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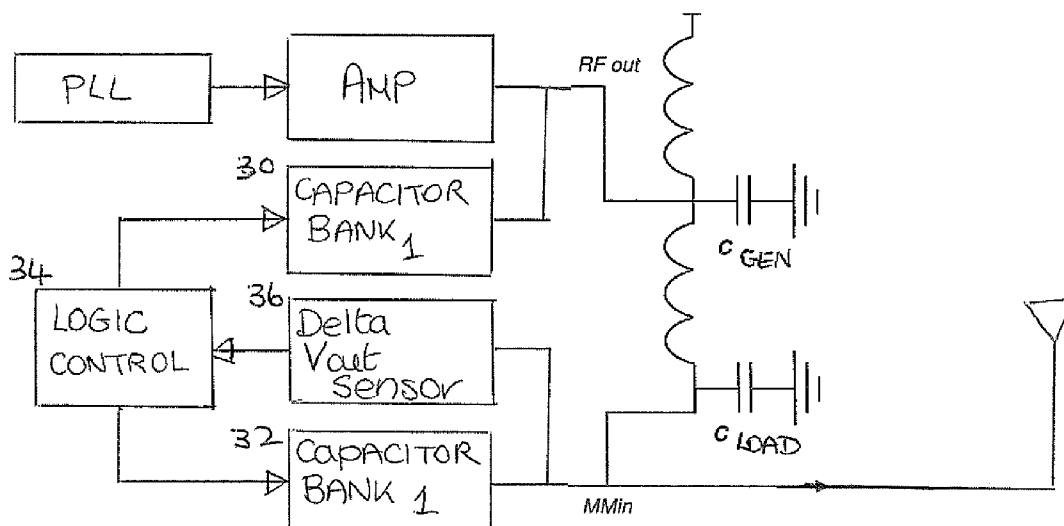
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(54) Title: TRANSMITTING DEVICE AND METHOD OF TUNING THE TRANSMITTING DEVICE



(57) Abstract: A transmitting device comprising a transmitter, an antenna and a tuning means comprising a matching network connectable between the transmitter and the antenna, the matching network comprising a plurality of capacitors; characterised in that the tuning means further comprises a means of selectively individually adjusting the capacitors to increase the output power of the transmitting device.

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Transmitting Device and Method of Tuning the Transmitting Device

Description

Field of the invention

5 This invention relates to a transmitting device and method of tuning same.

Background of the invention

Short range, license-free, wireless applications operating in the Industrial Scientific Medical (ISM) bands (e.g. door openers, tire pressure monitoring systems (TPMS), wireless mice and wireless local area networks (WLANs)) have become
10 popular in recent years. Such applications typically comprise one or more transmitting devices, which transmit a radio signal to one or more receiving devices. On receipt of a signal from the transmitting device(s), the receiving device(s) take an appropriate action.

15 Transmitting device(s) are typically mobile, handheld devices, which comprise a transmitter (for generating signals), an antenna (for transmitting the signals) and a battery (as an internal energy source for such transmissions). However, the batteries are usually quite small. Thus, power consumption is a critical factor in the design of such transmitting device(s).

20

The antenna in a transmitting device is a load on the device's transmitter. Maximally efficient power transfer between a transmitter and an antenna is only achieved when the transmitter impedance is the complex conjugate of the antenna impedance. However, the sensitivity of antenna impedance to surrounding
25 conditions is making the task of matching the impedances of antennas and transmitters quite difficult. Attempts to solve this problem have been ongoing for some time.

Integration Associates (Automatic Antenna Tuning RF Transmitter IC Applying
30 High Q Antenna – White Paper Ver. 1.0 (IA ISM-WP1), Integration Associates Inc.,

2004) and Micrel (MICRF103 QwikRadio (trademark) ASK Transmitter FINAL, June 2002) have proposed a solution in which a single capacitor adjusts the reactive part of antenna impedance. However, any reduction in impedance mismatch achieved by this method would be limited, as it does not take into
5 account the resistive components of the antenna impedance and transmitter impedance. Moreover, the Integration Associates and Micrel solutions are only applicable to source current transmitters, as the measurements used to match the impedances are phase differences between the base and collector of a transistor in a switched current source configuration.

10

US Patent Application US2005219132 describes a system in which two capacitors of a PI matching network are tuned. Impedance matching is achieved by measuring the voltage and the phase difference between the input and output of the matching network. However, the system described in US2005219132 requires
15 A/D convertors and a phase comparator and would be difficult to implement at the frequency of 868MHz typically employed in automotive applications.

20

US Patent Application US2005003771 describes a circuit for automatically tuning a resonant circuit in a transceiver. The circuit adjusts a single capacitor connected
between the two outputs of a differential amplifier, wherein the adjustments are made on the basis of the phase difference between the input and the output of the amplifier. However, in a similar manner to the Integration Associates and Micrel solutions, the circuit in US2005003771 only provides reactive impedance matching. Furthermore, the circuit does not work with Class C amplifiers.

25

More generally, by using only a single adjustable capacitor, prior art solutions available at frequencies of 434-868 MHz have limited ability to match the impedances of a transmitter and antenna. In particular, whilst the prior art solutions provide reactive impedance cancellation, they do not provide conjugate
30 matching.

Summary of the invention

The present invention provides a transmitting device and method of tuning the transmitting device as described in the accompanying claims.

Brief description of the drawings

5 Figure 1 is a block diagram of a transmitting device with a matching network between the antenna and transmitter;

 Figure 2 is a block diagram of a tuning apparatus in accordance with one embodiment of the invention, given by way of example;

 Figure 3 is a circuit diagram of a voltage sensor in the embodiment of
10 Figure 2;

 Figure 4 is a Smith chart showing the operation of the optimisation algorithm employed in the embodiment of Figure 2;

 Figure 5a is a Smith chart of a detuned matching network for a transmitting device operating at 433 MHz;

15 Figure 5b is a Smith chart showing the different matching points possible with an adjustment of a first capacitor in a matching network controlled by the embodiment of Figure 2 in the transmitting device of Figure 5a;

 Figure 5c is a Smith chart showing the different matching points possible with an adjustment of a second capacitor in the matching network controlled by the
20 embodiment of Figure 2 in the transmitting device of Figure 5a, following the adjustment of the first capacitor in Figure 5b;

 Figure 6a is a Smith chart showing the operation of a conventional matching network in a transmitting device under free field conditions;

 Figure 6b is a Smith chart showing the operation of the conventional
25 matching network of Figure 6a, wherein the impedance of the antenna has been altered by the hand-effect;

 Figure 6c is a Smith chart showing the operation of a matching network controlled by the embodiment of Figure 2 in a transmitting device under free field conditions; and

30 Figure 6d is a Smith chart showing the operation of a matching network controlled by the embodiment of Figure 2 in Figure 6c, wherein the impedance of the antenna has been altered by the hand-effect.

Table 1 shows the power loss of a conventional matching network, prior art reactive impedance matching network and matching network controlled by the embodiment of Figure 2 under free field conditions and when the impedance of an antenna has been altered by the hand-effect.

Detailed description of the preferred embodiments

Referring to Figure 1, a transmitter 10 comprises a data source 12 whose data modulates an RF signal (from an RF source 14), which is subsequently amplified by an amplifier 16. The signal from the transmitter 10 is forwarded through a matching network 18 to an antenna 20 for transmission to a receiver (not shown).

Remote key or TPMS transmitting devices typically employ high Q antennas (that have a highly reactive impedance due to their small size). Accordingly, all its components must be very accurately tuned. For example, the antenna and transmitter impedance must be well defined. However, antennas are very sensitive to detuning. For example, interaction with nearby objects (e.g. the human body [the so-called 'hand effect'] or a car) can drastically change the impedance of an antenna.

As previously mentioned, for maximum efficiency, the impedance of an antenna (Z_{LOAD}) should be matched to the impedance of its transmitter (Z_{GEN}). In practise, the matching network 18 achieves this matching. The matching network 18 is in effect a transformer that changes the U/I ratio between the transmitter 10 and the antenna 20. The matching network 18 typically comprises at least two capacitors C_{LOAD} and C_{GEN} and an inductor L . By varying the inductance (L) and capacitances C_{LOAD} and C_{GEN} , the matching network 18 may be tuned to the impedance of the antenna 20.

Once tuned, a matching network 18 is optimal for only one impedance. Thus, any changes in the impedance of the antenna 20 will affect the efficiency of the transmitting device. Indeed, in extreme conditions, the loss in efficiency can be as high as 10dB with a small loop antenna. In such cases, the only way to maintain optimal matching between the impedances of the antenna 20 and transmitter 10 is by manual adjustment of the matching network 18.

Some prior art solutions, automatically adjust the capacitance of the transmitter to minimize the reactance presented to the power amplifier. Another approach is to widen the characteristics of the antenna and matching network by lowering the quality factor of both. In this case, surrounding conditions have less effect on the impedance of the antenna. However, the overall efficiency of the transmitting device is reduced.

Alternatively, the transmitting device may be specifically designed to cope with a wide variety of environmental conditions by increasing the RF power of its transmissions. However, this wastes battery energy, thereby reducing battery life or increasing battery size and cost. This is especially problematic in automotive applications, which are particularly sensitive to cost and energy issues.

20

The present invention extends on the structure of a conventional matching network, by integrating its capacitors C_{LOAD} and C_{GEN} into a chip that automatically adjusts both of them to maximise the output power of a transmitting device. More particularly, and referring to Figure 2, the present invention comprises two capacitors C_{LOAD} and C_{GEN} connected to ground, wherein the capacitors are adjustable by means of a plurality of parallel capacitor banks 30, 32 switched by a state machine 34. The capacitors C_{LOAD} and C_{GEN} are typically provided in a PI arrangement. Other arrangements are also possible (e.g. T arrangement, differential arrangement, etc.) but are less convenient to implement.

30

The state machine 34 is further connected to a voltage sensor 36. The voltage sensor 36 measures the output power of the transmitting device as a voltage on one of the capacitors C_{LOAD} and C_{GEN} (since voltage is related to the square of power at fixed impedance). Accordingly, the present invention
5 measures the voltage directly at the input to the antenna system. This contrasts with the prior art systems that measure power, for example, at the input to the matching network. However, measurements of voltage directly at the input to the antenna provide a more reliable parameter than measurements at the input to the matching network.

10

The output power measurement provided by the voltage sensor 36 is not an absolute value. However, only relative measurements are needed to detect an increase or decrease in the output power of the transmitting device. Referring to Figure 3, the voltage sensor 36 comprises a logarithmic detector 40 with a given
15 gain (expressed in mV/dB) which converts an input RF signal to a DC voltage on capacitor C1. This voltage is compared by comparator U5 with a previously sampled voltage in capacitor C3. The output from the comparator U5 will be high (i.e. value = '1') if the RF signal and the detected DC voltage on capacitor C1 is greater than a previously stored one. Any change of DC level greater than the
20 offset of comparator U5 is detected. Hence, it may be necessary to have some amplification in the logarithmic detector 40 to achieve the required sensitivity.

Returning to Figure 2, the state machine 34 implements an algorithm that tunes the capacitors C_{LOAD} and C_{GEN} by optimising the output power of the
25 transmitter. Accordingly, the output power measurement from the voltage sensor 36 is forwarded to the state machine 34, which then decides, in accordance with the algorithm, which of the two capacitors C_{LOAD} and C_{GEN} should be changed to optimize the output power of the transmitting device.

30 By adjusting the two capacitors C_{LOAD} and C_{GEN} in this fashion, the impedance matching range of the present invention is considerably increased, both in the real and imaginary directions. In particular, the present invention

overcomes the limitations of the prior art by acting on both the reactive and resistive parts of the impedances and thereby providing conjugate matching of the antenna to the transmitter. In higher power systems, all three elements of a matching network (i.e. the two capacitors C_{LOAD} and C_{GEN} and the induction coil) are often variable. However, this is not practical in a fully integrated system. Furthermore, the complexity of the optimization algorithm would become excessive, particularly in a "mobile" environment.

By using peak voltage measurements rather than phase measurements, the present invention functions regardless of the nature of the transmitter. Thus, the present invention is operable with high efficiency Class-C transmitters. Further, as the matching network (i.e. of the capacitors C_{LOAD} and C_{GEN}) usually has a high Q, the invention also compensates component tolerances in the matching network and drift (thermal, ageing, etc).

15

The present invention automatically adjusts the matching network between a transmitter and an antenna (or any load) and optimizes power transfer therebetween even if:

the antenna impedance changes (e.g. in handheld devices);
and/or the matching network components vary (and the high Q of the matching network makes all such variations critical).

Since the present invention automatically adjusts the matching network in a transmitting device regardless of its surrounding conditions, the power sent to the antenna is always at a maximum. In particular, the improvements in power transfer provided by the present invention can be as high as 10dB. As a result, the RF power to the antenna in the transmitting device can be reduced, thereby saving battery energy and enabling the size and cost of the battery to be reduced.

The present invention is not restricted to automotive applications and in particular is also applicable to any system employing remote sensors or peripherals (e.g. alarms, weather stations etc.). These systems may use Zigbee, Bluetooth etc.

5

The optimization algorithm optimizes each capacitor C_{LOAD} and C_{GEN} one after another, in accordance with the impedance ratio. Several optimization paths can be programmed (which may be necessary for high Q matching network).

10 The optimization of each capacitor C_{LOAD} and C_{GEN} is done by ramping up or down a register that switches the capacitor banks 30, 32. The optimisation algorithm stops when the maximum output power is found or when the register reaches a limit (or a maximum or minimum value is found for one of the capacitors C_{LOAD} and C_{GEN} if the absolute optimum cannot be reached). The optimisation
15 algorithm may employ a hill-climbing approach or any other suitable optimisation approach.

Figure 4 shows a variety of impedance matching possibilities for a given transmitting device. The impedance matching possibilities are depicted as black
20 dots and collectively represent the search space within which the optimization algorithm can search to find the optimal matching impedance. The triangle represents the impedance of the transmitter (Z_{GEN}) and the cross X represents the impedance of the antenna (Z_{LOAD}). In effect, the optimization algorithm finds the black dot closest to the cross (X). In other words, the optimization algorithm finds
25 the matching impedance (shown by a square) that most closely matches the antenna impedance.

Referring to Figure 5a, we see an intentional detuning of a matching network at 433MHz, so that the output impedance of the network is no longer 50Ω.
30 Referring to Figure 5b, by changing the capacitance of capacitor C_{LOAD} in 16 steps of 3pF, various matching points are joined. Referring to Figure 5c, by additionally

changing the capacitance of capacitor C_{GEN} in 16 steps of 0.5pF, a network of matching points is drawn. The present invention is able to match all those points perfectly and the surrounding location with minimum mismatch.

5 Performance Test

Let an antenna have an impedance of $4+j100\Omega$ in a free field. A conventional matching network is designed to match a 50Ω transmitter to the antenna impedance of $4+j100\Omega$. Let the antenna's impedance when modified by the hand-effect be $10+j70\Omega$. The loss in output power of the transmitting device arising from the mismatch of the transmitter impedance with the modified antenna impedance is calculated. Similar calculations are performed for a matching network controlled by the present invention.

Referring to Figure 6a, under free field conditions, the conventional matching network achieves close matching with the antenna impedance; and the loss in the output power of the transmitting device is -0.04dB . However, referring to Figure 6b, when the antenna impedance is altered by the hand-effect, the conventional matching network is no longer capable of matching the antenna impedance; and the loss in the output power of the transmitting device is -8.82dB .

Referring to Figure 6c, under free field conditions, the matching network controlled by the present invention also achieves close matching with the antenna impedance; and the loss in the output power of the transmitting device is -0.05dB . However, referring to Figure 6d, when the antenna impedance is altered by the hand-effect, the matching network controlled by the present invention, in contrast with the conventional matching network (of Figure 5b), is still capable of achieving close matching with the antenna impedance; and the loss in the output power of the transmitting device is -0.63dB .

A similar study was performed of the network controlled by the present invention wherein only the C_{GEN} capacitance was changed (i.e. to provide only reactive impedance cancellation in a similar fashion to a number of the aforementioned prior art systems). Table 1 compares the performance of a conventional matching network, the reactive cancellation only network and the matching network controlled by the present invention (in which both capacitors are adjusted). Referring to Table 1, it can be seen that the present invention has superior performance compared to the conventional matching network and reactive part cancellation approach. In particular, the present invention has a power loss of approximately 5dB less than the reactive cancellation approach and 8dB better than the conventional matching network in the present example.

Alterations and modifications may be made to the above without departing from the scope of the invention.

Claims

1. A transmitting device comprising a transmitter 10, an antenna 20 and a tuning means comprising a matching network 18 connectable between the transmitter 10 and the antenna 20, the matching network 18 comprising a plurality of capacitors C_{LOAD} and C_{GEN} ; characterised in that the tuning means further comprises a means of selectively individually adjusting the capacitors C_{LOAD} and C_{GEN} to increase the output power of the transmitting device.

2. The transmitting device as claimed in Claim 1, wherein the capacitors C_{LOAD} and C_{GEN} comprise a plurality of capacitor banks 30, 32 and the means of selectively individually adjusting the capacitors C_{LOAD} and C_{GEN} comprises a one or more switching means operable by a state machine 34.

3. The transmitting device as claimed in Claim 2 wherein the state machine 34 is connectable to a voltage sensor 36 that comprises a means of measuring the output power of the transmitting device as a voltage on one of the capacitors C_{LOAD} and C_{GEN} .

4. The transmitting device as claimed in Claim 2 or Claim 3 wherein the switching means comprises a means of ramping up or down a register that switches the capacitor banks 30, 32.

5. The transmitting device as claimed in any one of Claims 2 to 4 wherein the means of selectively individually adjusting the capacitors C_{LOAD} and C_{GEN} comprises a hill-climbing optimisation algorithm.

6. The transmitting device as claimed in any of the preceding Claims, wherein the capacitors C_{LOAD} and C_{GEN} are provided in a PI arrangement.

7. An Industrial Scientific Medical (ISM) band wireless transmitting device comprising the transmitting device as claimed in any of the preceding claims.

8. A door opening device comprising the transmitting device as claimed in any one of claims 1 to 6.

9. A tire pressure monitoring system (TPMS) comprising the transmitting device as claimed in any one of claims 1 to 6.

10. A method of tuning a transmitting device comprising a transmitter 10 and an antenna 20, the method comprising the step of providing a matching network 18 between the transmitter 10 and the antenna 20; the matching network comprising a plurality of capacitors C_{LOAD} and C_{GEN} ;

characterised in that the method further comprises the step of individually adjusting the capacitors C_{LOAD} and C_{GEN} to increase the output power of the transmitting device.

11. The method of claim 10, comprising the additional step of measuring the output power of the transmitting device by providing a voltage sensor 36 that measures the voltage on one of the capacitors C_{LOAD} and C_{GEN} .

12. The method of claim 10 or claim 11 wherein the step of individually adjusting the capacitors C_{LOAD} and C_{GEN} comprises the steps of:

providing voltage measurements from the voltage sensor 36 to an optimisation algorithm;

operating the optimisation algorithm to control a state machine 34; and

employing the state machine 34 to switch the capacitors C_{LOAD} and C_{GEN} .

AMENDED CLAIMS

[Received by the International Bureau on 12 November 2007 (12.11.07);
original claims 1-12 replaced by amended claims 1-13]

1. A transmitting device comprising a transmitter (10), an antenna (20) and a tuning means comprising a matching network (18) connectable between the transmitter (10) and the antenna (20), the matching network (18) comprising a plurality of capacitors (C_{LOAD} and C_{GEN}); characterised in that the tuning means further comprises a means of selectively individually adjusting the capacitors (C_{LOAD} and C_{GEN}) to tune the matching network (18) to the impedance of the antenna (20).

2. The transmitting device as claimed in Claim 1, wherein the transmitting device further comprises a state machine (34), configured to:-

- receive a measure of a voltage at the matching network (18); and
- use the measure of the voltage to control the means of selectively

individually adjusting the capacitors (C_{LOAD} and C_{GEN}).

3. The transmitting device as claimed in Claim 2 wherein the state machine (34) is connected to a voltage sensor that is configured to provide a measure of a voltage at the matching network (18) by measuring a voltage on one of the capacitors (C_{LOAD} and C_{GEN}).

4. The transmitting device as claimed in any one of the preceding claims, wherein the capacitors (C_{LOAD} and C_{GEN}) comprise a plurality of capacitor banks (30, 32) and the means of selectively individually adjusting the capacitors (C_{LOAD} and C_{GEN}) comprises a one or more switching means operable by the state machine (34).

5. The transmitting device as claimed in Claim 4 wherein the switching means comprises a means of ramping up or down a register that switches the capacitor banks (30, 32).

6. The transmitting device as claimed in any one of the preceding claims wherein the means of selectively individually adjusting the capacitors (C_{LOAD} and C_{GEN}) comprises a hill-climbing optimisation algorithm.

5 7. The transmitting device as claimed in any one of the preceding Claims, wherein the capacitors (C_{LOAD} and C_{GEN}) are provided in a PI arrangement.

8. An Industrial Scientific Medical (ISM) band wireless transmitting device comprising the transmitting device as claimed in any of the preceding claims.

10 9. A door opening device comprising the transmitting device as claimed in any one of Claims 1 to 7.

15 10. A tire pressure monitoring system (TPMS) comprising the transmitting device as claimed in any one of Claims 1 to 7.

20 11. A method of tuning a transmitting device comprising a transmitter (10) and an antenna (20), the method comprising the step of providing a matching network (18) between the transmitter (10) and the antenna (20); the matching network comprising a plurality of capacitors (C_{LOAD} and C_{GEN});

characterised in that the method further comprises the step of individually adjusting the capacitors (C_{LOAD} and C_{GEN}) to tune the matching network (18) to the impedance of the antenna (20).

25 12. The method of Claim 11, comprising the additional step of measuring a voltage at the matching network (18) by providing a voltage sensor (36) that measures the voltage on one of the capacitors (C_{LOAD} and C_{GEN}).

30 13. The method of Claim 11 or Claim 12 wherein the step of individually adjusting the capacitors C_{LOAD} and C_{GEN} comprises the steps of:
providing voltage measurements from the voltage sensor (36) to an optimisation algorithm;

operating the optimisation algorithm to control a state machine (340; and employing the state machine (34) to switch the capacitors C_{LOAD} and C_{GEN} .

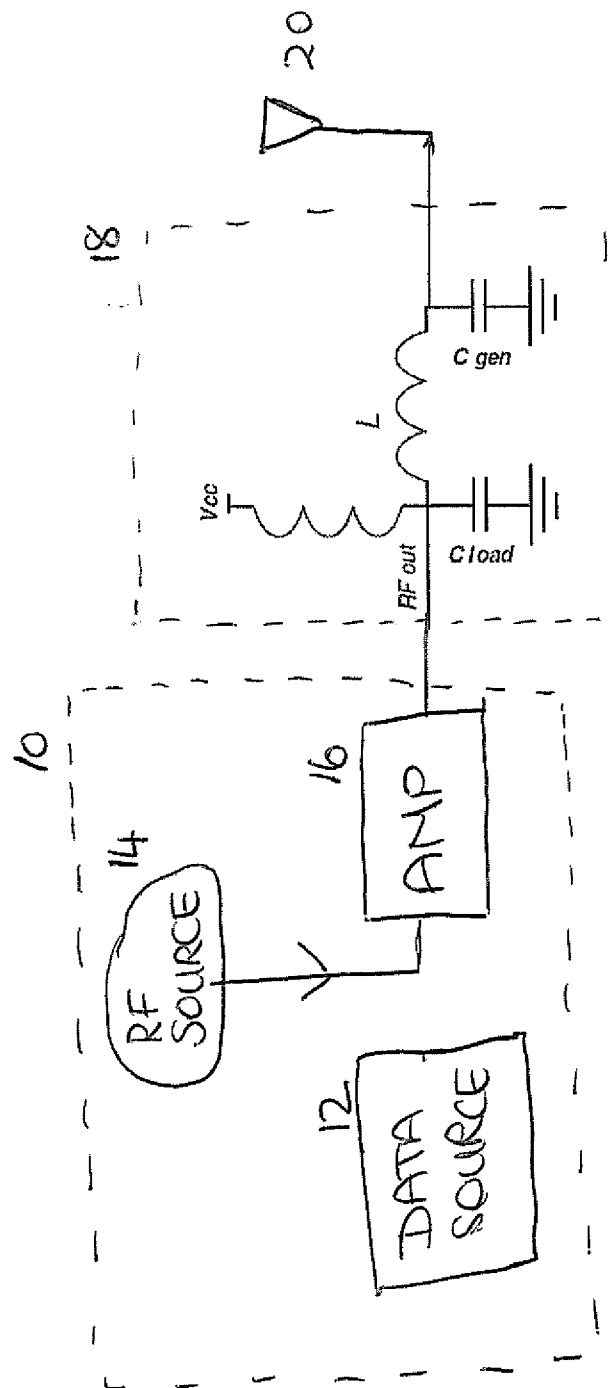


FIG. 1

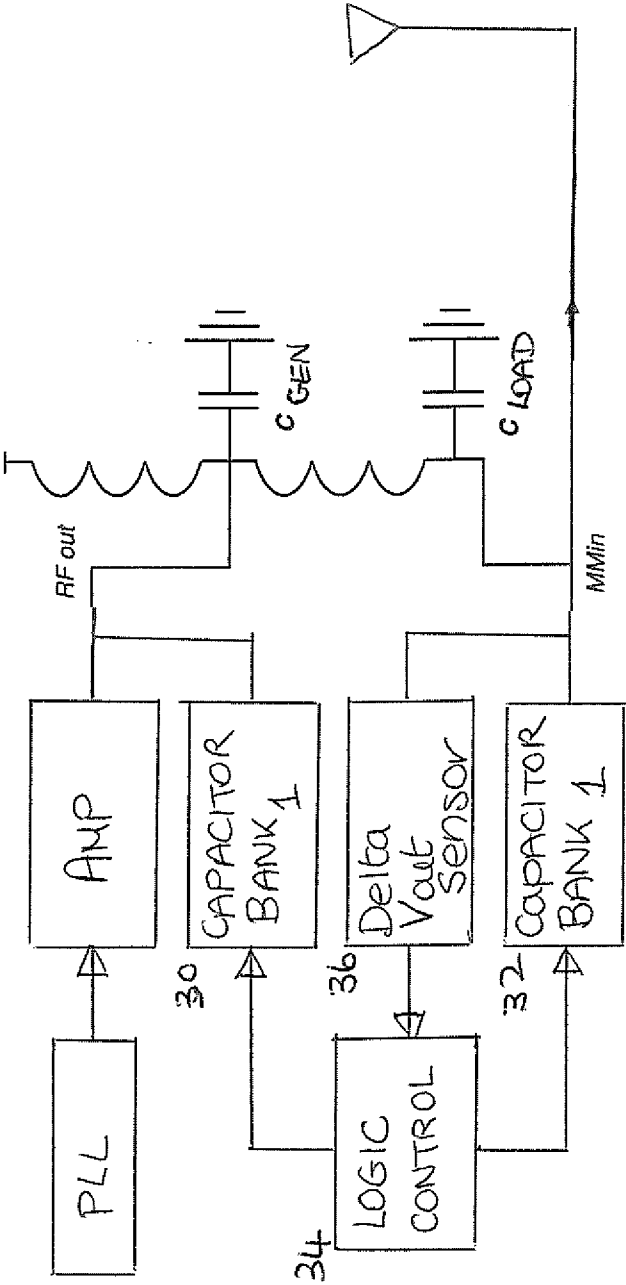


FIG. 2

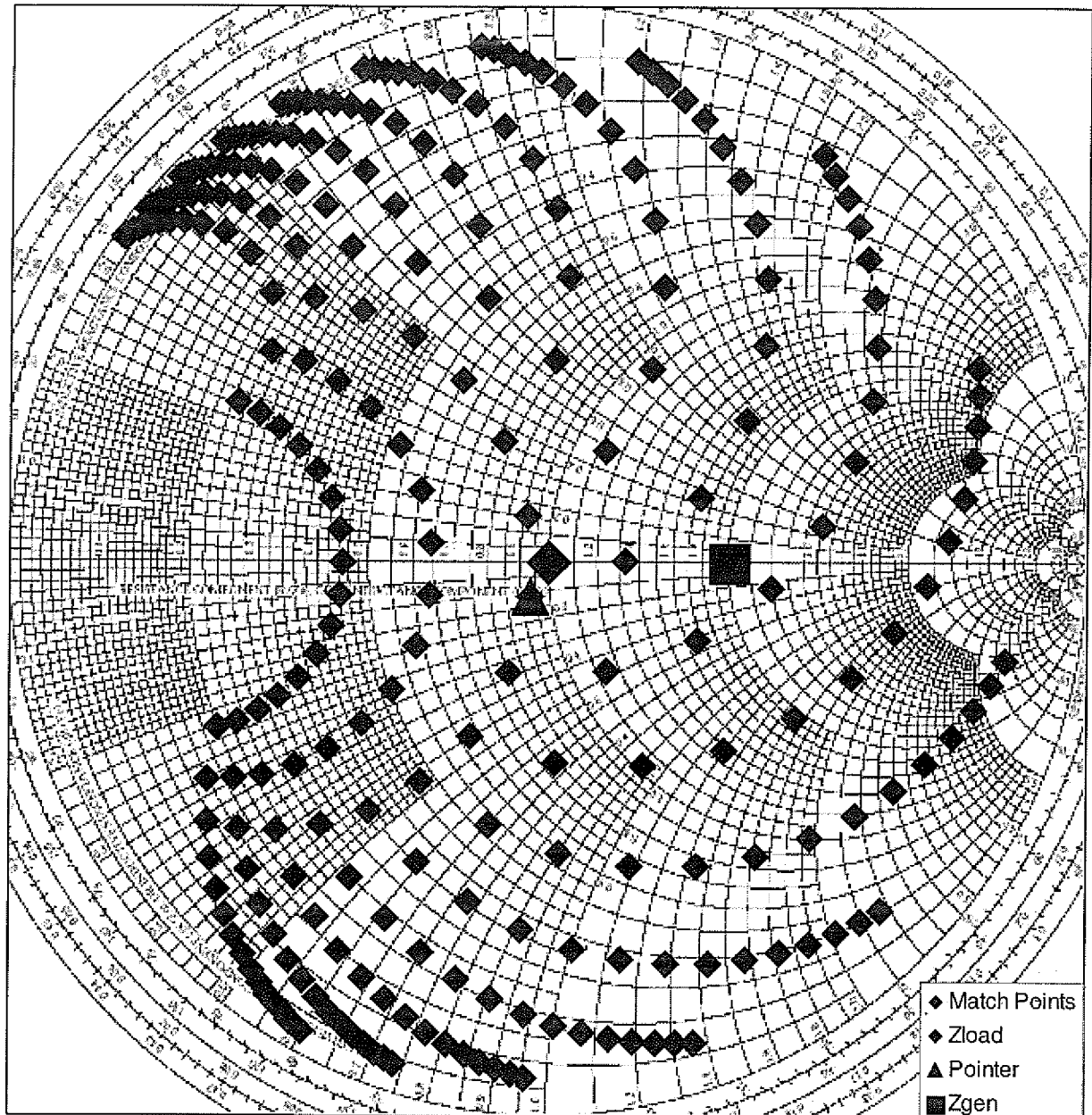


FIG. 4

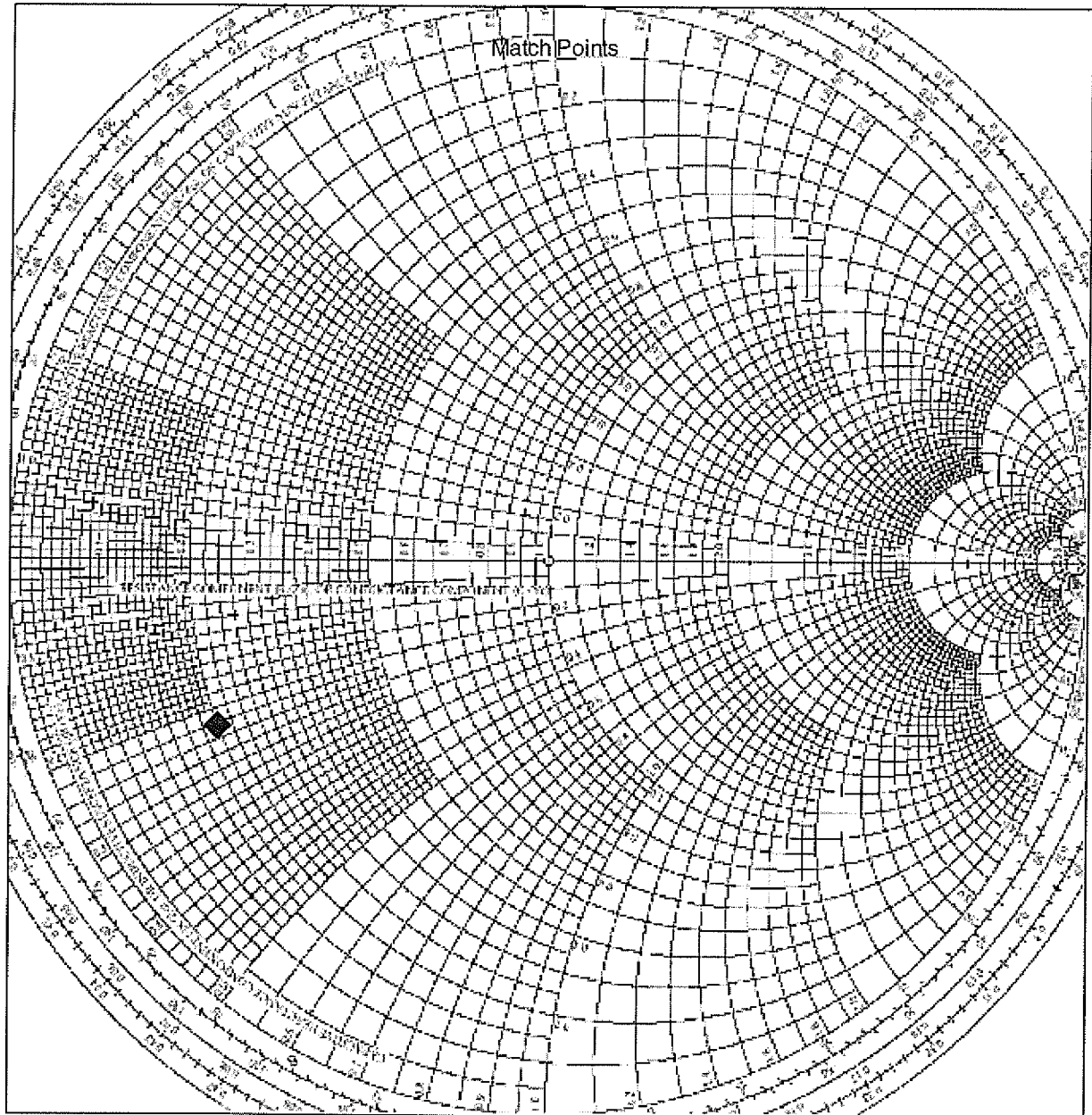


FIG. 5A

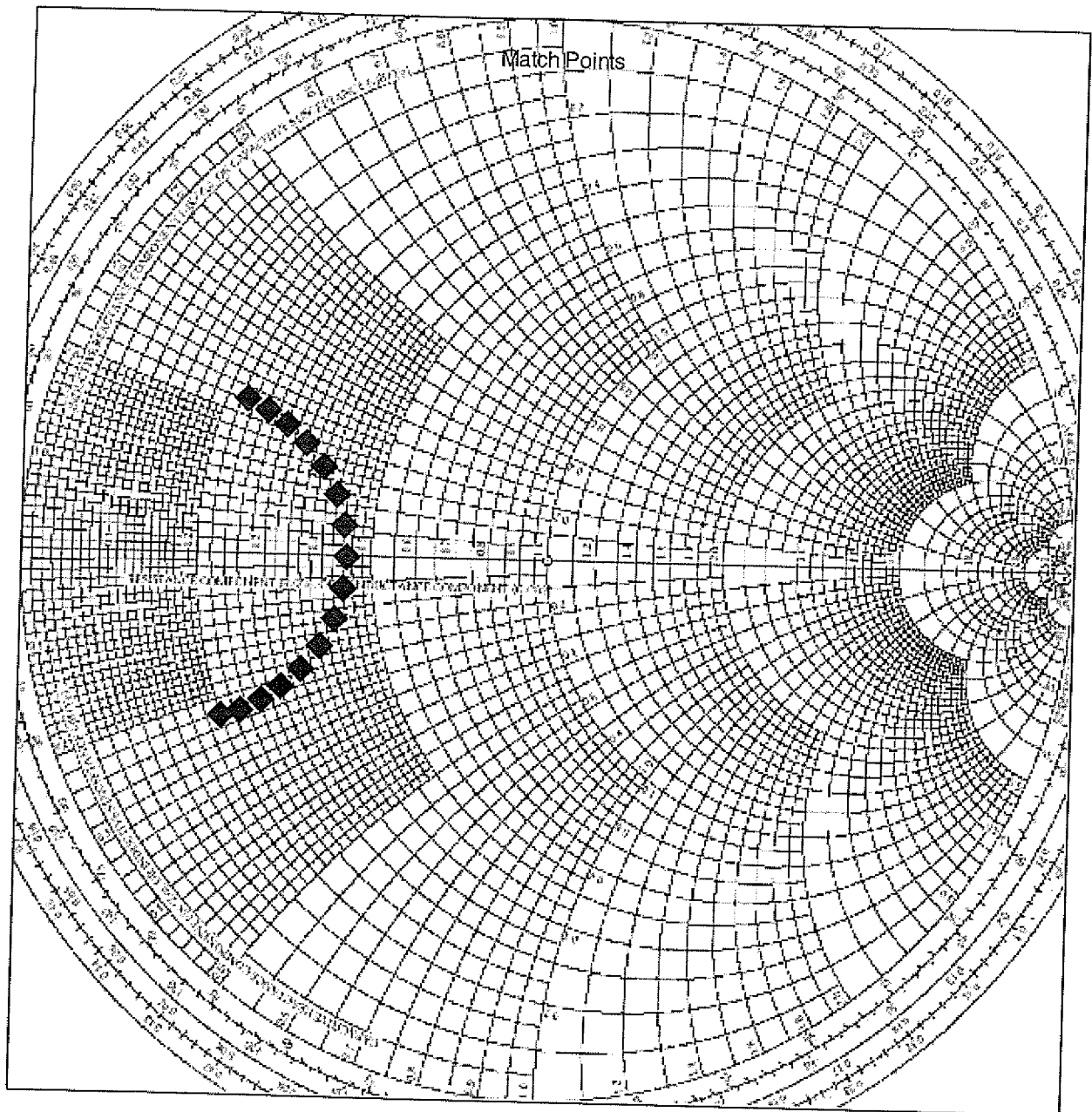


FIG. 5B

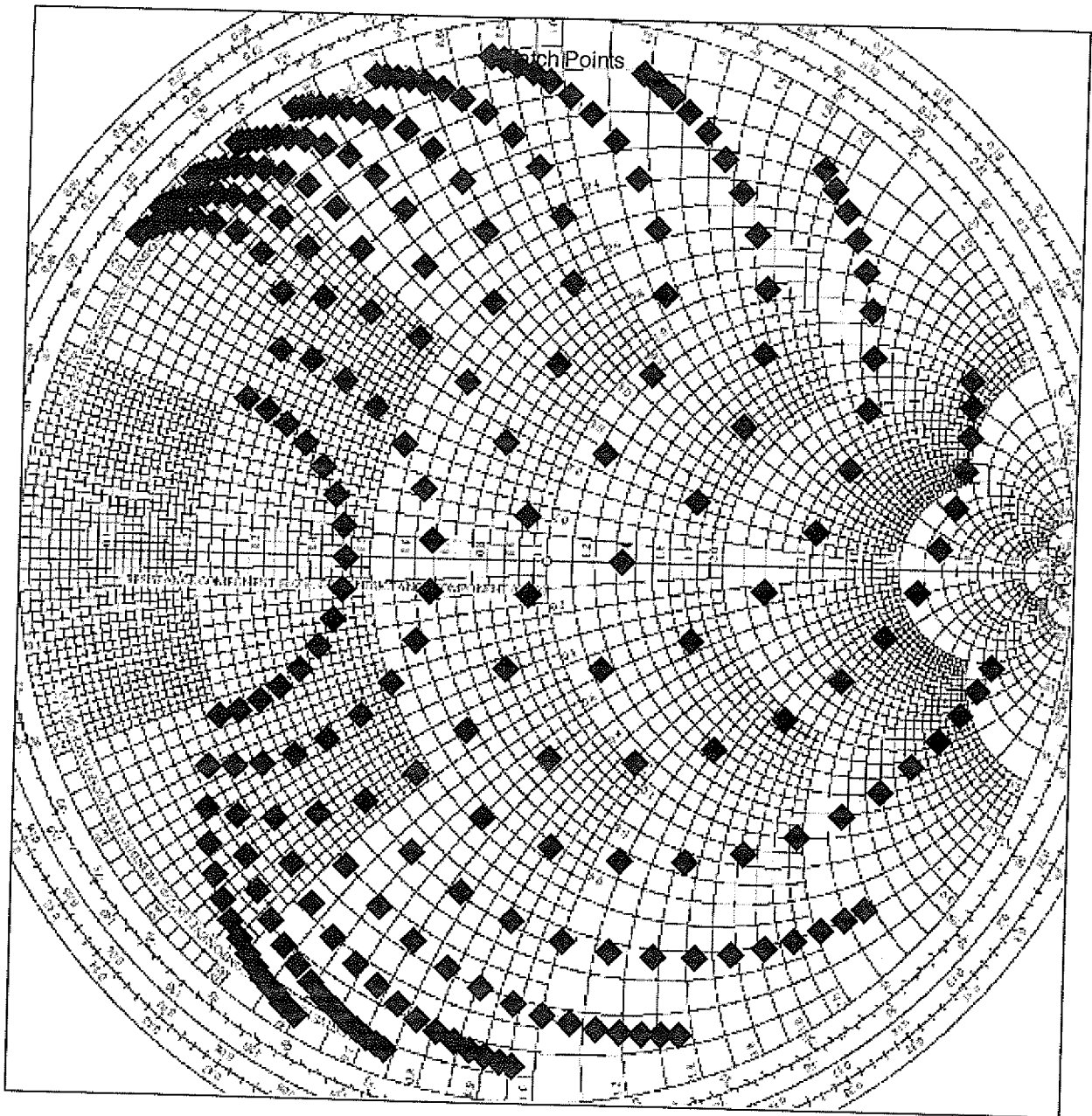


FIG. 5c

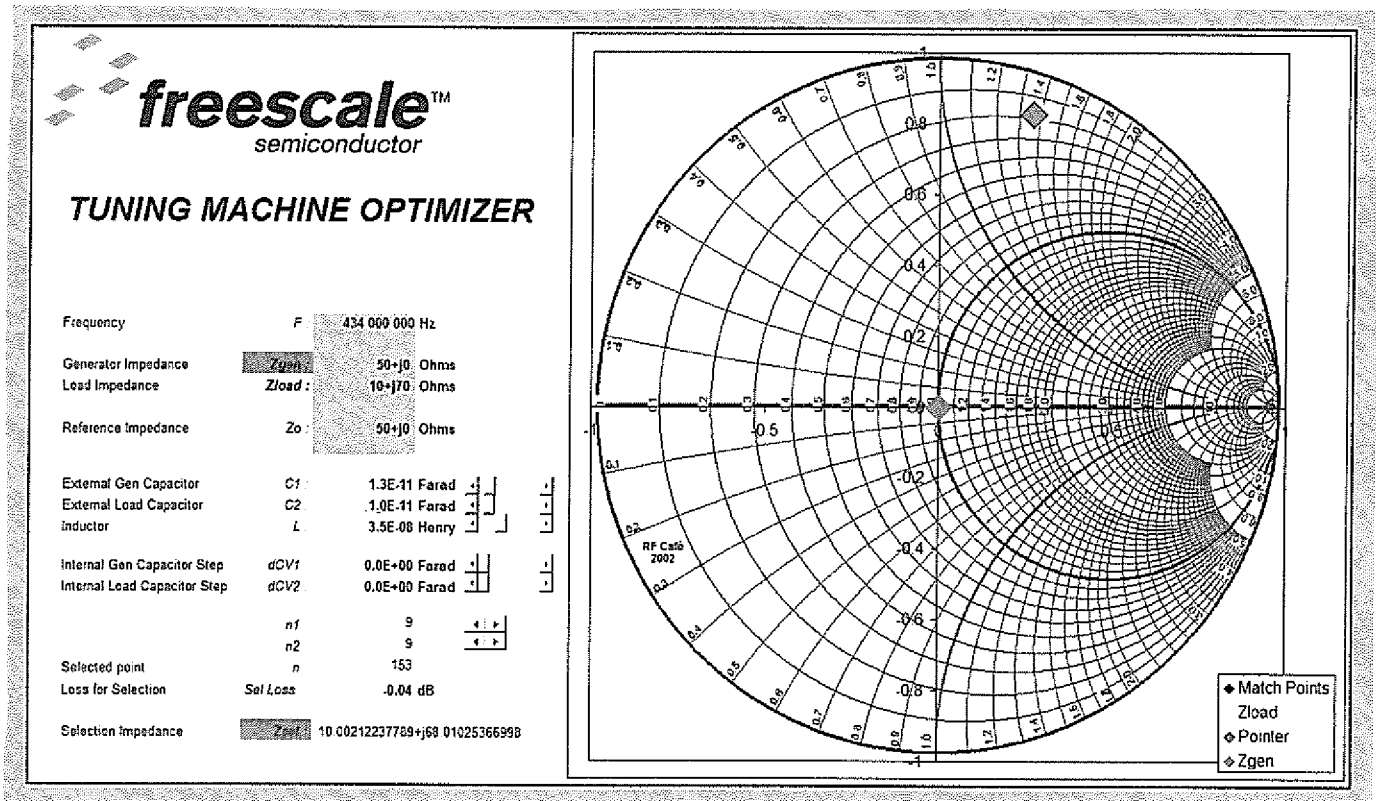


FIG. 6A

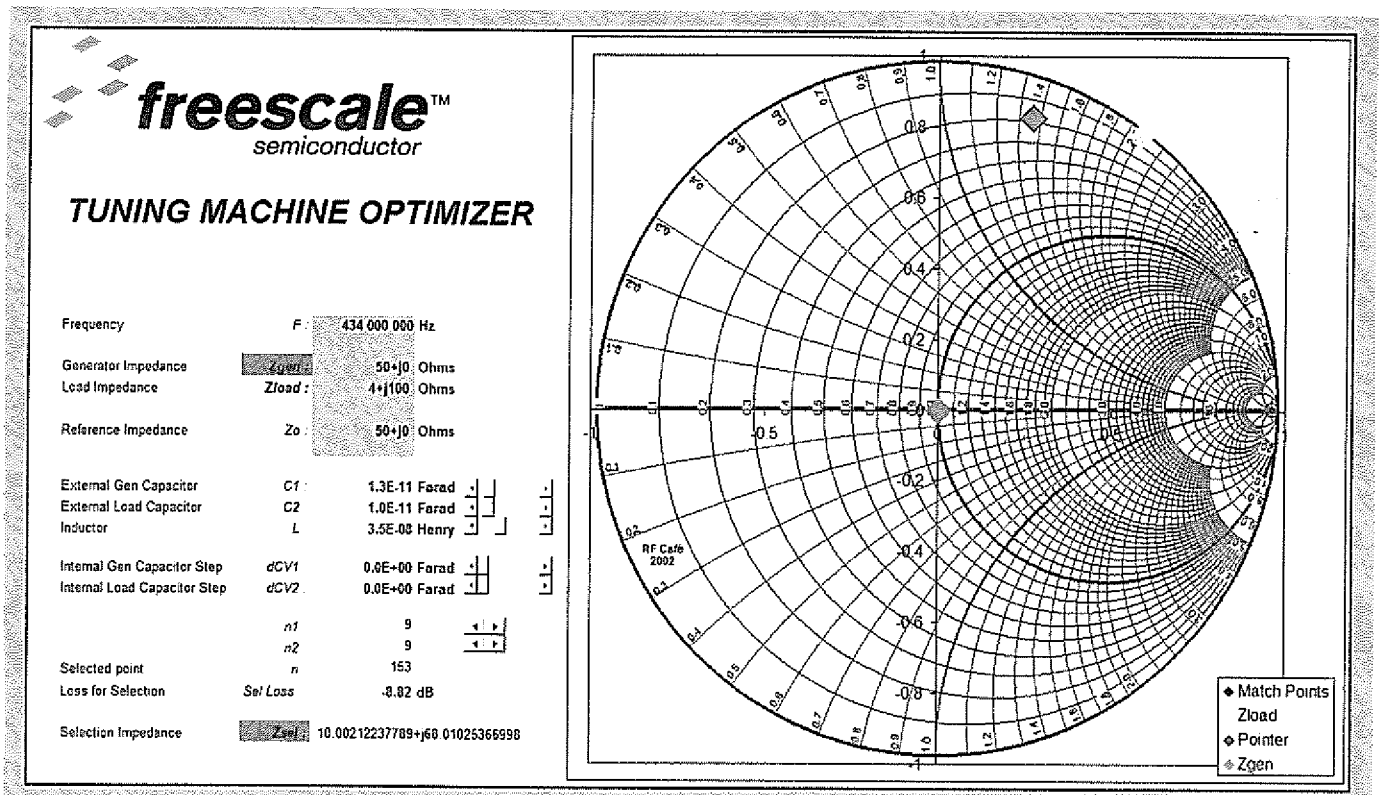


FIG. 6B

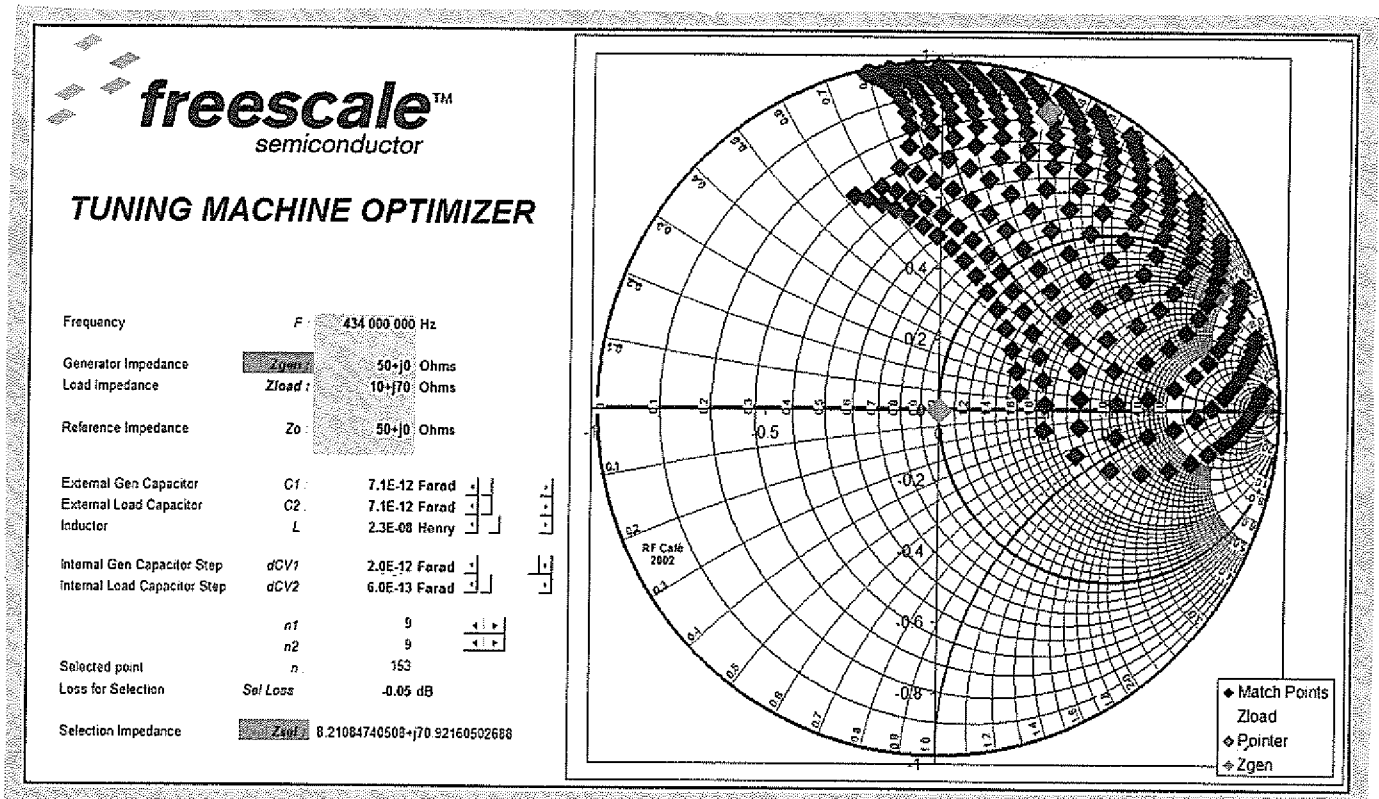


FIG 6C

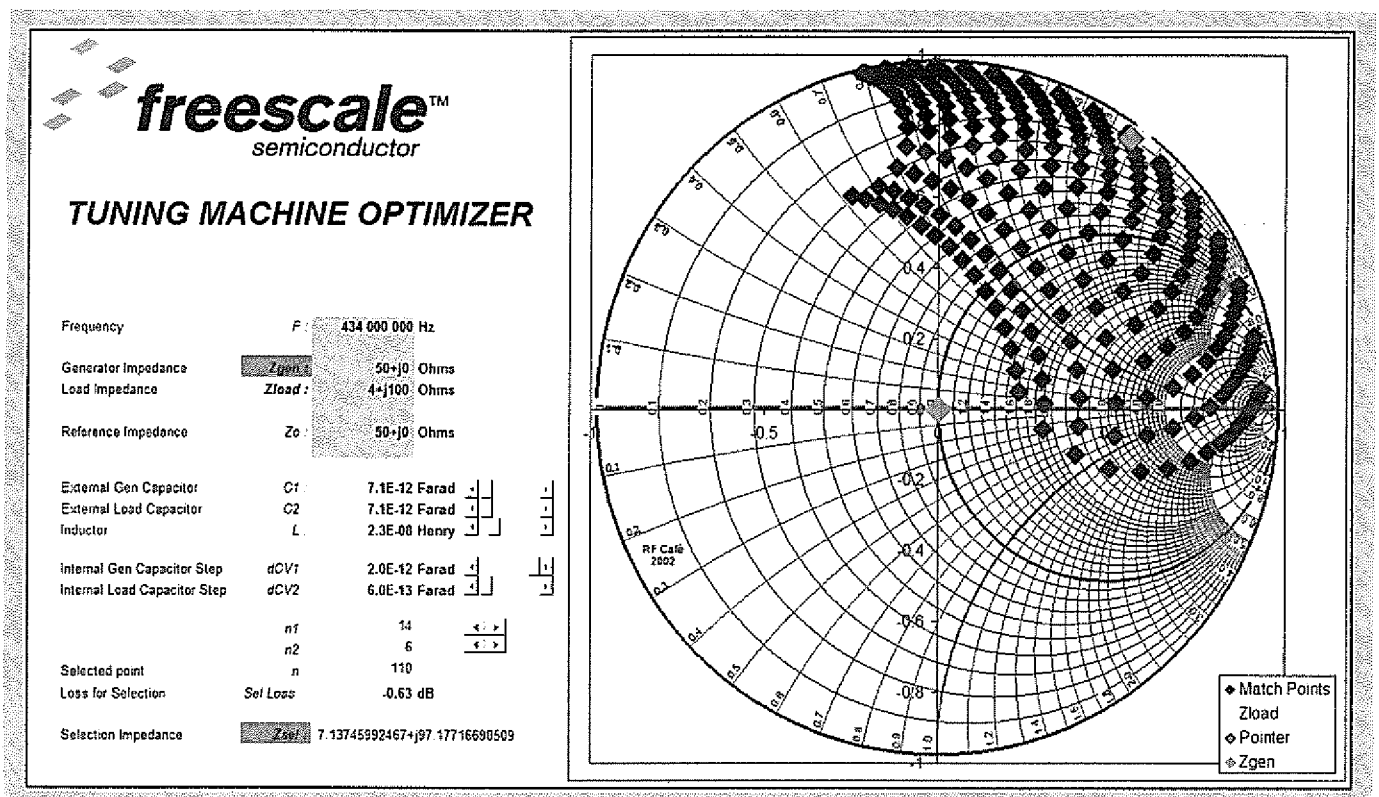


FIG 6D

Table 1: Variability of Power Loss in a Transmitting Device Under Different Operating Conditions with Different Impedance Matching Networks

Type of Impedance Matching Network	Power Loss under Free Field $Z_{out} = 10 + j70$	Power Loss with Hand Effect to Antenna $Z_{out} = 4 + j100$	Variability
Present Invention	0.05dB	0.63dB	0.58dB
Reactive Impedance Matching Only	0.05dB	5.81dB	5.76dB
Conventional Matching Network	0.04dB	8.82dB	8.78dB

INTERNATIONAL SEARCH REPORT

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PCT/IB2006/054096

A. CLASSIFICATION OF SUBJECT MATTER
INV. H03H7/38 : H03H7/40

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)
H03H

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 practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 509 500 A (MCNAIR ROBERT J ET AL) 28 April 1970 (1970-04-28) column 4, line 52 - column 15, line 37; claims 1,2; figures 1,7,11 -----	1-12
X	US 3 906 405 A (KOMMRUSCH RICHARD S) 16 September 1975 (1975-09-16) column 2, line 40 - column 6, line 15; figure 2 -----	1-12
A	US 3 643 163 A (BRUCK GEORGE) 15 February 1972 (1972-02-15) figure 5 -----	1-12
A	US 3 129 386 A (DALY CARL C) 14 April 1964 (1964-04-14) figure 1 -----	1-12

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

☒ See patent family annex.

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2 July 2007

Date of mailing of the international search report

10/07/2007

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INTERNATIONAL SEARCH REPORT

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Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 3509500	A	28-04-1970	NONE	
US 3906405	A	16-09-1975	NONE	
US 3643163	A	15-02-1972	NONE	
US 3129386	A	14-04-1964	NONE	