Paper

A 100 W ISM 2.45 GHz-band power test system

Wojciech Wojtasiak, Daniel Gryglewski, and Wojciech Gwarek

Abstract—This paper describes development of solid-state microwave power test system (MPTS) operating over 2.3 to 2.6 GHz with the output power level of 100 W for industrial applications in material processing, and for designing of microwave power industrial equipment. The MPTS unit consists of four major parts: PLL synthesizer, high power solid-state amplifier, detector probes for return losses and leakage measurement and microcontroller. The MPTS system is able to operate in either single fixed-frequency regime, or in swept mode with self-tuning for minimum reflection of a heated load.

Keywords— microwave precise heating, high power solid-state amplifier , push-pull GaAs FET, synthetsizer, power measurement unit.

1. Introduction

Despite theoretical advantages of microwave power systems, modern industrial applications of microwaves are still limited. The main reason is that there is only one relatively low cost, high power microwave source available – the magnetron. It provides much distorted microwave signal with respect to an amplitude and spectrum purity. Moreover its frequency behavior is strongly dependent on the heated load properties. On the other hand, many industrial applications in material processing require microwave heating with precise frequency and amplitude control based on the feedback from the time varying process parameters. Such requirements can be only fulfilled by solid-state high frequency stability high power sources (HPS). They are based on synthesized VCO high power solid-state amplifiers (SSPA). Other advantages of HPS as compared to magnetrons and other microwave tubes are also important. In particular, the SSPAs require lower voltage operation and simpler cooling system, and are more reliable. However, the magnetrons achieve higher efficiency and higher output power levels at low cost. In fact, a fundamental disadvantage of HPSs lies in their thermal limitations. The basic components of HPSs are microwave transistors of a proper output power level. Currently, due to the development of wireless personal communications market, the demand for high power solid-state transmitters is on the rise. This demand is also the reason for the fast development of high power microwave transistors technologies.

This paper presents the concept and practical development of a 100 W ISM 2.4 GHz-band microwave power test system (MPTS). It is built as a modular structure with power amplifiers based on a new generation high power push-pull GaAs FETs [1]. These transistors operating in class AB (cw) achieve up to 300 W (240 W available in commercial market) output power level at W-CDMA frequency band. The MPTS system includes four major sections: a synthesized VCO based on PLL subsystem with digital variable attenuator and switch for AM modulation, power measurement probes with diode detectors, high power amplifier and microcontroller (μC). It is assumed that this PC controlled system will be used for a variety of functions including:

- delivery of microwave power up to 100 W at a single frequency with precise control of power level and frequency;
- measurement of reflection coefficient versus frequency at high power levels;
- automatic tuning of the frequency of the system to the minimum of reflection from the load changing in time;
- precise measurement of leakages from microwave industrial systems versus frequency with the dynamic range between the maximum input power and minimum detected leakage up to 100 dB.

Other functions may be subject to PC programming depending on particular needs.

2. Concept of MPTS

The idea and the block diagram of the MPTS system is shown in Figs. 1 and 2. The MPTS can operate in either single fixed-frequency regime, or in swept mode with self-tuning for minimum reflection coefficient of a resonant load such as a cavity partially filled with the heated material. The reflection characteristics are continuously extracted using power measurements obtained from the detector probes

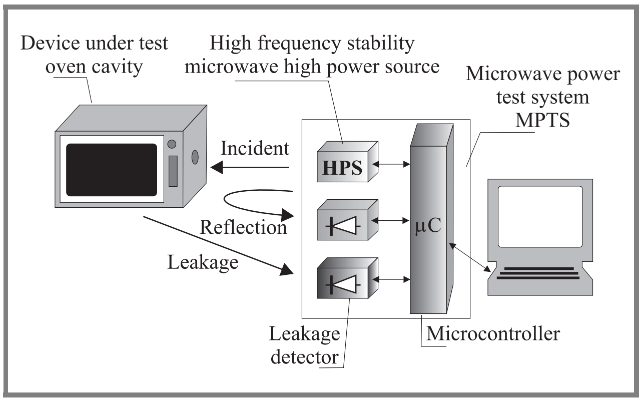

Fig. 1. The concept and block diagram of the MPTS system.

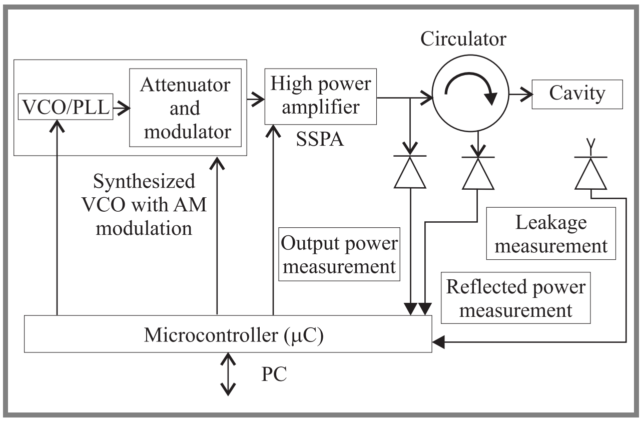

Fig. 2. The block diagram of the MPTS system.

placed at the output SSPA and in the third arm of the circulator. The setting and control of the output frequency and output power level over a 15 dB dynamic range as well as all calculations are realized by means of an 8-bit microcomputer with 4 KBytes flash memory (PEROM) [2]. The PC is used as the user interface for programming various functions of the setup and displaying the basic parameters and measured characteristics.

3. Synthesized VCO

The synthesized VCO is based on PLL subsystem. To realize VCO the IBM HBT transistor (IBM43RF0100) and the varactor diode (MA46477-120 by M/ACOM) were chosen.

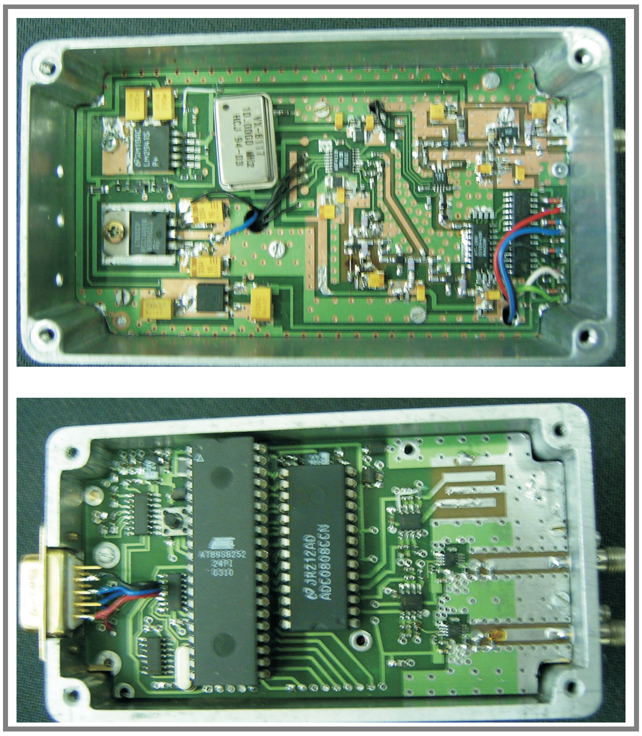

Fig. 3. The view of synthesized VCO (microwave part and microcontroller with detectors).

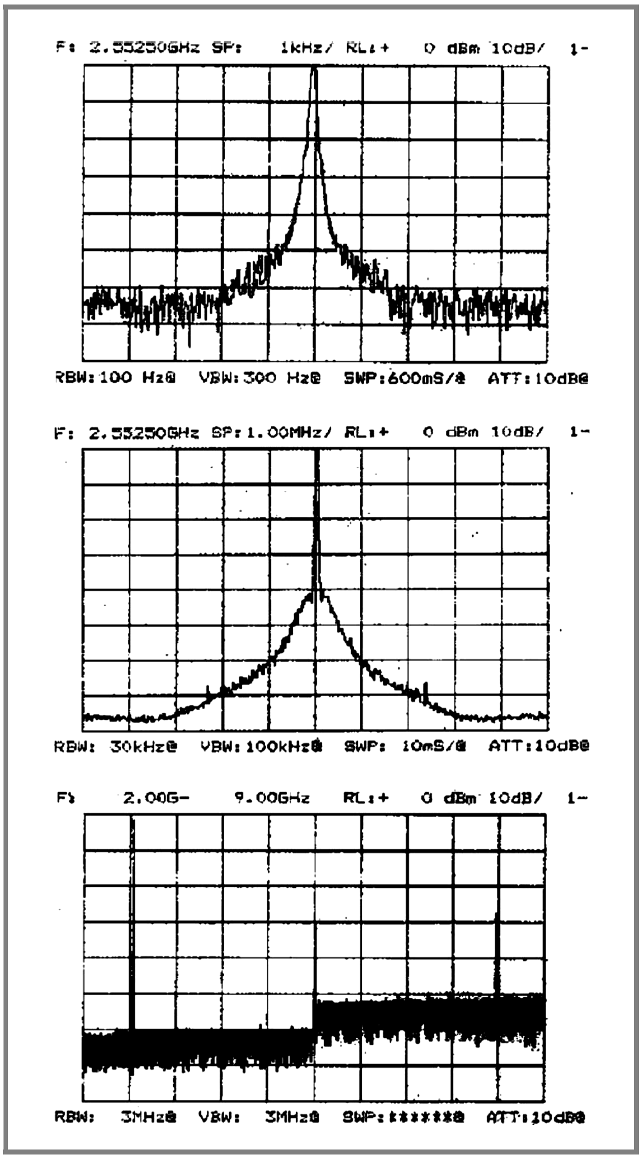

Fig. 4. The spectrum of synthesized VCO.

The small-signal approach with the Nyquist criteria was used for the design. The oscillator structure was optimized by means of ADS microwave simulator (Agilent Technologies) in microstrip technique. The limitation of the pulling effect was achieved by reduction of coupling between microstrip resonator and varactor. The basic component of PLL subsystem is a VLSI monolithic circuit AD4118 (ANALOG DEVICES) integrating adjustable frequency prescaler, phase/frequency detector, charge pump, and reference oscillator/buffer functions. The device requires an external loop filter and there is no need to use other active components. The practically realized synthesizer operates over the wide 2.2 to 2.8 GHz frequency range with minimum frequency resolution $\Delta f = 250$ kHz and is fully programmable. The long-term frequency stability as well as phase noises level of the synthesizer depends mainly on the stability of reference frequency standard. As reference source the TCXO crystal oscillator is used in synthe-

sizer. To achieve a high isolation and an appropriate output power level two monolithic amplifiers (ERA-3 and ERA-3 by MiniCircuits) at the oscillator output were applied. The output part of synthesizer was especially developed for the class AB SSPA driving purpose. This subsystem includes a high gain, more then 14 dB, 1 W power amplifier with the class AB AlGaAs/GaAs HJFET SHF0289 manufactured by SIRENZA driven by another monolithic amplifier ERA-5. To obtain a required output power level dynamic, the digital attenuator AT270 (by M/ACOM) was applied. As AM modulator, the switch HMC174 (HITTITE) was used. The AM modulation is an option of MPTS (turn on/off from PC). It is applied the sensitivity of leakage measurement. Both components are GaAs MESFET monolithic devices and low cost. The view of the complete synthesized VCO and its spectrum are presented in Figs. 3 and 4.
The AD8314 (ANALOG DEVICES) was chosen for incident and reflected power detection purposes. The probe

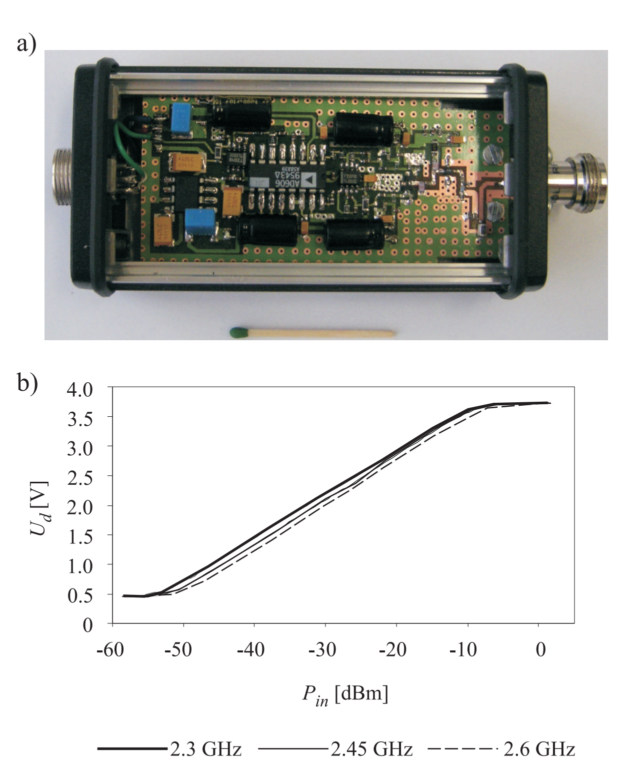

Fig. 5. (a) The photos of the leakage detector and (b) its characteristics $U_d = f(P_{in})$.

for leakage measurement is equipped with a two-Schottky-diodes detector followed by a logarithmic narrow-band amplifier AD606. The leakage detector and its characteristics $U_d = f(P_{in})$ has been shown in Fig. 5.

4. High power amplifier SSPA

The SSPA consists of the 10 W driver amplifier with a class A GaAs MESFET to achieve high gain and the 100 W balanced amplifier with push-pull GaAs FET operating in class AB, and 2-way divider/combiner as shown in Fig. 6.

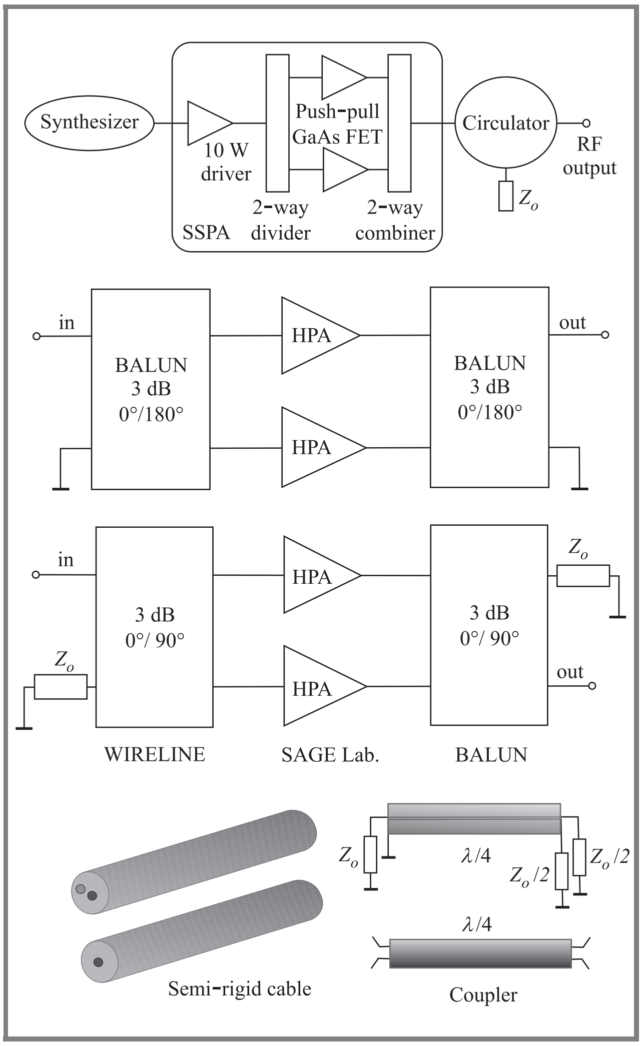

Fig. 6. Block diagram of the 100 W SSPA and the combining technique with semi-rigid cable.

The active components of the SSPA are the common source FETs: the 10 W L-band FLL120MK as driver and push-pull FLL1200IU-3 of $P_{sat} = 120$ W at 2.45 GHz, both manufactured by FUJITSU [1]. The surface-mount 3 dB/90° WIRELINE couplers, developed and patented by SAGE Lab., were used as 2-way divider/combiner [3]. All elements used in the design are commercially available. The WIRELINE couplers consist of a pair of wire center conductors surrounded by a continuous dielectric insulator and shielded by a drawn or extruded outer jacket. Finally, the construction has the physical properties of semi-rigid coaxial cable with the electrical features of a TEM coupled line. These couplers also reduce sizes of a board circuit. The insertion loss of WIRELINE 2-way divider/combiner is less than 0.2 dB within the desired band.
The basic concern in high power amplifier design is appropriate matching at the input and output of the transistor,

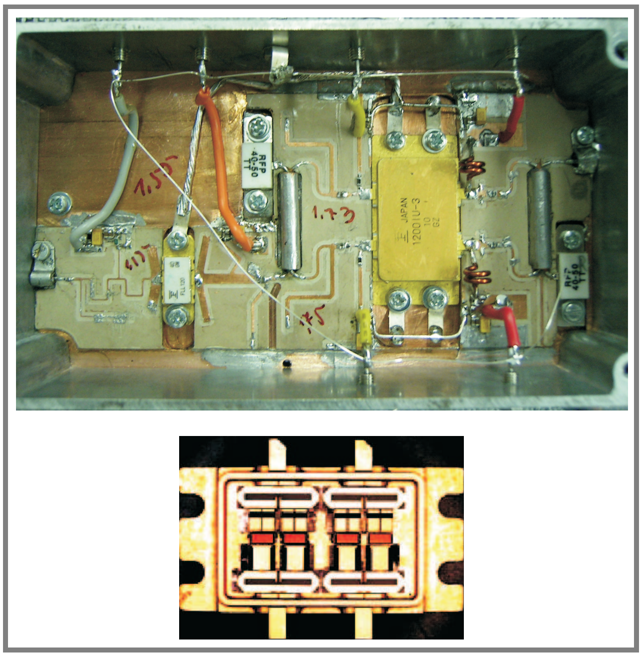

Fig. 7. The view of the 100 W amplifier with FLL120MK as the driver and FLL1200IU-3 push-pull transistor.

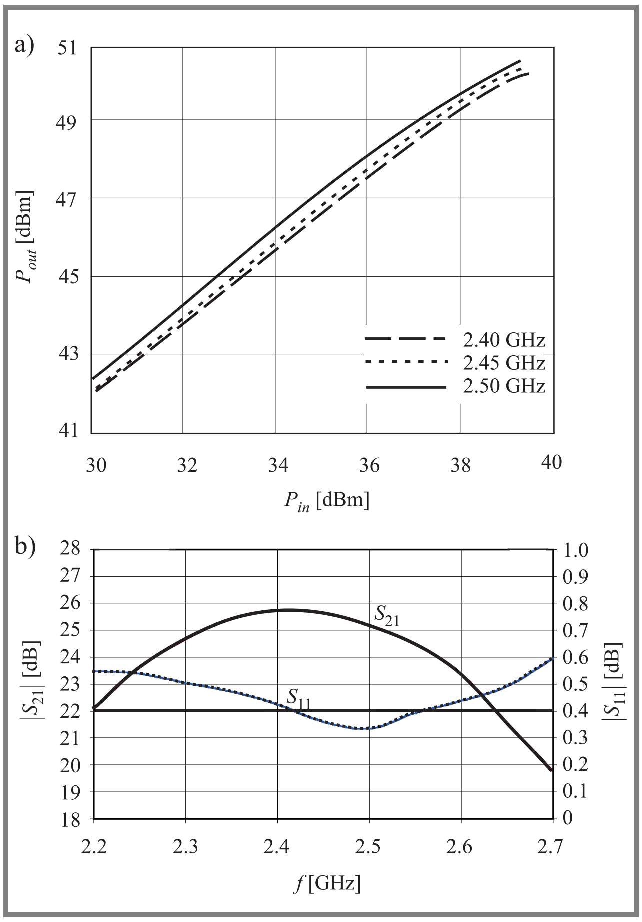

Fig. 8. (a) The $P_{out} = f(P_{in})$ small-signal gain and (b) reflection versus frequency of the 100 W amplifier with FLL1200IU-3 push-pull transistor.

and it is necessary to know the values of input and output impedances within a given frequency range. For high power transistors, the only practical way to determine is the source/load-pull technique. Numerical methods based on transient analysis or harmonic balance are not currently effective due to the very complicated transistor structure. In general, measurement methods of optimum source and load impedances for different amplifier requirements are well known and applied. However, in the case of high power transistors this technique causes many problems because the measured impedances usually have a very low real part. It can be assumed the error of the best source/load-pull technique amounts to within about 10% [4]. Therefore, to achieve optimum or at least satisfactory results, some re-tuning is necessary, in particular for the output matching section. Some of the high power transistors available on the market include internal matching circuits helping to achieve satisfactory performance at a specific frequency. They are, however, very difficult to tune in a wider frequency range. The view of the 100 W amplifier (SSPA) with FLL1200IU-3 push-pull GaAs FET (transistor consist of four chips and its structure) and its power characteristic is shown in Figs. 7 and 8. To reduce the dimension of the amplifier, the Rogers substrate RT/DUROID 6010 was used.

5. Performances

Here is the summary of the features of the developed MPTS (Fig. 9):

- frequency band from 2.3 to 2.6 GHz, set by a microcontroller with 250 kHz step;
- long-term frequency stability more than 10^{-7} and phase noises: –75 dBc/Hz 1kHz;
- output power level up to 100 W, controlled within 15 dB range with 0.5 dB step;
- AM modulation: square wave with frequency 2 kHz that can be switched on/off by software;
- output: N type connector 50 W from circulator integrated with high power load;
- leakage detector: more than 45 dB dynamic (up to –105 dB below the maximum power generated by the power module), VSWR less than 1.2;
- microcontroller software: full setup for operating regime, output power level, range and step frequency;
- PC interface: connection RS-232 or USB;
- PC control software: graphical presentation of measurement results – reflection and leakage versus frequency.

Fig. 9. The view of the 100 W ISM 2.4 GHz power test system.

6. Conclusions

The MPTS system has been successfully realized. It makes available many new practical applications of microwave power, such as microwave-driven chemical reactions or precise measurements of material parameters, heating efficiency, and system leakage.

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