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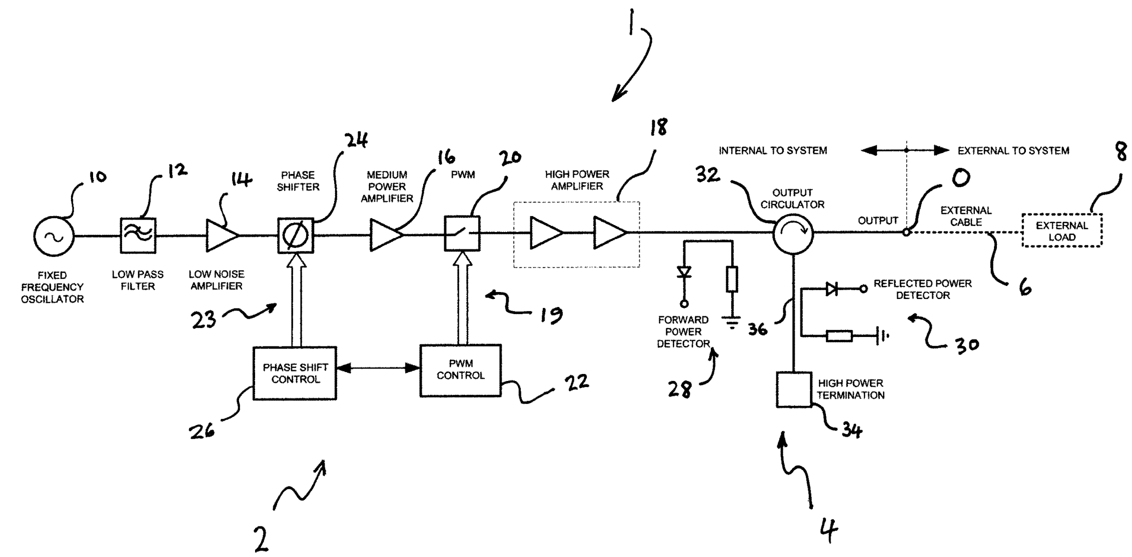
(56) Documents Cited:
**WO 2011/061486 A1** **JP 2005017138 A**
**US 20100176789 A1** **US 20070216420 A1**

(58) Field of Search:
INT CL **A61B, G01R**
Other: **EPODOC, WPI, INSPEC**

(54) Title of the Invention: **Microwave systems**
Abstract Title: **Microwave system with 360° phase shifter to measure VSWR**

(57) A microwave system 1 comprises a microwave source 2 producing a fixed frequency source signal and a detector arrangement 4. A phase adjustment arrangement 23 including a phase shifter 24 applies several cycles of 360$^0$ phase change to the source signal. In operation, transmission line 6 carries a forward power signal from the source to a load 8 and a reflected power signal from the load 8 to the source, and the waveforms generated on the transmission line 6 by the forward and reflected power signals combine to form a voltage standing wave. The detector 4 determines the voltage standing wave ratio (VSWR). By applying a phase change of at least 360 degrees with the phase shifter 24, the VSWR is effectively averaged over a cycle and is independent of the length of the transmission line 6. The microwave system may be used in a microwave surgical tool.

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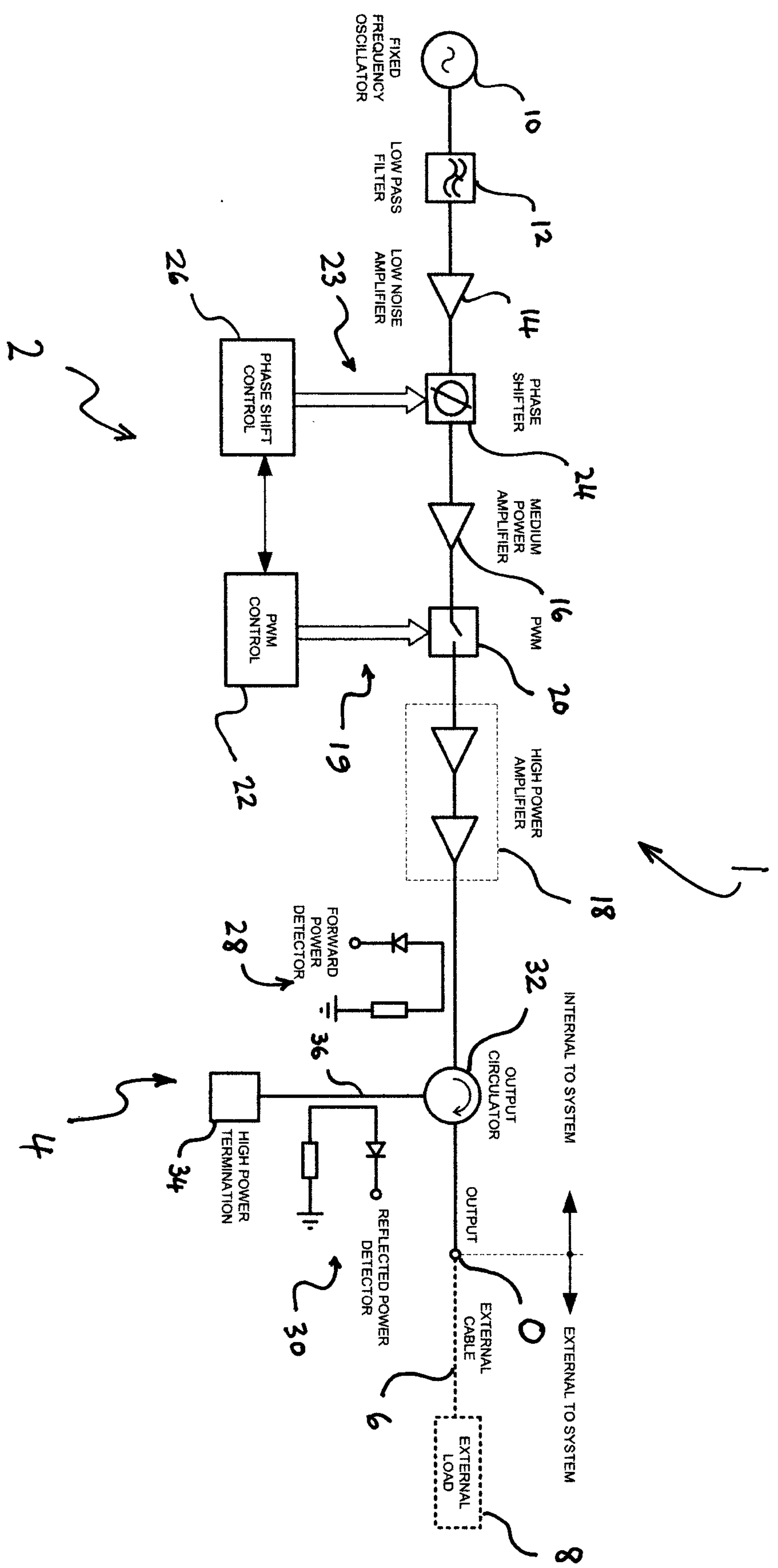
FIXED FREQUENCY OSCILATOR
10
LOW PASS FILTER
12
LOW NOISE AMPLIFIER
14
PHASE SHIFTER
24
23
PHASE SHIFT CONTROL
26
2
MEDIUM POWER AMPLIFIER
16
PWM
20
PWM CONTROL
22
19
HIGH POWER AMPLIFIER
18
1
FORWARD POWER DETECTOR
28
32
INTERNAL TO SYSTEM
OUTPUT CIRCULATOR
36
HIGH POWER TERMINATION
34
4
REFLECTED POWER DETECTOR
30
OUTPUT
O
EXTERNAL CABLE
6
EXTERNAL TO SYSTEM
EXTERNAL LOAD
8

# MICROWAVE SYSTEMS

## Field of the Invention

The invention relates to microwave systems.

## Background to the Invention

A microwave system typically comprises a microwave source arrangement and a detector arrangement, which together form microwave apparatus, and a load and a transmission line connecting the apparatus and the load. Such systems are used to generate high power microwave energy for use in, for example, heating and drying, scientific research, microwave chemistry and medical procedures.

It is desirable to know the forward and reflected power levels in a microwave system in order to determine its output power. This is particularly the case in medical applications.

In a microwave system, the forward and reflected power signals generate sinusoidal waveforms on the transmission line, travelling in opposite directions. Superposition of these waveforms occurs to produce a composite signal (known as a voltage standing wave). The ratio of a voltage maximum to an adjacent voltage minimum of the voltage standing wave is termed the voltage standing wave ratio (VSWR). The ratio provides an indication of the level of reflected power, and is determined by the detector arrangement using a detected voltage which is proportional to reflected power.

Microwave systems commonly use a single frequency, constant phase mode of operation, which generates a static voltage standing wave on the transmission line, assuming a constant load. The physical length of the transmission line combined with the load determines the phase and hence amplitude of the voltage standing wave at the detector arrangement.

Assuming a constant load, changes in transmission line lengths due, for example, to manufacturing tolerances or requirements of different applications, will cause the phase of the standing wave at the detector arrangement to change. In turn, this causes a change in the amplitude of the standing wave at the detector arrangement, resulting in a change to the detected voltage and, hence, what is determined to be the VSWR. In other words, the measured reflected power level is transmission line length dependent.

Other effects, such as changes in the load length and thermal variations, will also result in changes to the system electrical phase length which will lead to measurement variations and uncertainty.

Depending upon the application to which the system is being put, the inability to accurately measure reflected power may have significant consequences. For example, in the case of tissue ablation in the treatment of cancer, it may be critical.

WO-A-2011/061486 discloses a technique based on utilising a variable output frequency, which provides improved accuracy in measuring reflected power/VSWR. Varying the output frequency causes the effective electrical pulse length of the transmission line to change in relation to the frequency change. This controlled change in frequency causes the phase and amplitude of the reflected signal impinging on the detector to change. If the frequency change is sufficient to cause the phase of the standing wave to change by at least one complete cycle ($360^{\circ}$) at the detector, the detected voltage will effectively average the value of the reflected voltage standing wave. This averaging effect provides improved accuracy in measurement compared to a fixed frequency, constant phase set-up, and substantially negates the effect of transmission line length variation. However, a problem is that, at the frequencies at which microwave systems operate and with the permissible bandwidths at those frequencies, the variable frequency technique requires relatively long transmission lines (for example, 1.7m at 2.45GHz and 1.1m at 5.8GHz) to achieve a $360^{\circ}$ phase change at the detector arrangement. The longer the transmission line, the greater the system power losses.

**Summary of the Invention**

According to a first aspect, there is provided a microwave system comprising:

microwave apparatus comprising a microwave source arrangement producing a fixed frequency source signal and a detector arrangement;

a load; and,

a transmission line connecting the apparatus and the load;

wherein, in operation, the transmission line carries a forward power signal from the apparatus to the load and a reflected power signal from the load to the apparatus, and the waveforms generated on the transmission line by the forward and reflected power signals combine to form a voltage standing wave; and

wherein the detector determines the VSWR; and

further comprising a phase adjustment arrangement for adjusting the phase of the source signal by at least 360°.

The change in phase of the source signal causes the phase and amplitude of the reflected signal at the detector arrangement to change. The detected voltage will effectively average the value of the reflected voltage standing wave. In this sense, the system according to the first aspect operates similarly to a variable frequency system. However, unlike a variable frequency system, a system according to the first aspect has no minimum transmission line length requirement, enabling it to be used in applications where short length transmission lines are preferable. Also, shorter transmission lines means reduced system power loss and improved overall efficiency, which is important in certain applications. In addition, a fixed frequency microwave source can be optimised for the frequency of operation. A variable frequency source has to be capable of delivering the desired output power over the operational bandwidth. Achieving the operational bandwidth often results in a reduction of the source efficiency compared to a fixed frequency design.

The phase adjustment arrangement may comprise a mechanical mechanism or an electrical mechanism. An electrical mechanism may bring about a continuous (swept) change of phase, a number of discrete phase steps or may include algorithms to generate a sequence of phase steps or random phase steps. Electrical mechanisms may include, for example, analogue or digital phase shifter MMICs. Reflective style phase shifters, switched filter phase shifters or high pass/low pass phase shifters could also be used, but these individually tend to have less than 360° of phase adjustment and would need cascading to provide the required functionality.

The source arrangement may comprise a low power stage, prior to a medium and/or a high power amplification stage, in which case the phase adjustment arrangement is preferably located such that phase adjustment is applied at the low power stage.

Further preferably, the phase adjustment arrangement should automatically repeat or have an external control to enable phase adjustment to be turned on and off. The rate of phase adjustment should align to the system requirements. A continuous wave (CW) mode or a pulse width modulation (PWM) scheme may be used to control average output power. If PWM is used, it is preferable to ensure that at least $360^{\circ}$ of phase shift occurs during the minimum pulse width used in the system. Improved measurement reliability will result if a number of, for instance 5 to 10, $360^{\circ}$ phase cycles can be performed within the minimum pulse width.

The detector arrangement may comprise output circulators/directional couplers, and operating at a fixed frequency is advantageous for these. The insertion loss and isolation of the circulator can be optimised for a fixed frequency. Similarly the directivity of the directional coupler can be optimised for single frequency operation. All of these aspects help to improve the system performance by minimising losses and optimising the performance of the detector electronics.

According to a second aspect, there is provided apparatus comprising the microwave source arrangement and the detector arrangement of the first aspect.

According to the third aspect, there is provided a method comprising using the system according to the first aspect.

**Brief Description of the Drawings**

Figure 1 is a block schematic diagram of a microwave system.

**Detailed Description of the Illustrated Embodiment**

With reference to figure 1, a microwave system 1 has microwave apparatus consisting of a microwave source arrangement 2 and a detector arrangement 4. The system 1 further has a line 6, typically between 0.5m and 4m in length, connected at one end to an output O of the apparatus, and at the other end to a load 8 in the form of an item that either absorbs or radiates the output signal from the apparatus.

The microwave source arrangement 2 has a microwave oscillator 10, a low pass filter 12, a low power amplification stage 14, a medium power amplification stage 16 and a high power amplification stage 18. The oscillator 10 operates at a single, fixed frequency. The source arrangement 2 also has a pulse width modulation arrangement 23, comprising a pulse width modulator 20 and a pulse width modulator control 22, for controlling average output power. In addition, the source arrangement 2 has a phase adjustment arrangement 23 comprising an electrical phase shifter mechanism 24 and a phase shift control 26. The phase adjustment arrangement 23 is between the low and medium power amplification stages 14, 16.

The detector arrangement 4 has a forward power detector 28, a reflected power detector 30, a circulator 32 and high power termination 34. The circulator 32 is optimised for the fixed frequency of the oscillator 10.

A forward power signal is sent from the microwave source arrangement 2 via the circulator 32 to the output O. From there it is carried by the transmission line 6 to the load 8. Due to impedance mismatching, power is reflected by the load 8. The reflected power signal is carried from the load 8 by the transmission line 6 to the output O. The forward and reflected power signals generate sinusoidal waveforms on the transmission line 6. Superposition of these waveforms occurs to produce a composite signal known as the voltage standing wave. The ratio of a voltage maximum to an adjacent voltage minimum of the voltage standing wave is known as the voltage standing wave ratio (VSWR). Its value provides an indication of the level of reflected power. The VSWR is determined by the detector arrangement 4.

Before entering the circulator 32, the forward power signal from the microwave source arrangement 2 passes the forward power detector 28 which detects the voltage of the forward power signal. After reaching the output O, the reflected power signal encounters the circulator 32, which diverts the reflected signal on to a secondary signal path 36 which terminates in the high power termination 34. In travelling along the secondary signal path 36, the reflected power signal passes the reflected power detector 30 which detects the voltage of the reflected power signal. The VSWR is determined using the voltage measurements from the two detectors, 28, 30.

The phase adjustment arrangement 23 brings about a continuous (swept) change of phase in the signal leaving the microwave source arrangement 2. Multiple 360° phase cycles are performed during the minimum pulse width used by the system 1. The cycles automatically repeat. The phase adjustment is applied at the low amplification stage 14. The adjustment causes the phase and amplitude of the reflected power signal to change. The voltage detected will effectively average the value of the reflected voltage standing wave. As a result, the VSWR provides an accurate indication of the reflected power. The VSWR is unaffected by changes in transmission line length.

**CLAIMS**

1. A microwave system comprising:

microwave apparatus comprising a microwave source arrangement producing a fixed frequency source signal and a detector arrangement;

a load; and,

a transmission line connecting the apparatus and the load;

wherein, in operation, the transmission line carries a forward power signal from the apparatus to the load and a reflected power signal from the load to the apparatus, and the waveforms generated on the transmission line by the forward and reflected power signals combine to form a voltage standing wave; and

wherein the detector determines the VSWR; and

further comprising a phase adjustment arrangement for adjusting the phase of the source signal by at least 360°.

2. A system of claim 1, wherein the phase adjustment arrangement comprises a mechanical mechanism or an electrical mechanism.

3. A system of claim 2, wherein the electrical mechanism brings about a continuous (swept) change of phase, a number of discrete phase steps or includes algorithms to generate a sequence of phase steps or random phase steps.

4. A system of claim 2 or 3, wherein the electrical mechanisms is an analogue or digital phase shifter MMICs, a reflective style phase shifter, a switched filter phase shifter or high pass/low pass phase shifters.

5. A system according to any of claims 1 to 4, wherein the source arrangement comprises a low power stage, prior to a medium and/or a high power amplification stage, and the phase adjustment arrangement is located such that phase adjustment is applied at the low power stage.

6. A system according to any preceding claim, wherein the phase adjustment arrangement automatically repeats or has an external control to enable phase adjustment to be turned on and off.

7. A system according to any preceding claim, further comprising a pulse width modulating arrangement for controlling average output power,

wherein the at least 360° phase shift of the source signal occurs during the minimum pulse width.

8. The system of any preceding claim wherein the detector arrangement comprises a circulator/directional coupler.

9. Microwave apparatus for the system of any preceding claim.

10. A method comprising using the system of any of claims 1 to 8.

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| **Application No:** | GB1412904.3 | **Examiner:** | Ian Rees |
| **Claims searched:** | 1 to 10 | **Date of search:** | 4 January 2015 |

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular relevance |
|---|---|---|
| X | 1 - 10 | US 2007/0216420 A1 JAKLITSCH. See paragraphs 0020 to 0026. |
| X | 1 - 10 | JP 2005017138 A NEC. See figure 1, EPODOC abstract and WPI abstract number 2005-085644. |
| A | - | US 2010/0176789 A1 ZOUGHI. |
| A | - | WO 2011/061486 A1 EMBLATION LTD. |

Categories:

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art. |
| Y | Document indicating lack of inventive step if combined with one or more other documents of same category. | P | Document published on or after the declared priority date but before the filing date of this invention. |
| & | Member of the same patent family | E | Patent document published on or after, but with priority date earlier than, the filing date of this application. |

**Field of Search:**

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC$^{X}$ :

Worldwide search of patent documents classified in the following areas of the IPC

A61B; G01R

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI, INSPEC

**International Classification:**

| Subclass | Subgroup | Valid From |
|---|---|---|
| G01R | 0027/06 | 01/01/2006 |
| A61B | 0018/18 | 01/01/2006 |