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A LOW-COST RF DRIVER FOR ACOUSTO-OPTIC MODULATOR

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ABSTRACT

We report in this paper the construction of a simple, low-cost, yet functional RF driver for an acousto-optic modulator (AOM). This circuit is built as an alternative to the relatively expensive commercially available one. The construction follows the ARRL guide in designing an 80 MHz transistor power amplifier with an LC matching network to deliver about 1 W of power to a 50Ω load (the AOM) either continuously or pulsed. Care must be taken in the circuit construction in order not to generate too much power which can destroy the costly AOM. The finished circuit can drive an AOM to diffract a laser beam to a first-order with 80% efficiency. The diffracted beam is then used a light source in an optical fibre heterodyne interferometer to produce an 80 MHz or 160 MHz optical beat signal.

Keywords: RF driver, acousto-optic modulator, optical fibre heterodyne interferometer.

ABSTRAK

Pada makalah ini kami melaporkan pembuatan rangkaian sederhana namun fungsional untuk mengoperasikan suatu modulator akusto-optik (AOM). Rangkaian ini dibuat sebagai alternatif menggantikan rangkaian yang tersedia di pasaran dengan harga yang mahal. Pembuatan rangkaian ini mengikuti petunjuk ARRL dalam perancangan transistor penguat daya pada frekuensi operasi 80 MHz dengan rangkaian LC sebagai penjodoh impedansi untuk memberikan daya sebesar 1 W baik kontinyu maupun terpulsakan pada beban 50 Ω. Perancangan harus dilakukan dengan seksama agar jangan sampai daya yang diberikan terlalu berlebih yang dapat merusak AOM. Rangkaian ini dapat mengoperasikan AOM untuk mendifraksikan sinar laser dengan efisiensi 80% untuk orde difraksi pertama. Sinar laser yang terdifraksikan ini digunakan sebagai sumber cahaya bagi interferometer heterodin serat optik untuk menghasilkan sinyal layangan pada frekuensi 80 MHz atau 160 MHz.

Keywords: *Rangkaian driver RF, modulator akusto-optik, interferometer heterodin serat optik.*

I. INTRODUCTION

In optical systems the use of a modulator (a device to modulate or change the intensity or direction of the light passing through it) is frequently needed, such as in wideband analogue optical communication systems, switching for digital information recording, pulse shaping, beam deflection, etc. [1]. There are several types of modulator, for example: mechanical choppers, electro-optic modulators, magneto-optic modulators, and acousto-optic modulators or the Bragg cells . In a typical material used as an acousto-optic modulator (AOM), the applied acoustic wave will vary its refractive index creating a kind of diffraction grating which in turn will modify the properties of light propagating through that material (its direction is switched, its intensity is amplitude modulated, and its optical frequency is shifted by the amount of the acoustical frequency). Acousto-optic modulator is frequently used especially for laboratory experiments because of that three capabilities. To generate the acoustic wave in the material we need an electronic circuit called the RF driver. In this paper we report the construction of such circuit as an alternative to the relatively expensive commercially available one. Being low cost, there are no fancy digital displays and programming capabilities, yet the constructed circuit is capable to modulate the laser beam to be used as the light source in an optical fibre heterodyne interferometer.

II. THEORY OF ACCOUSTIC-OPTIC MODULATOR

An acousto-optic modulator is based on transparent crystal such as TeO_2, $LiNbO_3$, and $PbMoO_4$ where its refractive index is dependent on external pressure. The pressure is generated by acoustic waves from a piezoelectric transducer. The waves form a set of horizontally oriented lines of equal refractive index (a Bragg diffraction grating) which is moving at the acoustic velocity v_{ac} (see Figure 1). The grating is capable of partially reflecting an incoming beam [2]. Input and output beams form the same angle Θ with the normal to the surface. However, only at certain angles (called the Bragg angles) there will be a new beam direction. Constructive interference of all partial waves is obtained when the length *2s* is a multiple of one optical wavelength in the material [2]:

$$2s = 2\lambda_{ac}\sin\alpha = \frac{m\lambda}{n} \quad \text{……………………..(1)}$$

with $\lambda_{ac} = \frac{v_{ac}}{f_{ac}}$ where λ_{ac}: acoustic wavelength, v_{ac}: acoustic velocity, α: Bragg angle inside the crystal, *m*: order of the refracted ray, λ: optical wavelength in air, and *n*: refractive index of the crystal.

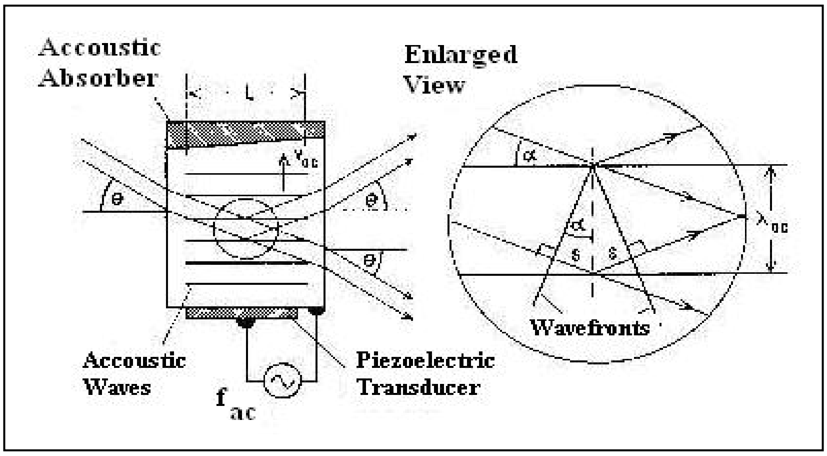

Figure 1. Acousto-optic modulator [2].

The first-order Bragg-angle Θ of the deflected beam can be calculated from the above equations with the help of Snell's law at the interface between the crystal and air [2]:

$$\sin\Theta = n\sin\alpha \text{ , or}$$

$$\sin\Theta = \frac{\lambda f_{ac}}{2v_{ac}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Note that at a fixed acoustic velocity the Bragg-angle is only depend on the drive frequency and the optical wavelength (the refractive index *n* is eliminated).

Interestingly, the optical frequency of the deflected beam (f_{out}) could be higher or lower than the frequency of the input beam (f_{in}) [2]:

$$f_{out} = f_{in} \pm f_{ac} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

If the beam is directed against the direction of acoustic propagation, then the output frequency is higher than the input frequency (and vice-versa).

The optical power of the deflected beam which is depend on the electric drive power can be calculated from a deflection efficiency η equation as follows [2]:

$$\eta = \frac{P_1}{P_0} = \sin^2\frac{K}{\lambda}P_{RF} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

where P_1: optical power in the deflected beam, P_0: optical power in the non-deflected beam with no drive power, K: device-typical constant, λ: optical wavelength in air, and P_{RF}: electric drive power.

To operate an acousto-optic modulator, typically we need an RF driver which can deliver power on the order of hundreds of milliwatt to obtain, for instance, a 80% efficiency. For an intensity modulation of the deflected beam, the RF power must be amplitude-modulated. Switching of the beam is obtained by switching the RF source on and off. In the next section we will report the construction of a low-cost RF driver for that purposes.

III. CONSTRUCTION OF RF DRIVER

The acousto-optic modulator for our applications is model N23080 from Newport EOS that use TeO_2 as the interaction material. According to its data sheet [3], the spectral range for this modulator is 440 – 850 nm (suitable for red He-Ne laser or near infra-red laser diodes). The operating acoustic frequency is 80 MHz, the deflection angle is 11.9 mrad at λ = 633 nm (red He-Ne laser), and the maximum-efficiency is 85% at maximum RF power of 1 W. The block diagram of our circuit for this modulator is presented in Figure 2. We will only describe this circuit very briefly, however we believe the readers can follow our explanations and even modify this RF driver.

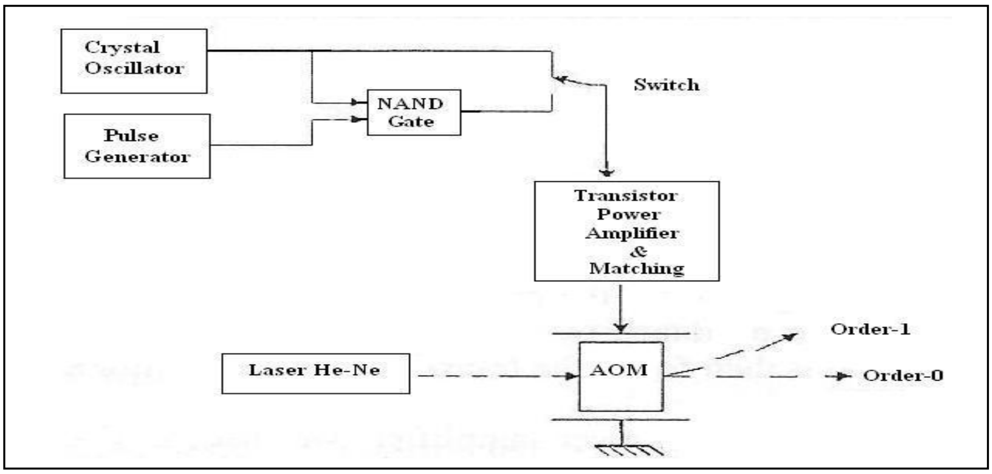

Figure 2. Block diagram of the system.

For the 80 MHz frequency source, we use a hybrid TTL crystal oscillator type MXO-12B which is a combination of crystal technology and thick film hybrid integrated circuit processing. Using a +5V DC input, it produces 80 MHz TTL compatible signal with a high stability.

For the pulse generator, we use combination of a voltage-controlled multivibrator IC type MC4024 and a retriggerable monostable multivibrator IC type 74LS123, see Figure 3. The MC4024 is used to produce a square wave which frequency can be varied by an input voltage (2.5 – 5 V DC). The value of external capacitor Cx (471 pF) is determined from the graph of the frequency-capacitance product given in its data sheet [4] to produce the minimum and maximum frequency (about 250 KHz and 1 MHz, respectively, in this case). This square wave is then fed to the 74LS123 to obtain a train of pulse. The values of resistor R_T and capacitor Cx, which determine the width of the pulse, can be determined from the graph of pulsewidth as a function of capacitance given in its data sheet [5]. For our applications, we need a variable pulsewidth between 100 to 200 ns so that the value of external capacitor Cx is 100 pF and the maximum value of resistance R_T is 5 kΩ.

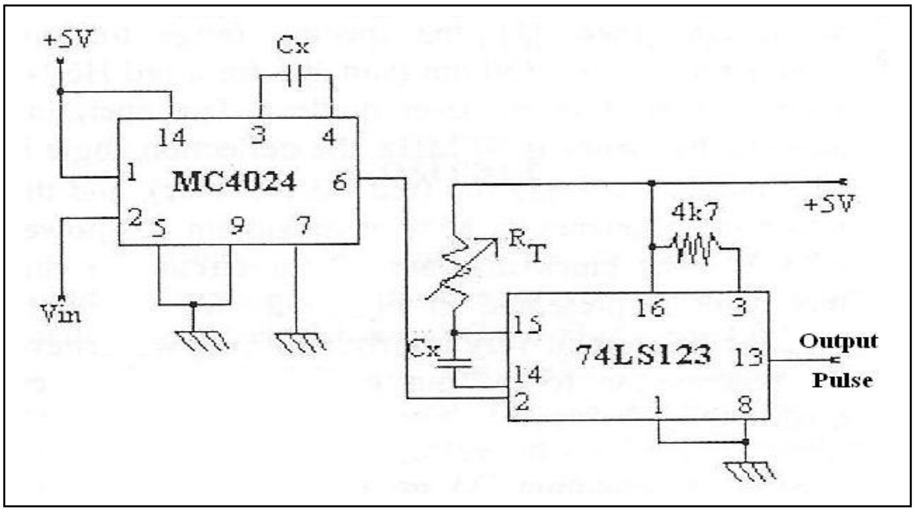

Figure 3. Pulse generator.

If we want to drive the AOM continuously, the 80 MHz signal is fed directly to the transistor power amplifier. However, if we want to drive the AOM with a sequence of RF burst (to intensity-modulated the deflected light), we then use a fast TTL NAND gate IC type 74S00 to gate the 80 MHz signal from the crystal oscillator with the train of pulse produced by the pulse generator. The gated signal is then fed to the transistor power amplifier.

For the power amplifier we use a C-class amplifier circuit (using a 2SC1971 transistor) with an LC matching network to deliver about 1 W of power to a 50Ω load (the AOM, see Figure 4).

The values of inductors L_1 and L_2 as well as the value of capacitor C_1 are determined using the ARRL (American Radio Relay League) guideline as follows [6]: Firstly, we must determine the transistor capacitance (C_{out}) and the quality factor of the network loaded Q_L. Here we use a conservative value of 100 pF for C_{out} and a suggested value of 4 for Q_L (in the interest of stability it is common practice to use a low-Q network). The transistor impedance Z_{Q1} is then calculated:

$$Z_{Q1} = \frac{V_{CC}^2}{2P_0} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where V_{CC} is the supply voltage (12 volts) and P_0 is the output power (1 watt) so that Z_{Q1} = 72Ω. We then calculate the reactance of inductor L_1, that is X_{L1}, using the following equation:

$$X_{L1} = (R_{IN} Q_L) + X_{C(OUT)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where $R_{IN} = Z_{Q1}$ = 72Ω and $X_{C(OUT)}$ is the reactance of the transistor capacitance at f = 80 MHz so that X_{L1} = 308Ω. We can then determine the inductance of $L_1 = X_{L1}/(2\pi f)$ = 610.3 nH. Next, the values of the inductance L_2 and capacitance C_1 can be calculated from the following equations:

$$X_{L2} = R_L B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

$$X_{C1} = \frac{A}{Q_L + B} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

where:

$$A = R_{IN}(1 + Q_L^2) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

and $B = \sqrt{(\frac{A}{R_L} - 1)}$ ………………………..(10)

where R_L is the load impedance (50Ω) so that we have L_2 = 390.3 nH and C_1 = 13 pF.

Using the above component values as a guideline, we then construct the two inductors using single-layer air-core coils and choose a 30 pF ceramic variable-capacitor for the C_1. Before connecting to the AOM, we firstly use a 50Ω dummy load and trim the value of C_1 while observe the output rms voltage using an oscilloscope. Care must be exercised when trimming, especially in the pulsed mode where the peak-to-peak pulse voltage is greater than 12 V DC, in order there is no excessive power which can destroy the costly AOM.

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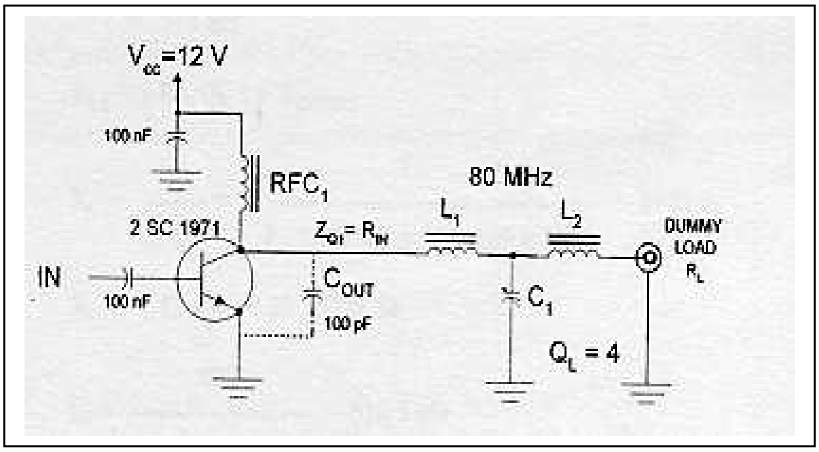

Figure 4. The transistor power amplifier.

IV. PERFORMANCE TEST

As mentioned above, we use a 50Ω dummy load before connecting this RF driver to the AOM. Figure 5 shows the output voltage of this circuit when C_1 is trimmed to give an rms voltage around 6.25 Vrms in the continuous mode so that the power delivered to the load is about 0.9 watt. Figure 6 shows the output voltage of this circuit when operated in the pulsed mode.

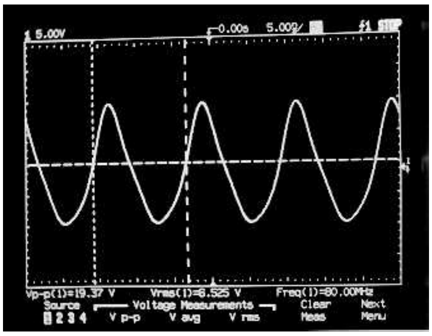

Figure 5. Output voltage, continuous mode.

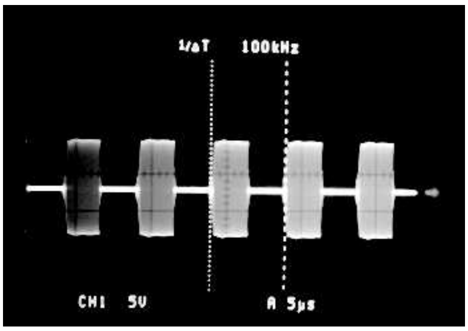

Figure 6. Output voltage, pulsed mode.

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After certain that the delivered power will not greater than 1 watt (either continuously or pulsed) we then replace the dummy load with the AOM. As expected, driven by this circuit the AOM can diffract a beam of He-Ne laser (see Figure 7). Using an optical power meter, we measure the zero- and first- order diffracted beam as 2.05 mW and 1.65 mW, respectively, giving a diffraction-efficiency of about 80%. We then use this diffracted laser beam as a light source in our experiment on optical fibre heterodyne interferometer. If we mix interferometrically the zero-order beam with the first-order beam, we obtain an 80 MHz beat signal. If we mix interferometrically the first-order beam with itself, we then obtain a 160 MHz beat signal. This system can be used for example as an under-water acoustic sensor (hydrophone) where we can obtain the acoustic signals which modulate the phase of light propagating in the fibre by demodulating the beat signal produced by the interferometer.

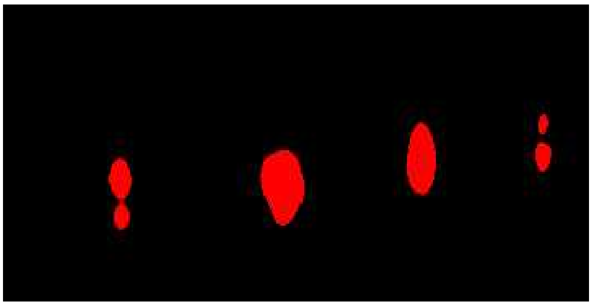

Figure 7. The diffracted laser beam.

CONCLUSIONS

We have designed, constructed, and tested a simple and low-cost RF driver for our AOM. There are no fancy digital displays and programming capabilities in our circuit, yet it is capable to drive the AOM with 80% efficiency (close enough to the 85% maximum efficiency). We use this circuit for our laboratory experiments with AOM such as the optical fibre heterodyne interferometer. From our explanations, we believe the readers can construct a similar or even a better circuit for their own applications.

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5. Data sheet of 74LS123, Texas Instruments Corp.