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The Aerovox Research Worker

The Aerovox Research Worker is edited and published by the Aerovox Corporation to bring to the Radio Experimenter and Engineer, authoritative, first hand information on capacitors and resistors for electrical and electronic application.

VOL. 24 NOS. 5 AND 6 | MAY - JUNE, 1954 | Subscription By Application Only

Balanced Modulators

By the Engineering Department, Aerovox Corporation

THE *balanced modulator* is a special form of mixer circuit to which a carrier voltage and a modulating voltage are applied simultaneously and in which the carrier is suppressed and only the sideband products appear in the output. The balanced modulator finds application in test instruments, electronic control equipment, and in suppressed-carrier, carrier-current, and speech-scrambling communication circuits. Acquaintance with this type of detector is essential to an understanding of many modern electronic systems.

Circuit Configuration

Figure 1 shows the basic arrangement of the balanced modulator. The grids of V_1 and V_2 are 180 degrees out of phase for input e_1, the modulating voltage, and are in phase for input e_2, the carrier voltage. The modulating voltage thus sees pushpull grids, and the carrier parallel grids. The grid bias (B_1) and plate supply voltage (B_2) are proportioned so that the tubes operate in the square-law region of their dynamic characteristics. Analytically, the circuit is considered to consist of two single-tube square-law modulators in back-to-back connection.

Basic Operation

The carrier frequency (fc) usually is higher than the modulating frequency (fm). Thus, it often, but not necessarily always, is true that fc is a radio frequency while fm is an audio frequency. The circuit output consists of the upper and lower sidebands, fc-fm and fc-fm. The carrier frequency, fc, is suppressed by the symmetrical circuit and accordingly does not appear at the output terminals.

Performance of the balanced modulator resembles somewhat the characteristics of a pushpull amplifier wherein only odd-numbered harmonics resulting from tube operation appear in the output, although even-numbered harmonics are present in the plate current. Plate current changes, in opposite directions, in the primary of transformer T_3 (Figure 1) produce the output voltage, e_3.

Application of the low-frequency modulating voltage, e_1, to the grids out of phase, through the center-tapped secondary of transformer T_1, causes a half-wave pulse of carrier frequency, fc, from plate to plate, for each half-cycle of e_1. Symmetrical operation prevents distortion products, due to non-linear operation of V_1 and V_2, from reaching the output.

Since the carrier, (e_2, f_2) is applied to the two grids in the same phase, this component is balanced out of the circuit, the completeness of suppression depending upon the symmetry of the circuit.

Sufficient symmetry for complete suppression of the carrier actually is difficult to obtain in the simple circuit of Figure 1 because of the effects of wiring capacitances, dissimilar tube characteristics, and unbalance in the transformers. In order to adjust the circuit for close balance, capacitive and resistive adjustments are included, as shown in Figure 2. Here, potentiometers R_6 and R_{12} are the resistance balances, and the dual trimmer, C_6-C_7, is the capacitance balance. With the modulating voltage removed and only the carrier voltage applied, the various balancing controls are adjusted for carrier null at the OUTPUT terminals.

Typical Tube Circuit

Figure 2 is a pentode-type balanced modulator circuit of the variety em-

Printed monthly by Aerovox Corporation, New Bedford, Mass., U. S. A.

TYPE	MANUFAC-TURER	Max. Operating Inverse Voltage	Max. Peak Current (ma.)	Max. Average Current (ma.)	Max. Surge Current (ma.)	FORWARD		REVERSE	
						Test Volts	Cur-rent (ma.)	Volts	MA.
1N40	CBSH	25	60	22.5	100	1.5	12.75	—10	0.035
1N40	SYL.	25	60	22.5	100	1.5	12.75	—10	0.040
1N41	CBSH	25	60	22.5	100	1.5	12.75	—10	0.040
1N41	SYL.	25	60	22.5	100	1.5	12.75	—10	0.040
1N42	SYL.	50	60	22.5	100	1.5	12.75	—100	0.625
1N71	SYL.	40	200	60	1000	1.0	15	—30	0.30
1N73	CBSH	60	60	22.5	100	1.3	15	—10	0.05
1N73 G9	GE	—	—	22.5	100	1.3—1.7	15	—10	0.05
1N74	CBSH	60	60	22.5	100	1.2	15	—10	0.05
1N74 G9A	GE	—	—	22.5	100	1.2—1.8	15	—10	0.05
CK709	RAY	60	—	50	—	—	—	—	—
CK711	RAY	80	—	35	—	—	—	—	—

CBSH CBS-Hytron
GE General Electric
RAY. Raytheon
SYL. Sylvania

SPECIAL 4-DIODE BALANCED GERMANIUM MODULATORS.

TABLE 1.

ployed in wave analyzers. The input transformer has been replaced by a phase inverter, V_1, which converts the single-ended modulating-voltage (f_1) input to out-of-phase input for the grids of V_2 and V_3. The carrier (f_2) is applied, through transformer T_1, to the cathodes of V_2 and V_3 in parallel.

In this circuit, the frequency responds to T_2 usually is such that the modulating frequency, f_1, could not be passed, even if stage feed-through should chance to occur. In wave analyzer applications, the modulator output is presented to the input of a highly-selective bandpass filter for transmitting only one sideband.

Efficient operation of tube-type balanced modulators requires tubes matched for transconductance (and often for plate and screen currents, as well), and closely regulating electrode voltages. Center-tapped transformers are designed for close balance between sections and for equal small capacitances between the extremities of primary and secondary windings.

Diode-Type Balanced Modulators

The non-linear volt-ampere characteristic of semiconductor diodes suits these simple 2-terminal components to the function of modulation. Connecting four such *matched* diodes into a suitable symmetrical circuit yields a simple, compact balanced modulator requiring no bias and filament potentials.

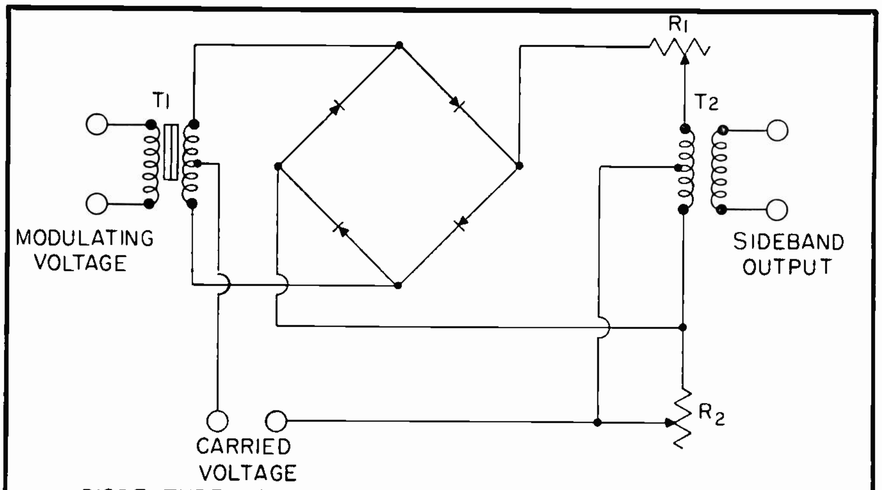
Originally, copper oxide rectifiers were used for this purpose but they are limited with respect both to maximum signal voltage and frequency. While copper oxide modulators still are preferred for certain low-frequency applications, they have been supplanted largely by germanium diodes because of the superior voltage and frequency characteristics of the latter.

Figure 3 shows three common diode-type balanced modulator circuits. While the particular mode of operation is somewhat different for each circuit, the modulating action is about equal in the end result. The balanced arrangement of matched diodes results in suppression of the carrier and transmission of upper and lower sidebands. The circuits in Figures 3(A) and 3(B) permit a common connection between modulation input and sideband output, and this common point can be grounded. This is a desirable feature in some instances. The circuit of Figure 3(C) provides no such path. However, Figure 3(C) allows both the carrier and modulation voltage sources to have a common connection, which can be grounded, while Figures 3(A) and 3(B) necessitate floating the carrier source. Choice of circuit therefore will be governed by prevailing installation and operating requirements.

Observe that the diodes, D_1, D_2, D_3, and D_4, in Figures 3(A) and 3(B) are connected together in a conventional bridge circuit. The different arrangement in Figure 3(C), however, is a configuration known as a *ring modulator* or *double-balanced modulator.*

The diode-type modulator has been described as a carrier-operated switch. In this respect, it may be considered to open, short, or reverse consists of diodes D_1 and D_2 and the two halves of balancing potentiometer R. The carrier voltage switches the lower end of L_1 alternately to ground at the carrier rate.

In the double-tuned output transformer, L_1C_1 and L_2C_2 each is tuned to resonate at the output frequency (sideband). For efficient operation of the circuit, the impedance Z_1 of the modulating source must be low for the carrier frequency, and the output impedance Z_2 must be low for the modulating frequency. Capacitance to ground must be kept as low as possible at the junction of D_1 and D_2. Capacitance between the transformer windings, L_1 and L_2, likewise must be minimized.



DIODE-TYPE MODULATOR FOR HIGH CARRIER SUPPRESSION

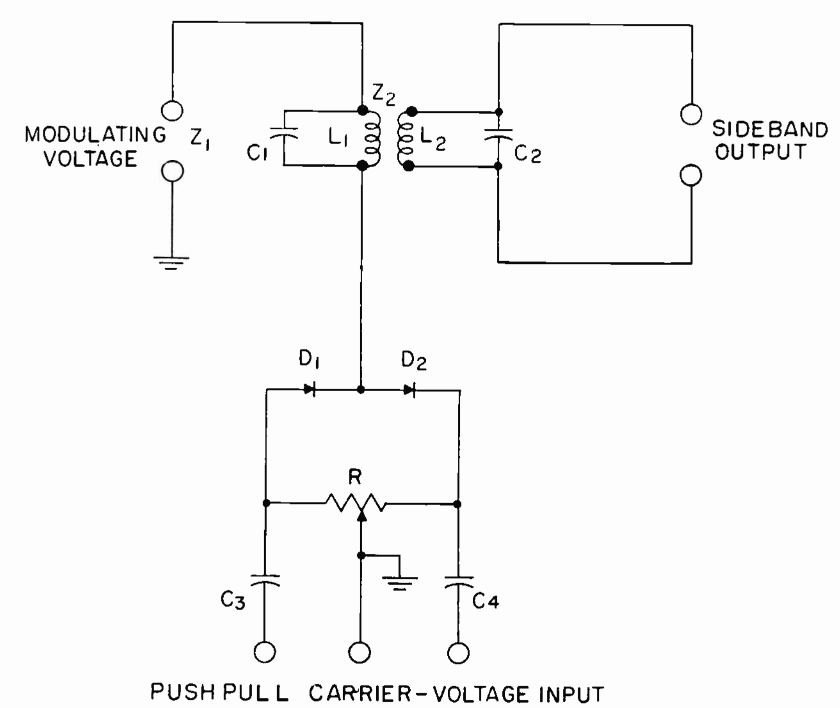
FIGURE 4

Intermodulation products generated in this circuit are said to be lower than 60 db when the carrier amplitude is 3 volts and the modulating signal amplitude 0.1 v.

Balanced Modulator as DC-AC Inverter

If a d. c. voltage is substituted for the carrier in a balanced modulator, the output will have the frequency of the carrier and will be proportional to the applied d. c. voltage. This action provides a simple means for changing small d. c. potentials to proportionate a. c. voltages for measurement or control. Thus, small d. c. voltages may be measured with a suitably calibrated a. c. millivoltmeter.

The diode-type balanced modulator is an attractive DC-AC inverter for low power levels, since it uses no tubes, requires no d. c. supply voltages, and is ready for instant operation. The semiconductor-diode type offers the additional advantage of freedom from contact potentials.



SERIES-DIODE BALANCED MODULATOR

FIGURE 5

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