Shielding Effectiveness Measurements

MRI apparatuses need a good shielding in order to work correctly. Normally they require a Shielding Effectiveness (SE) better than 80-90dB. Very often 100dB is the target. Therefore, the SE cabin has to be regularly verified to guarantee that performances are achieved and maintained over time,.

SE measurement, at a glance, does not seem to be a difficult task as it is merely the measurement of a ratio between two levels. The first level is the power, irradiated by a known transmitter (TX) and received by a receiver (RX) at a certain distance with nothing in between. The second level instead is measured in the same setup but with the shield between TX and RX. Since normally power is expressed logarithmically (usually in dBm), the SE is quantified as the difference between the two above levels and expressed in dB.

As for the apparent simplicity, SE measurements are usually performed by making use of non-dedicated systems, i.e., an RF generator and a spectrum analyser. However, this approach requires a lot of manual interventions as well as a good RF knowledge thus results might depend on the operator's skill.

SE-Measurements with RF generators and spectrum analysers

Seen the apparent easiness, SE measurements seems to be quite straightforward: a RF generator can be used as a source and a general-purpose spectrum analyzer to receive the signal. However, if we dive into the matter more deeply, we can see some hurdles.

First of all, the system must have the required dynamic range, or sensitivity, in order to fulfil the requirement. To increase the dynamic range (i.e. the difference between maximum and minimum level), one can either boost the generated level or improve the receiver sensitivity.

Boosting the generator can be done up to a level after which it becomes unfeasible and, first of all, unsafe. That is, a level around 30dBm (1W) is very close to the maximum and above this value we have to cope with many disadvantages such as regulations, danger of radiation, heat, consumption, etc..

On the other side, RX sensitivity can be improved by reducing the Resolution Bandwidth (RBW). For example, a band reduction of a factor 10 leads to have 10dB improvement in sensitivity. Theoretically, one could go down to a very narrow BW, 1Hz or even narrower, and have an excellent sensitivity. But also this technique has some restrictions as narrowing too much the RBW leads, once more, to drawbacks such as

- Scan speed: a scan using narrow RBW can be tremendously slow while the time spent for the test should be fast enough to avoid potential troubles here below mentioned.
- Spurs: spurious signals (not necessarily self-generated but also coming from the surroundings), which are normally buried by higher noise, may pop up minimizing thus the advantage of a better sensitivity.
- Accuracy and drift of frequencies (both received and transmitted). This point is worth expanding.

The use of a narrow RBW create the requisite that tunings of both transmitter and receiver must be very accurate and stable otherwise the signal might be neglected altogether . Although one may think that a good quality generator and spectrum analyzer could overcome the problem, the needed accuracy may result to be much higher than the one on the market. As a numerical example, we decide to use a 10Hz RBW in order to have enough sensitivity and make the test at 300MHz. To get an accurate measure, tunings should not be more different than 1/3 RBW (3Hz) from each other. 3Hz at 300MHz means 3/300e6 = 1e-8 or 0.01PPM, which would be very much better that any real oscillator.
Therefore, TX and RX must be "aligned" for every single frequency that is used for the test. Aligning TX and RX requires skill and takes time. Indeed, as the operator cannot know where the exact received frequency is, the operator must scan a sufficiently wide spectrum to make sure the signal is tuned (and a narrow RBW takes quite a lot). Once more, this operation should be done for every single frequency of the test. Skipping this stage could leads to have a very inaccurate reference making consequently meaningless every subsequent measurements.

Additionally, oscillators have their own thermal drift, which makes the absolute frequency moving (drifting) over temperature and therefore time. Normally, TX and RX have completely different hardware and thus different oscillator behaviour and, in the worst case, they may drift in opposite directions. As a result, the whole testing should be quite fast to avoid the aforementioned phenomenon, and after a definite time re-alignment should be done.

Of course, using a wider RBW could mitigate the alignment problem but would reduce the RX sensitivity and thus, the dynamic range might result to be not sufficient. For example, assuming 30 dBm (even though most RF generators do not reach such a high level) as the maximum allowed power at TX-antenna and considering an antenna-to-antenna attenuation of around 30 - 40 dB, it is clear that, to be able to detect a 100dB, a noise floor better than – 130dBm / -140 dBm is required. Such a sensitivity cannot be obtained using wide RBW.

As we hinted previously, a typical test procedure takes a long time to be performed. A typical procedure starts doing the level-reference (calibration), measuring the received absolute value, tuning both TX and RX frequency by frequency, and recording them. The two antennas see each other with no shield in between them. The alignment can be

done at this time. Then, the cabin door is closed and both TX and RX are tuned frequency-by-frequency. It is important to remember that TX and RX will not have the same tunings but the ones measured previously. For all frequencies the received power is taken, at the RX frequency, and subtracted from the level recorded during the first stage. Additionally, for every single frequency cabin must opened, TX tuned, door closed again, RX tuned.
Tests require a long time to be performed and, apart from being a waste of time, the problem is that in such a long time the drift maybe have taken place making the result worthless.

The thing is that every mistake leads to have an over-estimation of performance as all the level values will be measured lower then the actual ones resulting thus in, apparently but erroneously , excellent shielding performance.

To avoid all the above pitfalls a good quality set of spectrum analyzer and RF generator is not sufficient as, first of all, the operator must be very skilled and very RF experienced.

SE measurements with the SEMS

The SEMS is a kit that includes both TX and RX, which are specifically designed for SE measuring. All the test phases (i.e., frequency alignment, level calibration, measuring frequency by frequency, tuning TX and RX differently) are quickly and automatically done. No external actions nor operator decisions are required.

The use of a very narrow RBW is possible thanks to (i) a fast fully self-alignment in frequency and (ii) to a fine tuning separated for both TX and RX. Furthermore, as RX and TX oscillators are exactly the same and designed to warm at similar rate, the drift is extremely low, i.e. certified less than 0.03 PPM in 20 minutes.

SE measurements with the SEMS require short times (in the order of tens of second) to be performed as the operator does not have to set anything. Also, TX and RX are tuned to the exact actual frequency without any external intervention. Thus, either connected or unconnected mode, stability and accuracy of the setup are guaranteed.

Nevertheless, roughly 15 minutes after the last calibration (earlier than the certified figure) the SEMS warns the operator that the calibration procedure must be restarted, assuring in this way that the system keeps always the full accuracy regardless the operator’s activities.

A typical test performed with the SEMS starts with its calibration. T**he operator sets RX and TX at the correct distance and press Cal Key.**

For every frequency of the test the SEMS

- Tunes both TX and RX automatically.
- Gets a spectrum around the tuned frequency
- Records the frequency offset.
- Records the power level, measured at the tuned frequency, to use it as reference.
- (Optionally) Passes through all the recorded frequencies with the TX switched OFF measuring thus the dynamic range.
- (Optionally) warns or stops if the dynamic range is below the need.

The operator has only to wait, a few seconds, and nothing else.

The Operator then closes the door and presses measure key.

For every frequency of the test the SEMS

- Tunes both TX and RX automatically using the recorded frequency along with their offset.
- Gets the power level at the tuned frequency.
- Subtracts this level from the reference recorded.

The operator can now browse the results frequency by frequency and, optionally, can store them so that they can be retrieved later by a PC.

SE measurements with the SEMS are very fast and easy, and first of all, do not require particular skills as all phases are automatically done and very little is asked to the operator.

Conclusion

Although a set made of a general-purpose spectrum analyzer and an RF generator can be used, the procedure requires a very skilled and experienced operator otherwise the result can be very misleading. Moreover, the procedure requires a lot of manual actions that have to be made very carefully. Every mistake and every carelessness lead to have an **over estimation in performance**, which means that a badly shielding chamber could be certified as full performing!

On the contrary, the SEMS makes everything automated so that little actions are needed by the operator. Because of this, there is very little space for making mistakes and, as a result, no particular skill or RF experience is required. Additionally, even for the unlikely event of a mistake or failure, the result is an **under estimation in performance** which would definitely lead to investigate about the cause of the poor performance and therefore the root of problem.