SUPERCAPACITORS USAGE IN PASSIVE RADAR AUTONOMOUS STATION

Svetoslav Zabunov, Garo Mardirossian

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mails: svetoslavzabunov@gmail.com, garo.mardirossian@gmail.com

Keywords: *Passive Radar Station, Multistatic Passive Radar, Supercapacitors, Remote Sensing Equipment*

Abstract: *The current article presents an autonomous multistatic passive radar station power storage technology. The autonomous station is connected through wireless means to data server. It has solar batteries as power source and utilizes supercapacitors for energy storage. The station requires no maintenance and is expected to function without aid for at least 10 years. It may require only cleaning in cases of being contaminated with soil and debris as a result of meteorological conditions. The main challenge in such a device is the design of the unit for storing energy during the night hours where there is no solar radiation. The number of charge and discharge cycles of the energy storage module is at least 3650 for 10 years period but may increase tenfold or more due to intermittent surges in power demand during burst communication sessions or high energy consumption transient computational operations. Another factor contributing to increase of the number of charge/discharge cycles is the irregularities in solar irradiation due to the uneven cloud cover and other weather phenomena. Most battery chemistries would degrade significantly throughout the lifetime of the station and beyond a fraction of the expected 30000 charge and discharge cycles.*

Supercapacitors are a new technology for energy storage suitable for stationary apparatuses providing such long periods of operation and large number of charge/discharge cycles reaching millions. This paper elaborates on the benefits of implementing supercapacitors as major energy storage unit in stationary autonomous devices for remote sensing applications and specifically for autonomous solar powered base stations for passive radars. To achieve clarity we disclose the deployment of supercapacitor power bank as part of a complete design of multistatic passive radar station and we analyse the power requirements of all modules in such a station. Further, comparison with wide spread rechargeable battery technologies is provided and all the benefits and drawback of supercapacitors thereof are established.

ИЗПОЛЗВАНЕ НА СУПЕРКОНДЕНЗАТОРИ
В АВТОНОМНА БАЗОВА СТАНЦИЯ НА ПАСИВЕН РАДАР

Светослав Забунов, Гаро Мардиросян

Институт за космически изследвания и технологии – Българска академия на науките
e-mails: svetoslavzabunov@gmail.com, garo.mardirossian@gmail.com

Ключови думи: *Базова станция за пасивен радар, Мултистатичен пасивен радар, Суперкондензатори, Уреди за дистанционни изследвания*

Резюме: *Настоящата статия представя технология за съхранение на енергията, необходима за работата на автономна базова станция за мултистатичен пасивен радар. Автономната станция е свързана безжично към сървър за данни. Тя разполага със соларни панели, от които получава енергия за работата си. Енергията се съхранява в суперкондензаторен модул. Станцията не се нуждае от поддръжка и се очаква да работи поне 10 години без прекъсване. Единствено е възможно нейното почистване, ако настъпи замърсяване вследствие метеорологичните условия. Основното предизвикателство в устройството е конструкцията на модула за съхранение на енергията по време на тъмнина, нощ, или други ситуации на липса на слънчева светлина. Броят на зарежданията и разрежданията на модула за съхранение на енергията е поне 3650 за 10 години, но може да се увеличи десетократно или повече поради краткотрайни нараствания в консумираната мощност поради комуникационни сесии или ограничени по време изчислителни задачи, които изискват голяма мощност. Друг фактор допринасящ към увеличението на броя зареждания/разреждания е промяната в слънчевото греене като резултат от неравномерността на облачна структура и други метеорологични явления. Повечето широко разпространени химически формули на акумулаторни батерии предполагат* *деградиране на батериите значително преди крайния брой зареждания/разреждания по време на експлоатацията на станцията, който брой се предвижда да е поне 30000.*

Суперкондензаторите са нова технология за съхранение на електрическа енергия, подходящи за стационарни устройства. Те предоставят много дълъг период на експлоатация и голям брой цикли на презареждане от порядъка на милиони. Настоящата статия дискутира предимствата на внедряване на суперкондензаторите като основен модул за съхранение на енергията при стационарни автономни устройства за дистанционни изследвания и по-конкретно при автономни базови станции за пасивни радари, захранвани със соларни панели. За да се постигне яснота ние разглеждаме приложението на суперкондензаторите в една завършена конструкция на станция за мултистатичен пасивен радар и анализираме изискванията към мощността на всички звена в тази станция. Също така статията прави сравнение между по-разпространените технологии на акумулаторни батерии и суперкондензаторите и извежда предимствата и недостатъците на последните.

Introduction

Remote sensing applications require specialized equipment to carry out data acquisition, data processing in situ, communications and transfer of collected and processed data, data storage, etc. Remote sensing devices are either spaceborne, airborne or Earth's surface based. All spaceborne and airborne applications along with sea sailing equipment require autonomous power sources while Earth based devices may or may not need such power unit. Those Earth based apparatuses that are stationary and located far away from energy infrastructure do require autonomous power systems such as solar panels and rechargeable batteries for energy storage.

Passive radars are remote sensing systems consisting of one or more base stations [1-3] (see Fig. 1). Each base station is, in most cases, non-mobile and located at a distance from city infrastructure or power lines – in areas of low radio interference, i.e. in forests, mountains, distant valleys, structural basins, etc. The unavailability of external power source raises the need for an autonomous one.

There is a variety of power sources that can be used in autonomous remote sensing devices. Some of the available variants are:

- Primary (non-rechargeable) chemical batteries
- Nuclear batteries
- Thermoelectric generators using gas combustion
- Thermoelectric generators using solar heat
- Thermoelectric generators using geothermal energy
- Solar panels
- Solar heat Stirling engine generator
- Wind turbines
- Sea tides generators
- Internal combustion engine generators
- Water column energy generators

Many of these power sources are cumbersome, require specific natural resources in the vicinity of the station, have short life or require frequent maintenance and supply of fuel. As such they are inappropriate for long life remote sensing base stations located in random hardly accessible regions. The following subset lists the more widely used power sources that do not require frequent maintenance:

- Primary chemical batteries
- Solar panels

Primary chemical batteries provide adequate power supply independent from external factors, thus guaranteeing constant maximum power output and being perfectly suitable for the unpredictable and irregular power demand of many remote sensing devices. The major drawback of primary cells is their very limited energy storage. Devices with high power requirements operating for prolonged periods of time would require very large banks of primary cells, which are costly or even not feasible.

Solar panels happen to be the preferred alternative. They have one significant drawback – the power output is not constant and depends of external factors. An energy storage unit is thus required. In satellites where solar power is also often the preferred power source, the electrical energy from the solar panels is stored in capacitors or secondary (rechargeable) cells. The same options are valid for Earth based devices. While secondary batteries have higher power density, they do lack longevity and provide limited number of charge/discharge cycles in comparison with supercapacitors. For devices located at Earth's surface power density is seldom an issue and here is where supercapacitors come into favour. They have much lower power density in comparison with rechargeable batteries but also have a number of benefits such as:

- Charge and discharge cycles in the range of millions
- Very high efficiency of the charge and discharge cycles
- Long life
- High surge current of charge and discharge
- Wide temperature range of operation having no noticeable degradation of efficiency especially at lower temperatures

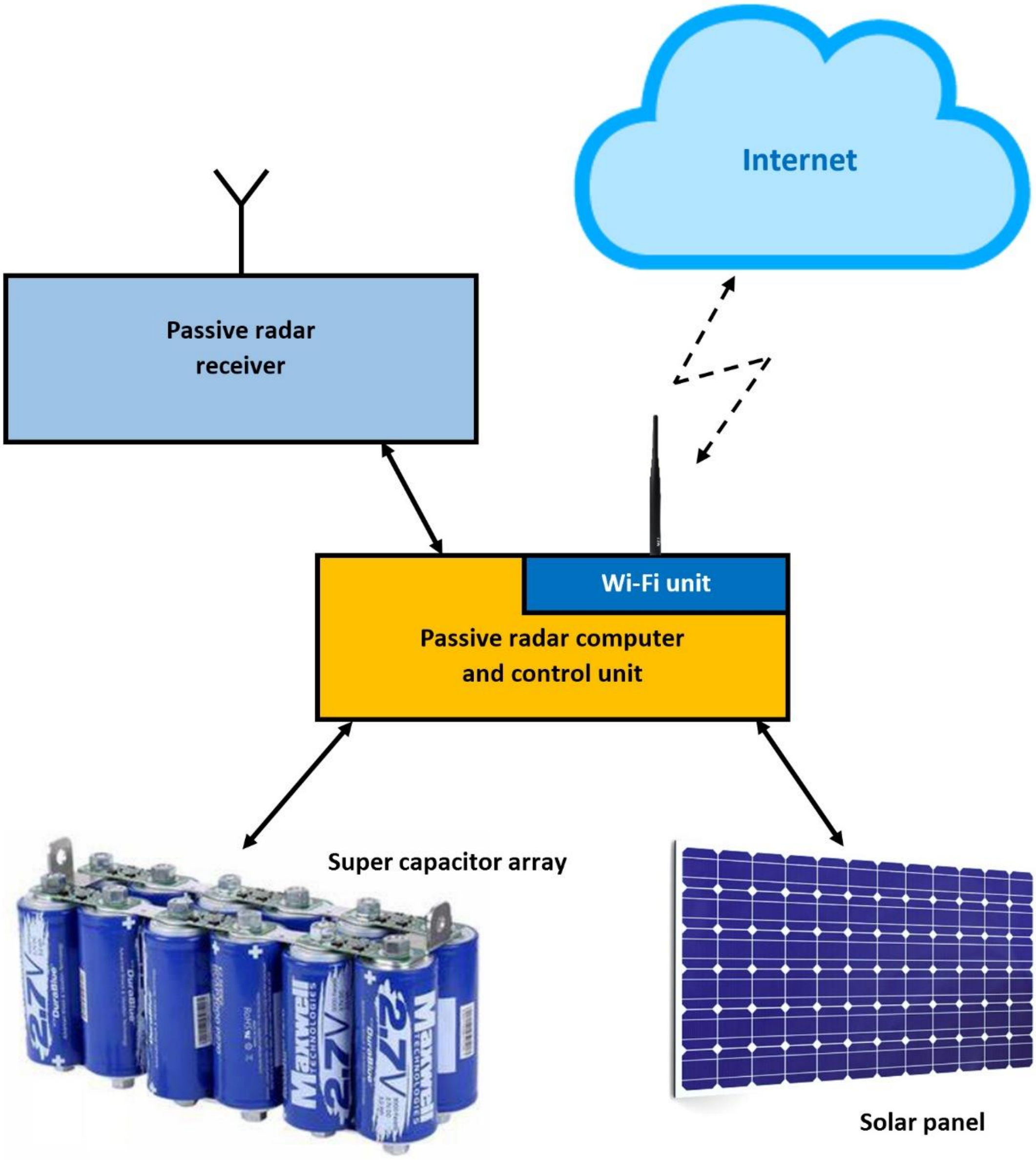

Fig. 1. Passive radar system employing solar panel power supply and supercapacitors energy storage

Multistatic passive radar station

This article discusses the implementation of supercapacitors in multistatic passive radar base station (Fig. 1). Although the approach is suitable for any stationary remote sensing platform, the implementation of supercapacitors as energy storage unit is demonstrated best when viewed as part of a complete device design. Passive radar stations are notorious for their high power consumption that may happen intermittently in bursts or take place for certain medium duration periods of time, both during the day and night hours [4, 5]. Hence, these remote sensing devices are good examples of the applicability of supercapacitors as power storage unit in remote sensing base stations.

The employed design in this article is of an autonomous passive radar station. The latter consists of antennas, radio receiver, control and computational unit, communications module and energy source. The passive radar station uses communication systems that are wireless due to its In-the-field nature. Various wireless networks may be incorporated such as satellite phones, terrestrial cell phone networks, proprietary wireless networks, and wireless Internet access. The last option is getting increasingly available in many locations. More specifically, in the cases of passive radar station Wi-Fi networks are available when the station is positioned near research or scientific facilities. For these reasons, the currently discussed design relies on Wi-Fi wireless Internet access. With the use of range extenders Wi-Fi communication may be established at long distances of few to few tens of kilometres. We should mention that the implementation of Wi-Fi radio link in the passive radar station renders the latter an Internet-of-things (IoT) device. Available Wi-Fi modules are of various kinds, for example single board modules and standalone devices. On the other hand, if a dedicated personal computer, such as a notebook, is involved in the design of the station it is this computer that will provide the whole system with a Wi-Fi connection hardware.

As it was already stated, a multistatic passive radar system requires, in most cases, significant computational power. The core of the station, for this reason, is a high performance computer. In accord with the implemented algorithms, a single board computer or a notebook might be utilized. Recent developments of single board computers do include Wi-Fi modules, so everything said so far for the laptop option in regard to the Wi-Fi radio link holds for the case of implementing a single board computer.

To be able to fulfil high demand computations, the computer graphics card, also known as graphics processing unit (GPU), is most likely to be utilized by the installed software for computations [6-8]. The GPUs installed in modern personal computers provide high performance parallel computing that outperforms any modern central processing unit (CPU). Even single board computers lately come equipped with inbuilt GPU. The GPUs are power hungry and may require anywhere from 2 to 200 watts of power to run at full capacity depending on the number of cores they involve, the chip die technology they are manufactured with, etc.

As a conclusion, it is beyond doubt that the major power consumer in the passive radar station is the GPU. Energy demand by any of the other systems is tens of times lower and does not impact significantly the energy consumption of the whole station.

Modern supercapacitors

Modern supercapacitors are provided in various capacities, but the most prominent large capacity cell is the 3000 farads cell weighing around 0.5 kg (Fig. 2). Most supercapacitors with the given capacity have maximum voltage of charge of 2.7 V (see Table 1). This voltage establishes energy in the range of 10935 J or 3.0375 Wh. Most cells with 3000 F capacity have energy density in the vicinity of 6 Wh/kg. Another important factor when choosing the supercapacitors for the passive radar autonomous station is the temperature range. Most parts exhibit wide temperature range of operation from –40°C to +65°C.

Table 1. Supercapacitor manufacturers and models suitable for remote sensing base stations

Manufacturer	Capacity [F]	Voltage [V]	Energy [Wh]	Weight [kg]	Energy density [Wh/kg]	Temp. range [°C]	Internal resist. [mΩ]
KEMET	**200**	**2.70**	**0.203**	**0.062**	**3.274**	**-25/+60**	**30.00**
AVX	**3000**	**2.70**	**3.038**	**0.500**	**6.076**	**-40/+65**	**0.20**
Eaton	**3400**	**2.85**	**3.836**	**0.600**	**6.393**	**-40/+65**	**0.23**
Cornell Dubilier	**800**	**2.30**	**0.588**	**0.074**	**7.946**	**-25/+70**	**10.00**
Maxwell Technologies	**3400**	**3.00**	**4.250**	**0.490**	**8.673**	**-40/+65**	**0.13**
Vishay	**100**	**3.00**	**0.125**	**0.020**	**6.250**	**-40/+85**	**22.00**
Würth Elektronik	**350**	**2.70**	**0.354**	**0.065**	**5.446**	**-40/+65**	**3.50**
Green-Cap	**3000**	**2.70**	**3.038**	**0.540**	**5.626**	**-40/+65**	**0.28**
SPS-CAP	**3000**	**2.70**	**3.038**	**0.548**	**5.544**	**-40/+65**	**0.29**
GDCPH	**3000**	**2.70**	**3.038**	**0.500**	**6.076**	**-40/+65**	**0.29**
IOXUS iCAP™	**3000**	**2.70**	**3.038**	**0.510**	**5.957**	**-40/+65**	**0.26**

This temperature range is suitable for field deployed base stations installed at locations in Bulgaria. Still another important characteristic of the supercapacitors is the number of charge and discharge cycles. For all products on the market this number is above half a million – adequate for the described application.

Additional parameters of interest are the internal resistance and leakage current. All supercapacitors have negligible internal resistance and for the 3000 F samples it is around 0.3 mΩ. The leakage current for these capacitors is around 5 mA which is too small to be of significance during the daily charging cycle.

Fig. 2. Some supercapacitors of the 3000 F range most suitable for designing energy storage modules

Comparison between supercapacitors and secondary batteries

There are many benefits of employing supercapacitors for energy storage over the best available types of secondary (rechargeable) batteries. These advantages were already mentioned. Supercapacitors, nevertheless, do have some drawbacks and these are:

1. Lower energy density. Most widely available energy density is only 6 Wh/kg while the secondary batteries of the Li-Ion type (most common) is around 216 Wh/kg or 36 times higher.
2. The voltage varies widely from the maximum completely charged voltage of 2.7 V to near 0 V when fully discharged. Special circuitry for utilizing the full energy capacity of the supercapacitors is required.

Energy requirements of a multistatic passive radar station and suitability of supercapacitors in providing the expected energy storage capacity

Our calculations show that powering a laptop based passive radar station with average power consumption of 100 W and 16 h dark time (worst case) requires 1600 Wh of stored energy. To achieve this energy capacity the station needs 550 cells having total weight of 270 kg. This figure surely seems a lot but it is the solar cells that establish station’s dimensions. And the latter are quite large. The needed solar cell area for 200 W power output under overcast sky is equal to 2000 W installed nominal power under clear sky. This makes for a solar cell area of 20 m^2. Having 270 kg of supercapacitor bank weight now seems adequate in relation to these dimensions of the station.

On the other hand, if lower power consumption computer is implemented, i.e. instead of a laptop, a single board computer with 5 W power consumption and we add another 5 W for the different modules in the base station such as radio receiver and Wi-Fi module, then we come to 10 W total power consumption. This is 10 times less than the first example leading to 27 kg super capacitors and 2 m^2 surface area of the solar cells rendering the base station suitable for easy carrying by two to four people. Whether we choose a laptop computer or a single board low power computer depends on the algorithms implemented [9–11].

Conclusion

To avoid radio noisy environment, a multistatic passive radar station needs to be deployed at locations where nearby infrastructure and maintenance personnel would be unavailable. Device of this kind requires endurance under harsh meteorological conditions. Another necessity is the establishment of a radio communication link to data servers. And finally, said device has to be equipped with an energy source with adequate power capabilities.

The last prerequisite is readily fulfilled by employing solar panels for energy generation and supercapacitors for energy storage. The supercapacitors, being the advisable solution for energy storage in this case, provide many gains over traditional energy accumulating components – secondary batteries. Implementation of supercapacitors in future projects of remote sensing devices is promising feat and the authors intend to investigate and research engineering venues and designs taking advantage of supercapacitors for energy storage [9, 10].

References:

1. Zabunov, S. & Mardirossian, G. (2021) Multistatic Passive Radar for Ionospheric Sounding, *SES 2021, Seventeenth International Scientific Conference, SPACE, ECOLOGY, SAFETY*, 20 – 22 October 2021, Sofia, Bulgaria.
2. Zabunov, S., G. Mardirossian, R. Nedkov (2020) Multistatic Passive Radar, *Bulgarian Patent Office,* Utility Model No 3928 / 29.10.2020, 1–3.
3. Zabunov, S. & Mardirossian, G. (2021) Multistatic Passive Radar employing Magnetic Loop Antennas, *Comptes rendus de l'Acad´emie bulgare des Sciences*, Tome 74, No 6, 2021.
4. HOWLAND, P. E. (1994) A Passive Metric Radar Using the Transmitters of Opportunity, *Int. Conf.on Radar*, Paris, France, 251–256.
5. HOWLAND, P. E., D. MAKSIMIUK, G. REITSMA (2005) FM radio based bistatic radar, *Radar, Sonar and Navigation, IEE Proceedings*, 152(3), 107–115.
6. SAHR, J. D., D. M. GIDNER, CHUCAI ZHOU, F. D. LIND (2001) Passive VHF radar for ionospheric physics, *Journal of Atmospheric and Solar-Terrestrial Physics*, 63(2–3), 117–122.
7. CARSON, S., D. KILFOYLE, M. POTTER, J. POTTER (2007) A passive, multi-static radar system, *2007 IET International Conference on Radar Systems*, Edinburgh, UK, 2007, 1–4.
8. PÖLÖNEN, K. (2016) Signal Processing Methods for Multicarrier Passive Radar and Communication Systems, Doctoral dissertation 69/2016, *Alto University publication series*, 13.May.2016.
9. ZABUNOV, S., G. MARDIROSSIAN, P. GETSOV, G. JELEV (2022) Internet-of-things stations system for passive radar. Utility model No 4279/08.07.2022, *Patent Office of Republic of Bulgaria*.
10. ZABUNOV, S., G. MARDIROSSIAN, P. GETSOV, G. JELEV, V. VASEV (2022) Multistatic passive radar with magnetic loop antenna. Utility model No 4337/25.10.2022, *Patent Office of Republic of Bulgaria*.