APP NOTE

RF energy harvesting with the AEM30940

Energy harvesting offers a new way of supplying low-power electronics like sensor devices for IoT solutions. Instead of using power from the grid or from a battery, energy harvesting uses the energy available around us.

Three main elements are essential in order to build an energy harvesting system:
- The harvester transforming energy into electrical energy;
- The AEM30940 managing the power from the harvester to a storage element;
- The storage element storing the energy for a later use.

In the particular case of RF energy harvesting, the harvester is an antenna. This high-frequency signal source requires to be combined with a matching network and a rectifier in order to provide DC voltage to the AEM30940. Other examples of harvesters could be electromagnetic generators, micro turbine generators, thermoelectric generators or photovoltaic cells. The choice of the energy source is related to the device environment.

The e-peas product AEM30940 is an *ambient energy manager* designed to extract and manage power from a harvester towards a low-power device. The AEM includes one internal boost, one buck and two linear converters. A coldstart circuit and a maximum power point tracking - MPPT - enable, respectively, to start as soon as possible to harvest energy and to extract the maximum power out of the harvester. Furthermore, this AEM stores the harvested energy in an external storage element while protecting it from overcharge and overdischarge. Eventually it provides 2 independent regulated voltages to supply an application circuit.

Figure 1 shows an RF energy harvesting system using the AEM30940 and a transceiver as RF signal source. Please note that the source could be a dedicated transceiver transferring only power or multiple transceivers transferring data and power. Be aware that the emitted power is controlled by dedicated organizations in charge of RF regulations. These regulations rules vary with the country and the device function. Based on the ETSI EN 302 208 regulation, we did first focus on the frequency bands (868 MHz or 915 MHz).
For other frequencies, please refer to applicable regulations.

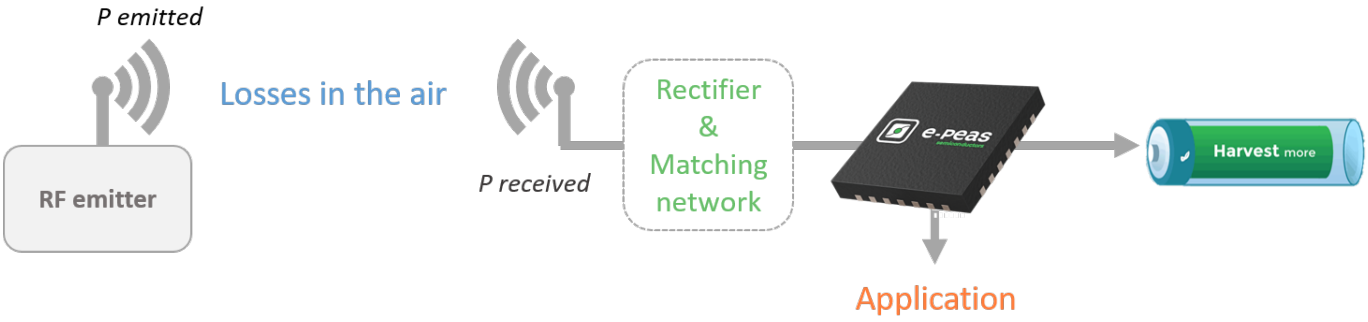


Figure 1: RF energy harvesting global system

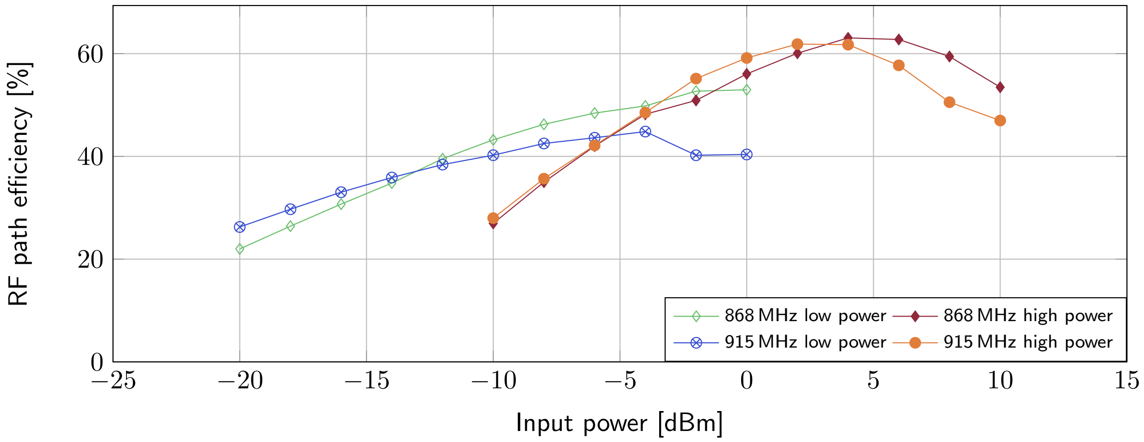
The ratio between the RF power emitted and the DC power harvested is usually poor because of losses in the air and losses on the PCB. Efficiency can be optimized with a dedicated emitter, the antenna's directivity, choice of low frequency, multiple antennas to point out the power, etc. Please note that using a non-dedicated RF source (such as WiFi, 3G, 4G or Bluetooth) prevents control on the antenna and on the real emitted power. It requires some previous tests to understand the truly available power.

Losses in the air can be theoretically estimated (no obstacles and reflections included), please find an online example here (*https://www.everythingrf.com/rf-calculators/free-space-path-loss-calculator*).

The RF global efficiency in the AEM30940 datasheet - called η*RF global* - shows the efficiency from the antenna to the storage. Please note that the efficiency provided is the one measured with *e-peas* design.
It must be characterized if another design is used.

The η*RF global* efficiency includes the boost efficiency and the losses on the PCB from the antenna to the AEM inputs.

Figure 2: Efficiency for 868 MHz *and* 915 MHz *frequency bands*



To build correctly an energy harvesting system, the most important condiseration is to ensure that enough energy will be harvested once it is available; and to ensure that enough energy will be stored to supply the load when no power is available at the source. For a light supplied device, it means harvesting energy during the day and storing it for the night.
Regarding RF supplied devices, it is the real emitted power, the time during which the source will be emitting and the distance to the RF source that will define the harvested energy.

As described below, the energy consumed by the device - called LOAD - must be lower than the energy available from the RF source at the device location. Moreover, the energy consumed when no power is emitted (see the duty cycle regulation rule) must be lower than the energy stored in the storage element. Therefore, the size of the storage element must be wisely chosen.

$$E_{LOAD} < E_{HARVESTED} \qquad \text{and} \qquad E_{LOADnoPower} < E_{STORED}$$

These conditions represent guidelines for the harvester and the storage element size. For a RF supplied device, the harvester choice implies the definition of the RF source frequency, the antennas and the maximum distance.
Antennas could imply some gain or losses: a gain related to directivity (intrinsic gain expressed in dBi) or losses in cables.

The storage element is sized based on the device consumption, the RF source duty cycle (even if it is not called "duty cycle" but "frequency hopping" imposed by regulation) and the autonomy required.
The autonomy refers to the time during which the device must be working without any power coming from the source.

Below, Tables 5 and 3 show the available total energy [J] over a 24h period to supply a load through HVOUT for a different distance and emitted power. The energy provided in the tables below is the total available energy to supply the load over a 1-day period. Please note that the period could be adapted to a month, a year or another defined time; it is determined to be a day in this document.

This energy represents the total energy available to supply a device. It is calculated below for different emitted power and distance. The same information given in terms of average power - *always over a 1-day period* - is provided on Tables 6 and 4.

The theoretical study here includes all losses from the source to the load: the theoretical losses in the air (with 1 dBi intrinsic gain added to the emitter and receiver antennas), the RF global efficiency from the receiver antenna to the storage element and the converter efficiency from the storage element to the supplied device. It does not include internal losses in the storage element.

Example of an 868 MHz RF supplied device working during the day; recharging over the night

Let's use an example of an application with advertizing BLE beacon sent each 9.5 s and some sensors measuring the temperature, the humidity and the luminosity. The global average consumption is about 50 µW during the day. We could assume that the sensors are used during the day and recharged wirelessly over the night. The source could be an 868 MHz RF transceiver following ETSI 302 208 regulation at 1 m. For simple calculation, let's consider that day and night are half of the day: 12 hours.

Since the device is used only half of the day and recharges half of the day, we are looking for a system getting in average 50 µW over the night, storing the energy and delivering those 50 µW back to the device during the day. By looking at Table 4, we can see that emitting 0.2 W at 1 m is enough to recharge the device - *since it is providing* 63 µW.
The same exercise could be done with a 915 MHz RF supplied device using the Table 6.

Table 1: Rounded available average power µW *over a 24h period Vs. distance / emitted power at* 868 MHz *- duty cycle of 93%*

Emitted power - **Distance** [m]	0.1 W	0.2 W	0.5 W	1 W	1.5 W	2 W
0.5	154	357	947	1787	2414	2860
1	28	**63**	201	456	710	930
2	4.7	12	37	80	151	210
5			3	8	15	22
10					2	3

Example of a 915 MHz RF supplied device working all the day

If a source is always available like a sensor used for predictive maintenance with a source on the roof, we can estimate the global consumed energy.
The distance between the emitter and the device could be of 5 m. The source could be an 915 MHz RF transceiver following FCC part 15 regulation at 5 m.

If, in this case, the device sends the measured data every hour through BLE communication and if each measure and radio communication consume 25 mJ; the global energy consumed over a day is about 600 mJ. By looking at Table 5, we can see that emitting 1 W at 5 m is enough to supply the device - *since it is providing* 800 mJ.
The same exercise could be done with a 868 MHz RF supplied device using the Table 4.

Table 2: Available total energy J *over a 24h period Vs. distance / emitted power at* 915 MHz *- duty cycle of 100%*

Emitted power - **Distance** [m]	0.5 W	1 W	1.5 W	2 W	2.5 W	3 W
0.5	91	179	224	279	332.2	378.8
1	14.5	39.9	56	76.4	112.1	129.5
2	3.4	7.9	14	19.5	25.9	32.3
5	0.33	**0.8**	1.45	2	2.6	3.4
10		0.08	0.2	0.3	0.46	0.57

Please note that:

- the internal LDO efficiency is fixed at 89 %, which is equivalent to the efficiency using a *HVOUT* voltage of 3.3 V from a storage voltage at 3.7 V;
- the followed regulation is the ESTI 302 208 for the 868 MHz frequency band and the source has no modulation as well as a duty cycle of 93%;
- the followed regulation is the FCC part 15 for the 915 MHz frequency band and the source has no modulation as well as a duty cycle of 100%;
- if another regulation must be respected at the RF source, the emitted power will be impacted.

Tables

Table 3: Available total energy J *over a 24h period Vs. distance / emitted power at* 868 MHz *- duty cycle of 93%*

Emitted power - Distance [m]	0.1 W	0.2 W	0.5 W	1 W	1.5 W	2 W
0.5	13.3	30.9	81.	154.4	208.5	247.1
1	2.4	5.4	17.3	39.4	61.4	80.3
2	0.4	1	3.2	6.9	13	18.1
5			0.28	0.7	1.3	1.9
10					0.1	0.28

Table 4: Rounded available average power µW *over a 24h period Vs. distance / emitted power at* 868 MHz *- duty cycle of 93%*

Emitted power - Distance [m]	0.1 W	0.2 W	0.5 W	1 W	1.5 W	2 W
0.5	154	357	947	1787	2414	2860
1	28	63	201	456	710	930
2	4.7	12	37	80	151	210
5			3	8	15	22
10					2	3

Table 5: Available total energy J *over 24h period Vs. distance / emitted power at* 915 MHz *- duty cycle of 100%*

Emitted power - Distance [m]	0.5 W	1 W	1.5 W	2 W	2.5 W	3 W
0.5	91	179	224	279	332.2	378.8
1	14.5	39.9	56	76.4	112.1	129.5
2	3.4	7.9	14	19.5	25.9	32.3
5	0.33	0.8	1.45	2	2.6	3.4
10		0.08	0.2	0.3	0.46	0.57

Table 6: Rounded available average power µW *over 24h period Vs. distance / emitted power at* 915 MHz *- duty cycle of 100%*

Emitted power - Distance [m]	0.5 W	1 W	1.5 W	2 W	2.5 W	3 W
0.5	1057	2076	2595	3229	3844	4383
1	168.2	461.3	648.8	84.3	1297.6	1499
2	39.65	91	162	225	300	374.8
5	3.8	9.6	16.7	23	30.7	39.22
10		0.96	2.16	3.8	5.3	6.6

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