Low Noise Readout Circuit for THz Measurements without Using Lock-in Technique

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***Abstract*—The lock-in technique is commonly used for measurements of very small DC signals in the presence of overwhelming noise. However, phase sensitive detection has its own limitations and it cannot be always easily applied in every test setup configuration. This work deals with a low noise readout circuit intended to operate with FET-based THz detectors, which in fact can replace the lock-in equipment and eliminate the need of THz wave modulation. This circuit can be also successfully deployed for processing of small DC signals produced by other sensors or detectors.**

I. Introduction and Motivation

Significant amount of labs dealing with terahertz measurements extensively use the lock-in technique. Namely, this technology is widely used to read the detector signal using backward wave oscillators or different solid-state THz sources (including those based on frequency multipliers). Such a technique, however, requires modulation of the THz beam and, moreover, a standard lock-in apparatus is usually a heavy (often rack-mounted) single-channel device equipped with a dedicated preamplifier to limit parasitic RC parameters. Most experimental studies concerning characterization of field effect transistors (FETs) for THz applications have been performed with such a setup. In this work, a solution which has a number of advantages over the classic system is shown.

II. Proposed Circuit

This paper introduces the readout circuit developed originally for measurements of THz radiation using field effect transistors. The detailed information on detection of this type can be found in [1]. Taking into account that the response of a FET illuminated with constant THz radiation is a small DC signal, it is crucial for a readout circuit to provide the 1/f noise suppression and the input offset cancellation. In case of common lock-in technique this is achieved by modulating the input stimuli of the detector, what results in readout circuit operating in fact with an AC signal.

Designed readout integrated circuit, fully described in [2], based on the chopper amplifier architecture, implements similar operation inside, hence the modulation of the input signal and expensive measurement equipment are no longer required. The overall structure of designed chopper amplifier is presented in Figure 1.

The input DC voltage signal V_{in} can be characterized by the magnitude A and single frequency component in $f = 0$. At the beginning of the signal path, it is applied to the modulator block, what results in V_m voltage at its output. From the frequency domain point of view, spectrum of DC signal is convoluted with a square wave spectrum producing signal with trigonometric Fourier series expansion given by equation (1).

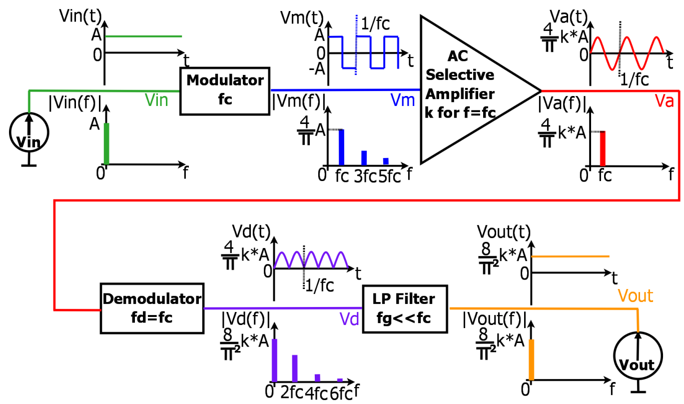

Fig. 1. Simplified architecture of designed integrated readout circuit (with signals illustrated in time and frequency domains)

$$V_m(t) = \sum_{l=1}^{\infty} \frac{2A(1-(-1)^l)}{l\pi} \sin(l\pi t) \qquad (1)$$

Modulated signal is next applied to the selective AC amplifier, resulting in V_a at its output. In an ideal, theoretical situation, only the frequency component $f = f_c$ is amplified (with k gain), the other ones are entirely suppressed (including external noises and interferences).

Demodulation process is made by a circuit similar to the modulator, but this time - considering the frequency domain - spectrum of the square wave (demodulator control) is convoluted with one of the amplified sine signal. As a result of this operation, a rectified sine wave is produced (V_d) with trigonometric Fourier series expansion given by (2).

$$V_d(t) = \frac{8kA}{\pi^2} - \sum_{l=2,4,6\ldots}^{\infty} \frac{16kA}{\pi^2(l^2-1)} \cos(l\pi t) \qquad (2)$$

At the end, the LP filter with cut-off frequency $f_o << f_c$ passes only the DC component of the rectified signal.

The circuit output wave V_{out} is a DC signal with $\frac{8A}{\pi^2}k \simeq 0,81Ak$ magnitude, where A is the input signal magnitude and k is the gain of the AC amplifier for the f_c frequency.

This attitude of a signal processing results in very good output noise parameters, due to the 1/f noise reduction - only signal component with a specific frequency (equal to the f_c) is amplified.

The readout circuit, implementing architecture presented in Figure 1, supporting a detector based on a silicon FET integrated with a patch antenna, as described in [3], has been manufactured in AMS C35 process. Afterwards, a complete readout system for 8-detector pixel-line has been developed - consisted of nine single-channel readout circuits and several of-the-shelf components.

III. Measurement Results

Figure 2 presents the results of the input referred noise measurement for single-channel readout circuit. The measurements were performed twice: with input shorted to ground and with resistor 100 $k\Omega$ connected to it.

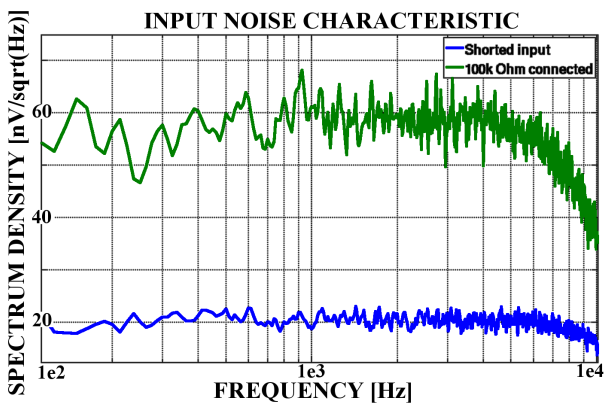

Fig. 2. Input referred noise spectral density for shorted input (blue) and connected 100 $k\Omega$ resistor (green)

The measured noise level - equivalent to the thermal noise of applied resistor - is consistent with theoretical equation $\bar{u}^2 = 4k_B T R \Delta f$. It is worth to notice that the spectrum density of the input referred noise stays constant with decreasing frequency, which proves the efficiency 1/f noise minimization techniques applied in the design.

The table presented below summarizes the most important parameters of the single-channel readout circuit.

TABLE I
Main parameters of the single-channel readout circuit

PARAMETER	VALUE
Bandwidth	0... 3.875 kHz
Gain	18.2/38.2/58.2 dB
Input impedance (at 100 Hz)	27 $M\Omega$
Input referred noise density (at 100 Hz)	22 $\frac{nV}{\sqrt{Hz}}$
Output SNR (with detector connected to input)	57 dB

As it was mentioned before, the single channel selective readout integrated circuits were used to develop the complete readout system targeted to handle the 8 element pixel-line. Eight ICs were applied as selective preamplifiers, while the ninth one was used as the demodulator and the output LP filter. This readout system was built as a digitally-controlled device, supporting several modes of operation. Figure 3 shows the result of exemplary measurements carried out with THz source from Virginia Diodes, Inc. providing 2mW of output power for 355GHz. Upper waveform shows the output signals from subsequent pixels, indicated by numbers above the trace. Unmodulated THz beam was centered in-between the fourth and fifth pixels. The lower trace in the Figure is triggering signal for an oscilloscope, its five time longer pulse denotes the first element within the measured pixel-line.

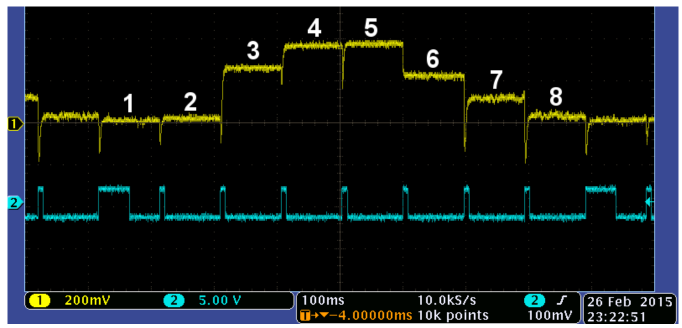

Fig. 3. Measurement of 8-detector line

IV. Conclusion

The low noise readout circuit intended to operate with FET-based THz detectors was briefly presented and described in this paper. Due to the chopper amplifier architecture implemented, it can successfully replace the lock-in equipment and eliminate the need of THz wave modulation.

The proposed circuit was from the first aimed at THz spectroscopy applications, by supporting the readout of the pixel-line consisted of FET-based detectors fitted with antennas tuned to different frequencies. Although it is worth to notice that with some minor modifications (e. g. by including parallel signal processing) it can be appropriate for other tasks, like imaging. Furthermore, it can be successfully deployed for processing of any small, low-frequency signals, produced by different sensors or detectors.

Acknowledgment

This work was partially supported by the National Centre of Research and Development (NCBiR) with project THzOnLine PBS1/A9/11/2012.

References

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