An Analysis of the Split-Load Phase Inverter

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A mathematical proof of the characteristics of the cathodyne phase inverter which has often been the subject of discussion as to its balance over the frequency range from lows to highs.

Designers often avoid using the split-load phase inverter due to a rather widely held impression that its high-frequency response is very poor. Using but one triode, it has a very high input impedance and is readily balanced at low frequencies to give an over-all gain of slightly less than two.

Referring to *Fig.* 1, it may be seen that the prejudice against this inverter grows from the apparent differences in source impedance seen by the plate and cathode output loads. The cathode source impedance, being that of an amplifier with degenerative voltage feedback, is low. At the plate terminal an amplifier with degenerative current feedback is seen, and here the source impedance is high. The shunting effects of inverter tube capacitances, wiring capacitances, and input capacitances of the following stage are then supposed to reduce the high-frequency gain more rapidly at the plate than at the cathode terminal. However, since these capacitances shunt both terminals simultaneously, the actual situation is rather favorable.

Based on the preceding discussion, we may make the following analysis. Where:

R_b = plate load resistance
R_k = cathode load resistance
r_p = dynamic plate resistance
μ = amplification factor
A_{pg} = grid to plate gain
A_{kg} = grid to cathode gain
Z = source impedance

$$A_{pg} = \frac{-\mu R_b}{r_p + (\mu+1)R_k + R_b}$$

$$A_{kg} = \frac{+\mu R_k}{r_p + (\mu+1)R_k + R_b}$$

$$Z_p = r_p + (\mu+1)R_k$$

$$Z_k = (r_p + R_b)/(\mu+1)$$

$$R_b = R_k = R$$

$$A_{pg} = -A_{kg} = \frac{-\mu R}{r_p + (\mu+2)R}$$

Often the two output terminals are shunted by approximately equal impedances. This will occur if the subsequent stage involves un-neutralized triodes so that their input capacitances

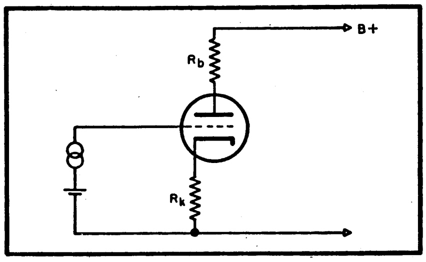

Fig. 1. Typical cathodyne split-load phase inverter circuit.

(which will be similar) make trivial the much smaller and mutually different wiring and inverter input capacitances.

C_p = plate shunting capacitance
C_k = cathode shunting capacitance
$C_p = C_k = C$
$X_c = 1/2\pi fC$

$$A_{pg} = \frac{-\mu \dfrac{R_b jX_c}{R_b + jX_c}}{r_p + (\mu+1)\dfrac{R_k jX_c}{R_k + jX_c} + \dfrac{R_b jX_c}{R_b + jX_c}}$$

$$= \frac{-\mu R}{r_p + (\mu+2)R} \times \frac{1}{1 + \dfrac{\frac{r_p}{\mu+2} R \Big/ \left(\frac{r_p}{\mu+2} + R\right)}{jX_c}}$$

$$A_{kg} = \frac{+\mu \dfrac{R_k jX_c}{R_k + jX_c}}{r_p + \dfrac{R_b jX_c}{R_b + jX_c} + (\mu+1)\dfrac{R_k jX_c}{R_k + jX_c}}$$

$$= \frac{+\mu R}{r_p + (\mu+2)R} \times \frac{1}{1 + \dfrac{\frac{r_p}{\mu+2} R \Big/ \left(\frac{r_p}{\mu+2} + R\right)}{jX_c}}$$

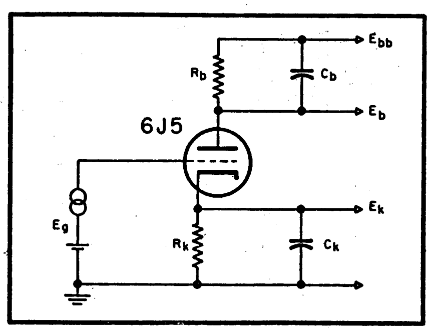

Fig. 2. Schematic of test set-up used to check calculations.

It is seen that the gain from grid to either cathode or plate output is identical, and with equivalent capacitances as would normally be encountered, the frequency response is the same at both outputs.

The high-frequency roll off will be the same for both plate and cathode outputs and the gain will be down 3 db from the mid-frequency value at:

$$f_o = \frac{1}{2\pi C \dfrac{r_p}{\mu+2} R \Big/ \left(\dfrac{r_p}{\mu+2} + R\right)}$$

To verify this derivation the experimental set-up shown in *Fig.* 2 was used.

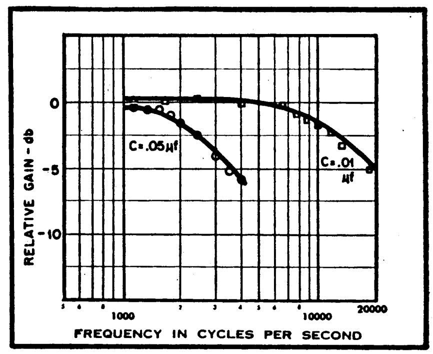

Fig. 3. Frequency response of test set-up under various conditions.

Relatively large values for C_k and C_p were inserted to minimize the unbalance created by the connection of test probes and also to bring the calculated 3 db frequency down to a convenient range.

Conditions of the experiment were as follows:

E_{bb} = 255 volts
E_b = 165 volts
E_k = 96.5 volts
E_g = 92.5 volts
$R_b = R_k$ = 68,000 ohms ± 10% (matched)
$C_b = C_k$ = either 0.05 mfd or 0.01 mfd ± 20% (matched)

Inspection of tube handbook curves

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since there are no modifications to the standard Magnecorder, it is obvious that this amplifier could be used for specific applications where its simplicity and compactness was desirable, yet the recorder can be brought back to the studio and used with the standard amplifier whenever necessary.

Parts List

C_1, C_2	10–10–20/450–450–25, electrolytic
C_3	.0025 µf, mica
C_4, C_5	.01 µf, 600 v. paper
C_6	1000 µf, 15 v. electrolytic, with insulating tube and mounting clip
C_7, C_9, C_{10}	40 µf, 450 v. electrolytic
C_8	20 µf, 450 v. electrolytic
C_{11}	.02 µf, 150 v. hearing aid type, paper
J_1	Cannon XL-3-13 receptacle
J_2	Cannon XL-3-14 receptacle
J_3	Single-circuit jack
J_4	Jones S-408-AB receptacle
J_5	Jones S-406-AB receptacle
L_1, L_2	Choke, 8 H. at 40 ma. Thordarson T-20C52
LS	4×6 in. loudspeaker, 3.2-ohm voice coil
M	VU meter, B scale, Simpson Model 45
P_1	Jones P-408-CCT cable plug
R_1, R_2	47,000 ohms, ½ watt
R_3	3300 ohms, ½ watt
R_4	1.0 meg, 1 watt
R_5	0.47 meg, 1 watt
R_6	1-meg volume control, audio taper
R_7	1800 ohms, ½ watt
R_8	0.22 meg, ½ watt
R_9	0.82 meg, 1 watt
R_{10}	0.22 meg, 1 watt
R_{11}	0.56 meg, ½ watt
R_{12}, R_{19}	300 ohms, 5 watt, Ohmite Brown Devil
R_{13}	27,000 ohms, 1 watt
R_{14}	8200 ohms, 2 watt
R_{15}, R_{16}	270 ohms, ½ watt
R_{17}	560 ohms, ½ watt
R_{18}	3900 ohms, 1 watt
RECT	Federal 1016 Selenium Rectifier
S_{1A-H}	8-pole, 2-pos. wafer switch, Centralab 1418
S_2	DPST toggle switch
T_1	30/50,000 input transformer, shielded, Triad HS-5
T_2	Output transformer, secondary impedances 500, 15, 8, 2 ohms, UTC S-14
T_3	Power transformer, 300-0-300 v. at 90 ma.; 5 v. at 3 amps; 6.3 v. at 2.5 amps.
Case for amplifier	Langevin Remote Control Cabinet, Type 1-A
Case for power supply	Bud Minibox, CU-2109

PHASE INVERTER

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indicate that:

$\mu = 18$

r_p = from 15,000 to 20,000

$f_o \approx$ 3,000 to 4,000 cps ($C = 0.05$ mfd)
$f_o \approx$ 15,000 to 20,000 cps ($C = 0.01$ mfd)

With an input to the inverter grid of about 2 volts (rms) results, Tables I and II, were obtained and plotted in *Fig.* 3.

TABLE I

Frequency (cps)	Relative Gain in db C = .01 µf	C = .05 µf
1090	0	-0.4
1350	0	-0.6
1550		-0.8
1740		-1.1
2000		-1.6
2400	0.1	-2.4
2950		-3.6
3400		-4.7
4000	-0.1	-5.9
6300	-0.5	
7600	-0.9	
8600	-1.1	
10000	-1.6	
11100	-2.1	
12300	-2.3	
14000	-2.8	
18400	-5.1	

TABLE II

Shunt Capacitance	"3-db" frequency Calculated	Observed
.05 µf	3200 - 4230	2700
.01 µf	16000 - 21100	14200
200 µµf	$3\times10^6 - 4\times10^6$	no data

It was found that the high frequency roll off was the same for both cathode and plate terminals. The calculation using 200 µµf should be representative for the loading presented by a triode in the subsequent stage.

It is believed that these results are

valid only when the peak a.c. grid signal is of the less magnitude than the quiescent grid bias since greater excitation will tend to cut off the inverter tube, making the dynamic plate resistance infinite. However, when loaded with substantially equal impedances and driven at a relatively low level, the high-frequency roll-off of this inverter is about the same as that of a cathode follower; and the roll-off is the same for both plate and cathode terminals.

INTERMODULATION TESTING

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with the generator section in *Fig*. 5. The low frequency, 60 cps, was chosen for convenience; it is believed sufficiently low to give an accurate check on amplifiers with output transformers of known high quality. This frequency is taken from one plate of the rectifier tube and dropped to a value of slightly over 3 volts, maximum, through a filter to reduce the higher harmonics in the line voltage. The 4000-cps oscillator uses a 6J5 triode and a tapped coil. A 150-mh r.f. choke will tune over a considerable range with a tap soldered at about one third out from center. The selector switch is set on 60 CY and a suitable voltage reading taken at the output terminals. Resistor R_7 is then adjusted so as to give the same voltage after switching to 4 KC. If desired, a 'scope can be used, but the foregoing is simple and accurate. Resistor R_9 across two contacts on the selector switch is for the purpose of setting the 4/1 ratio. CAUTION: The output potentiometer must be in the circuit at all times when these adjustments are made. The selector switch loads the circuit to the same extent in all positions, if connected as shown. The oscillator output can be adjusted over a wide range by means of the bias resistor. The generator as shown, will provide slightly over three volts of mixed signal. The separate 60- and 4000-cps cycle signals are convenient for general testing, and for checking the analyzer.

Analyzer Section

In the analyzer portion of the instrument a level control is used for setting the carrier to a predetermined equivalent of 100 per cent and is connected to the input jacks, as shown in *Fig*. 6. These pin type jacks are located adjacent to the generator output jacks so that the analyzer may be checked for operation by means of one short piece of bus bar bent to bridge both upper jacks. The large knob is used for selecting the appropriate functions. The voltmeter circuit used is sufficiently linear to warrant the assumption that it is so. It will read input levels of 5, 10, 25 and 50 volts, full scale, and was calibrated against an r.m.s. meter. The particular meter used, in the circuit shown, reads 0.25 volts, full scale, with the signal applied to the grid of the associated section of the 12AT7 tube. The right section of the selector switch permits measuring full