voltages is set to a mediate value in its range and the other bias voltage is varied in steps over its range. A frequency sweep test signal is applied via transmit amplifier **11** by network analyzer **44** for each step level. For example,  $VB_1$  is set to a mediate value of say 2.5 volts for a range of 5 volts.

[0038] Bias voltage  $VB_2$  is then sequentially set to n step values. For each step value, network analyzer **44** injects a frequency sweep signal via transmit amplifier **11**, receives the signal at receive terminal **48** and measures the OSB response with reference to the standard limit OSB value. The frequency sweep signal varies in frequency across the range of interest. With reference to FIG. 4, a first voltage value  $V1$  is marked when the OSB response first falls below the standard limit. A second voltage value  $V2$  is marked when the OSB response rises above the standard limit. The desired value of  $VB_2$  is calculated using the  $V1$  and  $V2$  values. For example,  $VB_2$  is simply the midpoint between  $V1$  and  $V2$ .

[0039] Referring to FIG. 5, there is shown a flow diagram of a calibration procedure **50** that is used by computer **42** to control microprocessor **12** and network analyzer **44** when calibrating test unit **10**. Calibration procedure **50** begins at a step **51** with the initialization of network analyzer **44** with the fail/pass standard limit. At a step **52**, microprocessor **12** is initialized to a  $VB_1$  value mediate of its range. Also,  $VB_2$  is reset to an initial step value.

[0040] Computer **42** at a step **53** issues a command to microprocessor **12** to apply the current  $VB_2$  step level of bias voltage to OSB circuit **30**. At a step **54**, computer **42** issues a command to network analyzer **44** to run a test signal frequency sweep. Computer **42** then at a step **55** determines if the OSB is less than the standard limit. If not, computer **42** next determines at a step **59** if the OSB was less than the standard limit during the previous step level. If not, the  $VB_2$  step level is incremented to the next step level. The process described by steps **53**, **54**, **55**, **59** and **57** reiterates until step **55** determines that the OSB is less than the standard limit.

[0041] When step **55** determines that the OSB is less than the standard limit, computer **42** next determines at a step **56** if in the previous step level, the OSB was greater than the standard limit. If not, the  $VB_2$  voltage level is incremented to the next voltage level at a step **57**. If the OSB was greater

than the standard limit in the previous step, the current bias voltage level is marked as a  $V1$  value that corresponds to the value  $V1$  in FIG. 4. The  $VB_2$  voltage level is then incremented at step **57**.

[0042] The process defined by steps **53** through **57** then reiterates until step **55** determines that the OSB is once again is not less than the standard limit. When this happens, computer **42** then determines if the OSB was less than the standard limit for the previous bias voltage level. If so the current bias voltage level is marked at a step **60** as a  $V2$  value that corresponds to the  $V2$  value of FIG. 4. Next, computer **42** calculates the  $VB_2$  value at a step **61**. For example, the  $VB_2$  value can be calculated as a value midway between the  $V1$  and  $V2$  values. The calculated  $VB_2$  value is then downloaded to microprocessor **12** at a step **62**.

[0043] Referring again to FIG. 3, an OSB circuit **30R** is coupled to the differential leads from switch matrix **26** to receive amplifier **30** to compensate for any OSB or CMR imbalance on these leads. OSB circuit **30R** is identical to OSB circuits **30**. A calibration procedure substantially similar to the one shown in FIG. 5 is used to calibrate OSB circuit **30R**, except that network analyzer **44** has its transmit terminal connected to test fixture switch matrix **46** and its receive terminal connected to the output of receive amplifier **13**.

[0044] It will be apparent to those of skill in the art that the active balancing technique can be applied on any differential signal for OSB and/or CMR.

[0045] The present invention having been thus described with particular reference to the preferred forms thereof, it will be obvious that various changes and modifications may be made therein without departing from the spirit and scope of the present invention as defined in the appended claims.

What is claimed is:

1. A test unit for conducting crosstalk measurements of a cable under test, said test unit comprising:
  - a plurality of pairs of output terminals, each pair of output terminals having a first terminal with a first parasitic capacitance and a second terminal with a second parasitic capacitance;
  - a first variable capacitor connected in circuit with said first terminal to form a first effective capacitance value including said first parasitic capacitance;
  - a second variable capacitor connected in circuit with said second terminal to form a second effective capacitance value including said second parasitic capacitance; and
  - a controller for setting said first variable capacitor to a first predetermined value and said second variable capacitor to a second predetermined value, said first predetermined value and said second predetermined value being selected such that said first effective capacitance value is substantially equal to said second effective capacitance value, whereby the effect of unequal values of said first and second parasitic capacitances on an output signal balance of said first and second terminals is minimized.
2. The test unit of claim 1, wherein said first variable capacitor is a first varactor and said second variable capacitor is a second varactor, and wherein said controller sets said first and second predetermined values by controlling a first

bias voltage and a second bias voltage applied to said first and second varactors, respectively.

**3.** The test unit of claim 2, wherein said first varactor is coupled in parallel with said first parasitic capacitance and said second varactor is coupled in parallel with said second parasitic capacitance.

**4.** The test unit of claim 3, wherein said first and second varactors are always reverse biased when a crosstalk measurement is performed.

**5.** A method of calibrating the output signal balance of a test unit, said test unit having first and second output terminals connected in circuit with first and second active devices, respectively, said first and second active devices having first and second capacitances that are controlled in value by first and second voltages, respectively, said method comprising:

setting said first voltage to a predetermined value;

sequentially setting said second voltage to n voltage values;

applying a test signal frequency sweep to said first and second terminals for each of said n voltage values;

measuring an output signal balance response during each test signal frequency sweep; and

deriving from said n voltage values and said output signal balance response a bias voltage value for said second voltage.

**6.** The method of claim 5, further comprising the steps of: storing a first value of said second voltage when said output signal balance response becomes lower than a predetermined limit;

storing a second value of said second voltage when said output signal balance response later becomes higher than said predetermined limit; and

calculating a bias voltage value based on said first and second values.

**7.** The method of claim 6, wherein said bias voltage value is intermediate said first and second values.

**8.** The method of claim 7, further comprising the step of utilizing said bias voltage value in said test unit.

**9.** The method of claim 8, wherein said predetermined value is used for said first voltage by said utilizing step.

**10.** The method of claim 9, wherein said predetermined value is about one half of a bias voltage range for said active devices.

**11.** The method of claim 10, wherein said active devices are varactors.

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