MICROWAVE CURRENT MONITORING IN ELECTRICAL POWER LINES

Edmar Camargo and Fernando Colombani*

ABSTRACT

A microwave system has been developed to operate at 24 GHz, for the remote monitoring of current in electrical power lines. The microwave radio link parameters are: a maximum distance of 100 meters between transmitter and receiver, + 3 dBm transmitter output power and a receiver noise figure of 12 dB. The measuring characteristics are: a wide instantaneous current range from 5 to 500 A, within a bandwidth up to 1 MHz and power line voltage of 13.8 KV.

INTRODUCTION

The monitoring of the electrical power line parameters consists nowadays of an important subject of study, since their adequate management and control can result in considerable saving of electrical energy. In order to have an efficient control of the energy flow, current and voltage sensors are strategically distributed along power lines, either of the transmission or the distribution types. Conventionally, the collection of voltage and current data is carried out by current and voltage transformers. However, depending on the high voltage value, these components become expensive, since they must assure a safe isolation from the measuring instrument to the mains.

In order to overcome these problems, some solutions have been proposed such as the VIP sensor[1] manufactured by Fisher Pierce, and the Power-Donut manufactured by NITECH[2]. The former uses a coil coupled to the magnetic field generated by the current flowing in the line, and the resulting sampled current is taken to a remote station through a cable. The latter uses the same principle, but the information is digitally coded and transmitted to a remote station by radio waves operating at 900 MHz. Recently, some optical sensors have also been introduced with good results[3]. However, none of these systems is able to fulfill the following requirements: low cost, light weight, wireless connection, reasonable accuracy and compatibility with present analogue measuring instruments.

This paper presents a current sensor intended to trade-off these requirements, using a short range microwave link to transmit the data collected near the line to a remote station. In the following sections it is described the radiolink system planning, the outline of the transmitter and receiver, and the design considerations for the microwave components.

SYSTEM PLANNING

The radio link was designed to operate at 24 GHz for its inherent compactness of the RF components and the possibility of using a small antenna with high gain. The system immunity to interference is enhanced by the use of frequency modulation techniques and by the resulting narrow propagation

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* Instituto de Eletrotécnica e Energia - Universidade de São Paulo
Av. Prof Luciano Gualberto, 1289 - CEP 05508 - São Paulo - Brazil

beamwidth. The system should be able to operate at a maximum distance of 100 meters, and be capable of measuring current in 13.8 KV electrical lines within a 5 to 500 A range, in a bandwidth of 1 MHz. In order to cope with present electrical systems, where analogue as well as digital instruments are in use, the radio link should also be able to operate with both systems by changing one circuit module.

The analogue link parametes were calculated for trading off the specifications of usual microwave components with a minimum signal/noise ratio of 35 dB. It was found that a transmitter power of 0 dBm and a receiver noise figure of 12 dB are capable of meeting these specifications with a frequency deviation of 10 MHz. According to Carson's Rule[4], the Transmission Bandwidth is in the order of 20 MHz. In the case of digital transmission employing 200 Kbits, it is expected a low BER, less than 10^{-6}, considering the same output power, link coverage and noise figure.

A. Transmitting Section

The transmitting section block diagram is represented in figure 1. It is composed of two low power coupling transformers, a DC regulator, a signal processor and the microwave radio. The first transformer supplies power to the DC regulator, which provides bias for the electronic circuits. The output voltage of the second transformer is prepared in the processor before being applied to the 24 GHz microwave VCO. The modulated carrier is then transmitted by a 20 dB gain horn.

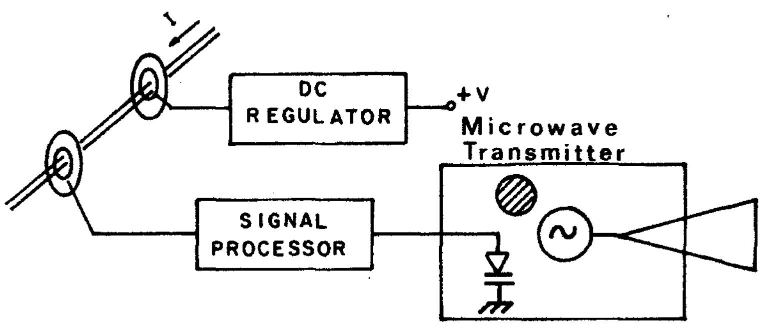


Fig 1 - Transmitter Block Diagram

B. Receiving Section

The receiving section illustrated in figure 2, contains a 20 dB gain horn, a microwave VCO, and a single balanced Schottky diode mixer. The resulting 70 MHz signal is delivered to a 4 dB noise figure IF amplifier. The modulated IF signal is demodulated using a monolithic PLL usually employed in TVRO systems. The signal is then applied to the signal processor which recovers the original information.

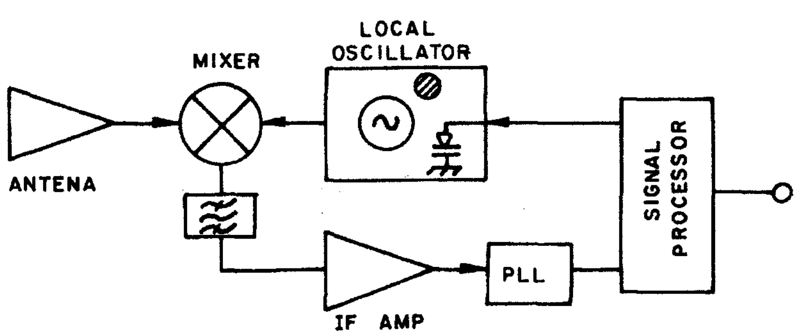


Fig 2 - Receiver Block Diagram.

MICROWAVE COMPONENTS

A. Microwave Oscillator

In order to realize a low cost 24 GHz oscillator, it was decided to employ a MESFET device operating in the harmonic mode[5]. By this technique, the device oscillates at 12 GHz, and its second harmonic is extracted from the drain port by an appropriate filter. For this purpose, a packaged MESFET type AT26836 by AVANTEK featuring a gate length of 0.5 µm, was employed. The advantages of this approach are: to obtain a high frequency signal with an inexpensive device; and, due to the presence of a fundamental filter in the output, the oscillator becomes rather insensitive to load variations. It must also be emphasized that the frequency deviation is also doubled in a harmonic oscillator, increasing the system signal-to-noise ratio.

The circuit parameters were determined through a non-linear simulation using PSPICE, studying the oscillating conditions for a grounded drain oscillator, and the second harmonic content on the drain current waveform. The oscillating conditions at the gate are achieved using a 12 GHz dielectric resonator (by Thomson), which also stabilizes the oscillator with temperature. The frequency modulation is obtained by coupling to the dielectric resonator, an open microstrip line resonator terminated by a MESFET, whose gate-to-source junction operates as a varactor. In spite of the series gate resistance presented by this device, the degradation in the oscillator phase noise was very low. The complete circuit was realized on 0.25 mm thick DUROID 5880 substrate, presenting an ε_r=2.2. The microstrip line mask of the circuit is shown in figure 3.

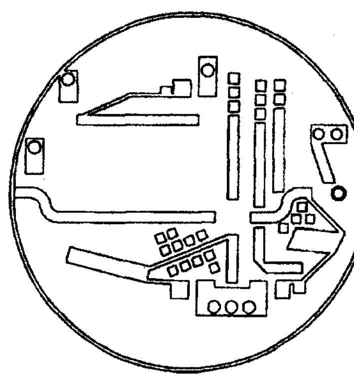


Fig 3 - Mask of the Harmonic Oscillator

This type of substrate is not adequate for highly stable oscillators, for its temperature sensitivity. However, this is not relevant in this application, since the receiver local oscillator is locked to the transmitter frequency. The resulting oscillator performance is listed in table I.

Output frequency	24 GHz
Output Power	+4 dBm
Frequency deviation @(V_{GS} = 0 to 2 volts)	8 MHz
Frequency Stability @(0 to 60°C)	+/-2MHz
Phase Noise @100KHz (meas. @ 12GHz)	98 dB

Table I - Oscillator Performance

B. Single Balanced Mixer

The single balanced mixer used in the receiver employs a 90° hybrid ring constructed on 0.25mm thick Duroid 5880 substrate. The diodes are Si Schottkybarrier beam-lead diodes type HP5082-2229 by Hewlett-Packard, which typically present a series resitance of 5 Ω and a zero-bias junction capacitance of 0.3 pF. The conversion loss for a LO power of +3 dBm is equal to 8 dB, and the LO to RF isolation is greater than 18 dB.

C. Antenna + Waveguide/Coax Transition

The antenna consists of a 12.5 cm pyramidal horn which presents 20 dB gain and 18 dB return loss at 24 GHz. The waveguide/coax transition is based on an electric field probe, introducing 0.1 dB insertion loss and presenting 20 dB return loss. This assembly acts as a high pass filter, with a cutoff frequency of 19 GHz, thus filtering the corona noise, emitted by the power lines. The probe is shorted to ground by a 90^0 microstrip line, which introduces another filter to the system, shorting any static discharge for protection of the electronic circuits.

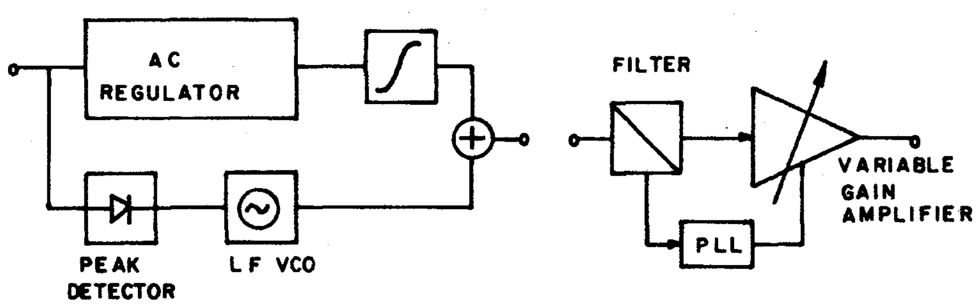
D. IF amplifier + 70 MHz PLL

A Silicon monolithic amplifier by AVANTEK, presenting 20 dB gain and 3.5 dB noise figure at 70 MHz, was employed as the IF amplifier. Undesired noise outside the transmission bandwidth is attenuated by the filter at the input of the IF amplifier. The PLL is of the type NE568 by Signetics, usuallly employed in TVRO systems. The application of this type of demodulator does not require control of the IF power level, as long as it operates within the specified range.

SIGNAL PROCESSOR COMPONENTS

A. Analogue Processor

The following approach was selected taking into consideration the wide measurement range required by the system, and the possibility of building a wide bandwidth low frequency VCO. Figure 4.a displays the transmitter block diagram, where the measured signal is divided into two other signals. The first contains the waveshape information within a bandwidth of 1 MHz, so that 1 µs current surges can be displayed by the waveform. This signal is applied to an AC regulator, which transforms the variable input signal into a constant peak-to-peak voltage, and then to an integrator to obtain a voltage proportional to the current flowing through the line. The second signal is transformed by a peak detector into a DC level, that controls a low frequency VCO, operating in the 500 KHz frequency range. Both signals are then added, and applied to the microwave VCO. Thus, the resulting information bandwidth is in the order of 1 MHz.



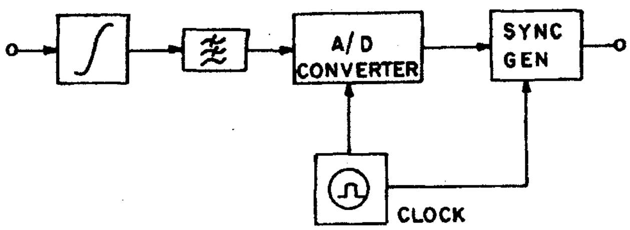
a.Transmitter b.Receiver

Fig 4 - Analogue Processor

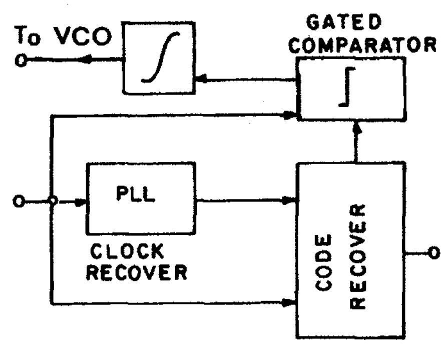
The receiver part of the analogue processor is depicted in figure 4.b. The 70 MHz PLL output voltage is used to lock the receiving microwave VCO to the transmitter. The processor contains a filter that separates the waveform from the modulated carrier containing the amplitude information, which will be demodulated by a low frequency PLL. Both signals are applied to a variable gain amplifier that recovers the original signal, to be conducted to conventional instruments.

B. Digital Processor

The digital processor located in the transmitter is represented in figure 5.a. The output signal from the integrator is filtered to 2.5 KHz and then applied to the A/D monolithic converter, which transforms the input signal into digital form. The waveform is sampled using 8 bits plus 2 control bits, composing a 10 bits digital signal. The digital output is then directly applied to the microwave VCO.



a.Transmitter



b.Receiver

Fig 5 - Digital processor.

The digital processor in the receiver is shown in figure 5.b, and consists of a low frequency PLL, for recovering the clock signal, and a sync circuit for extracting the digital information from the received code. The DC level of the control bits is employed to generate a correction signal, through a gate controlled by the sync circuit. This circuit is followed by an integrator, that locks the microwave VCO to the transmitted signal.

PERFORMANCE OF THE 24 GHz TRANSMITTER/RECEIVER

The microwave components described previously were developed and assembled to compose a transmitter and a receiver. The transmitter is depicted in the upper part of figure 6 and the receiver in the lower one. The electrical characteristics of the transmitter are mainly dependent on the oscillator performance. For the receiver, consisting of oscillator, mixer and IF amplifier it was obtained a conversion gain of 13 dB, and a noise figure of 12 dB. The transmitter will be housed in an aluminun cylinder measuring 3 inches in diameter and the receiver in a conventional squared cabinet. A brief estimative of the system accuracy was made by studying the sources of error. For the analogue system, the main source of error occurs in the transmitter, specifically in the low frequency VCO, since all other components are temperature stable and linear in a wide voltage range. The overall expected accuracy is in the order of 5%. For the digital system, the accuracy is entirely dependent on the analogue-to-digital converter, for which an accuracy better than 1.0% is expected.

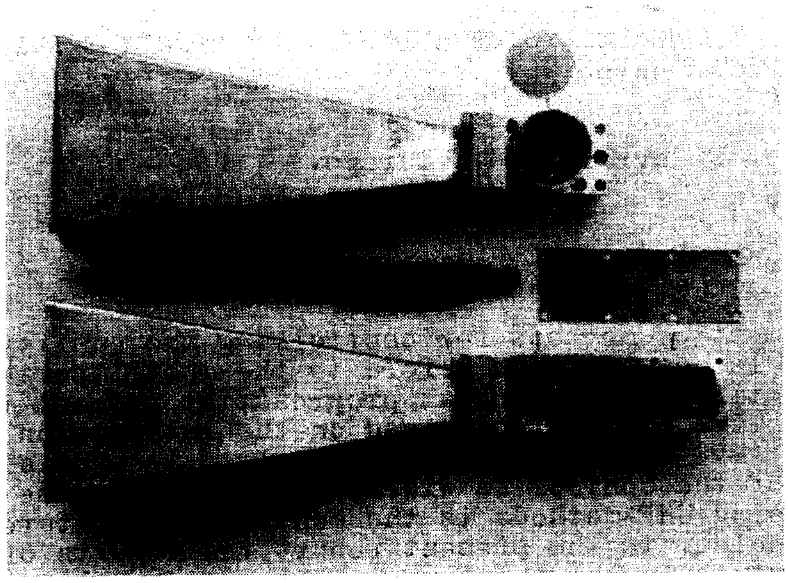


Fig 6 - Photo of the 24 GHz transmitter/receiver system

CONCLUSIONS

This paper presented a brief description of a microwave system designed to monitor the current flowing in electrical power lines. Details of the microwave transmitter and receiver have been given and their performance can be summarized by: transmitting power of + 3 dBm at 24 GHz and receiving noise figure of less than 12 dB. Field tests were not carried out since this system will be applied to different situations. In some cases it will employ the modulator/demodulator approaches described here and in others it will use previous digital designs where it will essentially replace cables and overcome the isolation problems associated with high voltage. Finally, it can be said that by employing digital signal processing, the system will result more expensive, but it presents several advantages concerning accuracy, temperature stability, and a further enhancement in its immunity to interference.

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