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A REVIEW OF HARMONIC SUPPRESSION PRACTICES FOR STANDARD BROADCAST STATIONS

In recent years, various articles have appeared in the literature covering the problem of controlling the R.F. harmonic radiation from standard broadcast stations so that requirements of the FCC Rules are complied with and so that no harmful interference is created to other radio services. An attempt will be made here to review most general practices in this field with due consideration to the present FCC Rules on R.F. harmonics.

The FCC Rules covering R.F. harmonics affecting all broadcast services will be briefly reviewed. Rules 3.40 and 3.317 require for AM and FM stations, having transmitter type approved since January 1, 1960, that the R.F. harmonics be attenuated at least 80 DB below the unmodulated carrier for powers in access of 5 K.W. For lower powers the Rules contain a formula which requires minimum attenuation values of 73 DB for 1 K.W. and 67 DB for .25 K.W.

The above Rules do not apply to transmitters type approved before January 1, 1960 ((3.317(e)(2), 3.46(C)) and as no values are given for these transmitters, it is generally considered that the attenuation is satisfactory if the harmonics are down 60 DB, providing that no harmful interference is being created to any radio service. It can be seen that January 1, 1960 is a significant date in considering compliance with the FCC Rules relating to harmonics. The equipment manufacturer can generally advise the broadcaster of the type approval date on his transmitter, or this information can be obtained from the FCC where it is available for inspection. Many broadcast transmitters being sold today were type approved before January 1, 1960.

For TV stations the FCC Rules (3.687(i)) require that the harmonics must be attenuated at least 60 DB below the visual transmitter power, but is is pointed out in the Rules that this is a temporary value. It also states that due to the utilization of high power by most TV stations, consideration should be given to providing higher than 60 DB of harmonic attenuation.

It is anticipated that broadcasters will experience little harmonic trouble with standard broadcast transmitters type approved by the FCC after January 1, 1960 due to the higher standards required for this equipment. The harmonic suppression ideas set forth in this article should be helpful in regard to older transmitters, but the circuits can be applied to any equipment to achieve further harmonic suppression.

The design of a modern transmitter incorporates features that result in low harmonic radiation. It is generally difficult, if not impossible due to type approval requirements of the FCC, to modify an existing transmitter to take advantage of all of these features.

Special attention is paid to the low power R.F. stages in a modern transmitter and design procedures are incorporated that will not generate serious harmonic products. This is achieved thru proper selection of the operating constants of the vacuum tubes (or transistors) and is outside the scope of this article. If harmonics can be prevented thru circuitry in the low power stages, then they do not have to be suppressed later at high power levels by means of special filters.

The modern transmitter has double shielded construction with all access openings having radiation leak-proof seals. With all power and control leads entering the transmitter protected by means of R.F. filters, and with the shielding provisions mentioned above, the harmonic radiation from the transmitter cabinet is reduced to a minimum.

It is standard practice in modern transmitters to incorporate specially designed harmonic filters in the output circuit of the equipment. These circuits can be added to most existing transmitters and the technique utilized will be generally reviewed.

If an AM transmitter is radiating a number of objectionalbe harmonics, such as the 2nd, 3rd and 4th, it may be necessary to install a filter that will reduce the amplitude of the entire harmonic band. Some older type transmitters working into shunt fed towers may require this treatment. A good filter for this purpose is the T network shown in Figure A. This network is easily designed for 90° phase shift, because under these conditions all three arms have the same reactance as the transmitter output load. For a 50 ohm transmission line all three arms are also 50 ohms, at the operating frequency of the station. This filter is generally installed in the output of the transmitter and shielded by locating it either in the transmitter enclosure or in a well shielded metal box. Although higher order phase shift networks with larger series arm inductors will in most cases provide superior harmonic attenuation, the equipment is more expensive due to the larger inductors and the higher capacitor current. In the 90° network, if it is not utilized for impedance matching, the current flowing in the capacitor is about 1.4 times the current flowing in each series arm.

Figure G shows the reactance and current relations to phase shift in a T network for the special case of 50 ohms input and output. The current ratio can be utilized to determine, the capacitor current if the phase shift and current in either series arm are known. If these currents are known, then the current ratio will provide information on the phase shift. If properly adjusted, and terminated, the input current to the T network will equal the output current.

The most bothersome harmonic from a transmitter is almost always the 2nd and this can be reduced to a satisfactory degree by installing a series circuit (Figure B), tuned to the 2nd harmonic, across the output of the transmitter (center of co-ax to ground). At the operating frequency of the station this circuit will look like a capacitor and this may create serious de-tuning of the output stage if the reactive values of this circuit are too low.. As this circuit obtains its harmonic attenuation characteristic thru shorting - out the harmonic, the quality of the filter decreases as the reactance values are increased. An approximate rule to follow is to utilize reactance values that are twice the load across which it is placed. If placed across a 50 ohm load, the capacitor and inductor should each have a reactive value of 100 ohms at the 2nd harmonic frequency. There is normally room in the transmitter enclosure to place this equipment.

The impedance, at the harmonic frequency, of the series filter circuit must be very low in comparison with the impedance across which it is placed in order to obtain good harmonic attenuation. Both impedances are referred to the 2nd harmonic frequency at which frequency large standing waves with associated large variations in impedance are bound to exist on the transmission line connected to the transmitter. The impedance at the point of filter connection, and at the harmonic frequency is generally unknown, unless measured with an R.F. bridge, and under some conditions can be of a very low magnitude. If such a condition is encountered, it will be found that the series type filter is inefficient, and the only solution may be a new location or a different type filter. Where a transmission line is utilized between the transmitter and the antenna coupling unit, it is normally possible to overcome the above mentioned trouble by changing the location of the filter to the other end of the line.

If the transmitter de-tuning by the series circuit in Figure B is too severe the circuit in Figure C can be utilized without any noticeable de-tuning. The added inductor is adjusted so that the entire circuit is parallel resonanat at the operating frequency, thereby presenting a very high impedance at this frequency. The series circuit must be precisely adjusted. for maximum 2nd harmonic attenuation before the parallel inductor is adjusted.

The circuit just described can be simplified as shown in Figure D, resulting in only one inductor and one capacitor being required. The adjustment must be performed in reverse, by first adjusting the bottom part of the inductor and the capacitor to parallel resonance at the station's operating frequency, and then adjusting the top part of the inductor for maximum attenuation at the 2nd harmonic. As these filters contain aprallel resonant circuits, the components must be sufficiently large to handle the circulating currents. If they are installed across a low impedance circuit, such as a properly terminated co-axial cable, the circulating currents are not severe.

A series circuit is occasionally installed in series with a broadcast transmitter output bus or transmission line center conductor to further attenuate harmonics, as shown in Figure E. As this filter does not provide very much harmonic attenuation by itself, it is not utilized to any extent.

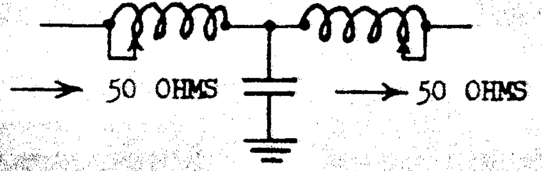
The antenna coupling unit found at most broadcast stations takes on the configuration of a T network as shown in Figure A, which offers further attenuation to the R.F. harmonics. Some coupling units, at stations operating with non-directional antennas, contain large inductors which were initially adjusted to utilize only a few of the available turns in the series arms. Usually large additional harmonic attenuation can be realized in these coupling units by re-tuning them for a higher phase shift, by utilizing more turns in the inductors. If the unit was originally tuned in for a low phase shift, say 45°, it can be properly re-tuned to 135° by utilizing more turns in the inductors and by utilizing the same capacitor.

If the station's antenna coupling unit takes on the configuration of Figure F, it is possible, if not tuned-in initially for this condition, to re-tune this circuit for additional harmonic attenuation. Generally the inductor located in series with the capacitor, in the shunt arm is utilized to adjust the value of the capacitor. In most cases, this series circuit can be resonated at the 2nd harmonic by adjusting the inductor. The two other inductors, in the series arms, are then adjusted with an R.F. Bridge so that the input to the T network matches the transmission line from the transmitter (normally 50 ohms).

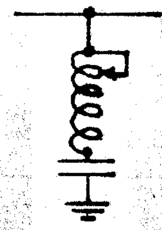
Any change that is made in an existing antenna coupling unit must take into consideration a possible higher circulating current in the capacitor. The capacitor current is almost proportional to the phase shift in a T network, and if any doubt exists regarding this current, it can be determined by means of a series R.F. ammeter. The current, as indicated by the meter, should not exceed the rating marked on the capacitor, when the transmitter is undergoing 100% tone modulation.

The circuit of Figure F can be modified to resemble that of Figure H, which provides additional circuits for harmonic attenuation. ~~The series circuit~~ in the shunt arm can be tuned to the 2nd harmonic and the parallel circuit in each of the series arms can be tuned to any combination of harmonic frequencies. In tuning each parallel circuit, the variable tap on the inductor associated with the capacitor is first adjusted for parallel resonance at the desired harmonic frequency. This operation must be performed on both parallel circuits before the complete network is adjusted for a proper input impedance at the operating frequency, by adjusting the remaining turns on the inductor associated with each series arm. As each series arm parallel circuit is resonant at the harmonic frequency, it appears like an inductive reactance at the operating frequency and the current thru the capacitor is low compaired with the current thru the inductance. Normally this type of T network must be adjusted for a high value of phase shift, due to the high residual inductive reactance in the parallel circuits in the series arms. Other more complicated circuits are available that overcome this shortcoming, but they will not be covered in this article.

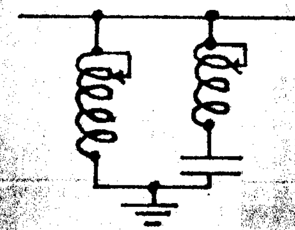
A



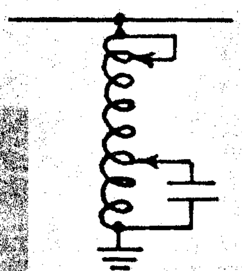
B



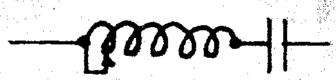
C



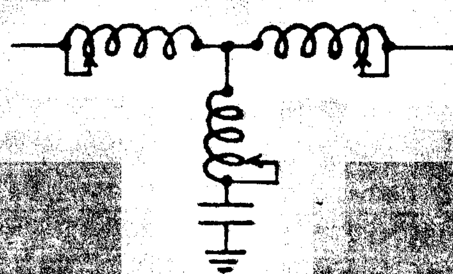
D



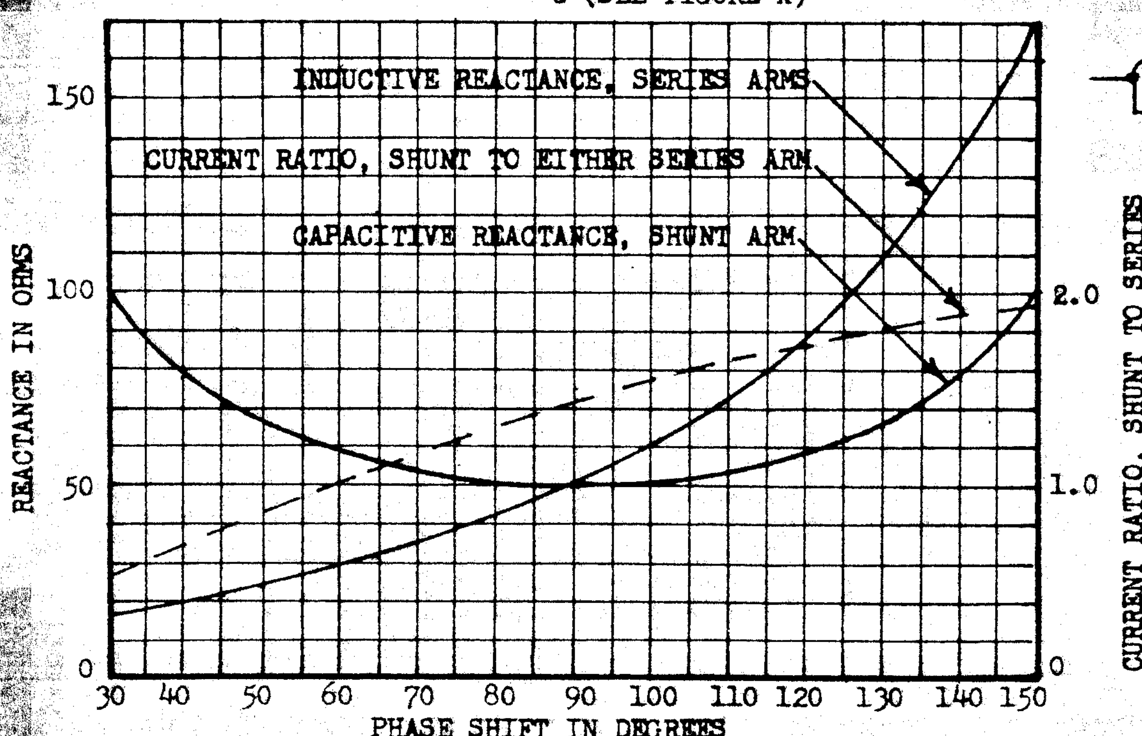
E



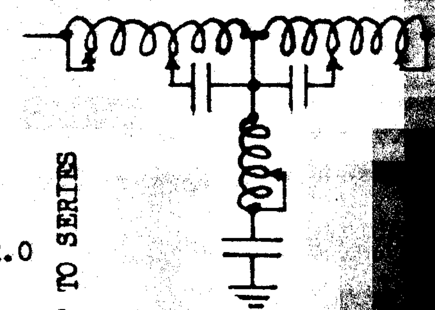
F



G (SEE FIGURE A)



H



ADJUSTMENT OF FILTER CIRCUITS & MEASUREMENT OF HARMONIC RADIATION

As a starting point, the most practical way to adjust a harmonic filter is by means of an R.F. bridge, if one is available. For preliminary measurements, a grid dip meter may also be utilized. This procedure together with the bridge operation will be briefly reviewed.

Series type filter circuits are disconnected from the transmitter circuit and the R.F. bridge connected to the filter at that point. With measurements being made at the desired harmonic frequency, the circuit is adjusted for zero reactance as indicated by the reactance dial on the bridge. If heavy components are being utilized, the resistive component as measured on the bridge should be very low. In adjusting parallel circuits by means of a bridge, the components can be connected in series and adjusted by utilizing the above procedure, or each branch can be adjusted seperately with one end of each branch grounded. In utilizing the latter method, the capacitive reactance (this may comprise a capacitor and inductance in series) must be adjusted to equal the inductive reactance, at the desired frequency. Better accuracy can be obtained on the R.F. bridge if the initial balance is set for inductance at 100 or 200 ohms (or even higher) on the reactance dial so that both inductive reactance (additive) and capacitive reactance (subtractive) can be read on the low part of the reactance dial.

In adjusting series type filters with a grid dip meter, the circuit can be disconnected from the transmitter equipment and the capacitor and inductor connected to form a parallel circuit. An alternate method is to run a good ground connection to the top of the filter circuit where it connects to the transmitting equipment, resulting in a parallel circuit. After making either of these changes in the filter (without changing their location), it is tuned to resonance at the harmonic frequency by means of the grid dip meter. Filters incorporating regular parallel circuits, generally must be disconnected from the transmitting equipment to prevent loading of the circuit, before any adjustments are made with the grid dip meter to the required frequency.

Filters should be left in metal enclosures, if utilized, and all normal ground connections should be left connected to the filters, where possible, during adjustment procedures.

A filter cannot be adjusted for maximum harmonic attenuation by means of an R.F. bridge or a grid dip meter because this measuring equipment disturbs the proper resonance of the circuit. For maximum harmonic attenuation, the filter should be adjusted with normal operating connections and with measurements or observations being made on or beyond the output of all equipment, with the transmitter operating normally.

The most widely used method of precisely adjusting a harmonic filter, after making preliminary adjustments with a bridge or dip meter, is by means of utilizing the S meter on a communications receiver located remote from the station. By means of telephone communication the filter can be adjusted for minimum deflection on the S meter at the harmonic frequency, thereby obtaining the ultimate efficiency from the particular installed filter.

If a harmonic filter is installed by a station to show compliance with FCC Rules, it is sometimes necessary to determine the DB improvement in harmonic attenuation. A measuring site, clear of buildings and power lines, should be selected approximately one mile from the station and field intensity measurements should be made at the station's operating frequency and at the required harmonic frequencies. It may be necessary to move closer-in to the station if the harmonics are of real low amplitude, but the possibility of spurious signals being generated in the measuring equipment should not be overlooked, resulting from high signal levels at the operating frequency. It is recommended that measurements be made at the same site, before and after the installation, or re-tuning of a harmonic filter. If interference is being created to a critical communications service it may be necessary to select a number of measuring sites and average out the measurements at all sites before and after suppressing the harmonic radiation.

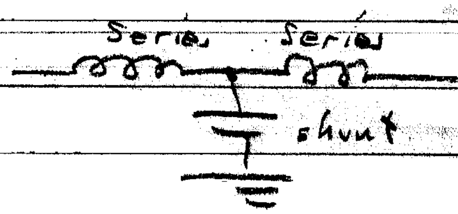
Harmonic measurements by means of field intensity meters are mostly relative in nature, and are generally utilized only to show an improved harmonic condition. Measurements of this type are not recommended on directional antenna systems due to the unknown horizontal pattern at the harmonic frequencies, except for relative purposes. Fortunately stations do not normally experience harmonic problems while utilizing their directional antenna systems, due to the high frequency attenuation provided by the phasing and coupling equipment. Second harmonic measurements on non-directional antennas of .3 wavelength height or lower, are fairly reliable. As the antennas and harmonics go higher, the high angle radiations at the harmonic frequencies are much stronger than the ground wave signals, and therefore measurements on the ground are not a true indication of absolute harmonic conditions. The high order harmonics from standard broadcast stations fall in a frequency band that can support interfering sky wave signals both day and night at great distances, unless properly suppressed.

In calculating the DB factor for harmonics the following formula is utilized: DB = 20 Log_{10} (MV/M at operating frequency / MV/M at harmonic frequency). This is the standard formula for voltage ratios and many engineers find it more convenient to consult the DB tables in reference books. Based on this formula, if the signal at the station's operating frequency measures 100 MV/M and at the same measuring site the 2nd harmonic measures .01 MV/M, the harmonic is attenuated 80 DB.

In performing R.F. harmonic measurements on transmitters in connection with type approval applications filed with the FCC, the present FCC Rule 2.524 requires that harmonics, and other spurious frequencies, be checked at the equipment output terminals when properly loaded with a suitable artificial antenna. This measurement procedure is not very practical for the average standard broadcast station in running down harmonics, due to the special measuring equipment and dummy R.F. load required. This method does not take advantage of the extra harmonic attenuation that is available to most stations in their antenna coupling units, and therefore does not produce results that reflect a more favorable normal operating condition.

~~and therefore does not produce a more favorable operating condition.~~

For 50 Ω



45° $X_{series} = -50 \tan(45/2) = -50 \times .414 = -20.7$

135° $X_{series} = -50 \tan(135/2) = -50 \times 2.414 = -120.6$

45° $X_{shunt} = 50/\sin 45° = 50/.707 = 71$ ohms

135° $X_{shunt} = 50/\sin 135° = 50/.707 = 71$ ohms

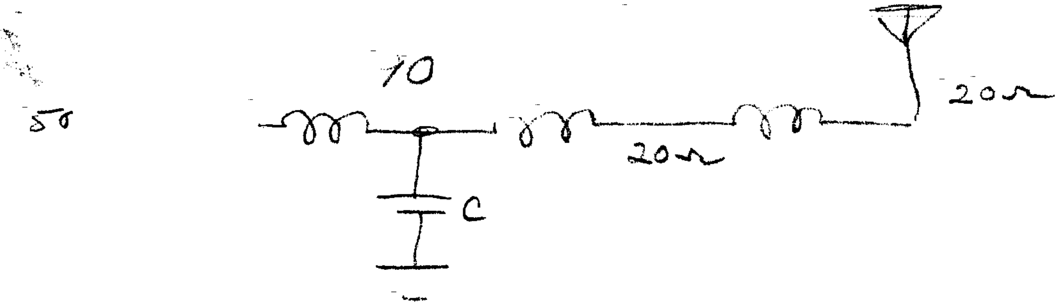
150° $X_{shunt} = 50/\sin 150° = 50/.5 = 100$

115° $X_{shunt} = 50/\sin 115° = 50/.906 = 55$

180
150
30

67
2 | 135

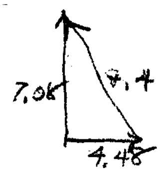
180
115
65



$$X = \sqrt{50 \times 20} = \sqrt{1000} \qquad 33.3\Omega$$

For 1K W Input 4.48 Amps
output 7.08 Amps

I_C



$$I_C \quad \sqrt{4.48^2 + 7.08^2} = \sqrt{20 + 50}$$

$$= 8.4 \text{ Amps}$$