Educator Oriented Prototype Amplitude Modulation Radio Exploits 40 MHz Capacitive Coupling Wireless Power Transfer

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ABSTRACT: This paper stimulates university students to put RF circuit theory into practical electronics involving wireless power transfer. A Hartley oscillator using a low noise MOSFET 2SK241 generates 40 MHz sinusoidal waves, which is linked by a double series resonant toroidal LC coupler to a power booster stage using twin bipolar transistors SS8050 in parallel. Two pairs of metallized plastic plates work as a capacitive coupling wireless power transfer system. A toroidal inductor compensates in series for the coupling capacitance to enhance the power transfer efficiency. A double current rectifier using twin point contact diodes 1N60 converts the RF power back into DC. A medium wave signal broadcasted from NHK Nagoya radio station is received at Toyohashi located 80 km apart with a ferrite bar antenna 2V59M followed by an RF folded cascode amplifier using complementary bipolar transistors 2SC1815 and 2SA1015. A point contact diode 1N60 is again used for AM detection. A constant current diode E-102 enhances the voltage gain in the audio amplification stage. A double emitter follower diamond buffer using two pairs of complementary transistors finally drive an 8 Ω sound speaker. Prospective wireless engineers should be able to learn much of analog RF circuitry from this educator oriented handmade masterpiece.

KEY WORDS: Hartley oscillator, resonant amplifier, wireless power transfer, double-current rectifier, folded cascode, diamond buffer

1. INTRODUCTION

The capacitive coupling is a fascinating solution for a variety of wireless power transfer schemes. However, it is not well deployed so far. One reason may be that the design approach differs from inductive coupling ones. To stimulate university student and even professional engineers, this paper presents a prototype of capacitive coupling power exciter for educational purpose.

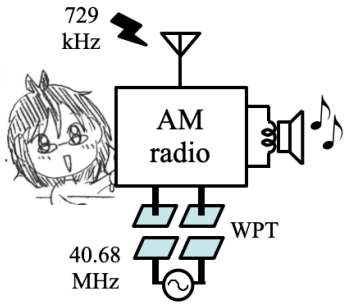

Figure 1 Fun to put WPT into practice

2. SYSTEM CONFIGURATION

We create a VHF power generator that excites an AM radio by way of capacitive coupler as shown in Figure 1. The frequency 40.68 MHz is chosen from VFH ISM bands. Although more challenging than HF bands in power electronics, it expects downsizing of coupling structure and impedance matching circuits. the radio reception frequency 729 kHz is chosen from the medium wave AM broadcasting as described later. The entire system block diagram is shown in Figure 2. The system configuration and constituent circuit blocks are described in the following sections.

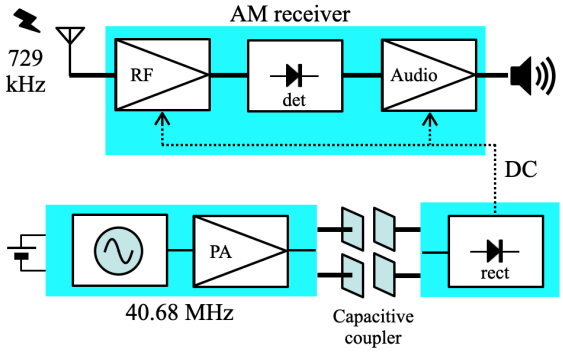

Figure 2 Entire system block diagram

3. VHF POWER EXCITER

The VHF power exciter begins with a Hartley oscillator employs low noise MOSFET 2SK241 shown in Figure 3. The oscillator generates 40.68 MHz sinusoidal waves. The oscillator is followed by a power booster stage through a double series resonant toroidal LC coupler shown in Figure 4. The two trimmer capacitors are adjusted for the coupler to exactly resonate at 40.68 MHz. This can be done by observing and maximizing the dc base or collector current in the final stage transistors. The final stage of this block is an RF power booster as shown in Figure 5. We use

twin bipolar transistors SS8050 in parallel for this booster stage. The transistors are tightly coupled to each other with a cupper tape so that we can prevent them from destructive thermal imbalance.

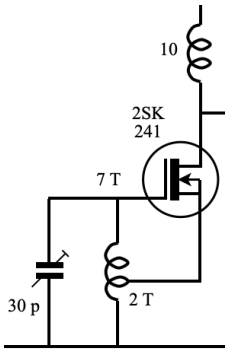

Figure 3 Hartley oscillator

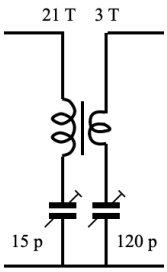

Figure 4 Series resonant transformer

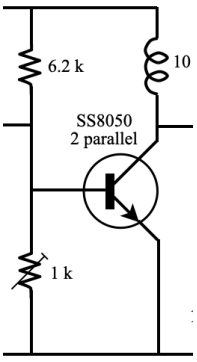

Figure 5 Power booster

4. CAPACITIVE WIRELESS COUPLER

Two pairs of metallized plastic plates face each other as shown in Figure 6. They work as a capacitive coupling wireless power transfer device. Before the capacitive coupler, a 120 pF trimmer capacitor is again used to make resonance at 40.68 MHz. A toroidal inductor of 21T compensates in series for the coupling capacitance to enhance the power transfer efficiency. Another inductor 22T works as a choke coil to make a dc path of the rectifying diodes that follow. The circuits shown in Figures 3, 4, and 5 form a wireless power exciter as shown Figure 7. After this exciter, a double current rectifier converts the RF power back into dc. This rectifier uses twin point contact diodes 1N60 as shown in Figure 8. The converted dc voltage is used as V_{cc} of the AM straight radio described in the next section.

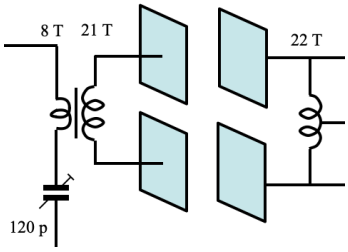

Figure 6 Parallel plate capacitive coupler

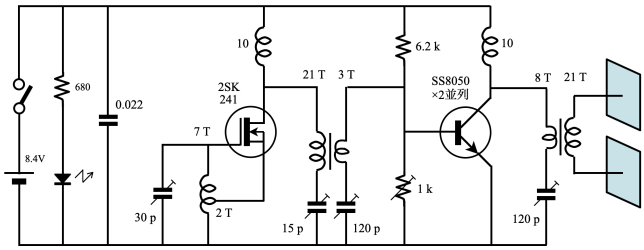

Figure 7 Wireless power exciter

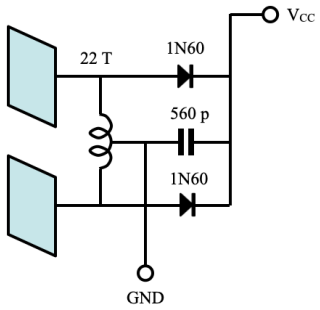

Figure 8 Double-current rectifier

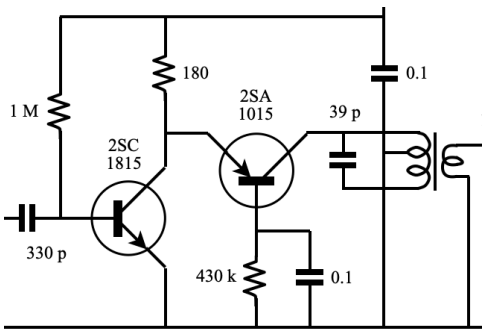

Figure 9 Folded cascode amplifier

5. AM STRAIGHT RADIO

A ferrite bar antenna 2V59M receives a medium wave signal broadcasted from NHK Nagoya radio station at Toyohashi located

80 km apart. The received RF signal is amplified by a folded cascode amplifier using complementary bipolar transistors 2SC1815 and 2SA1015 shown in Figure 9. A point contact diode 1N60 is again used for AM signal detection, and followed by a CRC low pass filter to extract the audio signal as shown in Figure 10. A constant current diode E-102 enhances the voltage gain in the first audio amplification stage shown in Figure 11. A double emitter follower diamond buffer uses two pairs of complementary transistors as shown in Figure 12. The base-to-base capacitor 33 μF effectively enhances the waveform linearity to the full swing amplitude. This stage finally supplies a sufficient audio current to drive an 8 Ω sound speaker.

6. CONCLUSION

We have prototyped an AM involving wireless power transfer for educational purpose. A Hartley oscillator using a low noise MOSFET 2SK241 generates 40 MHz sinusoidal waves. This oscillator is linked by a double series resonant toroidal LC coupler to a power booster stage using twin bipolar transistors SS8050 connected in parallel. Two pairs of metallized plastic plates work as a capacitive coupling wireless power transfer system. A toroidal inductor compensates in series for the coupling capacitance to enhance the power transfer efficiency. A double current rectifier using twin point contact diodes 1N60 converts the RF power back into dc. This dc voltage is used as Vcc for the radio reception. A medium wave signal of 729 kHz broadcasted from NHK Nagoya radio station is received at Toyohashi located 80 km apart with a ferrite bar antenna 2V59M followed by an RF folded cascode amplifier using complementary bipolar transistors 2SC1815 and 2SA1015. A point contact diode 1N60 is used for AM signal detection. A constant current diode E-102 enhances the voltage gain in the audio amplification stage. A double emitter follower diamond buffer using two pairs of complementary transistors with a base-to-base capacitive linearizer finally drive an 8 Ω sound speaker. This work will stimulate university students to put RF circuit theory into practical electronics involving wireless power transfer. Even professional engineers will also be able to learn pretty much of analog RF circuitry from this educator oriented handmade masterpiece.

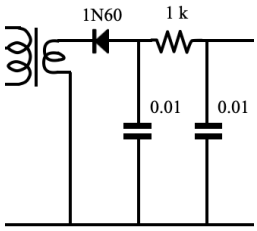

Figure 10 AM signal detector

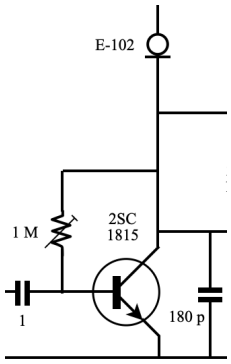

Figure 11 Audio voltage amplifier

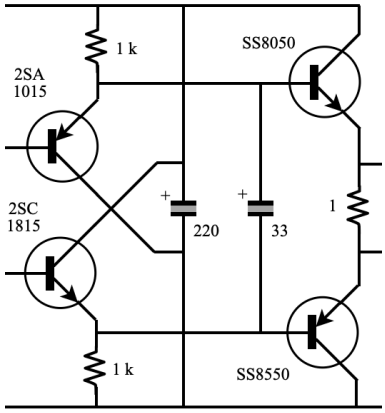

Figure 12 Diamond buffer

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REFERENCES

(1) T. Ohira and K. Araki, “Active *Q*-factor and equilibrium stability formulation for sinusoidal oscillators,” *IEEE Trans. Circuits Systems II*, vol. 54, no. 9, pp. 810-814, Sept. 2007.

(2) T. Ohira and T. Wuren, “Pseudolinear circuit theory for sinusoidal oscillator performance maximization,” *IEICE Trans. Electron.*, vol.E91-C, no. 11, pp. 1726-1737, Nov. 2008.

(3) T. Ohira, “Dedicated *Q* factor formulas stemming from oscillation frequency stability against source and load

deviations", *IEICE Electronics Express*, vol. 9, no. 7, pp. 616-621, April 2012.

(4) T. Ohira, "Power transfer theory on linear passive two-port systems (invited)," *IEICE Trans. Electron.*, vol. E101-C, no. 10, pp. 719-726, Oct. 2018.

(5) K. Yamada and T. Ohira, "Graphical representation of the power transfer efficiency of lumped-element circuits based on hyperbolic geometry," *IEEE Trans. Circuits Syst. II*, vol. 64, no. 5, pp. 485 - 489, May 2017.

(6) T. Ohira, "The *kQ* product as viewed by an analog circuit engineer," *IEEE Circuits and Systems Magazine*, vol. 17, no. 1, pp. 27-32, Feb. 2017.

(7) T. Ohira, "Power efficiency and optimum load formulas on RF rectifiers featuring flow-angle equations," *IEICE Electronics Express*, vol. 10, no. 11, pp. 1-9, June 2013.

(8) T. Ohira, "Linear algebra elucidates class-E diode rectifiers," *IEEE Microwave Magazine*, vol. 23, no. 12, pp.113-122, Dec. 2022.

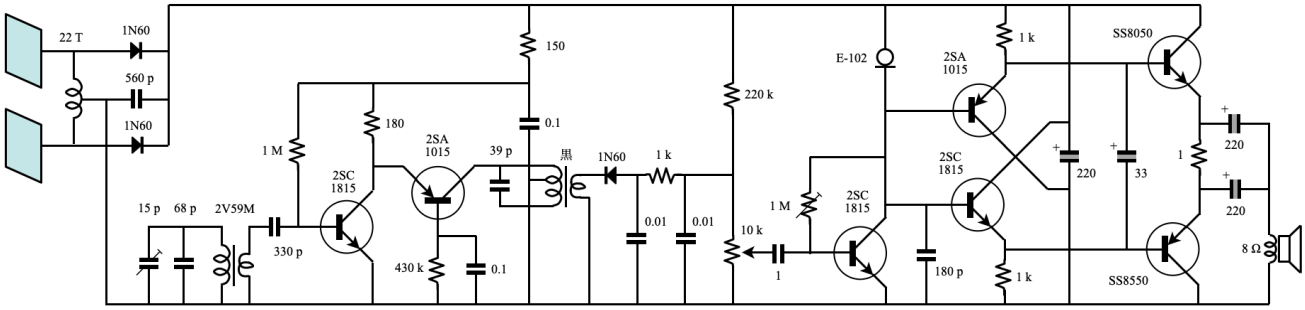

Figure 13 Wireless power receiver and AM straight radio

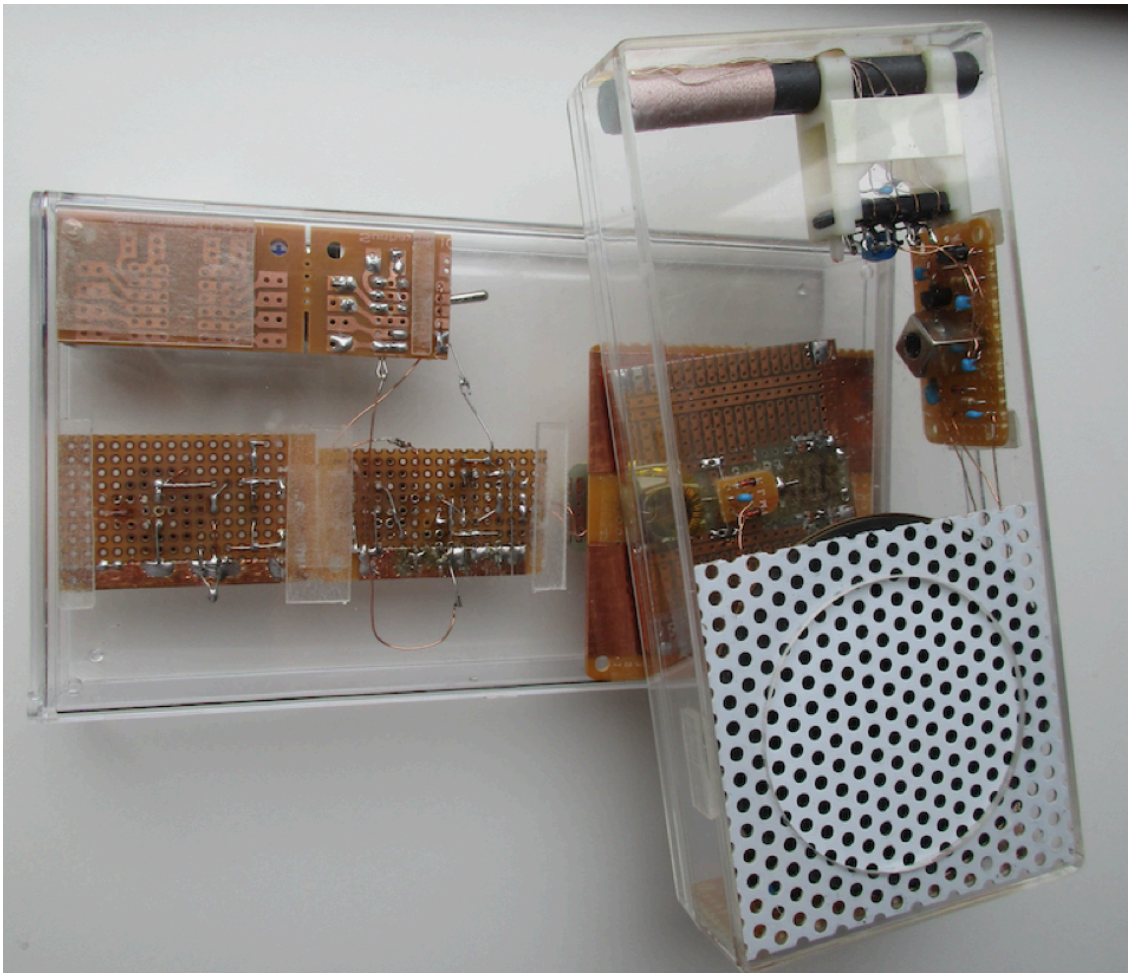

Figure 14 Entire system photograph