Concept for RF-safe electrophysiology pacing catheters using a transformer-based transmission line

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Objective

Electrophysiological (EP) interventions have proven to be a successful treatment for various cardiac arrhythmias [1]. During the interventions, catheters are used to map the electrical activity of the heart, to stimulate the heart and to perform radiofrequency ablation. At present, EP interventions are typically guided by X-ray fluoroscopy. Using MR as an alternative imaging modality offers several advantages like 3D visualization of the cardiac soft tissue in relation to the catheter, functional imaging and the absence of ionizing radiation [2]. Unfortunately, safety problems have so far excluded a clinical application, since excessive heating at the catheter tips can occur due to the coupling of the RF pulses to wired catheters [3]. As a consequence, it is indispensable to develop RF safe solutions for such catheters.

For the transmission of high frequency signals as for active catheter tracking, tip heating can be vastly suppressed by applying a transformer-based safe transmission line (STL) [4]. On the other hand, low frequency signals of intracardiac electrocardiograms can be recorded safely using highly resistive wires [5]. So far unaddressed is the problem of pacing pulses, which are used to stimulate the heart. These pulses typically last several milliseconds and lead to a direct current of a few mA between electrodes at the catheter tip. The pulses cannot be transmitted using a transformer based transmission line, and highly resistive wires are not adequate either, since most of the applied power would be lost in the resistive leads.

In this paper, a concept is presented to generate the desired DC pulses by transmitting a modulated high frequency signal via the transformer based transmission line in combination with a rectifier at the catheter tip.

Materials and Methods

A test setup of a rectifying circuit was built as depicted in Fig. 1a. It is crucial for the efficiency of the rectification to use diodes with fast recovery times, so Schottky diodes of the type BAS40 were employed (Infinion, 40V, 120mA, 100ps charge carrier lifetime). The typical patient load between the electrodes was mimicked by a resistor (Rpat) with a value of 150Ω. An SMD capacitor (C) of 1nF was used to smooth the DC output. The impedance of the assembly in Fig. 1a was measured at 63.8MHz as a function of the input voltage and is shown in Fig. 2. For maximal conversion, the impedance of the assembly (200Ω-i100Ω for applied voltages above 0.5V) was matched to the characteristic impedance of the transmission line as shown in Fig. 1b. In order to validate, whether sufficient DC energy can be transferred to the electrodes, the voltage at Rpat was monitored using an oscilloscope. The measurement was performed firstly for the plain rectifying circuit, and secondly with a STL containing 3 transformers (80cm long, -7.6dB total attenuation) connected to it, both with and without the matching circuit.

Results and Discussion

DC pacing pulses as shown in Fig. 2 could be generated with the rectifier from modulated RF pulses transmitted by the STL. The remaining ripple in the order of 20% lies in the MHz regime, which is physiologically irrelevant. A comparison of the DC voltages for the different configurations, i.e. rectifier alone/ with STL, with/ without matching network, is presented in Fig. 4 as a function of the input voltage (measured at 50Ω, amplitude value). Without the STL, the rectifier generated a DC output of about 0.8V from an RF input of 1V. The DC output was lower with the STL, which can be explained by its attenuation of 7.6dB. Even without matching, it was possible to achieve a DC voltage of 250mV with less than 1V input at the STL. For an input of 4V, a DC output of 1.6V was observed. This is sufficient, since more than 10mA are rarely needed for cardiac pacing. As a consequence, the matching circuit can be omitted without requiring unreasonable input power in order to keep the assembly as simple and as small as possible, which is desired for the implementation into a catheter. It has to be noted, that a proximal application of an RF-voltage of e.g. 4V does not imply any safety risk for the patient, since the physiologically effective pacing signals are generated at the tip only. The only modification, that has to be considered for the STL, concerns the matching circuit of the last transformer. Since an effective DC current will flow into the rectifier, this DC current must not be blocked by a series capacitor at the transformer. The transformers used in the applied STL could be matched by a single parallel capacitor as depicted in Fig. 1c, which allows the necessary DC current to flow.

Conclusion

DC pacing pulses can be generated with a simple rectifying circuit powered by the STL, thus avoiding RF heating. The necessary RF power remains moderate even in the case of an unmatched load, and no significant changes to the STL have to be made. Based on these promising results, a prototype catheter will be built for further evaluation. Moreover, the proposed concept is not limited to pacing, but can serve all applications, where a DC signal has to be transmitted in an RF-safe manner, e.g. a DC power supply inside the catheter.

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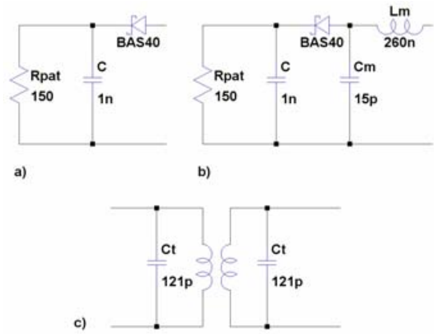

Fig. 1: Schematics of a) the rectifying circuit, b) including the matching circuit and c) the transformers of the STL

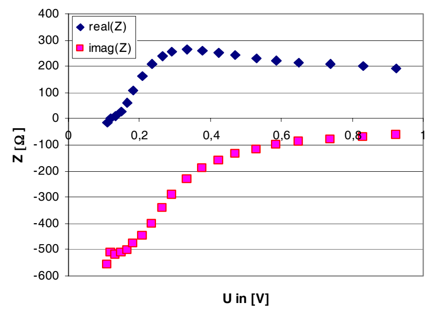

Fig. 2: Measured impedance of the rectifier at 63.8MHz for different AC input voltages

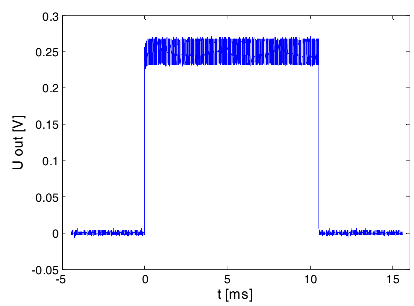

Fig. 3: Measured voltage at Rpat, (unmatched rectifier connected to the STL, pulsed AC input voltage 0.93V)

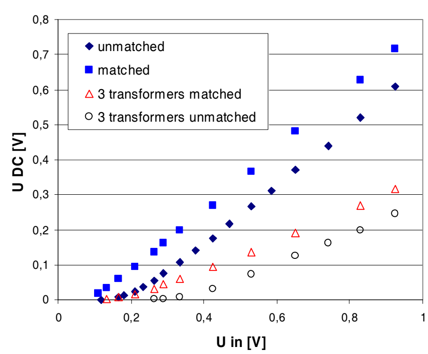

Fig. 4: Measured DC voltage for different configurations and AC input voltages