Satellite technology experiences in Iraq – intrusion, incursion, and future challenges

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Abstract

Recent tremendous developments of satellite technologies coupled with reduced cost of their manufacturing and launching have enabled more advanced applications. Global participation in space activity is growing as satellite technology matures and spreads. However, limited resources and lack of know-how due to many political and developmental issues prevent many nations from developing their space projects effectively, or building sustainable space programs. Concurrently, there is limited data or documentation on the space activities of Iraq. This paper presents the first comprehensive study of Iraqi past experiences for entering the space technology in addition to the current and future challenges, to the best of authors' knowledge. This includes the experiences of building a satellite launcher, satellite terminal, and earth station, with the presentation of the applied system architecture, technologies, and parameters, and shows the involved agreements and countries that helped to improve this technology in Iraq. Moreover, the study introduces a comparison between the

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experiences in terms of system specifications and orbital parameters experienced so far. Consequently, the outcomes of such study could be an appropriate preliminary benchmark for space technology improvers in Iraq and assistant countries to draw a broad idea of satellite technology experiences in Iraq and future challenges.

Keywords: Satellite technology, TigriSat, Al-Abid, KufaSat, Cubsat, Nanosatellite.

خبرات تكنولوجيا الأقمار الصناعية في العراق - الاقتحام والتوغل وتحديات المستقبل

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الخلاصة

أدت التطورات الهائلة الأخيرة في تكنولوجيا الأقمار الصناعية إلى جانب انخفاض تكلفة تصنيعها وإطلاقها إلى تمكين المزيد من التطبيقات المتقدمة. المشاركة العالمية في النشاط الفضائي تتزايد مع نضوج تكنولوجيا الأقمار الصناعية وانتشارها. بالرغم من ذلك، فإن الموارد المحدودة وقلة المعرفة بسبب العديد من الامور السياسية والإنمائية تمنع العديد من الدول من تطوير مشاريعها الفضائية بشكل فعال، أو بناء برامج فضائية مستدامة. في الوقت ذاته، هناك بيانات أو وثائق محدودة حول الأنشطة الفضائية في العراق، بناءا على ذلك، تقدم هذه الورقة أول دراسة شاملة للخبرات العراقية السابقة لدخول تكنولوجيا الفضاء بالإضافة إلى التحديات الحالية والمستقبلية، على حد علم المؤلفين. يتضمن ذلك خبرات بناء قاذفة قمر صناعي ومحطة قمر صناعي ومحطة أرضية، مع عرض بنية النظام المطبقة والتقنيات

والمعايير المستخدمة، ويظهر الاتفاقيات والدول المعنية التي ساعدت في تحسين هذه التكنولوجيا في العراق. علاوة على ذلك ، تقدم الدراسة مقارنة بين التجارب من حيث مواصفات النظام والمعايير المدارية التي تم اختبارها في العراق حتى الآن. وبالتالي، يمكن أن تكون نتائج هذه الدراسة معيارًا أوليًا مناسبًا لتحسين تكنولوجيا الفضاء في العراق ومساعدة الدول لرسم فكرة واسعة عن تجارب تكنولوجيا الأقمار الصناعية في العراق والتحديات المستقبلية.

1. Introduction

Satellite technology has played a fundamental role in global connectivity where many types of satellites provide data acquisition, research, telecommunications, safety and weather forecasts, navigation, business insights, environmental monitoring and defence. The space industry has seen a rapid increase in satellite launches. Lately, approximately 1000 is launched every year. However, a total of 1,400 satellites were launched in the year 2021 and there have been numerous organizations announcing their satellite constellation launches over the coming few years [1].

As international space community is growing, new countries are demonstrating interest and capability in space. In the beginning of the space era, the funding, expertise and accomplishments were dominated by the USA and USSR [2]. Gradually, however, many other countries have carved their own place in the spacefaring society and currently many developing countries are seeking to increase their level of space activity, such as Iraq. Although decent political support, limited technology, lack of expertise, funds, and underdeveloped human resources have made the Iraq experiences to space technology literally decent, this paper considers the full overview of the Iraqi experiences to initiate and implement space technology programs involving building satellite launcher, spacecrafts, and ground stations.

Iraq's attempts to enter the field of space was not born today, but there have been previous successful experiences in this field. Iraq joined the World Satellite Organization in 1975 after the establishment of the Space Communications Department at the General Organization for Telegraph, Post and Telephone. Then, in 1976, a ground station was opened in Dujail to work with satellites. The Dujail-1 station works with satellites above the Atlantic Ocean (AOR) and the Dujail-2 station works with satellites over the Indian Ocean (IOR). Iraq joined Intersputnik in 1980 through the Dujail-3 station. [3]

Iraq joined the Arab Satellite Communications Corporation (Arabsat) in 1985 as a contributing member. The Space Research Centre was established in the Scientific Research Council in 1987. During the International Telecommunication

Union (ITU) in 1985 and 1988, Iraq was granted two orbital positions (65.45E-50E) to place Iraqi satellites in them [4, 5].

Iraq has been interested in the peaceful uses of outer space and its global developments and activities as the other neighbouring countries and the different countries of the world. Entering this field has many benefits for the country, including [6-8]:

- Enhancing the security and military aspect and achieving sovereignty in the protection of borders, water and the environment and predicting natural disasters through the use of modern satellite images.
- Upgrading the level of communication technology, complete information services, cybersecurity and protection of information important to the state and people.
- Development and infrastructure in various fields including educational, technological, industrial, agricultural and economic with a great financial return that will be achieved.

Al-Tair satellite and Al-Abid launch vehicle (LV) program was the first Iraqi experience in entering the space technology, the details are explained in Sections 2 and 3. The efforts of satellite technology incursion after 2003 is discussed in Section 4, with full details of the second experience, TigriSat nanosatellite, discussed in Section 5. KufaSat design is also introduced in Section 6 before discussing latest developments and challenges in Iraq in Section 7.

2. Al-Tair (The Bird)

Iraq's government initiated a space program in the late 1980s to display the country's technological prowess to the rest of the world. From 1988 to 1990, Iraq's Scientific Research Council built a research facility to develop space technology at an Iraqi space center [9, 10]. Al-Tair project was begun by the Iraqi Space Research Center (SRC). It was civilian experimental satellite with main purpose to conducting communications and ranging experiments. Al-Tair satellite, shown in Figure 1, works in the UHF and VHF frequency ranges. The SRC successfully built two identical satellites that stored until today in the Ministry of Science & Technology in Baghdad.

(a) (b)

Figure -1 Al-Tair satellite (a) external view (b) some interiors

Al-Tair satellite is octagon shape with a height of 47 centimeters, a diameter of 74 centimeters, and a weight of 75 kilograms [9, 11]. With interior design consist of four separated sections to contain electronic equipment and resist explosion damage and vibration. Solar power is the main source of power for the satellite it contains seven solar panels and backup batteries.

The inner component of the satellite contain different communication systems such as managing data system, VHF and UHF radio frequency communication system that used to record and transmit the readings and information to the ground station also it is used to receive the commands requests from the ground station to the satellite, and attitude control system to maintain the correct orientation of the satellite to allow the antennas to face the accurate location of the ground station and also to point the solar panels toward the sun (energy source) and the control the temperature of the satellite passively by using light and dark painting to reflect or absorbs the heat [12]. However, the satellite designed to be fixed-rotation at his orbit above the region all time, and to archive that the scientist applies a technique that consist of two coils places on the top and bottom sides of the satellite to maintain the orientation of the satellite by interaction of these coils with the Earth's magnetic field.

The plan to launch the Al-Tair satellite was built on launching the satellite to LEO with a height of 350-400 kilometers aboard an Ariane 4 rockets, using Ariane 44L spacecraft [12], but this plan was halt because at that time the Iraq's relationship with the western world restrict the Iraqi government to obtain access to the Ariane 4 and due to that the whole project came to a halt [11]. And to prevent that from occur the Iraqi scientists built alterative plan to launch Al-Tair satellite using indigenous satellite launch vehicle (LV) system (indigenous space program) called Al-Abid.

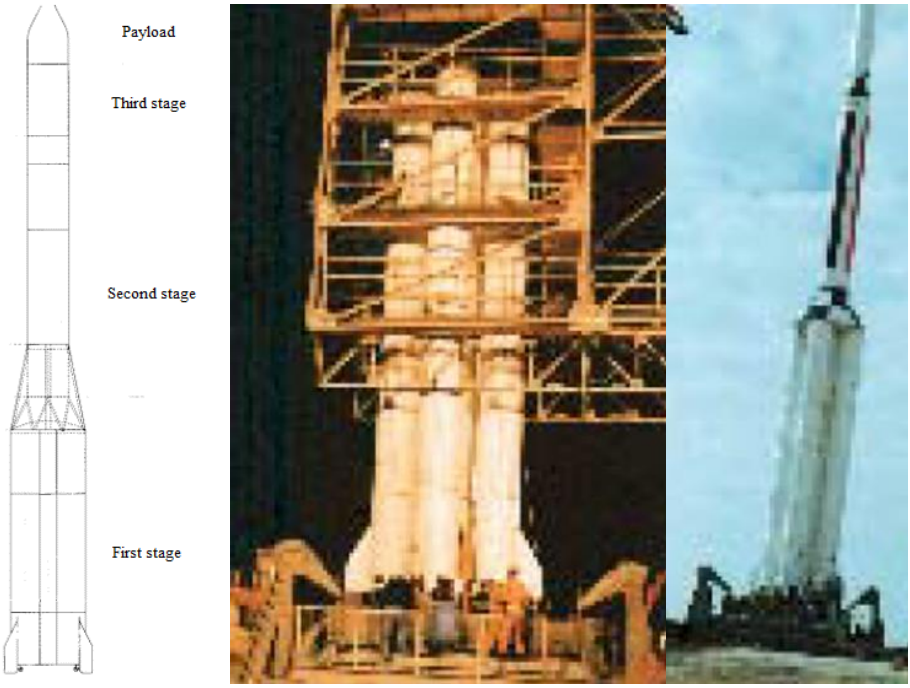
3. Al-Abid LV system

During the period from 1976 to 1991 the Iraq forced army takes a serious step in developing a missiles-rockets system started by importing variety of foreign missiles and rockets system. According to the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC) [10], these foreign suppliers trained the Iraqi unites on how to maintenance, launch, targeting, aiming, firing and using of these systems. An Iraqi modified version of the SCUD-B missile was developed, called Al Hussein rocket, to extend the missiles max range from 300 km to 600 km [13]. The successful modification of the SCUD-B missiles into Al Hussein missile was the key role of developing many projects including Al-Abid space launcher system.

Al-Abid, shown in Figure 2, was the first Iraq space launcher program developed by Iraqi scientists from both Space research center (SRC) and Iraqi forced army in 1988. The Al-Abid is a three stages rocket with a 25 meter long and weight of 48 tons as shown in Figure 2a. The first stage consisted of 5 clustered Al Hussein rockets (SCUD modified missiles) [13], second stage with one Al Hussein rocket and special rocket that work with solid-propellant rocket as third stage, More details of the satellite LV stages are listed in Table 1.

Table 1- Al-Abid LV stages

Stages	Contents	Diameter (m)	Mass (kg)
First stage	**5 rockets**	**0.88 each**	**48,000**
Second stage	**1 rocket**	**1.25**	**3,760**
Third stage	**payload**	**1.25**	**75 (Satellite mass)**



(a) **(b)** **(c)**

Figure -2 Al-Abid LV system (a) LV stages (b) LV preparation for launch (c) LV before launch

Al-Abid project mission was to place Al-Tair satellite at low earth orbit (200-500 km height) with a total load (100-300 kg) [10, 12]. The first physical test of the Al-Abid three-stage space launch system was held at Al-Anbar space launch pad, Iraq in

December 1989. The first stage was totally operating while the second and third stage dummies only to maintain the total weight of the rocket. A recorded footage showed the first seconds of launching Al-Abid. According to (SRC) it successfully takeoff for 45 second then it exploded. The scientist claimed that as success as it takeoff the ground they also conclude the explosion occur during the stage separation. And they were planning to do more launch experiment in the following years; unfortunately, the whole project was suspended after the gulf war in 1991 [13, 14].

4. Satellite technology experiences in Iraq after 2003

Against the backdrop of the information openness experienced by Iraq after 2003, which contributed to the entry of mobile networks and the establishment of more than 150 local satellites and radio frequencies broadcast on Arab and foreign satellites, the Iraqi satellite project emerged.

In 2012, an expanded committee was formed headed by the Ministry of Communications and representatives of the Ministries of State (Defense, Interior, Higher Education, Science and Technology, Planning) and security agencies from the National Security and the National Intelligence Service to supervise the Iraqi satellite. In 2013 a joint recommendation was issued by this committee to establish an Iraqi space agency, as well as a non-binding invitation was made to international companies (manufacturer, operator, investment) to design and build an Iraqi satellite.

The number of ground stations for space communications has now increased to (4) Stations belonging to the General Company for Communications and Informatics in the Ministry of Communications. The recommendations were approved by the General Secretariat of the Council of Ministers. The establishment of the Agency was postponed at that time because that stage was not suitable for its entry into force due to the financial situation of the country [15]. The recent work of the Iraqi satellite project began in 2012 and stopped for the past years due to the lack of financial allocations and the failure to approve the previous financial budgets of the state [15].

Iraq has another experience, although it is a smaller one in the field of satellites, where the Ministry of Science and Technology announced, in 2014, the launch of the first Iraqi satellite, "TigriSat”. It received its first signals at the ground station prepared for this in Baghdad. The first Iraqi satellite – Tigris Sat was launched on 19/6/2014 from the Yazani space zone in the Russian Federation. This satellite was small in size and intended for research purposes [16]. Its tasks were limited to the field of studies of desertification, dust and other climatic phenomena, as the satellite is working to send aerial images to two stations, the first in Baghdad and the second in Rome [17], where researchers study and analyze these images for the purpose of studying the process of desertification in Iraq and revealing its causes, knowing that the Italian government was part of the satellite project.

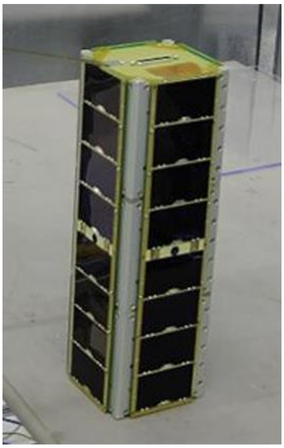
5. TigriSat

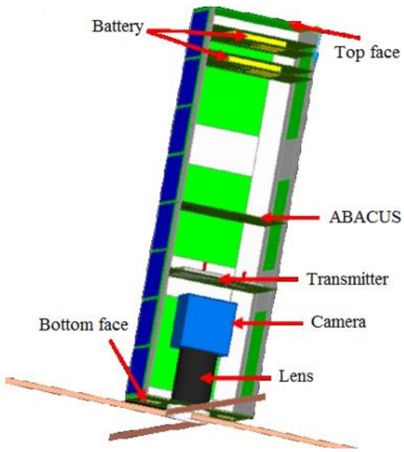
TigriSat is a civilian first Iraqi microsatellite deployed from a civilian scientific Italian satellite (UniSat 6), with an outer dimension of 100×100×340 mm3 and composed of 3-unit CubeSat [16]. TigriSat shown in Figure 3a is designed to carry a RGB camera for detecting and monitoring of sand and dust storms (SDS) occurring over Iraq and neighboring countries to identify the source of the aerosols and the origin of the storms [18]. The data collected is then transmitted to two ground stations - one in Baghdad, Iraq and the other in Rome, Italy. This small spacecraft designed by a group of 15 Iraqi postgraduate students in Aerospace engineering within Italian partnership. The aim was to prepare a group of engineer’s specialists in space and astronautically field with the support of Iraqi

Ministers of Science and Technology, Higher Education and scientific research, and Transport, and the Italian Air Force organized by Sapienza University of Rome [17].

The TigriSat has been lunched from Yasny (Russia) on June 19, 2014 by Dnepr launcher operated by International Space Company (ISC) Kosmotras. The small size of this satellite makes it so attractive because it can be launched from the ground base station until it reaches its orbit with a very low cost and short time development with respect to normal size satellite [19, 20]. The satellite contains the following main parts [16, 21]:

- RGB camera implement in the bottom side of the nanosatellite, as shown in Figure 3b, with a new scripted algorithm for dust detection,





(a) (b)

Figure -3 TigriSat satellite (a) external view (b) interior design

- Deployable VHF/UHF antenna for telemetry/telecommand and beacon, and S- Band antenna for payload data (imaging) to ensure the link with the earth station for uplink and downlink telemetry data and images. The nanoantenna had a seriously challenge because it has to be implemented in the bottom side of the TigriSat around the camera due to its radiation directions as shown in Figure 4.

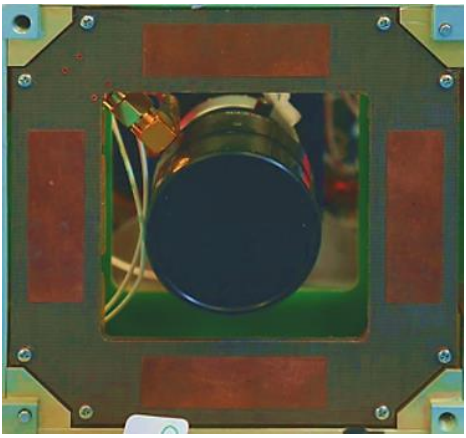
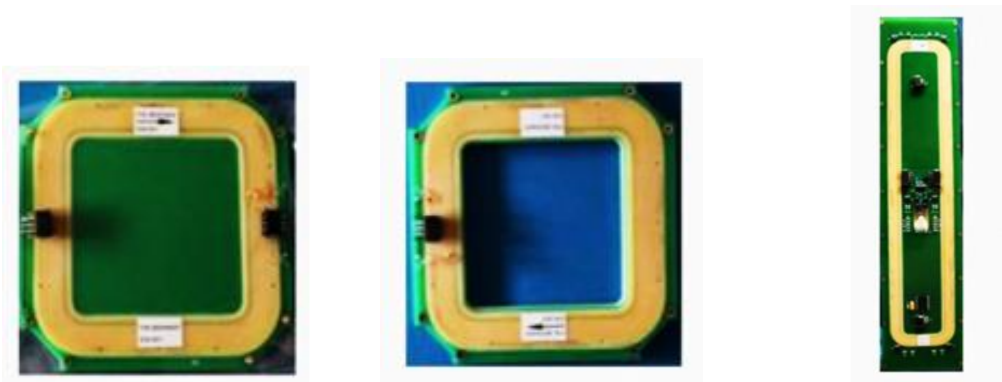


Figure -4 The S-band antenna and the camera with the lens going through the central hole of the antenna

The antenna was design with four rectangular patch, one on each side of the substrate around the hole for different radiation pattern, with a gain of 5.9 dBi for each single patch printed in a circuit board based on a Arlon DIClad 870 substrate material with a square hole in its center, and a size of 57×57 mm2 which is the size of the camera.

Whereas the outer side dimensions are 96×96 mm2 [22]. The Antenna SMA connector is connected to the camera as shown in 4igure 4 in the top left corner of the hole.

- Solar panels: covers the satellite five faces with three junction solar cells and batteries inside. Each cell has a 63×38 mm dimensions. These solar cells were distributed by 8 cells on the long faces and two in the small faces.
- Embedded magnetic coils inside the solar panels (top, lower, and side coils) to provide attitude control to enable nadir pointing active magnetic Attitude Determination and Control System (ADSC) as shown in Figure 5.

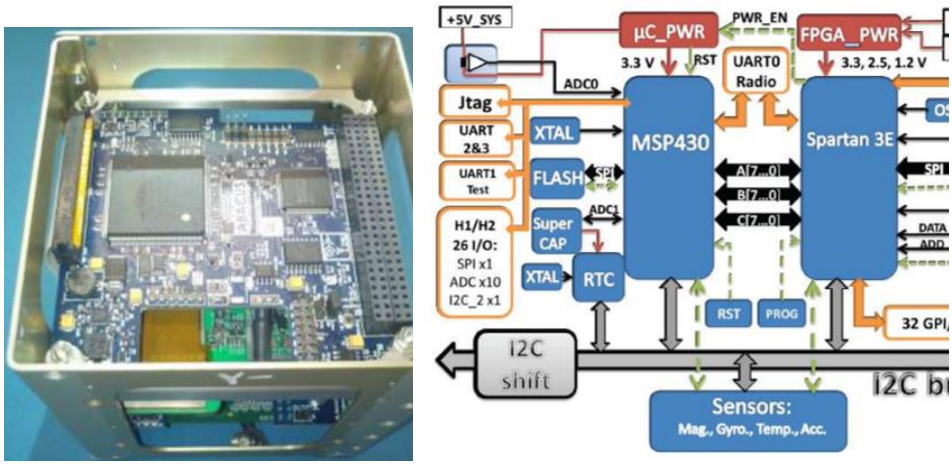


(a) **(b)** **(c)**

Figure -5 Embedded magnetic coils (a) Top coil (no. of turns = 320) (b) Lower coil (no. of turns = 320) (c) Side coil (no. of turns = 220)

- On-board computer (ABACUS) shown in Figure 6 that contains three main sections as follows:
  – Low power CPU for satellite housekeeping,

– FPGA for versatile operations (such as DSP, FEC, and ADCS),
– Attitude control system that contains rate gyroscope, passive magnetometer, accelerometer, and two temperature sensors. The temperature of the nanosatellite materials was verified by using a numerical simulation.



(a) **(b)**

Figure -6 on-board ABACUS (a) external view (b) bloc diagram of the design

The full specifications of the TigriSat nanosatellite specifications and orbital parameters are listed in Tables 2 [18]. Prior to launching process, the TigriSat main structural, electronic and propulsion components were attached to the satellite structure, connected to each other electrically, and then tested as an integrated system. The following step was integration of TigriSat with deploying Sat (UnitSat-6).

Table 2- TigriSat specifications

Bus	Cube sat 3U	**Contractor**	kosmotras
Dimensions	10×10×34 cm3	**Average velocity**	27108 km/s
Launch mass	3 kg	**Period**	97.7 minutes
Power	Solar cells, Batteries	**Reference system**	Geocentric
Rocket	Dnepr	**Regime**	LEO Sun synchronous
Launch site	OREN, Komarovsky	**Semi-major axis**	7025 km
Band	VHF. UHF. S-band	**Perigee altitude**	612.9 km
Downlink Frequency	435 MHz	**Apogee altitude**	696.3 km
Uplink Frequency	2450 MHz	**Inclination**	97.8o

UniSat-6 which contained TigriSat, LEMUR-1,AntelSat, and AeroCube 6, was launched on the 19th of June 2014 from Komarovsky Cosmodrome at the Yasny launch base (in Russia) on board a DNEPR-1 rocket to be placed in Sun Synchronous orbit . TigriSat was released from UniSat-6 by the Gauss satellite release system [23] shown in Figure 7.

Figure -7 Gauss satellite release system of UniSat-6

Since most of the Iraqi regions are deserts, it cause a sand and dust storms, which is the main challenge to be detected by a ground base station and require network that is hard to be maintained. Accordingly, the main objective of the small satellite is to detect the sand storms over Iraq. The sand storm should be detected by a camera mounted in the bottom side of the Nanosatellite [16]. The advantage of using satellite monitoring over the ground base station is to monitor a wide area which make it suitable for providing data forecasting incoming storms.

6. KufaSat

KufaSat is a 1U CubeSat Nanosatellite project sponsored by the University of Kufa. The students project was started at 2012. The main tasks was for imaging purposes and remote sensing, and also monitoring the Iraqi borders and the conflicting areas in Iraq [24]. The satellite will be launched and stabilized in LEO orbit with 600 km altitude with a 1.5 m long gravity gradient stabilizer to achieve passive attitude stabilization [25, 26].

The frequency for operation and the transmitted power are planned to be 435 MHz and 100 mW, respectively. The full satellite specifications are listed in Table 3 [25, 27, 28].

Table 3- KufaSat specifications

Bus	Cube sat 1U	**Beacon data rate**	1.2 kbps
Dimensions	10 × 10 × 10 cm3	**Payload data rate**	9.6 kbps
Launch mass	1.3 kg	**Semi-major axis**	6978 km
Power source	Solar cells, Batteries	**Inclination**	97^{o}
Tx power	100 mW	**Period**	96.684 minutes
Band	VHF. UHF. S-band	**Altitude**	600 km
Downlink Frequency	435 MHz	**Lifetime**	3 years
Modulation scheme	FSK	**payload**	CMOS camera

The dimension of the communication system follows the CubeSat standards and regulations. Consequently it was designed to be 7 × 9.5 × 1 cm3. The system was designed and implemented using commercial components to facilitate the system component modification and upgrade processes that fit any future developments based on applications. KufaSat main parts are:

- Payload CMOS camera,
- RF communication system with S-Band for imaging, UHF for satellite beacon and housekeeping, VHF for telecommand and software update,
- Attitude determination system contains 3-axis magnetometer, 6-axis sun sensors, and 3 gyroscopes.
- Attitude control system (3-axis stabilized control) using 1.5 gravity gradient stabilizer, and three magnetic coils.
- Solar panels covers the satellite faces with Lithium Polymer batteries inside.

The communication system algorithm along with the beacon and the payload encoding and decoding algorithms are three main algorithms that combined together to form the complete system software algorithm. In order to minimize the possibility of losing data and to keep the cycle of communication aligned during the satellite availability, a special timing approach was deployed [28]. KufaSat design has solar cells on all faces [29] as shown in the CAD model in Figure 8.

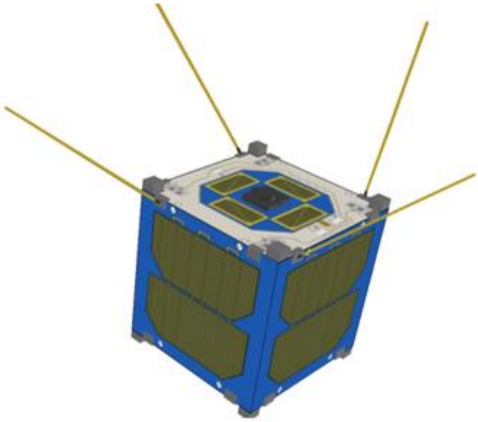


Figure -8 KufaSat model

To adapt the deployed communication system to many other CubeSat designs, the system was built as a software-defined communication system in terms of transmitter power, frequency, data rate, and modulation parameters designs [28]. KufaSat is to be launched in near future into nearly-circular LEO orbit of altitude 600 km and inclination angle is 97^{o}.

6. Latest developments and challenges

KufaSat The efforts of the staff of the Space Communications Department at the General Company for Communications and Informatics of the Ministry of Communications continue to complete the Iraqi satellite project and the need to prepare a road map for the project and start the steps of implementation.

Coordination was carried out with the Media and Communications Commission and ITU to ensure Iraq's orbital and frequency rights, and communicate with government stakeholders and private sector companies to identify their needs of satellite services and work to provide them at the lowest costs. Moreover, periodic reports were prepared on the activities of international companies in the marketing of satellite services and work to benefit from the best offers for the manufacture and launch of the Iraqi satellite, through communication and coordination with international space organizations and companies of manufacturing and operating satellites [30, 31].

In 2019, coordination was carried out by the Ministry of Communications and the French government and in coordination with the French company Airbus which is specialized in the manufacturing of satellites to complete the Iraq satellite projects and the Iraqi Space Agency in accordance with the Iraqi-French agreement concluded in 2015 [30]. The Egyptian side, which has experience in the field of launching satellites, has secured mediation with the French satellite manufacturer Airbus [31].

A loan was obtained from the French government to complete these two projects after the satellite project was stopped for a long time previously due to the economic conditions of Iraq [30, 32]. This prompted the Ministry of Communications to turn to the investing companies to carry out the manufacture and launch of the satellite. After two orbits have been allocated to Iraq, work is being done on launching two satellites. The first is for the Internet and communications and the second is for satellite channels [32].

The first stage of satellite project was accomplished in terms of completing the attraction of all bids to meet the special and general requirements of the project, in which high and sober specifications were determined for the project. The second stage will study the offers made in cooperation with some of the relevant ministries and institutions of the state and to take the decision to refer the project to one of the competent international companies this year [30]. It is expected that the Iraqi satellite will see the light of day within the next three years at a cost of up to 150 million USD [8, 32]. Experts in the field of technology believe that Iraq should not delay more than this time to achieve the electronic entitlement in light of the international race for decades in this field [15].

Conclusion

This paper gives an overview of space-related activities in Iraq. In the past years, only one satellite, “TigriSat” nanosatellite, had been launched successfully in space and operated normally. In addition to one failed experience of building a satellite launcher

"Al-Abed" carried a satellite "Al-Tair", and three future planned satellite launching programs "Kufasat" and another two recently planned national satellite. A Comparison between the Iraqi experiences is made as shown in Table 4 showing the main differences in specifications.

Table 4- Comparison between the satellites' parameters

Specifications	Al-Tair	TigriSat	KufaSat
Bus	**Octagonal sat**	**Cube sat 3U**	**Cube sat 1U**
Orbit	**LEO**	**LEO**	**LEO**
Dimensions	**h=47 cm, d=74 cm**	**$10\times10\times34$ cm^3**	**$10 \times 10 \times 10$ cm^3**
Launch mass	**75 kg**	**3 kg**	**1.3 kg**
Power	**Solar cells, Batteries**	**Solar cells, Batteries**	**Solar cells, Batteries**
Rocket	**Al Hussein (SCUD modified missiles)**	**Dnepr**	**Not planned yet**
Launch site	**Al-Anbar space launch pad**	**OREN, Komarovsky**	**Not planned yet**
Band	**UHF, VHF**	**VHF, UHF, S-band**	**VHF, UHF, S-band**
Purpose	**Conducting communications and ranging experiments**	**Detecting and monitoring of sand and dust storms (SDS)**	**Imaging and remote sensing**

The decent experiences and programs of satellite technologies in Iraq are due to the limited political support, lack of space technology expertise, funds, and unplanned strategy of human resources development and services.

Conflict of Interest: The authors declare that they have no conflicts of interest.

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