Demystifying Screen and Controlled Carrier Modulation

(with Applications)

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Another early SGM design (Figure 2) was patented by Ralph Baer in 1955. It is believed by this author that his patent was the foundation circuit by which many early Ham radio SGM systems were developed. Examine Baer's schematic closely and you will see many circuit similitudes between his circuit and circuits found in, for example, the DX-35 through the DX-60, the Cheyenne MT-1, Seneca, the Knight T-60 and T-150, the Lafayette KT-390, the Hallicrafters HT-40, the Drake TR-4, and the Johnson Challenger. (Figure 3).

The speech amplifier in figure 3 feeds the first stage of the modulator which is D.C. coupled to the grid of the "power" cathode follower. The cathode signal then modulates the screen voltage of the RF amplifier tube via a voltage divider/RC circuit.

These circuit modifications to SGM are called, "Controlled Carrier" (CC). Controlled carrier transmission can be defined as, "a method of modulation in which the **average carrier output** varies with the audio level, instead of remaining constant as in conventional plate modulated systems."

A CC transmitter can be designed to modulate at approximately >= 85% while automatically adjusting the **average carrier level** to accommodate the audio input signal. When the audio level increases the "average" carrier level increases as well. This action prevents over modulation. The CC version of SGM was designed to improve operating efficiency since the amount of peak power available is double that of a conventional AM transmitter system.

In practice, *unmodified* CC transmitters rarely achieve a modulation percentage of greater than 85%.

June 21, 1955 R. H. BAER 2,711,513

MODULATING SYSTEMS

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FIG. 1

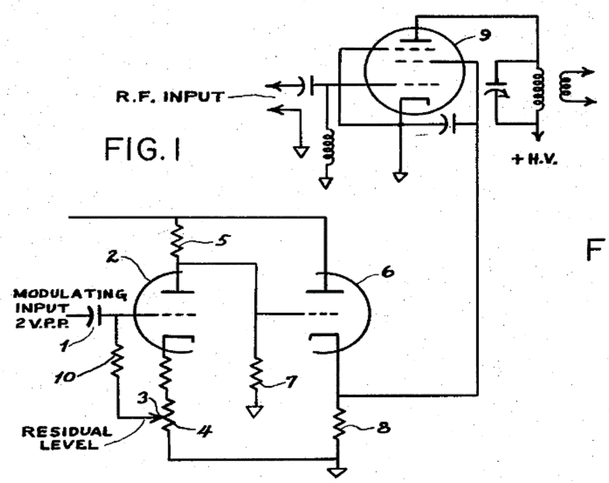

FIG. 2

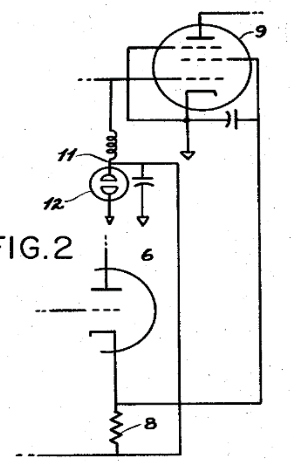

FIG. 3

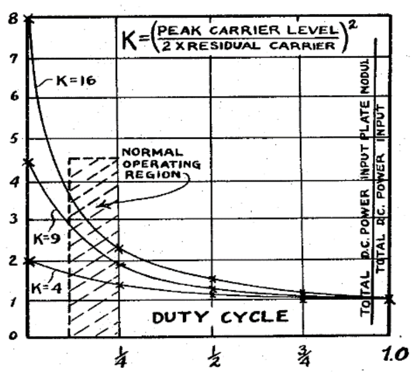

FIG. 5

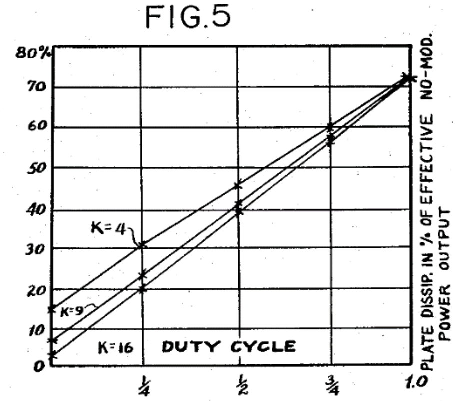

FIG. 4

K	RESIDUAL CARRIER LEVEL	RESIDUAL CARRIER POWER
4	0.250 PEAK MODUL. CARRIER LEVEL	0.250 EFFECT. NO-MODUL. POWER
9	0.165 " " "	0.110 " " "
16	0.125 " " "	0.062 " " "

INVENTOR.
RALPH H. BAER

BY Theodore Haffner
ATTORNEY

Figure 1.

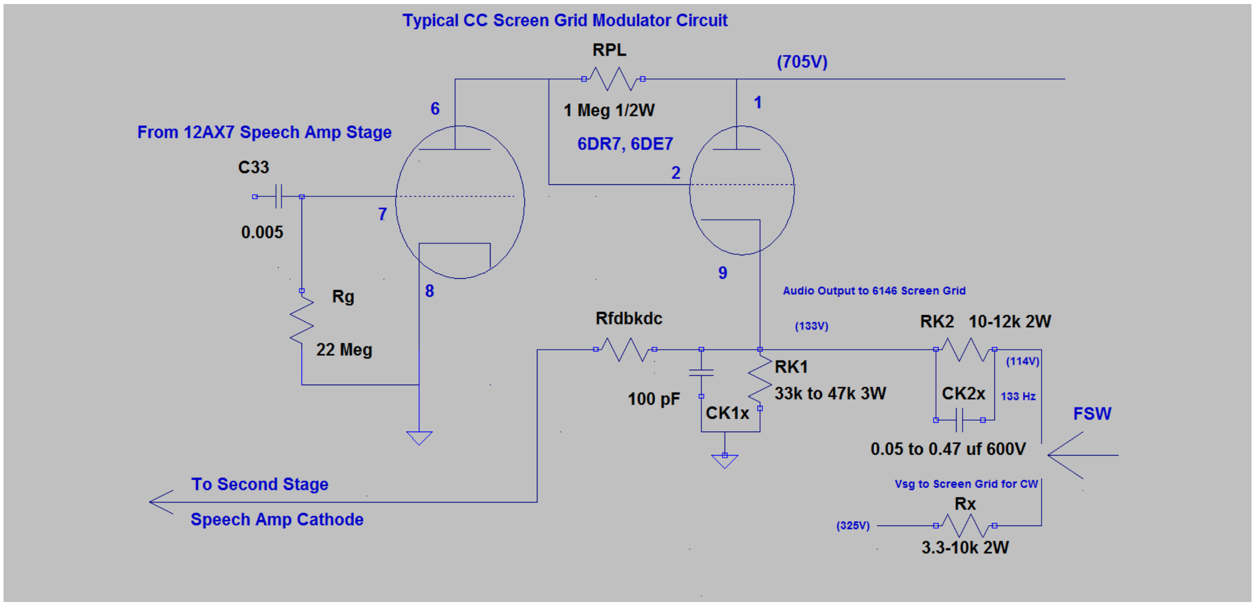

Figure 2.

Analysis of a Typical CC circuit:

Figure 3 above is a representative CC transmitter from the 1954 to the 1967 time frame. The first stage grid is biased to -1.0V by the 10-22 Meg grid leak resistor, which results in 30 volts on its plate (saturation). The *dynamic* plate signal voltage is a 30VDC signal with a superimposed audio pedestal. This voltage varies the bias of the second stage, a power cathode follower. The cathode voltage simply follows the grid voltage, but at a higher voltage, about 135V. The voltage divider drops the RF final's screen grid voltage to about 115 volts. The audio voltage at this point is typically 135V P-P. Audio feedback from the center of the RK1 and RK2 voltage divider is fed D.C. coupled back to the second stage of the speech amplifier to reduce distortion.

The DX-60 circuit is representative of many CC transmitters from the 1954 to the 1967 time frame using a dissimilar twin triode.

The first stage 6DR7/6DE7/6EW7 grid is biased to -1.0V by the 22 Meg grid leak resistor (or in some cases, a 10 Meg resistor), which, via the high value 1 Meg plate resistor, results in approx. 30 volts on its plate,. The dynamic plate voltage is a 30VDC signal with a superimposed audio pedestal. This voltage varies the bias of the second stage, a power cathode follower. That is, this operates as a saturated amplifier with an audio waveform (pedestal) riding on the 30 VDC.

The cathode voltage simply follows the grid voltage, but at a higher voltage, about 135V. The voltage divider (R26/R27) reduces the 6146 resting screen grid voltage to about 70 volts. The P-P audio voltage to the 6146 screen grid is typically 135V.

In some CC transmitters, Audio feedback (in the form of a 470k resistor) from the center of the voltage divider is fed D.C. coupled back to the second stage of the speech amplifier to reduce distortion].

When modifying these circuits for improved audio quality and higher modulation, this feedback circuit is in the form of an RC circuit in order to avoid upsetting the bias on the second stage's speech amplifier.

Let's examine the time constant circuit RK2/CK2x, with RK2 = 10k and CK2x = 0.05 uF. This circuit has a -3 dB point of 318 Hz. Without the 0.05 uF capacitor across Rk2, frequencies below 400 Hz would create little modulated carrier. I.E., this time constant circuit keeps the "average" carrier level up for audio frequencies from about 250 Hz to the frequency limit of the modulation circuit. CK2x also has a positive-bias "averaging" effect which keeps the modulating voltage from approaching zero volts.

The maximum audio frequency response of the total modulation circuit is determined, in part, by the parallel combination of CK1x, the final's screen grid RF shunt capacitor, and the tube's internal screen grid capacitance. The value of the final tube's screen grid RF shunt capacitance is the primary audio frequency limiting factor in a SGM circuit. Therefore, it is important to keep the **total screen grid circuit capacitance** at less than 1000 pF, for a shunting impedance of approximately 45 ohms at the lowest operating frequency. Therefore, the screen grid RF shunt capacitor should have a value of approximately 680 pF for a transmitter operating from 80 to 6 meters.

Any audio frequency pre-emphasis and roll-off or "de-emphasis," should be done at the speech amplifier and by the use of judicious feedback. Careful contouring of the frequency response also limits the total emitted RF bandwidth.

Another issue with these transmitter designs is the non-linearity associated with the level of modulating voltages verses the screen grid characteristic curves. While the 6146 is the most used RF final, its screen grid characteristic curve is not the most linear at the voltages found in these transmitters. Tubes such as the 6DQ5 and others have inherently more linear screen grid characteristics, but we're usually stuck with the 6146.

Modifying the value of RK2 can help, but that doesn't completely solve the problem. A 135 volt P-P audio signal assumes a quiescent voltage level of 67.5 volts, but the voltage commonly found in these transmitters is usually at least 115 volts as noted above. This voltage is too high for the median voltage level needed for the 6146's SG curve. In addition, the modulating voltage never approaches zero to achieve zero % modulation, because the modulating voltage is referenced above ground, with CK2x averaging this voltage above ground.

One of the better solutions is to 1.) remove CK2x and RK2, 2.) provide a Bipolar voltage to the modulator's cathode, 3.) directly couple the modulating voltage to the RF final's screen grid, and 4.) set the quiescent operating point of the RF final's screen grid to a median value that results in least distortion, by providing an adjustable bias to the control grid of the last modulating stage.

In the low power CC transmitters from 1955 to about 1965, little attention was paid to flattening the frequency response, limiting bandwidth, or linearity, as the emphasis was economy of operation.

Ham radio CC transmitters can be improved in terms of both audio quality and modulation percentage by consulting past issues of ER Magazine.

Another Low Power CC Circuit:

One more CC circuit:

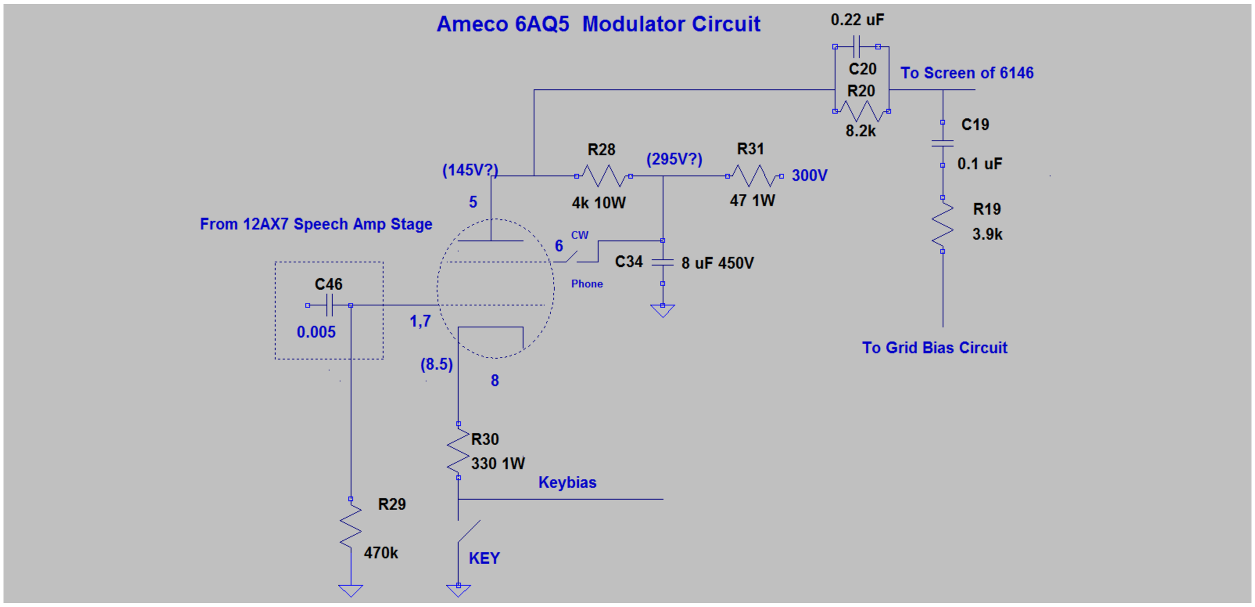

Figure 3.

CC circuit designs varied and the cathode follower circuit was not the only design to appear. Figure 4 is a simplified CC circuit that uses the "shunt modulator" method of SGM. The plate load resistor generates a varying screen grid bias with audio. This circuit design was chosen for the Ameco TX-86. A 6AQ5 is used as a current sink to vary voltage across R28. C20 and R20 act as the time constant circuit with a -3dB point of 88 Hz.

As you may have noticed, the -3 dB points for the various parallel RC circuits vary.

An unusual feature of this circuit is that some of the audio is fed back to the 6146's grid bias circuit to influence grid bias as a function of frequency.

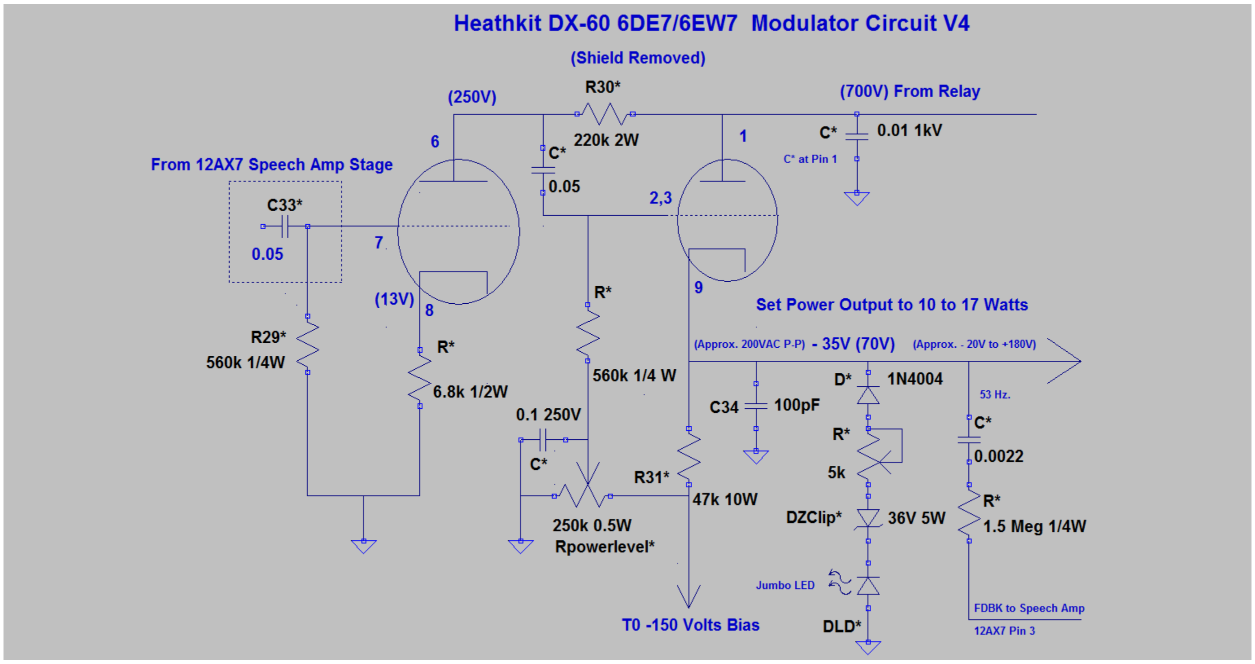
Heathkit DX-60 6DE7/6EW7 Modulator Circuit V4
(Shield Removed)
(250V)
R30*
220k 2W
(700V) From Relay
C*
0.01 1kV
C* at Pin 1
6
1
From 12AX7 Speech Amp Stage
C*
0.05
2,3
C33*
0.05
7
(13V)
8
9
R*
R29*
560k 1/4W
R*
6.8k 1/2W
560k 1/4 W
Set Power Output to 10 to 17 Watts
(Approx. 200VAC P-P) - 35V (70V)
(Approx. - 20V to +180V)
D*
1N4004
53 Hz.
C34
100pF
0.1 250V
R*
C*
5k
C*
0.0022
R31*
47k 10W
R*
250k 0.5W
Rpowerlevel*
DZClip*
36V 5W
1.5 Meg 1/4W
Jumbo LED
T0 -150 Volts Bias
DLD*
FDBK to Speech Amp
12AX7 Pin 3

Figure 4.

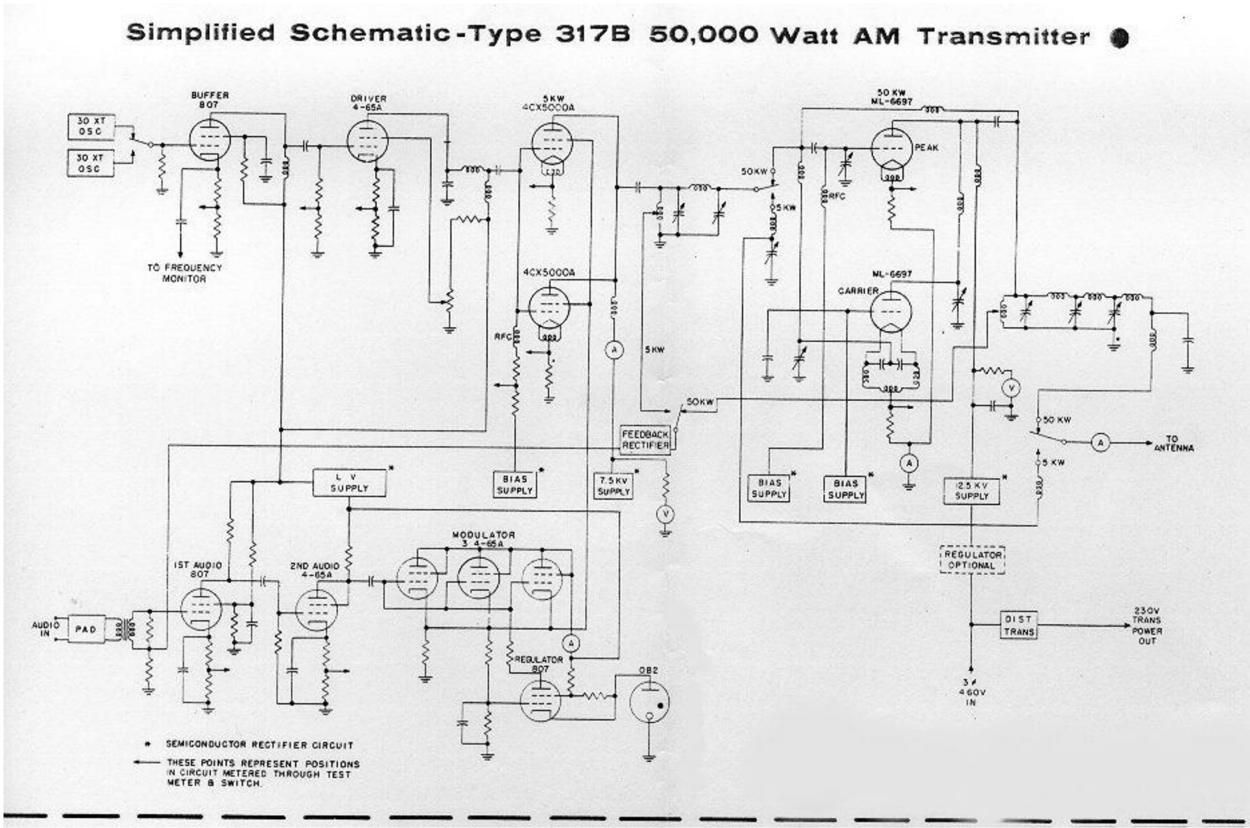

Figure 5.

Continental manufactured a number of standalone SGM transmitter's in the late 1950's with transmitter powers up to 10 kW. Figure 6 is a functional diagram of the Continental 317B broadcast transmitter which uses a 5kW screen modulated section to drive a Doherty linear amplifier.

The 5 kW screen grid driver section is one of simplicity. An 807 first audio amplifier feeds audio to a second audio amplifier, a 4-65A. The output of this second audio amplifier drives a modulator consisting of three 4-65's in parallel. The 4-65 cathodes then modulate the screen grids of two 4CX5000A RF amplifiers in parallel, producing 5 kW to feed the Doherty linear amplifier, which then increases power to 55 kW.

The modulator varies the voltage on the screens of the 4CX5000A's between 325 volts and 575 volts with a current of approximately 50 mA! Due to the power amplification efficiency of the 4CX5000A's, the average amount of modulating power needed was only 100 Watts.