AM Transmitter (The First Quadrant Modulation)

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Business Field:

- Semiconductor Quality Assurance support in Japan for foreign semiconductor company
- Analog related Circuit Design

Book:

TITLE: Operational Amplifier Specifications and Applications (Japanese)

This book refer operational amplifier specification, measurement method and application of the specification. This book covers DC/AC/Noise specifications. "Application of the specification" mean calculation method of errors on the application circuit. This book also has some suggestions of calculation method and measurement method for cases that difficult to calculate from ideal models, "know-how" in other words. 452 pages.

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Here is an AM radio transmitter.

At first, there is possibility of illegal depending on country, please check the law in your country before building.

This transmitter is not powerful one, please take care this point.

Features

- 3[V] battery operation and 5[mA] of power supply current
- Robustness to power supply voltage change
- Good linearity (Better sound)
- Low cost
- DC modulation

I believe this is good handmade present to the person who like AM radio sound.

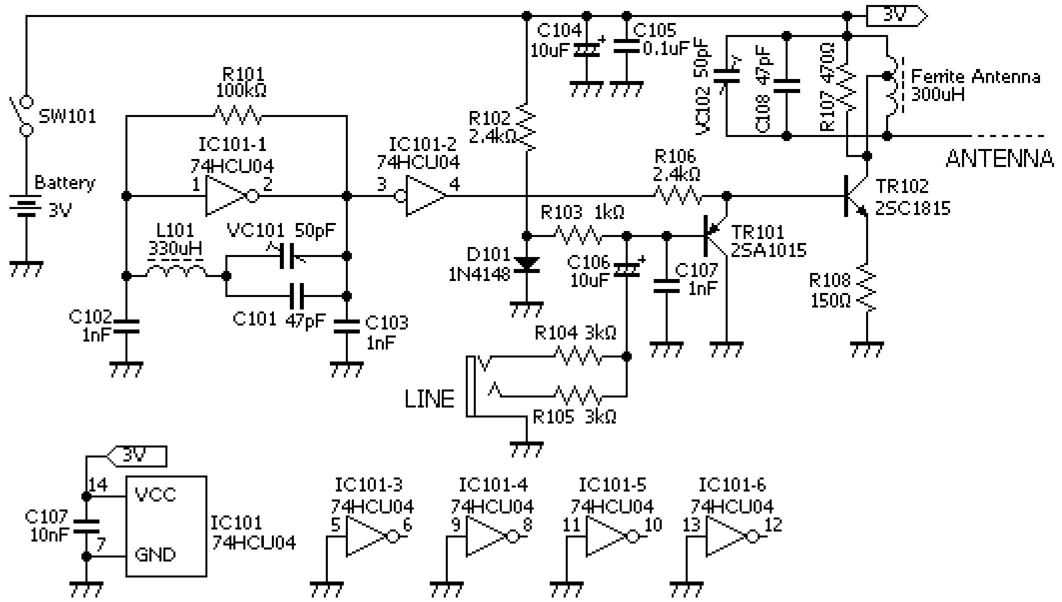

Figure 1. Circuit Diagram (All)

Basic Theory of the Circuit

Figure 1 is all of circuit diagram. You can transmit the sound from CD player for example. If you add microphone amplifier, you can transmit your fantastic voice too.

This circuit is for Japan. The frequency of AM radio broadcasting in Japan is from 531 to 1602[kHz] with 9[kHz] of separation and 15[kHz] of bandwidth. If your country has different frequency, you have to change some parameters. This transmitter uses ferrite antenna for an inductor, so you can use crystal radio parts for your country. From this, if you can get crystal receiver parts easily, you can modify the parameters also easily.

This circuit works only 3[V] of battery and power supply current is 5[mA]. You can get close to 100[%] of degrees of modulation.

IC101-1 and peripheral parts are the clap oscillator. Clap oscillator has better performance in frequency stability when power supply voltage change. The mechanism of the frequency stability is the following:

The cause of the frequency drift when power supply voltage change is the change of inverting amplifier (IC101-1 in this case) input/output capacitance. Clap oscillator has external large capacitors (C102 and C103) that connects to inverting amplifier's capacitance with parallel. Total capacitance at input/output is nearly equal to external capacitor because of large external capacitance. This is the mechanism of frequency stability.

We can get oscillation frequency (f) of Figure 1 from the following equation:

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{L101}\times\left(\frac{1}{C101+VC101}+\frac{1}{C102}+\frac{1}{C103}\right)} \quad (1)$$

C102 and C103 controls the feedback value. If you need more information, you can get them from some books regarding the electrical circuit.

This transmitter uses 74HCU04 (Unbuffered inverter) for the clap oscillator. The reason of adoption of 74HCU04 oscillator is low cost and reducing count of parts. I adopt Figure 2 circuit at first. You can use this circuit too.

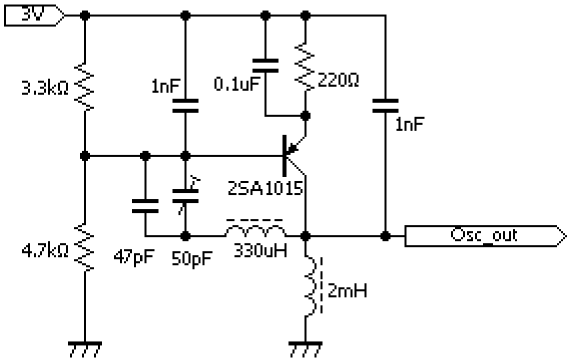

Figure 2. Transistor clap oscillator

IC101-2 oscillator output go into TR101 emitter and TR102 base through R106. TR101 base is biased 0.6[V] with D101 and add audio signal from the LINE jack. TR101 emitter is always 0.6[V] of higher voltage from the base itself. At TR101 emitter, IC101-2 supplies the square wave through R106, so square wave will have amplitude modulation.

Figure 3 is LINE jack signal (triangle wave) and modulated signal at TR101 emitter. You can recognize good linearity because of triangle wave. I designed 2[Vp-p] maximum for LINE signal.

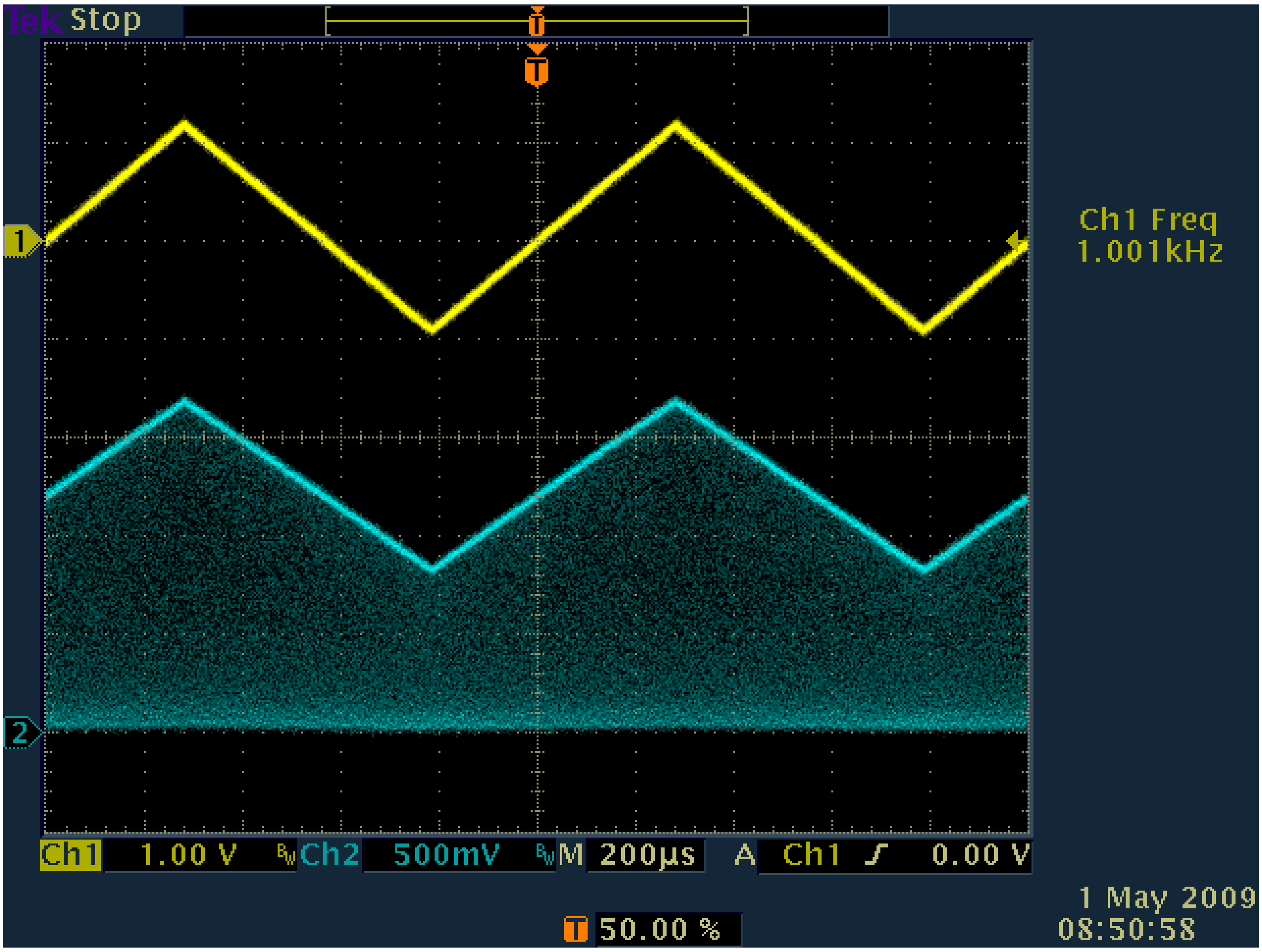

Figure 3 LINE signal (upper) and TR101 emitter (lower)

TR101 emitter voltage is the same as TR102 base voltage. TR102 emitter voltage is 0.6[V] of dropped voltage from the base itself. From this, TR102 emitter voltage follows TR101 base voltage, it means TR102 emitter and TR101 base are the same voltage. The difference of them is TR101 base is DC bias + LINE signal, TR102 emitter is modulated square wave.

Figure 4 is signals at LINE and TR102 emitter.

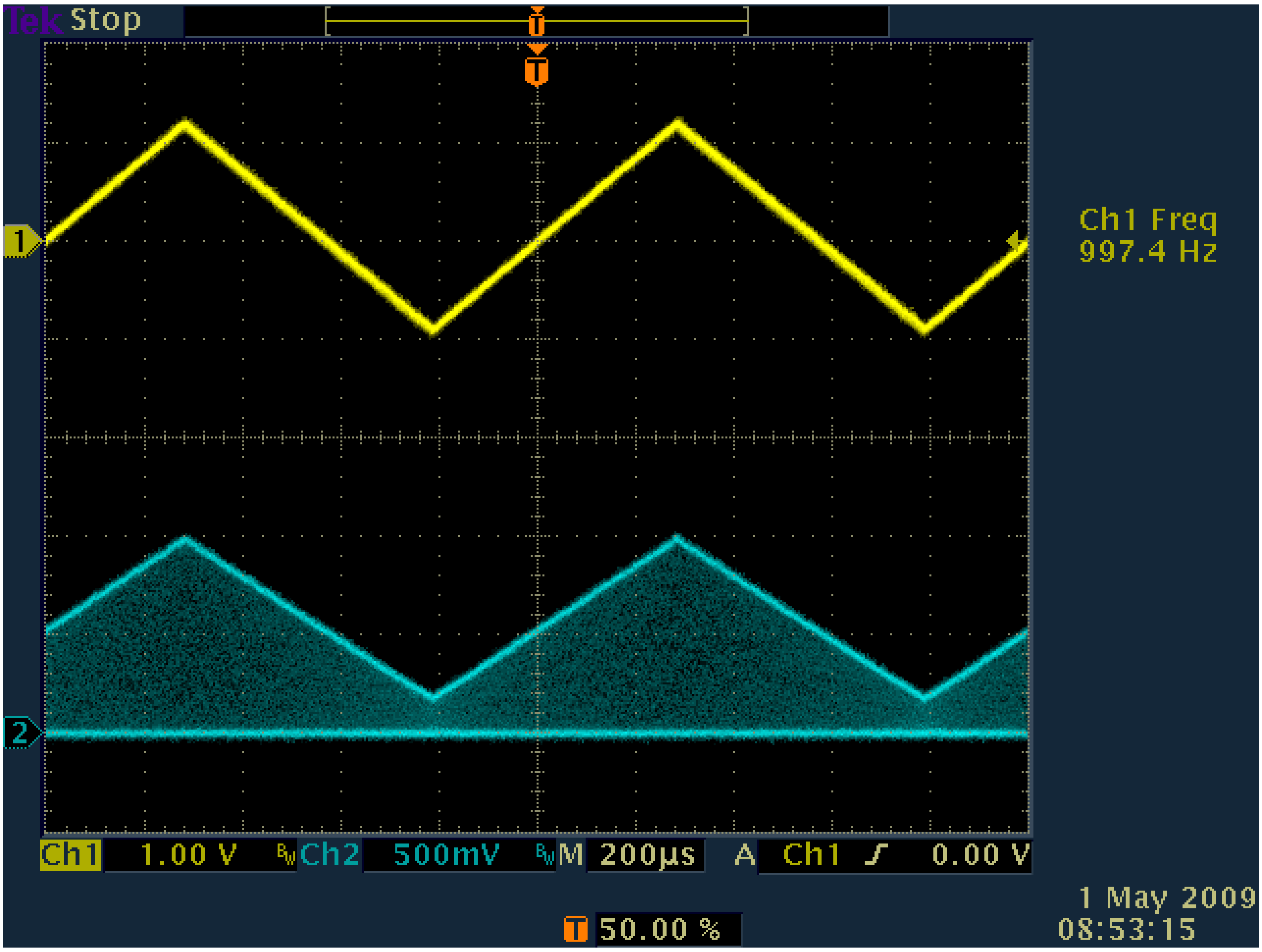

Figure 4. LINE signal (upper) and TR102 emitter (lower)

From the comparison of TR102 emitter in Figure 4 and TR101 emitter in Figure 3, you can recognize 0.6[V] of level shift. And you can also recognize good linearity at TR102 emitter.

This mechanism is also effective to stability of transmitter output power when power supply voltage change, because D101 voltage and R108 in Figure 1 determines output power.

Figure 5 is magnified wave form of Figure 4.

TR102 emitter voltage means the R108 (150[ohm]) voltage. And voltage convert to the current signal. This current is nearly equal to TR102 collector current and this current go into the tank circuit (resonance circuit) that consist of Ferrite Antenna and VC102||C108 in Figure 1.

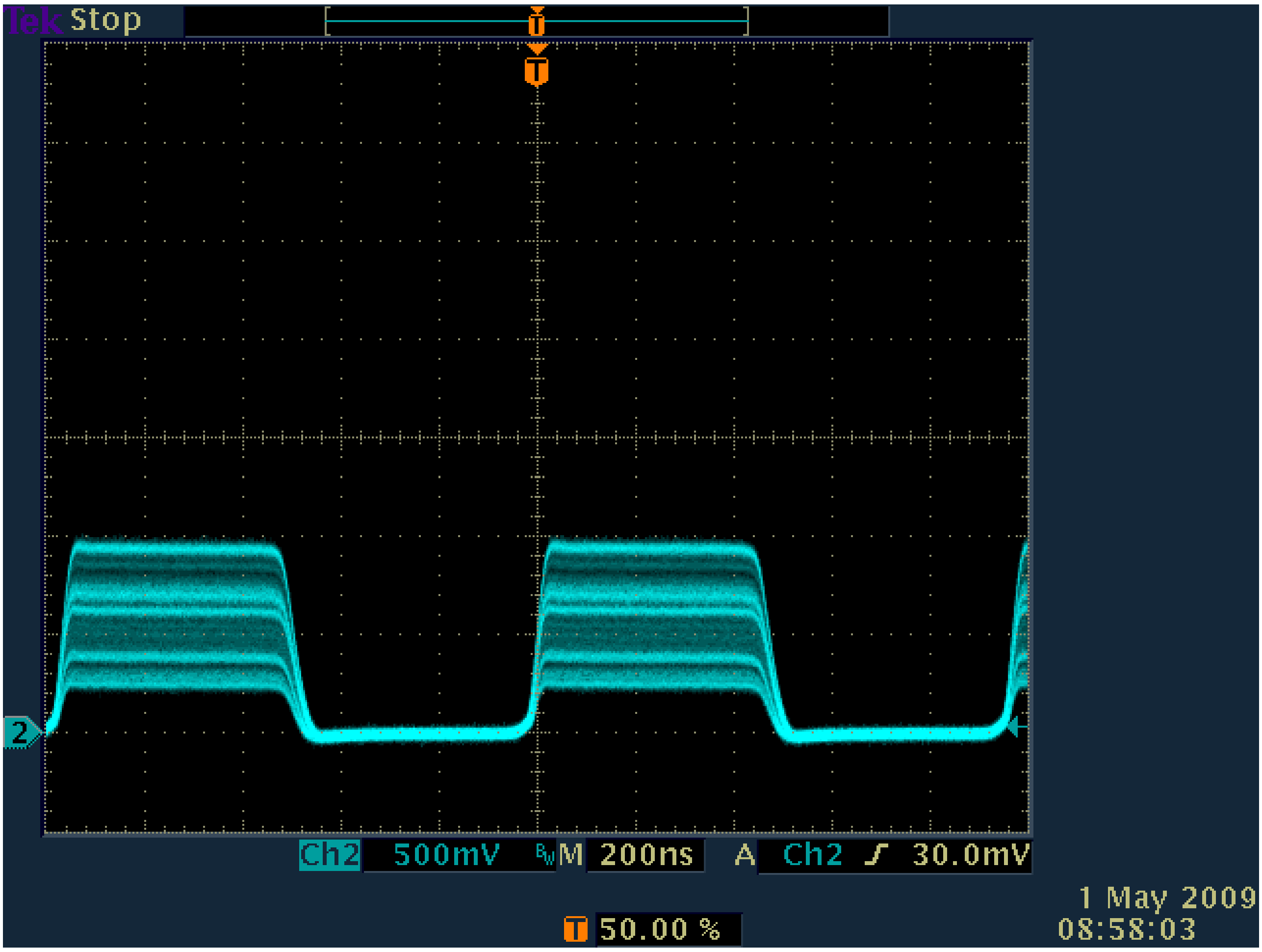

Figure 5. TR2 emitter (modulated with triangle wave)

The behavior of the tank circuit likes flywheel. Rotate the flywheel, flywheel will stop after keep rotation for some time. When apply step signal to tank circuit, tank circuit has oscillation for some time. We call "Flywheel effect" for this behavior. The time of oscillation depend on Q of the tank circuit. This transmitter uses oscillation of the tank circuit.

Figure 6 is IC101-2 output and TR102 collector (tank circuit) when no audio signal.

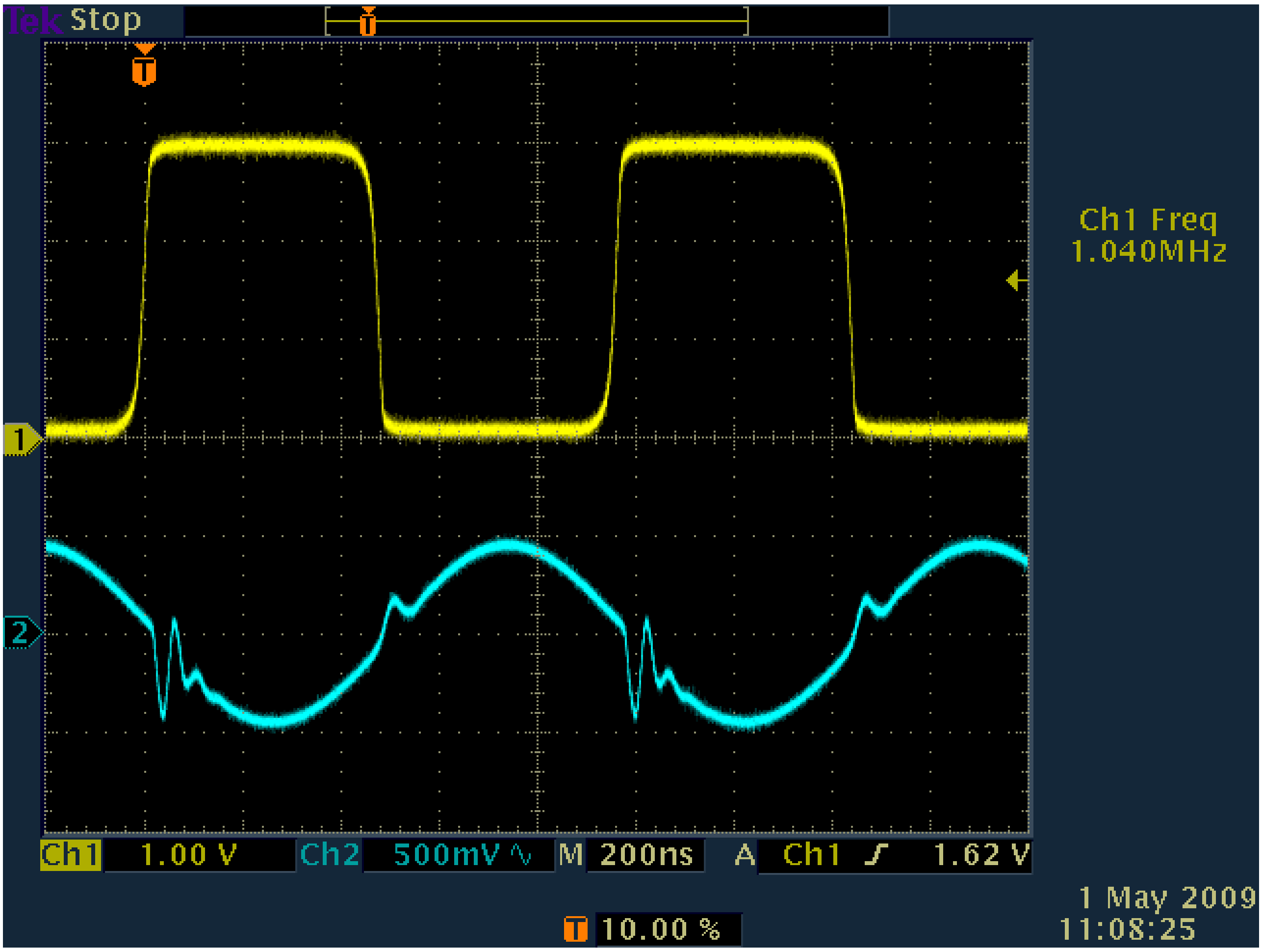

Figure 6. IC101-2 output (upper) and TR102 collector (lower)

From Figure 6, during IC1-2 outputs L-level (~0[V]), the current to the tank circuit also zero. However tank circuit generates wave form with oscillation.

TR102 collector in Figure 6 has spikes that come from switching current. Frequency of the spikes is the same as carrier frequency, so these spikes generate small signal. When you try 100[%] of degrees of modulation, spikes will effect. However when you use for transmitting of the music from CD, I think no problem, because an average degrees of modulation will be ~30[%].

When drives tank circuit with modulated current (Figure 4), the tank circuit oscillates and generates symmetrical wave form. Figure 7 is the wave form at the tank circuit (=TR103 collector).

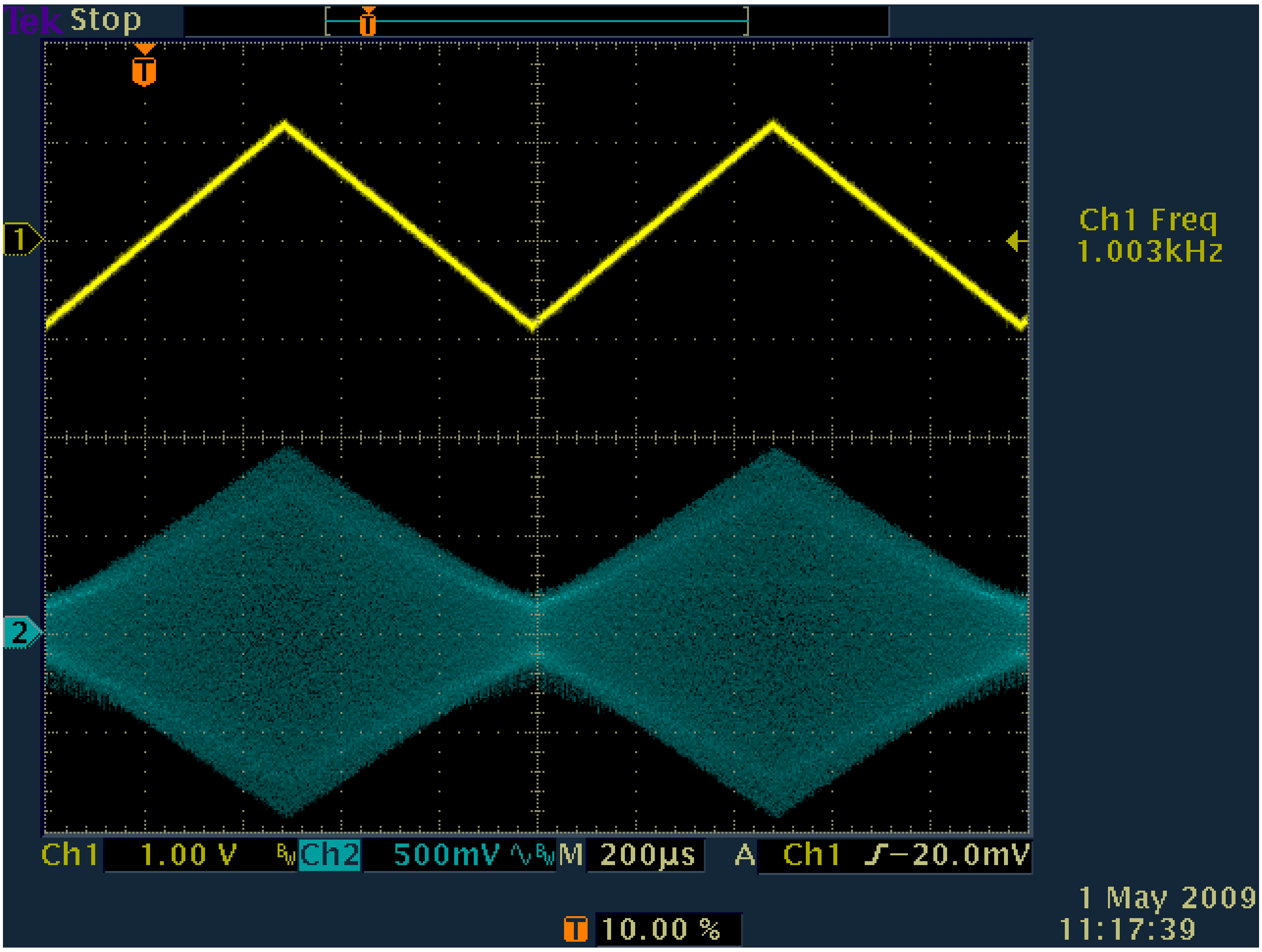

Figure 7. LINE signal (upper) and TR102 collector (lower)

Here is the amplitude modulated signal!

You can recognize the spikes (Figure 6) effect from Figure 7 lower wave form. The valley of triangle wave has some spikes. When remove these spikes, the wave form has good linearity. And Figure 7 lower oscillating wave form is on 3[V] DC.

The method of using tank circuit oscillation also use amplitude modulation that uses C-class amplifier. This method has good efficiency of the electric power, because circuit amplifies only half cycle. The tank circuit generates another half cycle. This AM transmitter works with 3[V] battery, so efficiency is important factor.

Performance Test Report

Here is frequency response test results from square wave response and sine wave response approach.

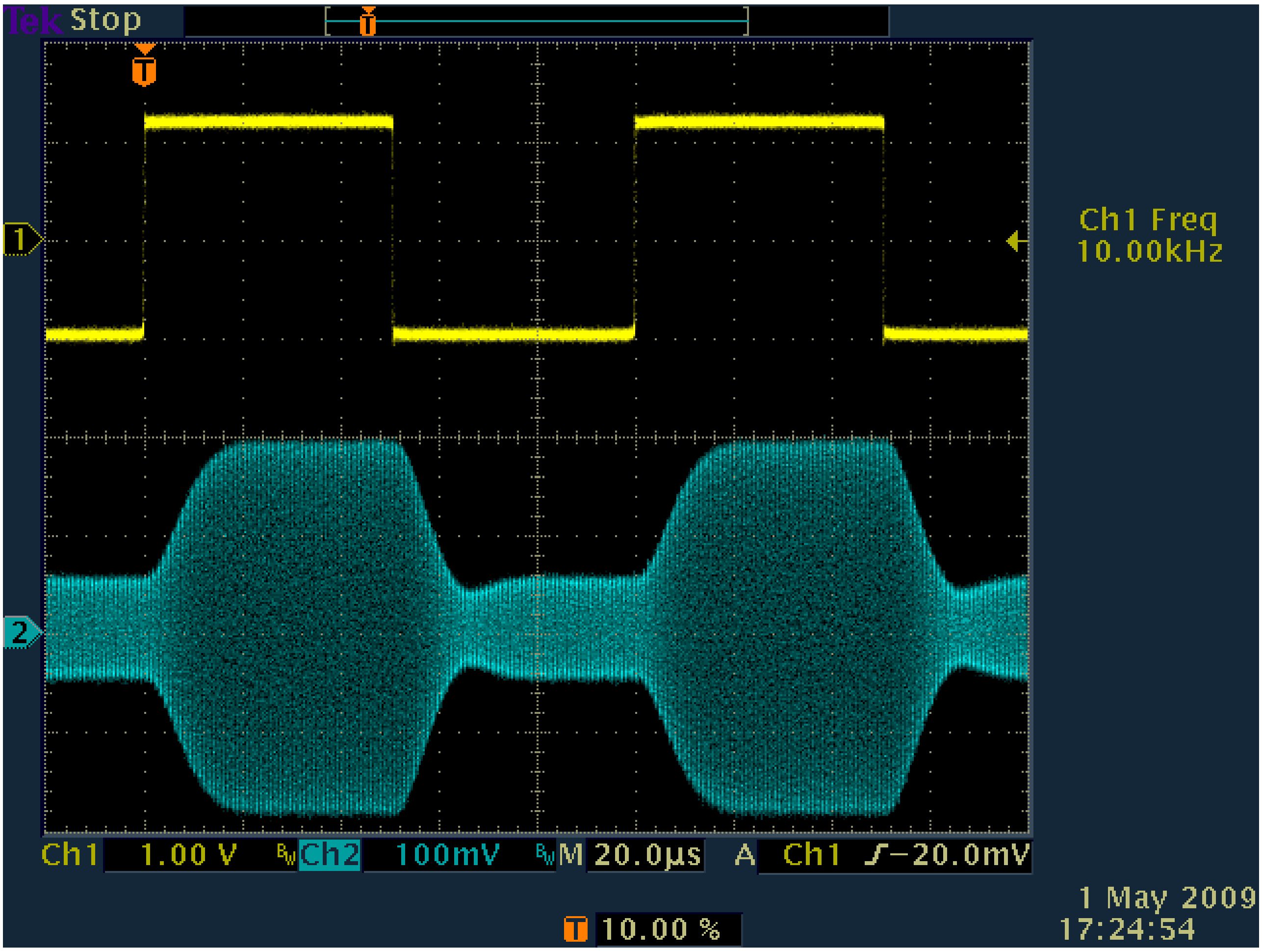

Figure 8. Square Wave Response

The frequency bandwidth of AM radio broadcasting is 15[kHz] (in Japan). A half of this frequency (=7.5[kHz]) is the maximum modulation (audio) frequency. My short wave radio has drastic attenuation characteristic at 6[kHz], it may come from IF (intermediate frequency) filter characteristic.

The test frequency of Figure 8 is 10[kHz], transmitter has good response.

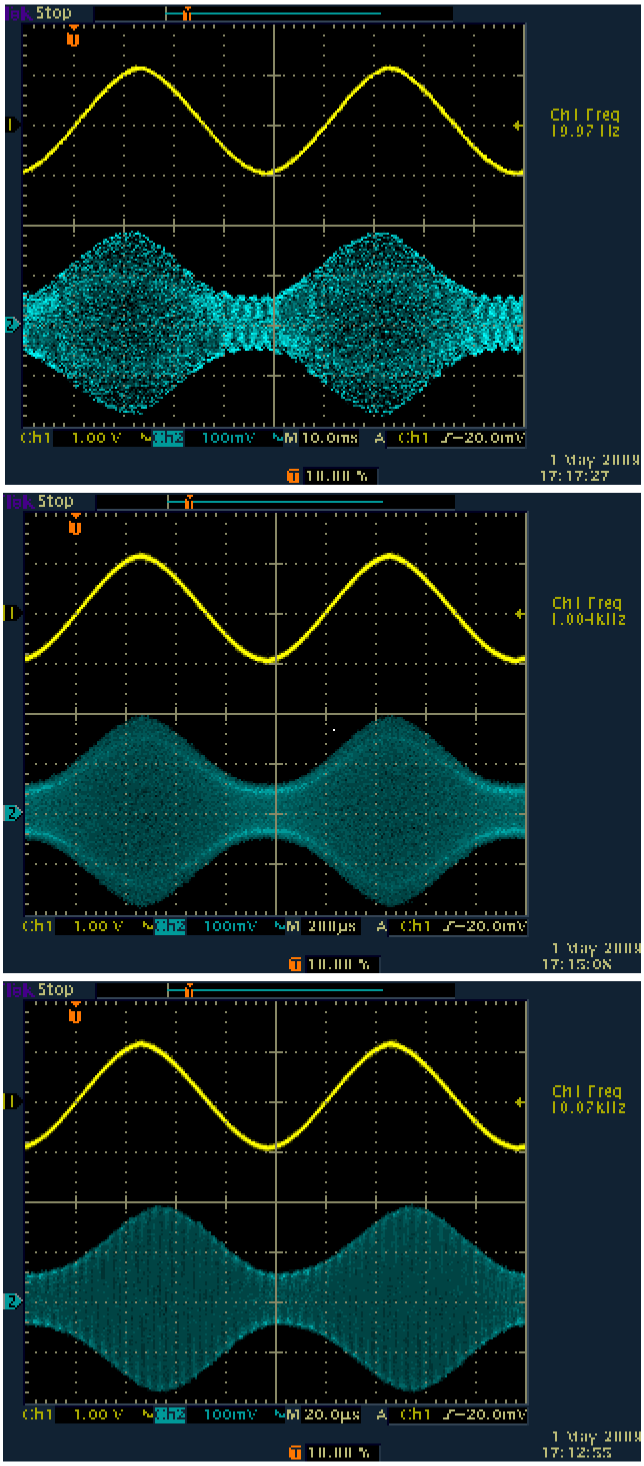

Figure 9. Frequency response at 20Hz (upper), 1kHz (mid), 10kHz (lower)

Figure 9 is sine wave response. There is difference of color tones of lower wave from. That comes from aliasing noise of digital oscilloscope. This mean these difference is not distortion of the carrier.

The comparison of LINE input signal (upper wave form of each picture) and modulated signal (lower wave form of each picture) in Figure 9, we can recognize amplitude and phase performance. There is no big dependency to LINE input signal frequency. This is the condition of better sound.

Application

The frequency of domestic AM radio broadcasting is depending on country (area). Country that close to the equator use 2-3[MHz] (tropical band). Russia use ~0.2[MHz] of lower frequency.

This transmitter is fro Japan. When you build this transmitter at another country, one problem is the oscillator that uses 74HCU04 (IC101 in Figure 1). I evaluated 10[MHz] oscillation and succeeded. Figure 10 is the circuit diagram and Figure 11 is the wave form. However 74HCU04 needs >2.1[V] of power supply voltage (it works 1.8[V] when 1[MHz] oscillation).

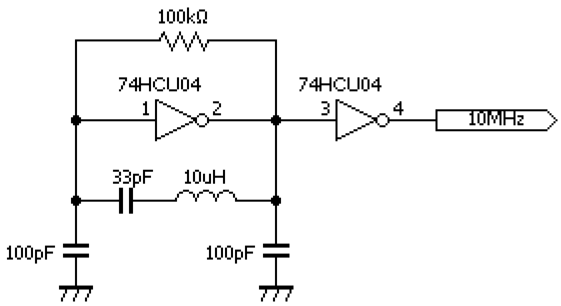

Figure 10. 10[MHz] oscillation test circuit

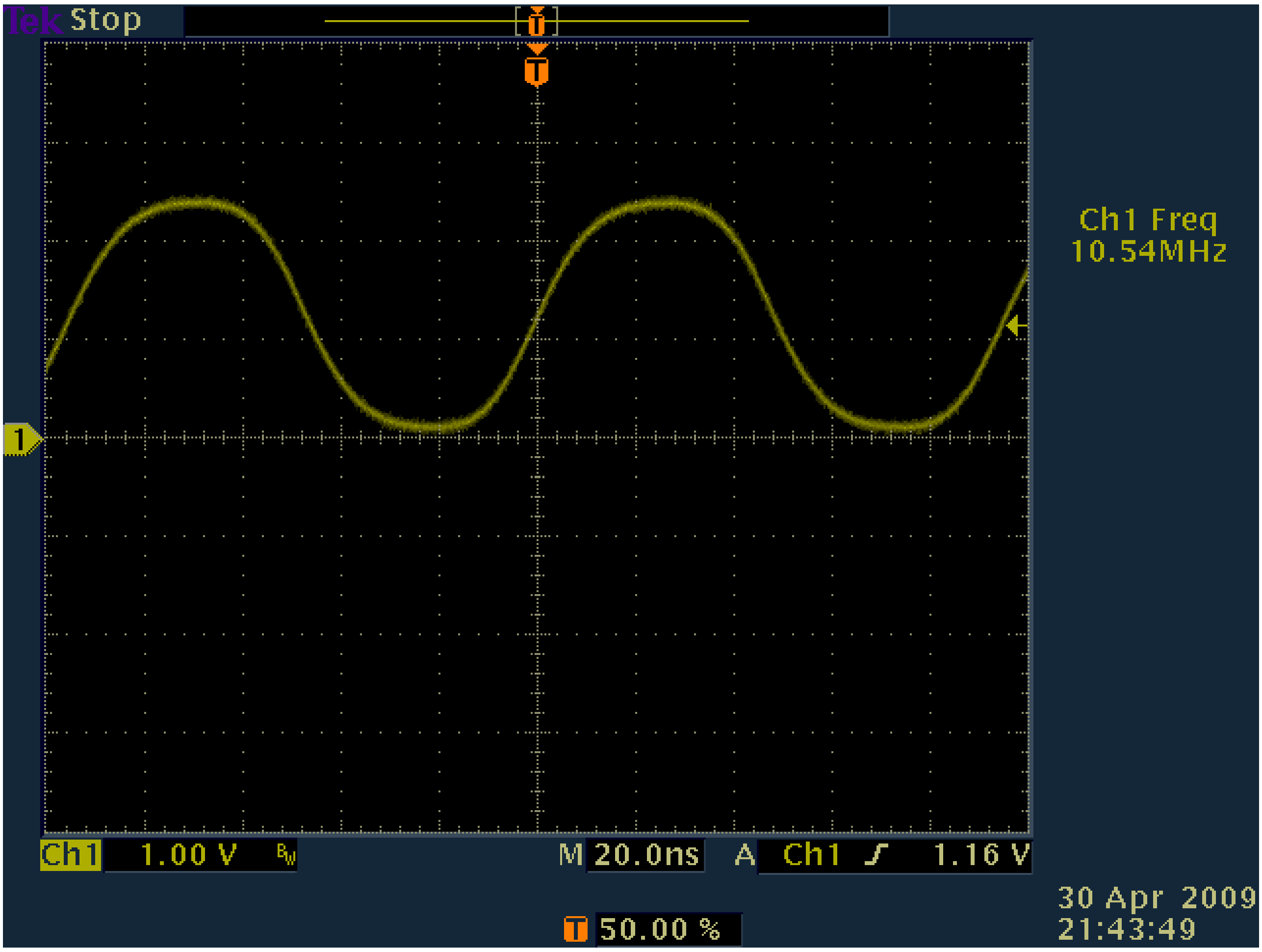

Figure 11. Wave form of 10[MHz] oscillation

This transmitter is for the music. I think we can use for the field of instrumentation too. This transmitter has good linearity, it accepts DC modulation and we can calculate degrees of modulation.

This transmitter works ~2[V] of power supply voltage. Many battery operation equipments require 1.2[V] for one battery. So you can use the used batteries for this transmitter. And frequency stability of power supply voltage change is also good. You don't need extra tuning. From 5[mA] of power supply current, you can use new alkali-batteries more than half years (2-3 hours for everyday).

If you feel bad sound quality, please change the position of transmitter or the radio receiver.

Why called "The First Quadrant Modulation"?

The mean of "The First Quadrant" is upper right side in the coordinate plane's one.

The current analog amplitude modulator uses four quadrant modulator such as Gilbert multiplier cell. The mean of four quadrant is the pole of carrier (C), baseband signal (B) and modulated signal (M) has the following combination:

$$(+C)\times(+B)=(+M)$$
$$(-C)\times(+B)=(-M)$$
$$(+C)\times(-B)=(-M)$$
$$(-C)\times(-B)=(+M)$$

We can call "phase" for "pole" instead. For example, C and M has the same pole in case of +B, C and M has inversed pole in case of -B. From electrical explanation of this is, "The phase of C and M depend on the phase of B"

When consider the amplitude modulation methodology, four quadrant multiplier is not necessity parts even two quadrant multiplier, because amplitude modulated signal doesn't have phase inversion. From this, we can modulate at the first quadrant.

Figure 4 indicates the first quadrant modulation. LINE signal will add 0.6[V] of DC voltage, from this, LINE signal becomes positive region. IC101-2 output (square wave) is also positive region. So all of signals are positive region and we can call the first quadrant modulation.

I got this idea and start the design the circuit of Figure 1. This modulator has linear characteristic essentially, DC modulation is acceptable, the circuit is suitable for lower power supply voltage and easy!

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