A METHOD for PRESUNRISE POWER REDUCTION

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New FCC Rules regarding AM operation prior to sunrise have brought about some new technical requirements for many stations. This article presents one method for achieving the large power reductions imposed in some cases. A derivation of the design formulas follows the main text.

Many AM broadcasters are faced with the problem of reducing their transmitter output power by a substantial amount in order to comply with the requirements of Section 73.99 of the Commission Rules. When, for example, the power of a 1-kw station must be reduced to approximately 100 watts, it usually is not practical to use the existing transmitter. The broadcaster would ordinarily have to purchase an additional transmitter (type approved) capable of operating at the lower power. From an economic standpoint, this is not practical since, at most, a broadcaster could only gain approximately two hours per day of operating time in the winter months. Therefore, the need for a simpler method is indicated. The following is one way of achieving power reduction for presunrise operation at a minimum cost.

Technical Approach

It is proposed to use the regular transmitter operating at its normal output power into a simple power-divider network, as shown in Fig. 1. This circuit principle was developed in the early 1940's by Earl Travis. In December 1943, Dr. George H. Brown of RCA introduced the technique[1] for power dividing in a two-tower directional system.

Principle of Circuit

Fig. 1 can be redrawn as shown in Fig. 2. For the sake of discussion, capacitive reactance is shown in the dummy-load branch. The circuit is basically a simple power divider. There are two equal (50- or 70-ohm) loads; R_L is a dummy load, and R_0 is the transmission-line resistance or common-point resistance. Reactances X_C and X_L are of opposite sign, and their values are uniquely determined by the power-division ratio and input impedance desired. In this case, the input impedance is selected to match the output of the transmitter (50 or 70 ohms). The power division is determined by FCC limits on power delivered to the antenna. The power division can be expressed in terms of a factor, M', as follows:

$$M' = \sqrt{\frac{P(hi)}{P(low)}}$$

where,

P (hi) = power dissipated in dummy load, and
P (low) = power fed to transmission line or common point.

The value of reactance for the high-power leg (dummy load) is:

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[1] Brown, George H. and John M. Baldwin, "Adjusting Unequal Tower Broadcast Arrays," *Electronics*, December 1943.

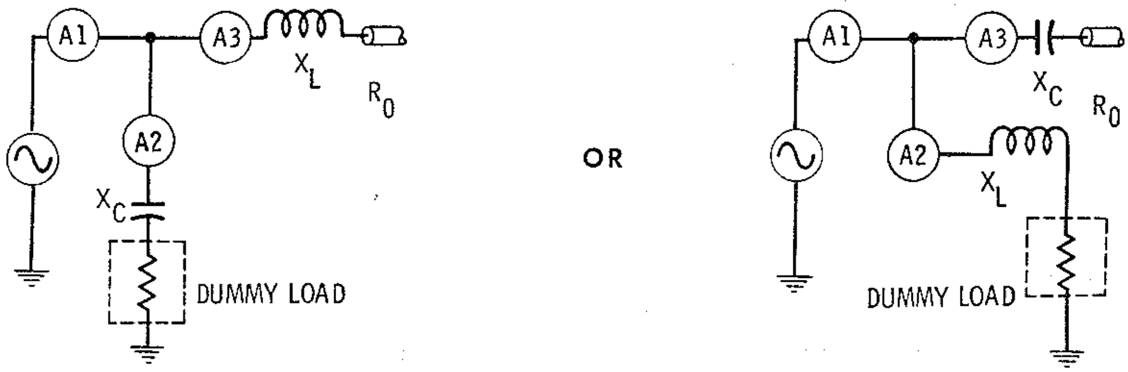


Fig. 1. "Power-dump" network may have either L or C in high-power branch.

$$X = \pm \frac{R_D}{M'}$$

where,

- X = value of positive or negative reactance in ohms.
- R_D = dummy-load resistance in ohms, and
- M = power-division factor defined above.

The value of the reactance for the low-power side (antenna or common point) is:

$$X = \pm M'R_o$$

where,

- X = value of positive or negative reactance in ohms,
- M' = power-division factor, and
- R_o = transmission-line or common-point resistance in ohms (must be equal to dummy-load resistance).

It will be demonstrated later that the input impedance will always be equal to the dummy-load and transmission-line impedance, provided certain design requirements are met. This is the same as saying that, under the required conditions, the feedpoint resistance will always remain equal to the load resistance, regardless of the power division between the two branches.

Practical Application

Assume a station is required to reduce its presunrise power to 100 watts from 1kw. The known parameters are:

(1) Frequency (assumed) = 1300 kHz
(2) Transmitter output = 1000 watts
(3) Allowable power to nondirectional tower or common point = 100 watts
(4) Transmitter output impedance ($Z = R$ at resonance) = 50 ohms

The following quantities may now be computed:

(5) Transmitter output current for 1 kw

$$I = \sqrt{\frac{P}{R}} = \sqrt{\frac{1000}{50}} = 4.48 \text{ amperes}$$

(6) Allowable line current to antenna or common point for 100 watts

$$I = \sqrt{\frac{100}{50}} = 1.41 \text{ amperes}$$

(7) Current in dummy load for 900 watts which must be dissipated

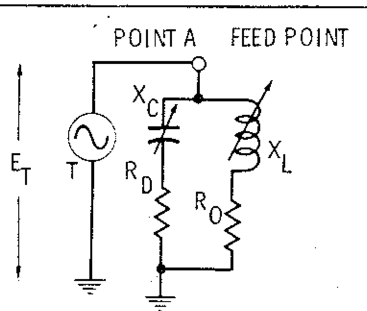
$$I = \sqrt{\frac{900}{50}} = 4.25 \text{ amperes}$$

(8) Power division factor

$$M' = \sqrt{\frac{P(hi)}{P(low)}} = \sqrt{\frac{900}{100}} = 3$$

(9) An inductor is selected arbitrarily for the high-power branch. The reactance is:

$$X_L = +\frac{R_D}{M'} = \frac{50}{3} = 16.7 \text{ ohms.}$$



- T = Transmitter (50- or 70-ohm unbalanced output)
- X_C = Variable capacitor in series with dummy-load resistor (50 or 70 ohms)
- R_D = Dummy-load resistor (50 or 70 ohms) having proper power rating (Note: Station loads should be able to handle 1300 watts for a 1-kw station.)
- X_L = Variable inductor in series with transmission line to nondirectional tower, or common point of directional antenna system
- R_o = Resistance of transmission line (50 or 70 ohms)
- E_T = Voltage across transmitter output

Fig. 2. Power-division circuit may be redrawn for more convenient analysis; explanation of terms used is included.

(10) Inasmuch as an inductor was selected for the high-power branch, a capacitor must be used in the low-power side. Its reactance is:

$$X_c = -M'R_o = -3 \times 50 = -150 \text{ ohms.}$$

(11) The magnitude of X_L and X_c have now been determined. The inductance and capacitance now can be found readily. The inductance is:

$$L = \frac{159 X_L}{f}$$

where,

L = inductance in microhenries,

$159 = \frac{1}{2\pi} \times$ conversion factor for units,

X_L = inductive reactance in ohms, and

f = frequency in kHz.

Then:

$$L = \frac{159 \times 16.7}{1300} = 2.04\ \mu h.$$

(12) The capacitance is determined by:

$$C = \frac{1.59 \times 10^8}{f X_c}$$

where,

C = capacitance in pf,

$1.59 \times 10^8 = \frac{1}{2\pi} \times$ conversion factor for units,

X_c = capacitive reactance in ohms, and

f = frequency in kHz.

Then:

$$C = \frac{1.59 \times 10^8}{1300 \times 150} = 816 \text{ pf.}$$

A variable capacitor is required, or a coil and capacitor in series may be used.

The circuit can now be redrawn as shown in Fig. 3.

Circuit Variations

It is obvious that different combinations of X_L and X_c can be selected to accomplish other desired power reductions, and the exact values of components will be governed by the amount of reduction required and the power levels involved. In many cases, it will be more practical to use variable capacitors and inductors to obtain the exact power ratio; in others, a fixed capacitor can be made equivalent to a variable unit by using a variable or tapped coil in series with the capacitor.

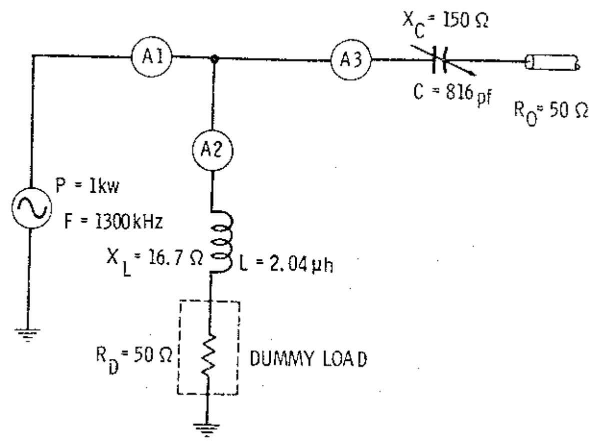


Fig. 3. Calculated values for power-divider components.

Switching, particularly where directional arrays are involved, can become tricky; however, the primary advantages of using such a "power-dump" circuit to dissipate power are:

(1) The transmitter operates at its normal output power regardless of how much the antenna power must be reduced.
(2) Most stations already have a 50- or 70-ohm dummy load that can be used for the system.
(3) No adjustments of the transmitter controls are needed.
(4) The cost for a well-engineered system is materially less than the purchase price of a new lower-power transmitter.

Fig. 4 illustrates a typical power reduction setup, assuming a nondirectional operation.

In practice, the station dummy-load and transmission-line or common-point resistance may not be exactly the same (several ohms difference). Hence, the adjustment of the circuit will have to be altered by changing the ratio of reactances, and a slightly different common-point resistance will result. Because the entire network will have to be measured to determine true powers, the proper common point can be determined by bridge measurements for the Commission.

The FCC

The circuitry described has been used in licensed stations to reduce the E_{rms} of a directional array when tall towers are used for vertical suppression, but the high E_{rms} of a tall-tower array cannot be tolerated. It should be acceptable to the Commission for reduction of power for presunrise operation. The Commission may accept logging of the dummy-load meter in lieu of a new antenna-base meter. It might also require an additional line meter on the output side of L to demonstrate

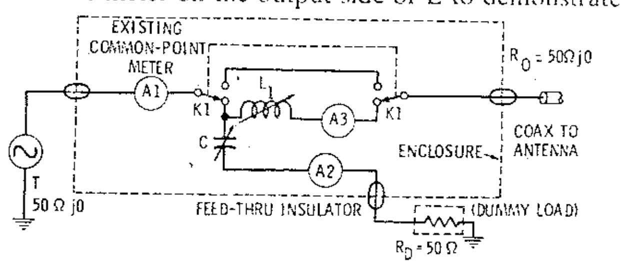


Fig. 4. Switching system for presunrise power reduction.

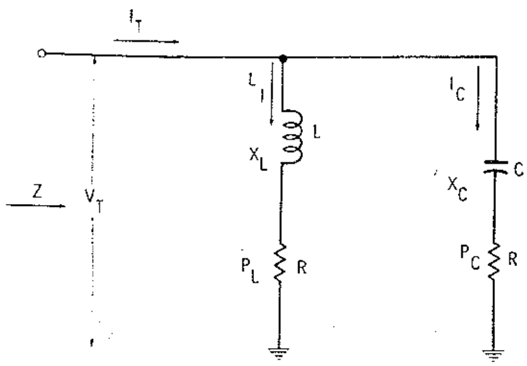


Fig. 5. Diagram shows nomenclature used in derivation.

the lower line current. However, the station attorneys and consulting engineers will have to explore this matter and obtain appropriate waivers if possible.

Conclusion

A simple power-divider technique has been explained which allows a broadcaster to meet presunrise power-reduction requirements without the purchase of a new transmitter. The principle is electronically straightforward, and it should provide a practical, economical method of power control for broadcasters who need to reduce their power by a ratio greater than about 2:1.

The author wishes to thank George P. Howard and J. K. Raines of the Multronics engineering staff for their suggestions and derivations.

Derivation

The following derivation shows the validity of the power-division method that is the subject of this article.

The nomenclature used in the derivation is shown in Fig. 5.

First it must be established that the input impedance, Z, of the network is equal to R. The expression for Z can be developed as follows.

The impedance of the left branch is

$$Z_1 = R + j\omega L,$$

and the impedance of the right branch is

$$Z_2 = R - j\frac{1}{\omega C}.$$

The corresponding admittances are

$$Y_1 = \frac{1}{R + j\omega L}$$

and

$$Y_2 = \frac{1}{R - j\frac{1}{\omega C}}.$$

and the admittance of the network is therefore

$$Y = \frac{1}{R + j\omega L} + \frac{1}{R - j\frac{1}{\omega C}}$$

$$= \frac{R - j\frac{1}{\omega C} + R + j\omega L}{(R + j\omega L)(R - j\frac{1}{\omega C})}$$

$$= \frac{2R + j(\omega L - \frac{1}{\omega C})}{(R^2 + \frac{L}{C}) + j(\omega L - \frac{1}{\omega C})}.$$

The impedance of the network is

$$Z = \frac{1}{Y} = \frac{(R^2 + \frac{L}{C}) + j(\omega L - \frac{1}{\omega C})}{2R + j(\omega L - \frac{1}{\omega C})}.$$

Rationalizing and collecting terms results in

$$Z = \frac{(R^2 + \frac{L}{C}) + j(\omega L - \frac{1}{\omega C})}{2R + j(\omega L - \frac{1}{\omega C})} \cdot \frac{2R - j(\omega L - \frac{1}{\omega C})}{2R - j(\omega L - \frac{1}{\omega C})}$$

$$= \frac{2R(R^2 + \frac{L}{C}) + R(\omega L - \frac{1}{\omega C})^2 + j(R^2 - \frac{L}{C})(\omega L - \frac{1}{\omega C})}{4R^2 + (\omega L - \frac{1}{\omega C})^2}$$

For the purpose of this article, it is required that Z be purely resistive and equal in magnitude to R. The reactive component of Z must therefore be equal to zero. This component is

$$j\frac{(R^2 - \frac{L}{C})(\omega L - \frac{1}{\omega C})}{4R^2 + (\omega L - \frac{1}{\omega C})^2}.$$

Setting this quantity equal to zero yields

$$(R^2 - \frac{L}{C})(\omega L - \frac{1}{\omega C}) = 0.$$

Either of the solutions

$$\omega L = \frac{1}{\omega C}$$

and

$$R^2 = \frac{L}{C}$$

satisfies this equation.

It is also necessary that the resistive part of Z be equal to R:

$$\frac{2R\,(R^2 + \frac{L}{C}) + R\,(\omega L - \frac{1}{\omega C})^2}{4R^2 + (\omega L - \frac{1}{\omega C})^2} \overset{?}{=} R$$

$$2R\,(R^2 + \frac{L}{C}) \overset{?}{=} 4R^3$$

$$2R^3 + 2R\frac{L}{C} \overset{?}{=} 4R^3.$$

It has already been determined that if $\frac{L}{C} = R^2$, Z is purely resistive. Under this condition

$$2R^3 + 2R\,(R^2) = 4R^3,$$

$$4R^3 = 4R^3,$$

and the network impedance is therefore equal to R (when R has the same magnitude in both branches), as desired.

The relationship of X_C, X_L, and R can now be established. It is known that

$$R^2 = \frac{L}{C},$$

$$L = \frac{X_L}{\omega},$$

and

$$C = -\frac{1}{\omega X_C}.$$

From these relationships, it follows that

$$R^2 = \frac{X_L}{\omega}\left(-\frac{\omega X_C}{1}\right)$$

$$= -X_L X_C.$$

It is still necessary to determine the relative magnitudes of X_L and X_C required for a given power division. The ratio of power in the two branches may be written

$$\frac{P_C}{P_L} = \frac{I_C{}^2 R}{I_L{}^2 R} = \frac{I_C{}^2}{I_L{}^2}.$$

It can be seen that

$$I_C = \frac{V_T}{\sqrt{R^2 + X_C{}^2}}$$

and

$$I_L = \frac{V_T}{\sqrt{R^2 + X_L{}^2}}.$$

For convenience, let M be defined as

$$M = \frac{P_C}{P_L}.$$

Then

$$M = \frac{\dfrac{V_T{}^2}{(\sqrt{R^2 + X_C{}^2})^2}}{\dfrac{V_T{}^2}{(\sqrt{R^2 + X_L{}^2})^2}} = \frac{R^2 + X_L{}^2}{R^2 + X_C{}^2}.$$

Since it has already been established that $R^2 = -X_C X_L$, it can be seen that

$$X_L = -\frac{R^2}{X_C}.$$

Substituting this expression in the previous equation gives

$$M = \frac{R^2 + (-\frac{R^2}{X_C})^2}{R^2 + X_C{}^2}.$$

Clearing of fractions and rearranging terms gives

$$MX_C{}^4 + (M - 1)\,R^2 X_C{}^2 - R^4 = 0.$$

Factoring gives

$$(MX_C{}^2 - R^2)\,(X_C{}^2 + R^2) = 0.$$

The solutions relating M, R, and X_C are obtained as follows:

$$MX_C{}^2 - R^2 = 0$$

$$X_C{}^2 = \frac{R^2}{M}$$

$$X_C = \pm\sqrt{\frac{R^2}{M}} = \pm\frac{1}{\sqrt{M}}R$$

(Only the negative solution has physical significance.) It is known that

$$X_L = -\frac{R^2}{X_C}.$$

Substituting the expression for X_C gives

$$X_L = -\frac{R^2}{-\frac{1}{\sqrt{M}}R} = \sqrt{M}\,R.$$

The values of X_L and X_C have now been defined in terms of R and the power-division ratio. With the reactances known, the values of L and C can be determined easily:

$$X_L = \sqrt{M}\,R,$$

$$\omega L = \sqrt{M}\,R,$$

and

$$L = \sqrt{M}\frac{R}{2\pi f}.$$

Also,

$$X_C = -\frac{R}{\sqrt{M}}$$

$$-\frac{1}{\omega C} = -\frac{R}{\sqrt{M}},$$

and

$$C = \frac{\sqrt{M}}{2\pi f R}.$$

When f is in kHz and R is in ohms, the inductance in microhenries is

$$L = 159\frac{\sqrt{M}\,R}{f},$$

and the capacitance in picofarads is

$$C = 1.59 \times 10^{8}\frac{\sqrt{M}}{fR}.$$

Expressions for the network current magnitudes may now be derived. By inspection, the total (input) current can be seen to be

$$I_T = \sqrt{\frac{P_T}{R}}.$$

Similarly,

$$I_L = \sqrt{\frac{P_L}{R}},$$

and

$$I_C = \sqrt{\frac{P_C}{R}}.$$

It is possible to express P_C and P_L in terms of P_T and M, as follows:

$$P_T = P_L + P_C,$$

and

$$\frac{P_C}{P_L} = M.$$

Rearranging gives

$$P_L = P_T - P_C$$

and

$$P_C = P_L M.$$

Substituting the latter into the former results in

$$P_L = P_T - P_L M.$$

Solving for P_L gives

$$P_L = \frac{P_T}{1 + M},$$

and substituting this result into the expression for I_L results in

$$I_L = \sqrt{\frac{P_T}{(1 + M)R}} = \frac{1}{\sqrt{1 + M}}\sqrt{\frac{P_T}{R}}.$$

Similar manipulations can be used to arrive at an expression for I_C:

$$P_C = P_T - P_L,\ P_L = \frac{P_C}{M}$$

$$P_C = P_T - \frac{P_C}{M}$$

$$P_C = \frac{M}{1 + M}\,P_T$$

$$I_C = \sqrt{\frac{\frac{M}{1 + M}\,P_T}{R}}$$

$$= \sqrt{\frac{M}{1 + M}}\sqrt{\frac{P_T}{R}}.$$

For convenience, the formulas derived above are tabulated here.

$$M = \frac{P_C}{P_L}$$

$$X_C = -\frac{R}{\sqrt{M}}$$

$$X_L = \sqrt{M}\,R$$

$$C = \frac{\sqrt{M}}{2\pi f R} = 1.59 \times 10^{8}\,\frac{\sqrt{M}}{fR}$$

$$L = \sqrt{M}\frac{R}{2\pi f} = 159\,\frac{\sqrt{M}\,R}{f},$$

where,

C is in picofarads,
L is in microhenries,
f is in kilohertz, and
R is in ohms.

$$I_T = \sqrt{\frac{P_T}{R}}$$

$$I_L = \frac{1}{\sqrt{1+M}}\sqrt{\frac{P_T}{R}}$$

$$I_C = \sqrt{\frac{M}{1+M}}\sqrt{\frac{P_T}{R}}$$

Note that in the foregoing derivation, there was no requirement that M be greater than 1. This means that either circuit branch may receive the greater power: if P_C is the larger power, M is a whole number, and if P_L is the larger power, M is a fraction. In either case, the proper results can be obtained.

In the main part of the text, factor M' was defined as $\sqrt{\frac{P(hi)}{P(low)}}$. If $P_C > P_L$, $M' = \sqrt{\frac{P_C}{P_L}} = \sqrt{M}$.

The formula given in the text for X in the high-power branch is $X = -\frac{R_D}{M'}$ (negative in this case because the branch is capacitive). The reactance in the low-power branch is given as $X = M'R_0$. Since $M' = \sqrt{M}$, and $R_0 = R_D = R$, the text equations reduce to $X = -\frac{R}{\sqrt{M}}$ for the capacitive (high-power) branch and $X = \sqrt{M}\,R$ for the inductive (low-power) branch.

By the same reasoning, if it is desired to make the high-power branch inductive, $M' = \sqrt{\frac{P_L}{P_C}} = \frac{1}{\sqrt{M}}$. The text equations become $X = +\frac{R}{1/\sqrt{M}} = \sqrt{M}\,R$ for the inductive (high-power) branch, and

$$X = -\frac{1}{\sqrt{M}}R = -\frac{R}{\sqrt{M}}$$

for the capacitive (low-power) branch. Thus the two sets of reactance formulas are equivalent as far as the results obtained are concerned.

Sample Calculations

The following two examples illustrate the use of the above formulas for determining power division and component values. In the first example, the capacitive branch carries the high power. In the second, the inductive branch carries the high power.

Example 1

(a) Frequency—1300 kHz
(b) Transmitter power—1000 watts, 50 ohms match
(c) Power reduction—10:1
(d) Use a capacitor in series with dummy load for dissipating 900 watts of power.

Then:

$$M = \frac{900}{1000 - 900} = \frac{900}{100} = 9$$

$$I_T = \sqrt{\frac{1000}{50}} = 4.47 \text{ amperes}$$

$$I_L = \frac{1}{\sqrt{1+9}}\sqrt{\frac{1000}{50}} = 1.41 \text{ amperes}$$

$$I_C = \sqrt{\frac{9}{1+9}}\sqrt{\frac{1000}{50}} = 4.24 \text{ amperes}$$

$$X_L = 50\sqrt{9} = 150 \text{ ohms}$$

$$X_C = -\frac{50}{\sqrt{9}} = -16.7 \text{ ohms}$$

$$L = \frac{159 \times 50 \times \sqrt{9}}{1300} = 18.4\ \mu h$$

$$C = \frac{1.59 \times 10^{8} \times \sqrt{9}}{50 \times 1300} = 7350 \text{ pf}$$

Example 2

(a) Frequency —1300 kHz
(b) Transmitter power—1000 watts, 50 ohms match
(c) Power reduction—10:1
(d) Use an inductor in series with dummy load to dissipate 900 watts.

Then:

$$M = \frac{1000 - 900}{900} = \frac{100}{900} = \frac{1}{9}$$

$$I_T = \sqrt{\frac{1000}{50}} = 4.47 \text{ amperes}$$

$$I_L = \frac{1}{\sqrt{1 + 1/9}}\sqrt{\frac{1000}{50}} = 4.24 \text{ amperes}$$

$$I_C = \sqrt{\frac{1/9}{1 + 1/9}}\sqrt{\frac{1000}{50}} = 1.41 \text{ amperes}$$

$$X_L = 50\sqrt{\frac{1}{9}} = 16.7 \text{ ohms}$$

$$X_C = -\frac{50}{\sqrt{1/9}} = -150 \text{ ohms}$$

$$L = \frac{159 \times 50 \times \sqrt{1/9}}{1300} = 2.04\ \mu h$$

$$C = \frac{1.59 \times 10^{8} \times \sqrt{1/9}}{50 \times 1300} = 816 \text{ pf}$$

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