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Design a Radio Receiver for Solar Activity Observation in VLF Band

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Abstract

Solar activity monitoring is important in our life because of its direct or indirect influence on our life, not only on ionospheric communications. To study solar activity, researchers need measuring and monitoring instruments, these instruments are mostly expensive and are not available in all universities. In this paper, a very low frequency radio receiver had been designed and implemented with components available in most markets to support the researchers, college students, and radio astronomy amateurs with a minimum input voltage less than 100µV, an output voltage less than 135 m V with no distortion and an overall gain of 34dB. A comparison had been done between two circuit structures using a workbench software program and experimentally done in the lab. Two antennas were experimentally tested and a loop antenna was chosen. The whole system was connected and tested to receive signals in the Lab and monitored on computer using HDSDR software program. Another experiment done outside the lab (at home), and the result was not good because of many high level interference noises.

Keywords: *Solar activity, ionospheric communication, very low frequency radio receiver*.

1. Introduction

The philosophy behind designing a very low frequency (VLF) receiver with a bandwidth of 10 to 40 KHz is to monitor the flare event indirectly by receiving the signals of distant VLF transmitters worldwide that are used for marine navigation and studying natural phenomena [1]. Studying solar flares is important because they have an effect on devices and infrastructures in this era [2, 3]. These signals propagate in ground wave and sky wave paths [4]. Sky wave propagation paths only occur in night time in normal solar conditions, while for distances less than 700km, ground wave propagation is more dominant [5]. If high solar activity flares occur, they will increase the ionization levels of these layers when they reach the earth's ionosphere, making the D layer more ionized and absorption levels will also increase [6]. At this moment, the D layer absorbs signals from 3 to 30 MHz and this is called high frequency (HF) block out, while signals from 10 to 40 KHz will be reflected to a distance less than 2000 Km in day time making the D layer a reflector mirror. By receiving a distant station (sky wave propagation) at day time from 10 to 40 KHz using a VLF radio receiver, it is an indirect indicator that a flare has occurred. In previous works [1-6], the circuits were designed using high cost components, software programs, and antenna systems, which is a problem facing researches in countries like Iraq, so the novelty in this paper is to design a VLF receiver from components available in the Iraqi markets.

2. Methodology

2.1 Monitoring Scenario

VLF beacons exist worldwide, and are used for marine navigation. For demonstration purposes, a Bafa Transmitter (beacon) located in Turkey with callsign TBB at a frequency of 26.7 KHz had been taken as a transmitter, and the VLF receiver is located in Baghdad. At day time in Baghdad, the receiver will not receive the signal at that frequency, but at night time with good ionosphere conditions and good antenna alignment, it could receive the signal of that transmitter. If TBB is heard at daytime in Baghdad it means that the signal was reflected from the D layer with a high degree of ionization because of solar flare occurrence.

2.2 Simulation

A VLF receiver's block diagram consists of an antenna, a preamplifier of 14dB gain, a main amplifier of 20 dB gain, and the amplified signal is displayed using computer software like HDSDR, which is a free license Software Defined Radio program under Windows used for many applications like radio astronomy, shortwave listening, spectrum monitoring, and analysis, as shown in Fig. 1.

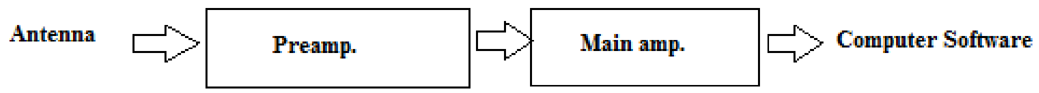

Fig. 1 shows VLF block diagram.

The VLF receiver had been simulated using the Electronics Workbench software, version 5.12.

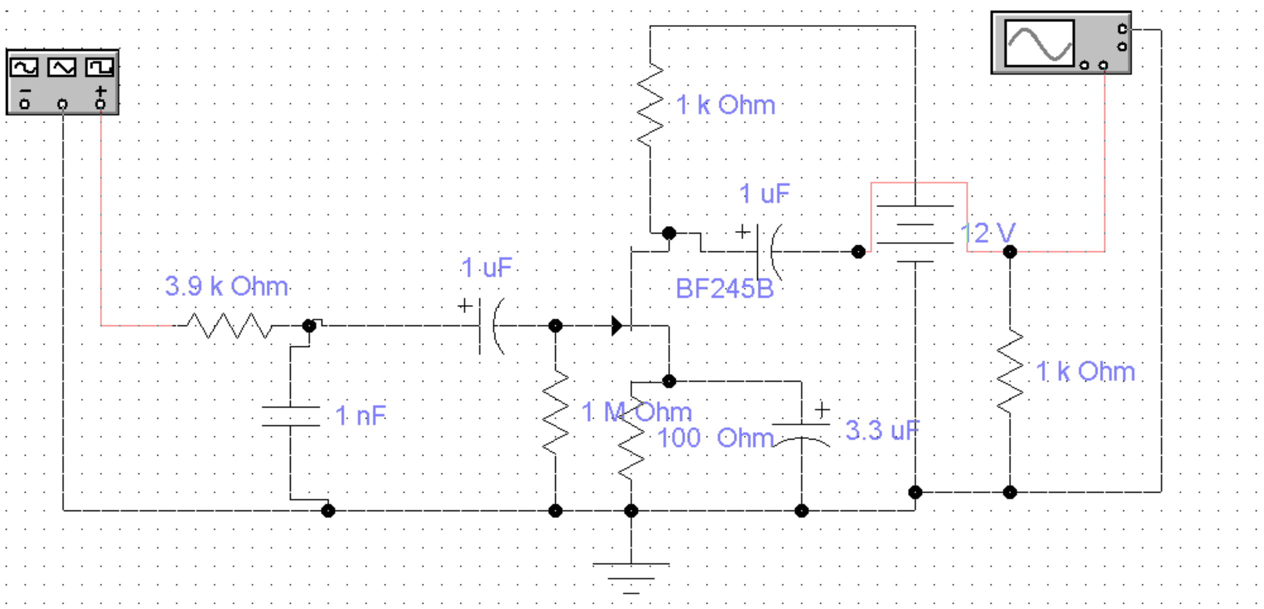

Fig. 2. Shows the simulated preamplifier circuit diagram.

The circuit in Fig. 2 consists of a low pass filter (LPF) of corner frequency (fc) around 40 KHz, and a JFET transistor (BF245B) in common source configuration with a gain of around 14 dB. The simulated results of the amplifier frequency response and Vo versus (Vs.) Vin are summarized in Fig. 3 and 4.

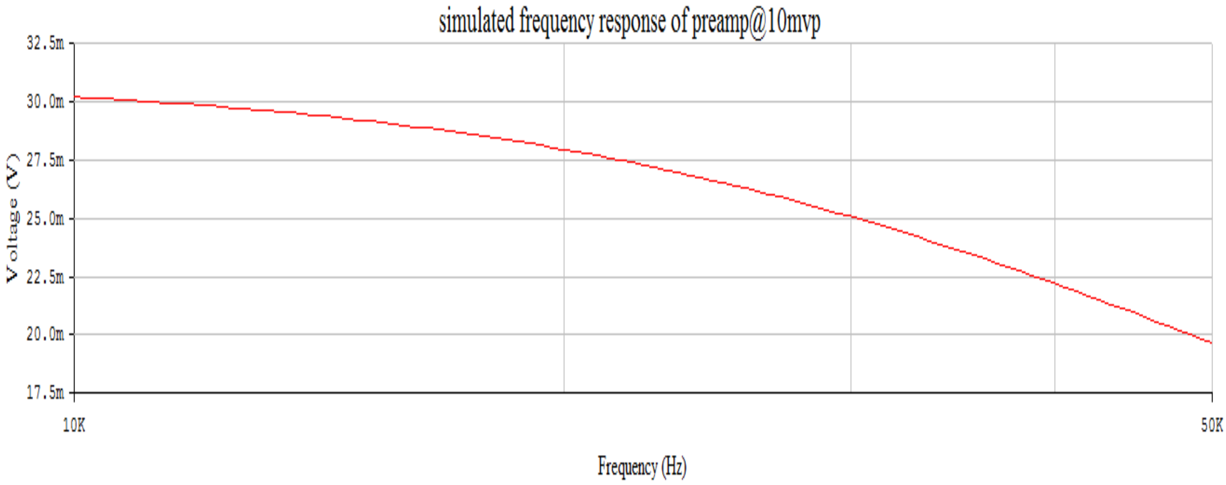

Fig. 3. Shows the simulated frequency response of the preamp.

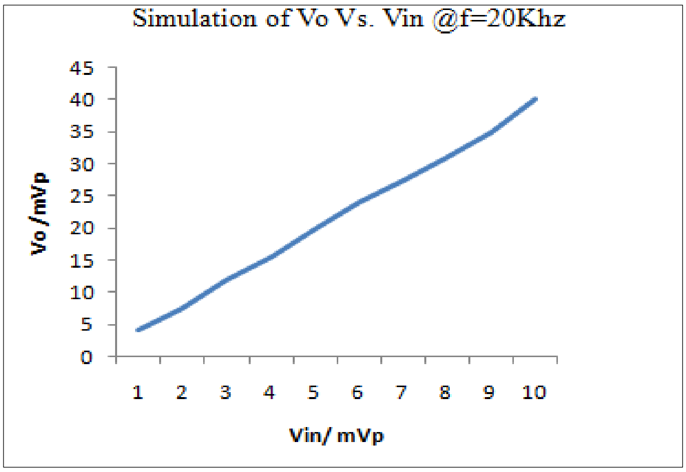

Fig. 4. Shows the simulation of Vo vs. Vin.

Fig. 4 shows the relation of Vo Vs. Vin (that was generated using the Electronic Workbench simulation program) which is a liner gain relationship of common source amplifier of the circuit in Fig. 2, in which the gain formula is simply illustrated in equation 1 as follows [7]:

$Vo = -gmViRD$ … (1)

Where Vo is the output voltage, Vin is the input voltage, gm transistor is the transconductance, and the RD is the drain resistor.

The main amplifier circuit of fig. 1 had been simulated using two designs, the first (design consists of a BPF of BW=30KHz and a BJT transistor (2n2222) in the common emitter configuration of 20 dB gain, as shown in fig, 5. The simulated frequency response and Vo vs. Vin is summarized in fig. 6 and 7.

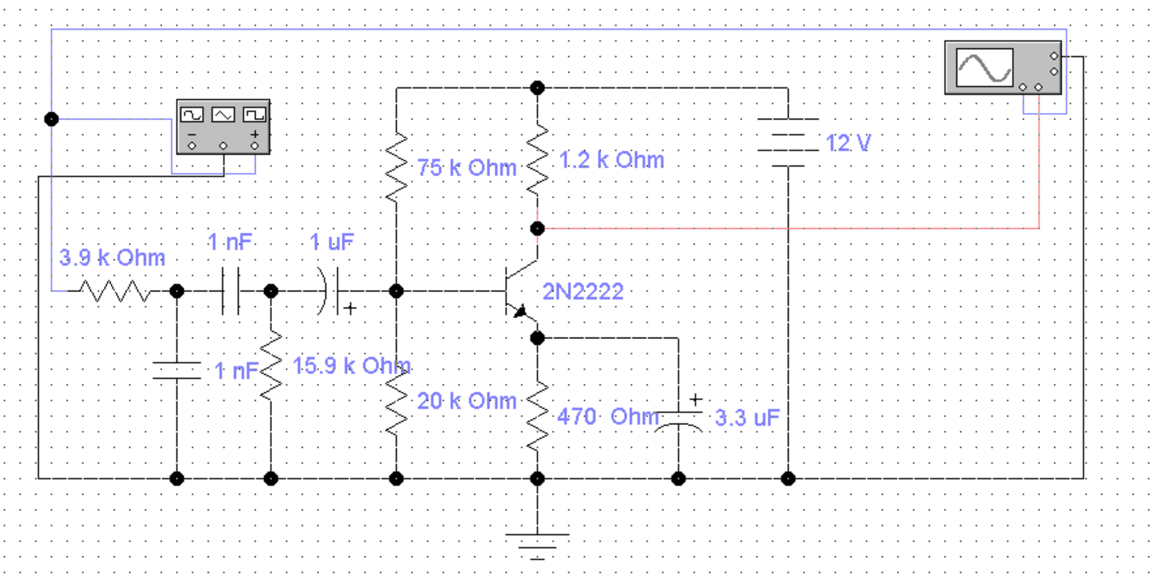

Fig. 5. Shows the simulated main amplifier (1st design).

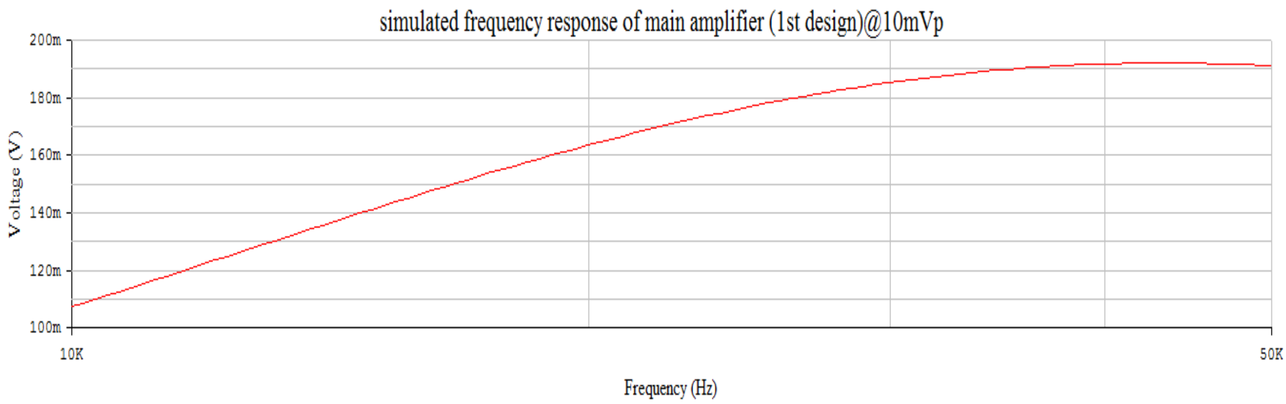

Fig. 6. Shows the simulated frequency response of the main amplifier (1st design).

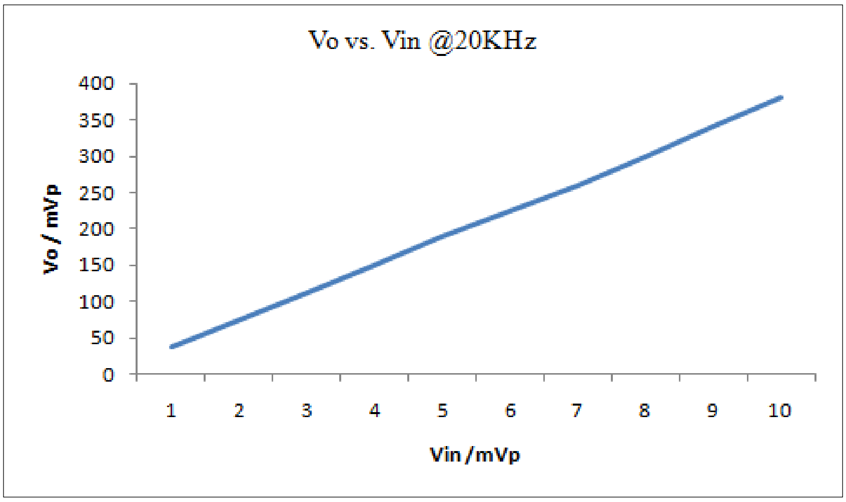

Fig. 7. Shows the simulation of Vo vs. Vin of the main amp. (1stdesign)

The second design consists of a tuned common amplifier with a variable inductance coil from 5mH to 8 mH, as shown in Fig. 8. The simulated frequency response and Vo Vs. Vin is summarized in Fig. 9 and 10.

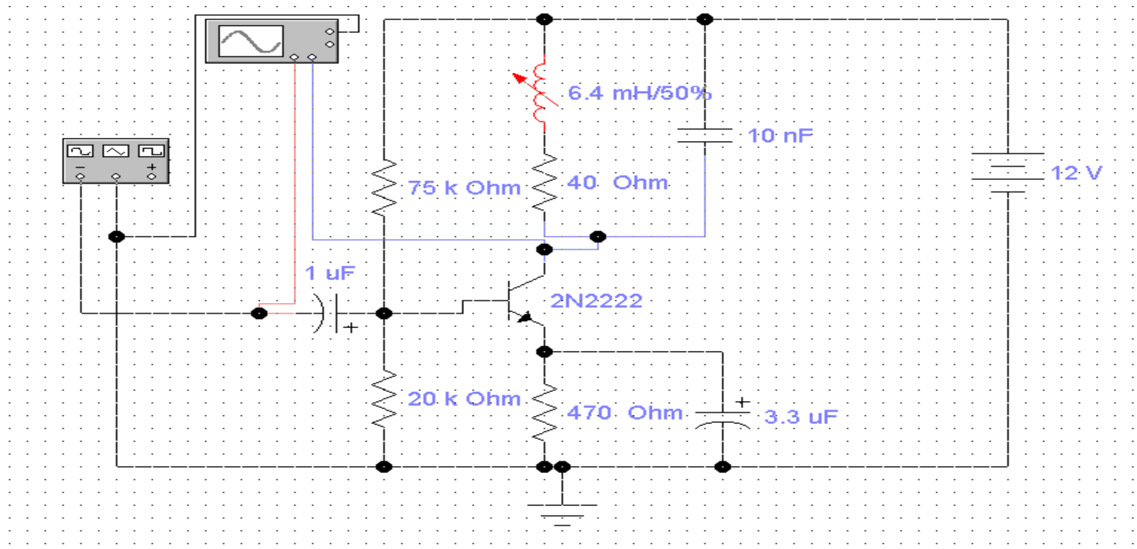

Fig. 8. Shows the simulated main amplifier (2nd design).

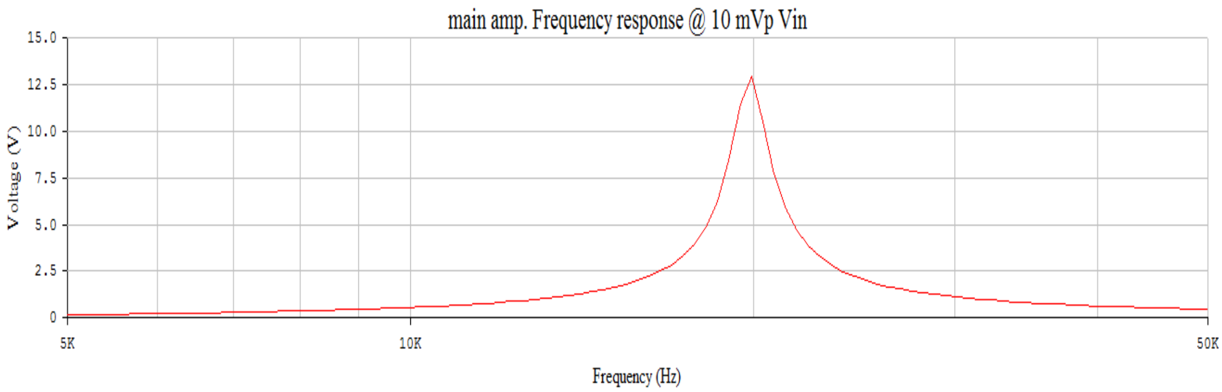

Fig. 9. Shows the simulated frequency response of the main amplifier (2nd design).

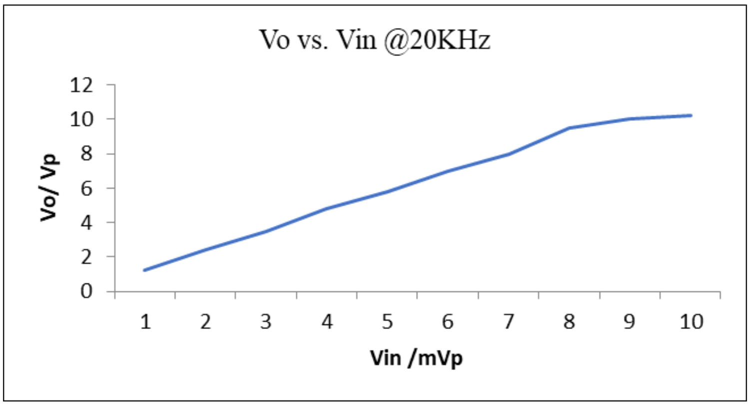

Fig. 10. Shows the simulation of Vo vs. Vin of the main amp. (2nd design).

2.3 laboratory Experiments

At the lab, the circuit in Fig. 2 had been tested by connecting it to the function generator; model UTG9002C-II, as shown in fig. 11. The input voltage (Vin) kept constant to 10 mVp while the frequency varied from 10 to 40 KHz, and the output voltage (Vo) was displayed using an oscilloscope UNI-T; model UTD2025CL. The practical frequency response and Vo Vs. Vin is shown in Fig. 12 and 13.

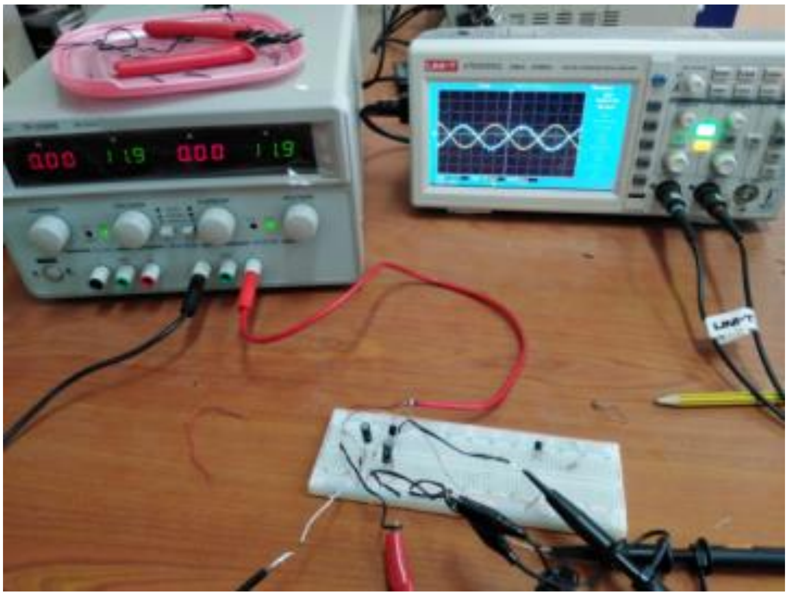

Fig. 11. Shows the preamp. circuit connected in the lab.

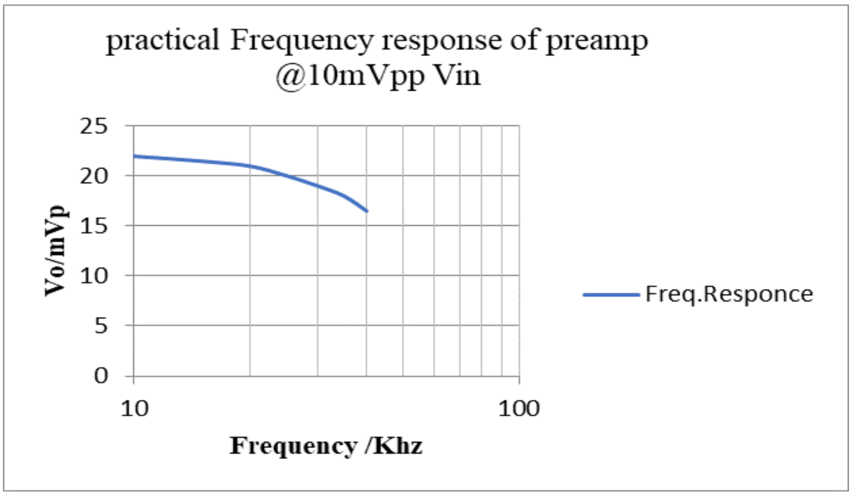

Fig. 12. Shows the practical frequency response of the preamp.

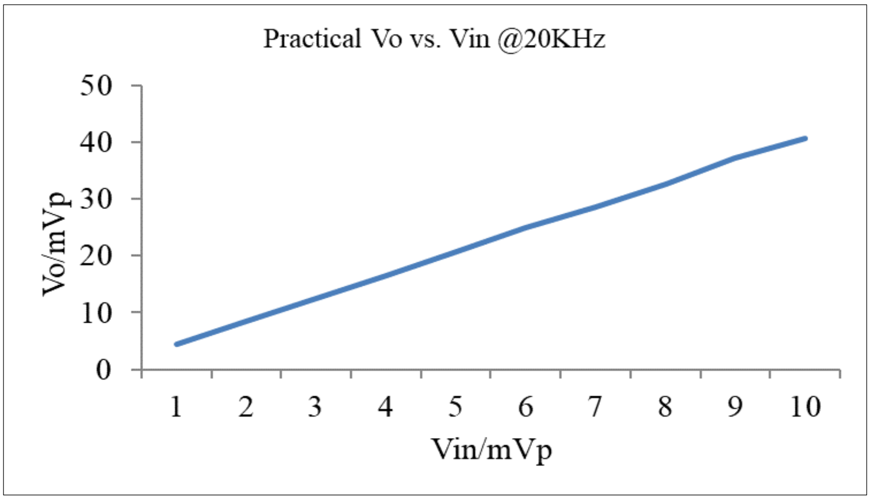

Fig. 13 shows the practical Vo vs. Vin of the preamp.

A 50cm whip antenna had been connected to the function generator. At a distance of 50cm, the circuit of Fig. 11 had been placed and a 50 cm whip antenna had been used. The frequency varied from 10 to 40 KHz, and the frequency response was measured as shown in Fig. 14.

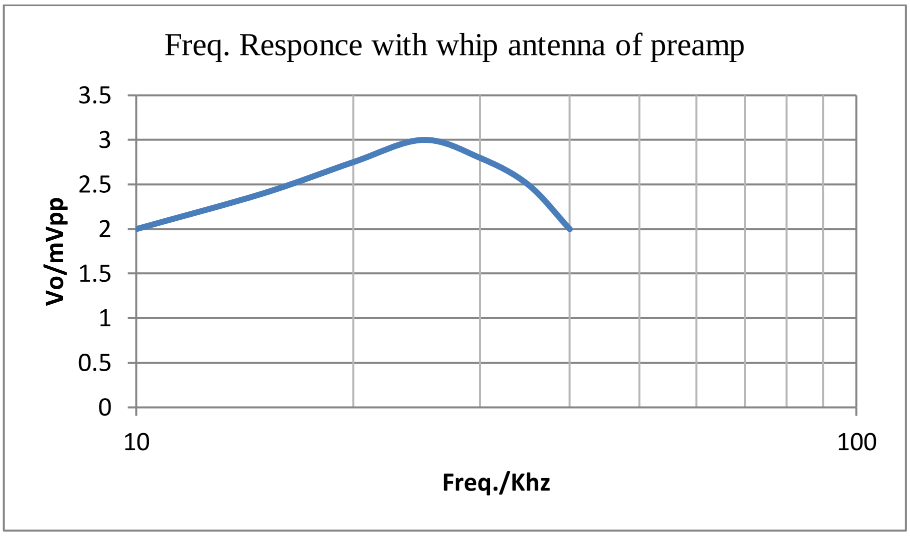

Fig. 14. Shows the frequency response of the preamp. circuit with a whip antenna.

A loop antenna with a radius of 20 cm was used instead of the whip antenna of the receiver, and the experiment was repeated. Fig. 15 summarizes the result

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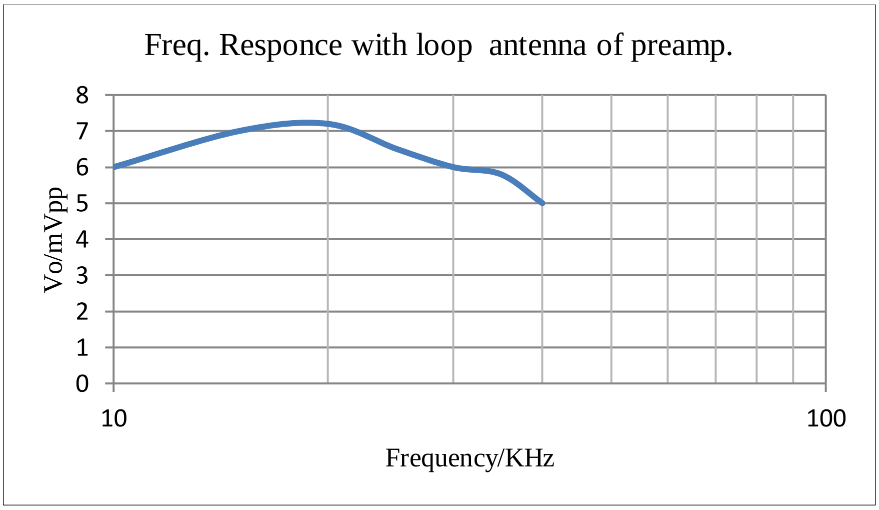

Fig. 15. Shows the frequency response of the preamp. circuit with a loop antenna.

Figs 16 and 17 show that the lab versions of the simulated circuits of figs 5 and 8 had been connected, and the results of the frequency responses are summarized in Figs 18 and 19. The Vo Vs. Vin relationships are summarized in figs 20, 21.

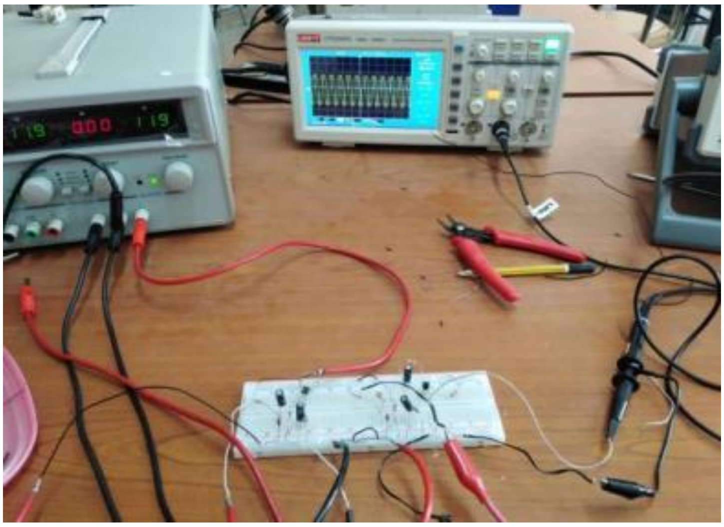

Fig. 16. Shows main amp. circuit (1st design) connected in the Lab

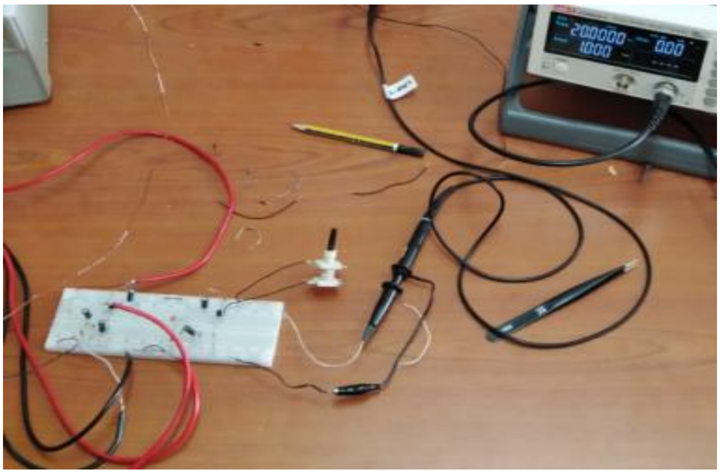

Fig. 17. Shows main amp. circuit (2nd design) connected in the Lab

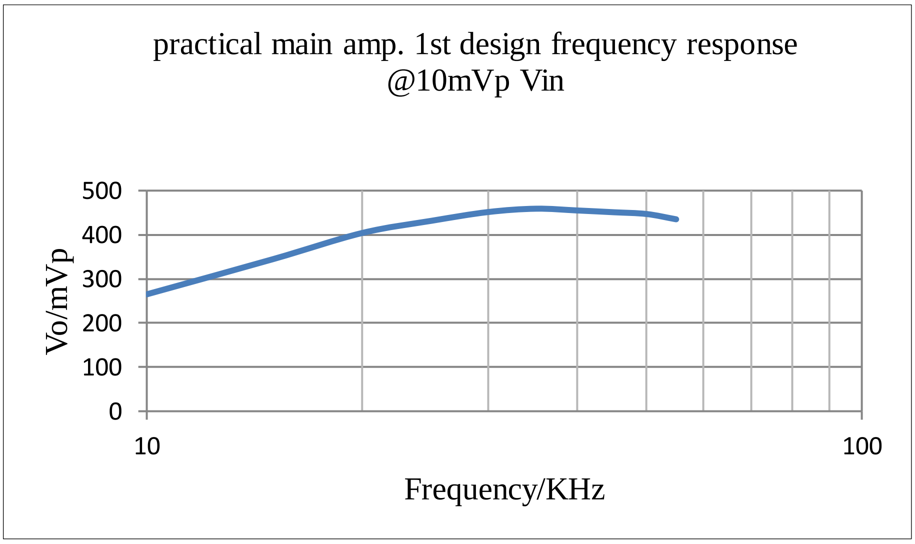

Fig. 18. Shows the practical frequency response of the main amplifier (1st design).

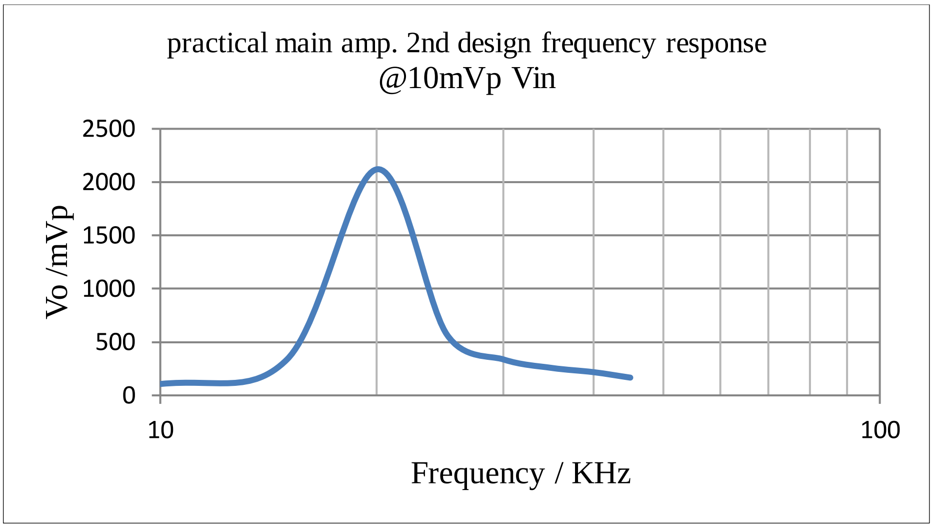

Fig. 19. Shows the practical frequency response of the main amplifier (2nd design).

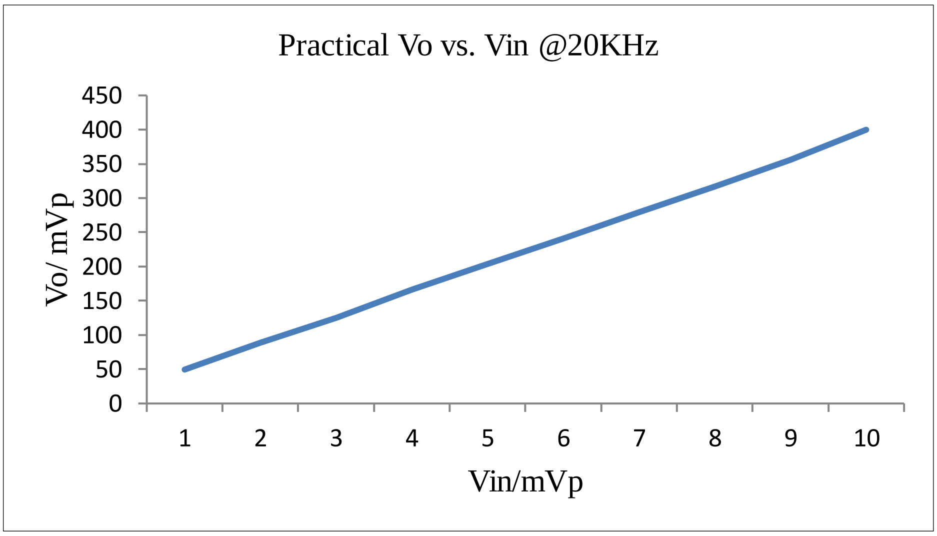

Fig. 20. Shows the practical Vo vs. Vin relationship of the main amp. (1st design).

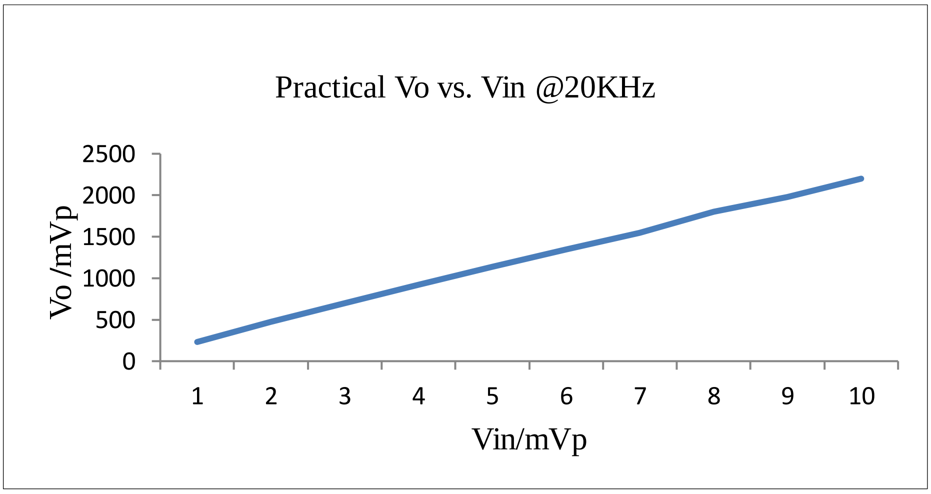

Fig. 21. Shows the practical Vo vs. Vin relationship of the main amp. (2nd design).

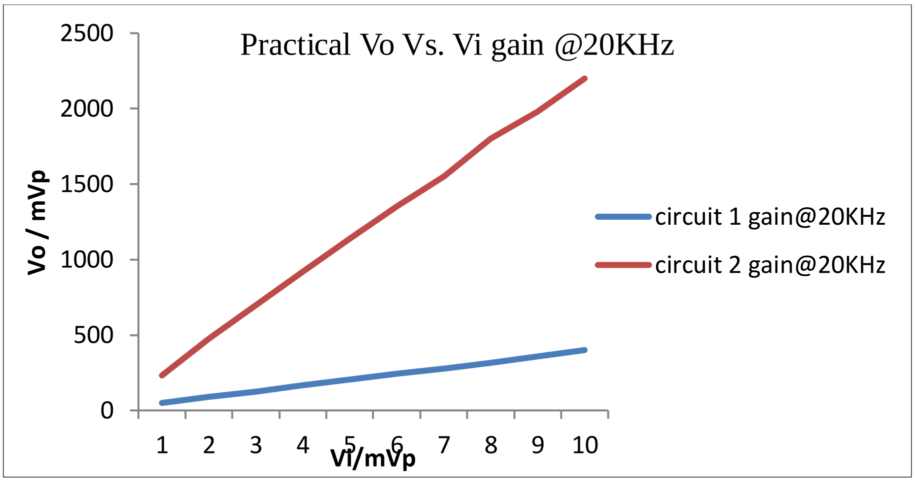

Fig. 22. Shows the practical Vo vs. Vin relationship in both designs.

In Fig. 23, a whole VLF receiver was connected consisting of a loop antenna, the preamplifier of fig. 11, and the main amplifier (2nd design) of fig. 17. The output signal was displayed on a computer using the HDSDR software

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Fig. 23 shows the complete VLF radio receiver

The system was tested in the lab. A signal of 20 KHz was transmitted using the function generator, and the output was displayed on an HDSDR screen, as shown in Fig. 24.

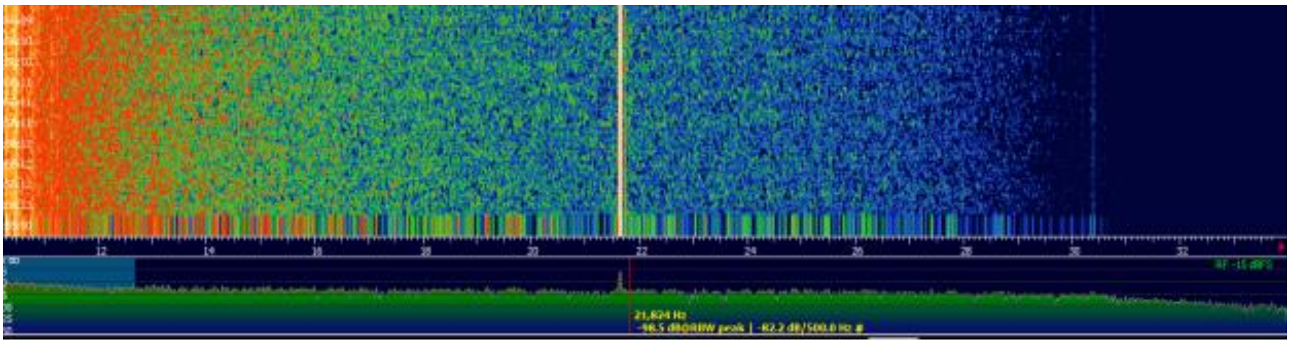

Fig. 24. HDSDR screen shows signal received in Lab.

The received experiment was repeated outside the lab environment (at home). The environment was so noisy, and the results are summarized in figs 25 and 26.

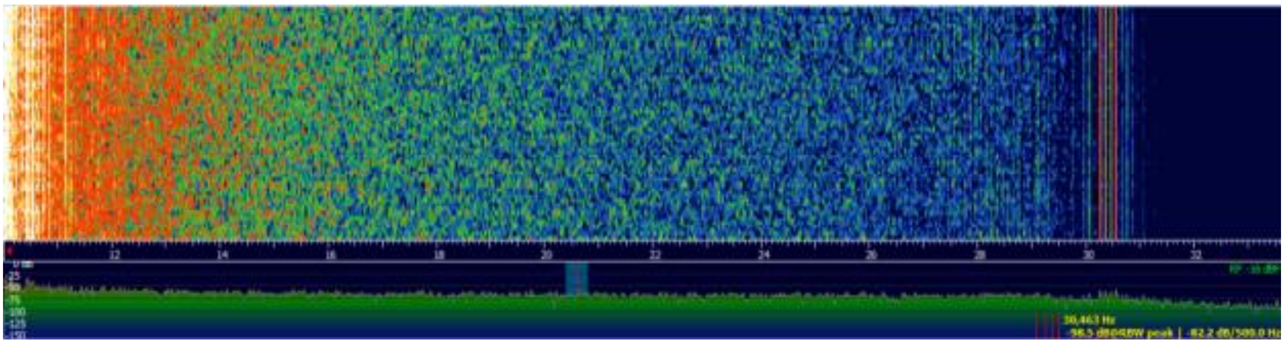

Fig. 25. HDSDR screen shows noise signals received at home (day time).

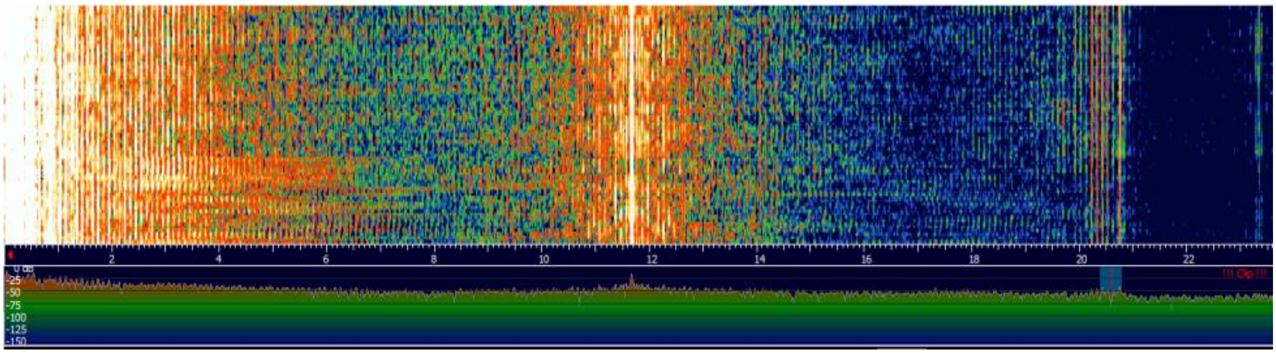

Fig. 26. HDSDR screen shows noise signals received at home (night time).

3. Discussion

From the simulation and experiments, using a loop antenna was better than using a whip antenna (had more gain), and the 2nd design of the main amplifier was better than 1st design (had a better frequency response). Fig. 10 shows that the transistor works in linear regions if Vin < 8mVp, while it works in saturation regions with a distorted Vo when Vin> 8 mVp [A]. fig. 21 shows that the transistor works in linear region (almost, with the hfe measured at 205). fig. 24 shows the received signal (in a lab environment) from the function generator as a transmitter, while in Figs 25 and 26 environmental noises had significant levels that effected the received signals because of man made noises like cell phone chargers, laptop chargers, LEDS Lights etc.

4. Conclusion

In this work, a VLF receiver structure had been proposed. A comparison between Electronic Workbench V5.1 and lab results had been done. Comparisons between two types of antennas had been done and the loop antenna was chosen. A complete system had been tested in two different environments, lab and home environments, and displays the received signal on a computer using HDSDR software program. Finally, to receive a flare with a high degree of success, it is better to setup the receiver outside the town (in rural area), because experimentally, the receiver failed to detect flare events in home environment because noise signals had significant levels which showed in the HDSDR software's program screen.

Acknowledgment

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تصميم مستلم راديوي لمراقبه النشاط الشمسي ضمن حزمة الترددات المنخفضة جدا

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الخلاصة

مراقبة النشاط الشمسي يعتبر مهم لحياتنا لان تغيره يؤثر بصورة مباشرة وغير مباشرة ليس فقط على الاتصالات الايونوسفيرية وانما على الحياة ايضا. لدراسة النشاط الشمسي يحتاج الباحثون معدات قياس ومراقبة، وهذه المعدات هي غاليه الثمن ولاتتوفر بكل الجامعات. في هذا البحث تم تصميم مستلم راديوي تم تنفيذه من عناصر متوفرة في الاسواق ليدعم الباحثين، طلبه الكليات وهواه الفلك الراديوي بأقل فولتية دخول اقل من 100 مايكروفولت، وفولتية الاخراج اقل من 135ملي فولت بلا تشوه وكسب كلي بحدود 34 ديبي. المقارنة بين دائرتين باستخدام برنامج workbench قد تمت وتم مختبريا تنفيذهما. هوائيان تم اختبارهما وتم اختيار الهوائي الحلقي. تم ربط النظام بأجمعه واختباره لاستلام الاشارات في المختبر وعرض الإشارة على الحاسوب باستخدام برنامج HDSDR. تم تنفيذ تجربة اخرى خارج المختبر (منزليا) والنتيجة كانت غير جيدة بسبب تداخل العديد من الضوضاء عالية المستوى.