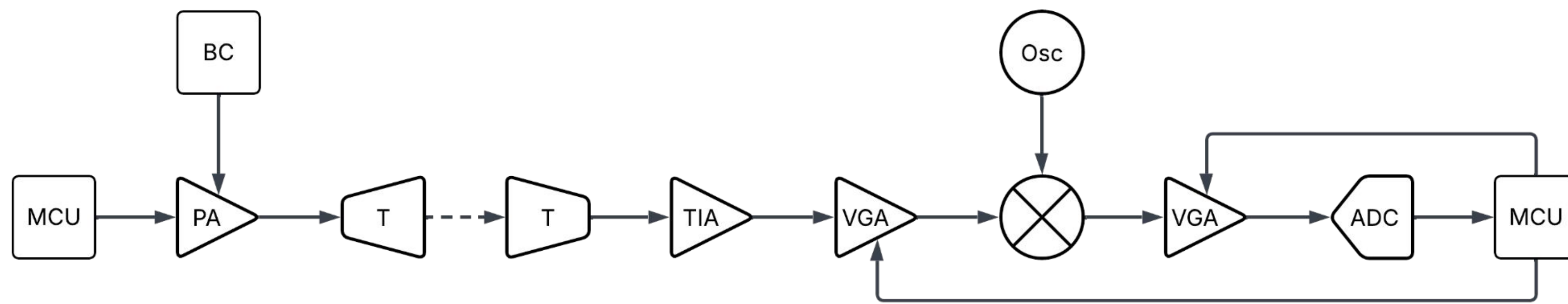


# Design of a Low-Power 40 kHz Ultrasonic Transceiver Front-End for RF-Restricted Environments

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How can a low-power ultrasonic communication system be designed to achieve reliable data transmission over meter-scale distances while maintaining minimal energy consumption and robustness to environmental noise?



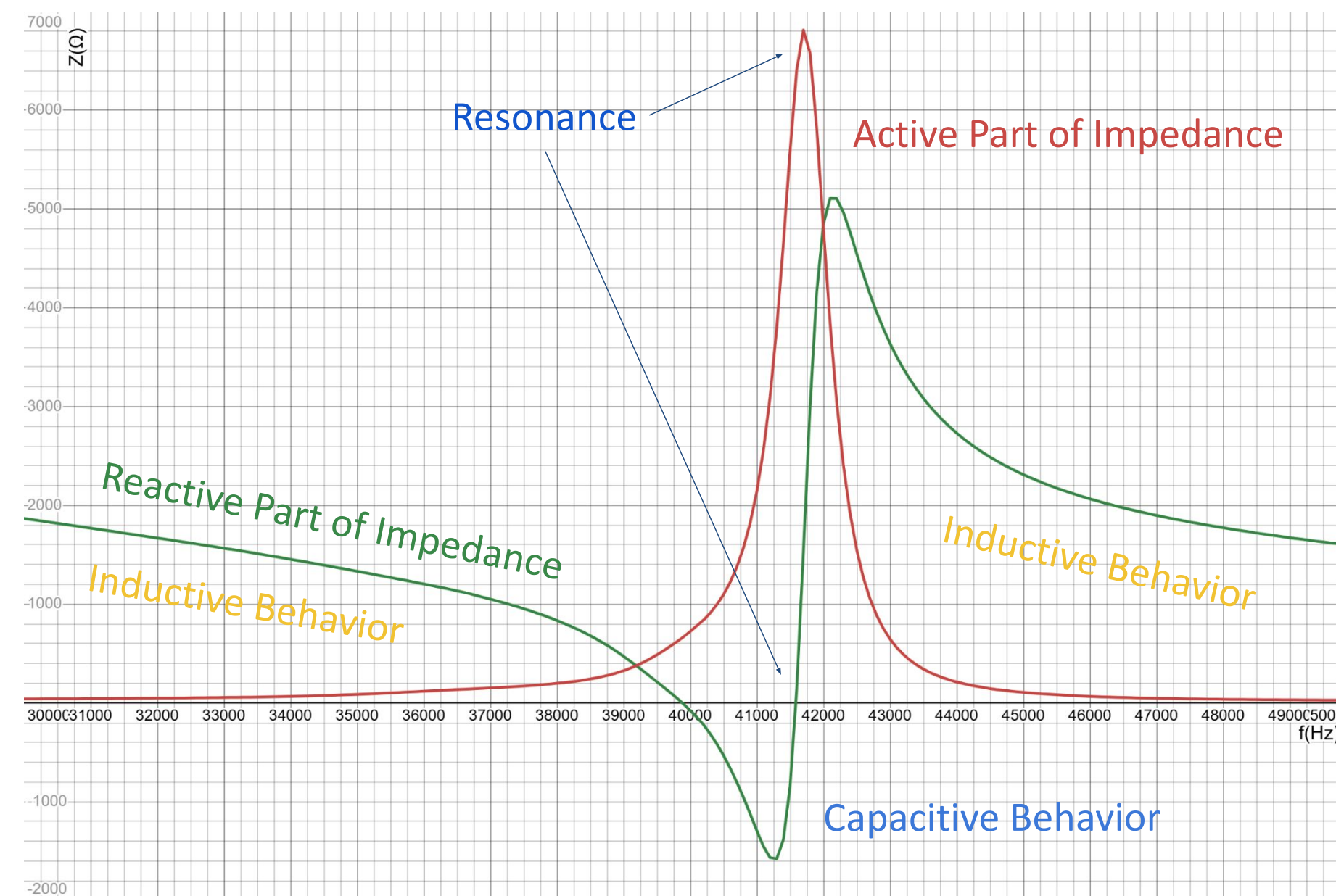
**Overall Design**

A modular ultrasonic communication system is developed to transmit data wirelessly using sound waves rather than radio frequency (RF) signals. The system is organized into distinct functional blocks, enabling independent design, testing, and improvement of each stage. This modular configuration facilitates understanding, debugging, and scalability for future applications.

On the transmitter side, a microcontroller (MCU) processes digital data and converts it into a sequence of binary signals. These signals control a switch-mode power amplifier (PA), which efficiently drives a piezoelectric ultrasonic transducer (T) operating at 40 kHz. The transducer converts the electrical signals into ultrasonic acoustic waves that propagate through air toward the receiver.

On the receiver side, a second piezoelectric transducer converts the incoming acoustic waves into an electrical signal. Mechanical vibrations in the transducer material generate a small electrical current through the piezoelectric effect. Because this signal is weak, it is initially amplified by a fully differential transimpedance amplifier (TIA), which converts the input current into a measurable voltage while minimizing noise. Subsequent variable gain amplifier stages further increase signal strength to accommodate varying conditions.

To recover the transmitted data, the amplified signal is mixed with a reference 40 kHz carrier, which shifts it to a low-frequency (baseband) signal for easier processing and analysis. The resulting signal is digitized using an analog-to-digital converter (ADC), enabling reconstruction of the original binary data.



**Transducer Impedance Characterization**

The ultrasonic transducer was characterized by measuring its electrical impedance over a range of frequencies to determine its resonant behavior. A distinct resonance peak was identified near 40 kHz, corresponding to the frequency at which the transducer achieves maximum mechanical vibration for a given electrical input. Operation at this resonance enhances energy transfer and minimizes the required drive power. This characterization also facilitates appropriate impedance matching with the transmitter and receiver circuitry, thereby maximizing signal transfer and improving overall system efficiency.

