DECCA AUSTIN INSULATORS

ONE VIEW OF INSULATION PROBLEMS FOUND IN BROADCAST ANTENNA SYSTEMS

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INTRODUCTION

A year ago, in Edmonton, we read a paper entitled "The Effective Insulation of Masts and Towers for AM Broadcasting". This paper presented a broad view of insulators as they apply to broadcasting stations. The paper being presented today is complementary but deals with one aspect, that of the voltage stress applied to guy strain insulators in the antenna system.

R.F. VOLTAGE STRESS

At the risk of being thought pedantic we want to quickly review the distribution of voltage on some typical antennas. Vertical radiators are almost universally used for AM broadcast transmission. The most commonly used electrical height of the vertical radiator is approximately one quarter or one half to five eighths wavelength. Again, it is now universal practice to insulate the base of the mast from ground and feed it at the base point.

Figure 1 shows the voltage distribution on a quarter wavelength mast. The dotted line is intended to represent the magnitude of the voltage, that is, the horizontal distance from the mast to the dotted line represents the relative voltage at that point. This is a common textbook way of showing this and the shape of the voltage curve is approximately sinusoidal. The antenna can be likened to an open ended transmission line, with the top being the open end. There will always be a voltage maximum at the top. The voltage at any point along the antenna depends on the current and impedance at that point.

Figure 2A shows the typical representation of the voltage on an antenna approximately one half wavelength in height. The way this is generally illustrated suggests that the voltage falls to zero a quarter wavelength down from the top. This is not strictly correct as the graph is intended to show phase as well as amplitude and, as such, the sine wave does have a node at this point.

If we concern ourselves only with voltage amplitude and forget phase, then Figure 2B for a five eighths radiator correctly represents the voltage distribution, and it will be noticed that there is a voltage minimum which is not necessarily zero a quarter wavelength from the top. With the antenna electrically greater than one half wavelength, the voltage at the feed point – assuming this is at the base of the mast – will be lower than it is a slight distance up the mast at the antinode which will occur one half wavelength down from the top of the mast.

Finally, Figure 3 shows the voltage distribution along an antenna which is considerably less than one quarter wavelength in height. In this situation the voltages at the top and bottom of the antenna will be substantially the same.

When we are considering insulation problems it is as well to think in tens of peak voltage since it is the peak voltage which produces the maximum stress on the insulation system. Figure 4 illustrates some typical values of peak voltage which may be encountered on a broadcast radiator driven by a 50 KW transmitter operating with 125% positive peak modulation.

The antenna system illustrated is an actual installation designed for 1 MW input. The voltages have been scaled down to represent 50 KW power and the voltage distribution is that determined from a computer program which was set up during the design stage. It will be noted that, because the antenna is electrically greater than one half wavelength, there is a voltage maximum just above the base insulator.

The calculations involved in determining the base voltage to be expected on this system are illustrated in Figure 5. These are quite conventional but it may be worth noting that for insulation purposes it is prudent these days to take into account the tendency to use higher than 100% positive peak modulation, and also to remember that normally the calculations are done using RMS values while for insulation studies these voltages should be converted to peak values. There is a three to one factor to bear in mind; that is, the conventional calculation for base voltage is done with carrier power only and generally as an RMS value. The peak voltage at the crest of positive modulation is about three times this value.

If you are considering a power change or the effect of power on system voltages, the voltages in the system will change as the square root of the power change. For example, a power change from 10 KW to 50 KW will raise the system voltages by a factor square root of 5 $\approx$ 2.25. There is an exception to this, which is worth bearing in mind, and this occurs when two transmitters on different frequencies are combined into one antenna system. The coupling and matching system will inevitably include isolation networks to ensure that one transmitter is effectively isolated from the other. The two transmitters will be functioning independently, and in circumstances where both are simultaneously fully modulated with the same polarity of modulation, the voltage on the antenna system will be the result of two superimposed peak voltages, the sum of which will be higher than that of a single transmitter of equivalent power. As an example, two 25 KW transmitters will, as far as peak voltages on the antenna system are concerned, be equivalent not to a 50 KW transmitter but to a 100 KW transmitter. This means the voltage will be 1.4 times as high as it would be with a single 50 KW transmitter. This phenomenon will, admittedly, only be of interest to those few stations which operate two transmitters into a common antenna.

STATIC VOLTAGE STRESS

Many broadcasters have experienced sparkover of guy strain insulators, particularly when these are of the ball or egg type. This phenomenon occurs when an electrical storm is over the station or nearby. In areas where dry blowing snow or dry blowing dust is present, sparkover of insulators is also frequently experienced. Most references in the literature dealing with the subject of insulation emphasize that for low and moderate powers on broadcasting antennas the radio frequency voltages are not particularly high and frequently the decision as to which insulators are specified is based on a consideration of these RF voltages only. The atmospherically induced charges on an antenna system frequently produce a voltage stress across insulators many times greater than that of the radio frequency voltage present.

On a normal day there is a voltage gradient between the earth and the ionosphere of about 100 - 300 volts per metre. This gradient is more or less uniform, so with 100 volts per metre the potential difference between earth and a point say 500 metres above the earth will be 50 KV.

In the vicinity of an electrical storm the voltage gradient becomes much steeper and may rise as high as 50 KV or more per metre. Figure 6A shows typical conditions which could exist with an electrical storm in the vicinity. The gradient illustrated is 5 KV per metre — quite a moderate level.

It is interesting to note the effect of introducing a grounded conductor such as an antenna mast into this previously uniformly distributed field. Figure 6B shows the distortion introduced. The mast is an equipotential surface assuming it is connected to ground through the matching network or by a static drain coil, as it should be. It will be noted that the distortion in the field produces a very steep voltage gradient near the mast and particularly so at the top of the mast. The air and any insulation is highly stressed, and not infrequently a partial discharge will be seen near the mast top. This is the same phenomenon that occurs when a person is standing in an open field with an electrical storm overhead or nearby. When the stress becomes sufficiently high you may feel your scalp tingling and hair standing on end. If you ever experience this, it is time to do something.

This would be an appropriate time to emphasize that the purpose of this paper is not to discuss lightning or lightning protection, but merely to consider this natural phenomenon in relation to the problems of antenna insulation. It has been somewhat difficult to find reliable information on the subject of lightning protection but there was an excellent book on this subject recently published in Canada, written by Mr. J. L. Marshall of the engineering staff, Canadian Broadcasting Corporation. Further details have been given in the Bibliography attached to this paper.

It will be noted that Figure 6B is scaled to be correct for a 550 KHz half wave antenna and a voltage gradient of 5 KV per metre. The curves are as accurate as can be shown on an illustration of this size and are the result of a mathematical analysis verified by measurements on a model in an electrolytic tank. See Reference (1). Figure 6B can, therefore, be scaled for other voltage gradients and for masts of other heights.

Though we have shown that the voltage gradient near the antenna can be very high indeed and there may be a partial discharge at the top of the mast or an actual strike by lightning, nothing significant has so far been mentioned as far as antenna insulators are concerned. The base insulator will be protected by its spark gap and even if lightning strikes the mast, it is not likely to damage the base insulator because of the protection afforded by the matching and coupling network which will probably provide all sorts of undesirable paths to ground. The serious problem as far as antenna insulators are concerned comes when one introduces an insulated guy system.

Each insulated segment of guy is itself an equipotential surface and will produce some distortion of the electric field in its immediate vicinity. Analysis and measurement have confirmed that the effect on the gradient near the mast is, however, very slight so even with the guy system introduced conditions are substantially the same as that shown on Figure 6B. It becomes very difficult on a small drawing to show what happens when all the guys are present but, in looking at Figure 6B it can be seen that there can be very high static potentials existing between two insulated sections of a guy, and this stress appears across the insulator isolating the sections.

The area shown enclosed in the dotted circle of Figure 6B is shown enlarged in Figure 7. Remembering that the mast or tower is at ground potential, and bearing in mind the steep, voltage gradient near the tower, the first guy section is at a potential of 500 KV and this appears across the insulator at the point of attachment of the guy to the mast. The first break-up insulator down from the top has only 50 KV across it since the next section of guy is at a potential of 450 KV. The situation further down the guy is shown in the small table, top right on Figure 7. It will be noted that it is the insulator adjacent to the mast and the bottom insulator that are most highly stressed in the system, and this is generally true for all similarly guyed masts.

A thorough study of static voltage phenomenon has been made in Yugoslavia by two engineers and their results published in “The Radio and Electronic Engineer” in December 1973. Further details are given in Reference (2) at the end of this paper. We have taken the liberty of extracting a relevant illustration and table from their paper, now shown in Figure 8. These workers made a mathematical investigation and verified their findings by measurements on an existing high power transmitting antenna. Their transmitter power of 400 KW is some eight times as high as we are concerned with here, but bearing in mind that RF voltage will vary as the root of the power, the RF voltages shown in the table can be divided by 2.8 to convert to a 50 KW system. The static voltages will remain the same but it will be noted that a very modest gradient of 1 KV per metre was used as the basis for the data in the table.

DISCUSSION OF INSULATION PROBLEMS

From the facts presented earlier in this paper it seems apparent that it is no simple matter to effectively insulate the guy system of a vertical antenna.

It is not really practicable to provide insulation sufficient to prevent a flashover of all insulators in a system under conditions of high static voltage. In Figure 7, shown earlier, 500 KV was given as the voltage stress on the insulator nearest the mast on the top guy in the system. In practice voltages do not generally build up to this level because insulation is not perfect and there is some leakage. Further, localized break down of air does occur on the metal fittings of insulators and a partial discharge will result in a drain of static charge allowing an equilibrium condition to be established.

Figure 9 shows one of the larger guy strain insulators in the Austin range and the wet flashover of this insulator is about 250 KV peak. We recommend a maximum R.F. working voltage of about 150 KV peak. It will be noticed that the radius of the edge of the shields is quite small and seemingly out of keeping with the practice in the power transmission industry and in other high voltage electrical equipment.

Generally the radius of curvature on a guard ring or voltage control would be much larger, but it should be borne in mind that the intent is generally to prevent corona or partial discharge so that breakdown occurs only through an arc or flashover. In the case of guy strain insulators which are in circuits which are electrically isolated and on which a high static potential can build up, it is better to allow localized breakdown of the air to occur so that the resultant current can bleed off the static charge. It is true that this will lower the flashover rating of the insulator but in the case of Austin insulators, the flashover is still relatively high and the loss of radio frequency energy small during conditions under which the static charge is draining off.

The insulator illustrated is adequate for low and moderate R.F. voltage working. If we were to increase the radius of curvature of the guard ring or voltage control in an effort to increase the R.F. working voltage, we could improve the insulator's capability if there was no problem with static charges. There is a limit to what a particular insulator will do when it has to contend with all the adverse factors of an outdoor environment and high voltage R.F. stress superimposed on a high D.C. static potential. The solution is to use an insulator designed for a higher voltage working or couple two or three together in a string.

What does seem important and apparent is that the insulation in the guy at the point of attachment to the mast should be adequate to ensure that a flashover at this point is unlikely to occur. This is the primary insulation point and it is good practice to put an insulator in this position that is capable of withstanding the system voltage without any assistance from the break–up insulators in the lower part of the guy. The break-up insulators should not be relied on as part of the primary guy insulation. They should be used to break up the guy into short lengths to ensure that no appreciable re–radiation of the signal occurs due to excessive R.F. current in a section of the guy. Though there is no virtue in providing break-up insulators which have a low flashover and leakage path, at least when economics dictate the use of such insulators the flashover will be limited to a relief of the static charge on the adjacent guy segments and - at most - will cause a relatively minor disturbance to the functioning of the antenna system. If one insulator flashes over it is highly probable that all those below it will flashover in turn and there will be a momentary grounding of the whole of the guy below the top insulator. Depending on the sensitivity of the system to such a disturbance, this may or may not cause an interruption to transmission.

Having provided good insulation at the point where the guy attaches to the mast and accepting less effective insulators for the break-up function, the next improvement can be made by putting an insulator with long leakage path and high flashover voltage at the base of the guy prior to its tie–off to the anchor point. This will minimize any possibility of the guy system becoming grounded and discharges across the remainder of the break–up insulators will be limited to small ones due only to static potentials which build up between adjacent guy segments.

Various attempts have been made to incorporate static drains across insulators to prevent the build–up of any appreciable voltage stress. Conductive glazes have been used in the high voltage power transmission industry and attempts made to use these for radio systems. The conductive glaze has been visualized as a means of dissipating a static charge, but in the radio field they have not proved very effective. In the power transmission field the primary function of the partially conductive glaze is to provide a loss and generate some heat which helps to get rid of any conductive moisture film on the insulator. Expensive radio frequency energy has to be thrown away to produce any worthwhile amount of heat in a radio system. The purpose of an insulator is to prevent R.F. current flowing in the guy - not encourage it. Some use is made of static drain resistors bridging break-up insulators but again, power must be lost in these devices and experience has shown that lightning strikes on the system frequently blow these drain resistors to pieces.

Protective devices are available which, in the event of an insulator flashover, will sense an unfavourable load condition being presented to the transmitter and momentarily interrupt its output. If the guy insulation system is adequately designed, there is little possibility of a power arc developing across an insulator as a result of a breakdown caused by a static discharge. Some transmitting systems are more susceptible to loading conditions than others and it may be necessary to interrupt the transmitter output even for a momentary discharge across a break-up insulator.

We will not attempt to discuss protective systems in detail but two will be mentioned. In one system current flowing to ground at the bottom of each guy is sensed and when this exceeds a preset value, a relay or other device momentarily shuts the transmitter off. This is a somewhat cumbersome system as it means that sensing devices have to be scattered around the field at the guy anchor points and all the data brought back to the transmitter building. A second system works on a principle similar to that of a reflectometer, which senses the change in the amplitude and phase of the signal at some point in the transmission line connecting the antenna system to the transmitter. Again, when predetermined limits are exceeded, a momentary interruption is made to the transmitter output. Stations frequently complain that in the presence of electrical storms or blowing dust or blowing snow their transmitter is going on and off like a machine gun. We suggest that the behaviour of these systems be looked into and if the insulation is inadequate to prevent a power arc being established, an improvement in the insulation could remove the necessity for such sensitivity of the protective device. If a power arc cannot be maintained because the insulation is adequate, then the occasional sparking over of a break-up insulator in a guy can perhaps be tolerated without the necessity of continually interrupting the transmitter. No hard and fast rule can be given, as every system is unique in some respect, but we suspect that some of the trouble is unnecessary.

Some antenna systems suffer more than others due to their location being at a coastal area where salt laden spray is prevalent. In operating a proprietary low frequency navigational system in many parts of the world, we have accumulated some experience with guyed vertical radiators at coastal sites where salt contamination is the order of the day. The sequence of events is well defined. The insulator is clean and dry initially. It is then exposed to salt-laden mist or rain and leakage develops. This phase is not too serious, but eventually the weather conditions change and the insulator dries off. Though the water evaporates, some salt remains and a dry salt film coats the insulator. This doesn’t do any particular harm but eventually high humidity or a light drizzle wets the insulator and moistens the salt coating. Under these conditions leakage again occurs and the situation can be much worse than it would be in a heavy downpour that drenches and washes the insulator. Once this cycle starts it never ends. The salt remains and every time it becomes moist excessive leakage is experienced. Depending on the characteristics of the antenna system this can detune it, reduce aerial current and, under extreme conditions, put the station off the air. These extremes are not usually experienced on the antenna systems used at broadcast frequencies, but excessive leakage and power loss can certainly occur. No really satisfactory solution to this problem has been found but two palliatives are offered. One involves the use of a protective grease and the other an insulator design providing a long leakage path.

There are several greases available: one a silicone base grease such as a Dow Corning product, or an English grease called Dussek. These greases are extensively used by power transmission companies attempting to cope with similar problems on their transmission lines. Greases are effective for a short period of time but, depending on the degree of contamination, the grease will have to be cleaned off and renewed every two to five years. If you are not prepared to do this there isn’t much to be gained by trying to use grease.

In the electrical power transmission field it is common practice to put skirts on insulators. These have a dual function. They are intended to increase the surface leakage path and also to provide protected areas which are kept relatively free of contaminants. In our own transmitting systems we make extensive use of what we call a “polyfinned” insulator, and the appearance of one of these is shown in Figure 10. You will note that the fins are relatively large, close together, and there are quite a number of them. We have found this configuration to be more effective than a smaller number of more elaborately shaped fins.

CONCLUSION

To sum up, in areas where insulators become contaminated special measures may have to be taken but we would emphasize that the static voltage stress across insulators in an antenna system is likely to be many times greater than any radio frequency voltage present, consequently with low or high power transmitters good insulation is vitally important.

We, at Austin, will continue our investigation of insulator performance, and, as fresh knowledge and information become available to us, we will be pleased to present it to you.

REFERENCES: (1) Unpublished communication from
R. W. Naylor, M.A.Sc., Toronto, Ontario
Mr. Naylor is a Consultant to
Decca Radar Canada (1967) Limited.

(2) Static Voltages on the Guy Insulators of
M.F. and L.F. Broadcast Tower Antennas
By Professor J. V. Surutka, D.Sc., and
D. M. Velickovic, D.Sc.
Published in "The Radio and Electronic Engineer"
vol. 43, No. 12, December 1973.

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By J. L. Marshall, Managing Engineer (Transmission)
Engineering Division, Canadian Broadcasting
Corporation.
Published (1973) by John Wiley & Sons, Toronto.

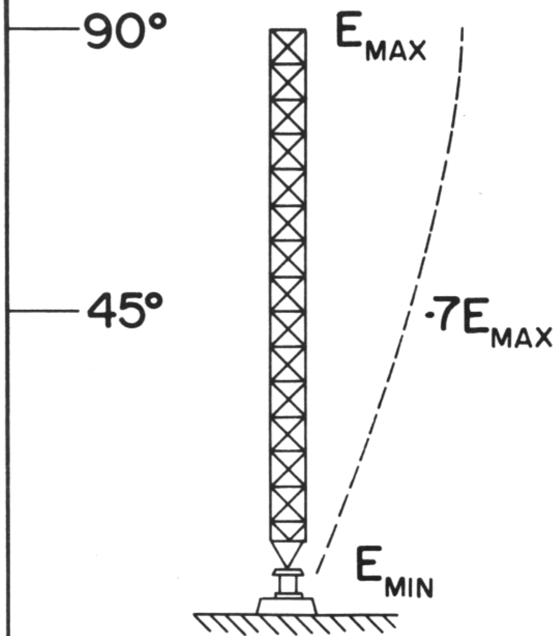


FIG. 1 $\frac{\lambda}{4}$ RADIATOR

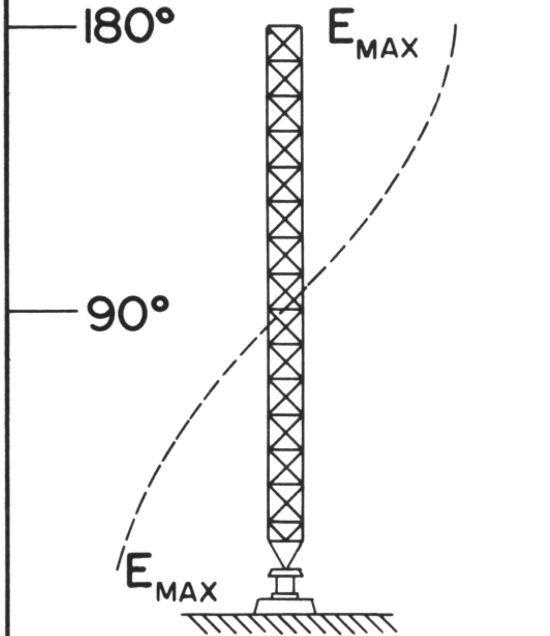


FIG. 2A $\frac{\lambda}{2}$

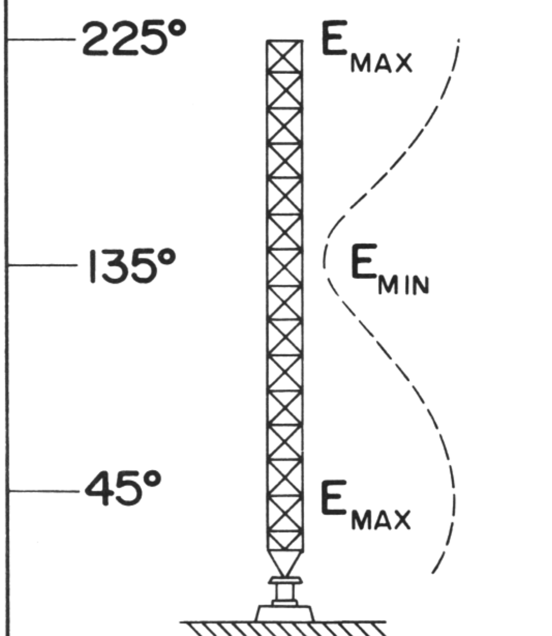


FIG. 2B $\frac{5}{8}\lambda$

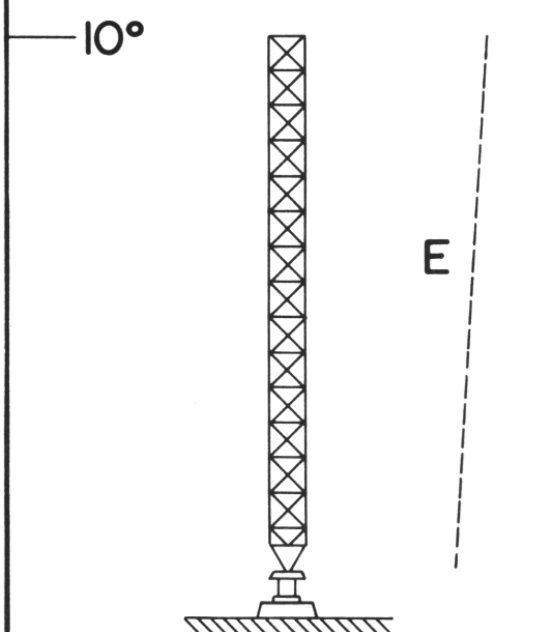
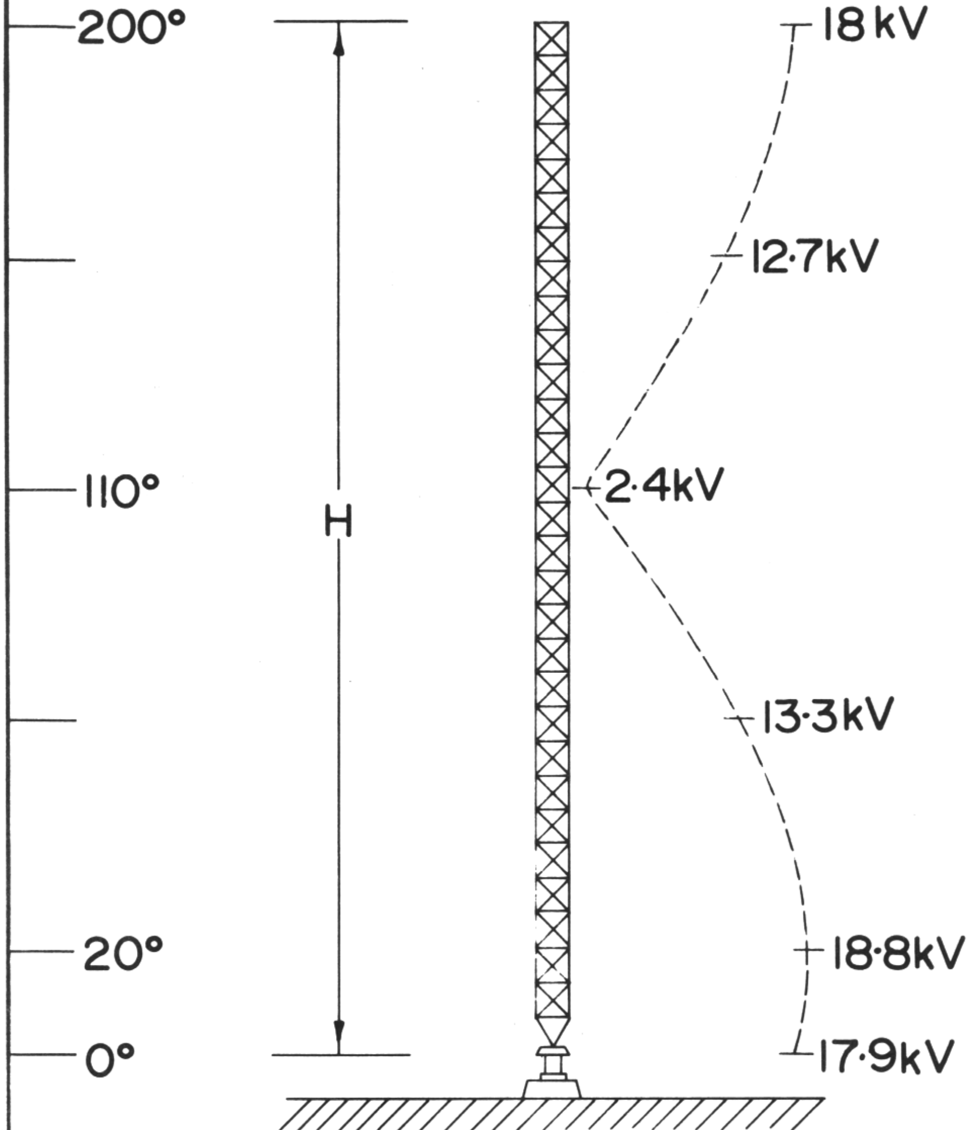


FIG. 3 $<< \frac{\lambda}{4}$



$H > \frac{\lambda}{2}, Z_0 = 300$ Ohms

PEAK VOLTS AT CREST OF 125% POSITIVE MODULATION FOR 50kW INPUT.

FIG. 4

BASE IMPEDANCE OF MAST (FIG. 4) $= 200 - j300$ Ohms

$= 360$ Ohms

FEED(AERIAL) CURRENT FOR 50kW INPUT $= \sqrt{\frac{P}{I}} = \sqrt{\frac{50{,}000}{200}}$

$= 15{\cdot}8$ Amps

BASE VOLTAGE E $= 15{\cdot}8 \times 360$

$= 5{\cdot}7$kV

WITH 125% POSITIVE MODULATION, THE BASE VOLTAGE AT THE CREST OF MODULATION WILL RISE TO $E = 5{\cdot}7 \times 2{\cdot}25$

$= 12{\cdot}8$kV

THE CURRENT AND VOLTAGE AMPLITUDES SHOWN ABOVE ARE RMS VALUES, SO PEAK BASE VOLTAGE WITH 125% POSITIVE PEAK MODULATION IS $E_{PEAK} = 12{\cdot}8 \times 1{\cdot}4$

$= 17{\cdot}9$kV

FIG. 5

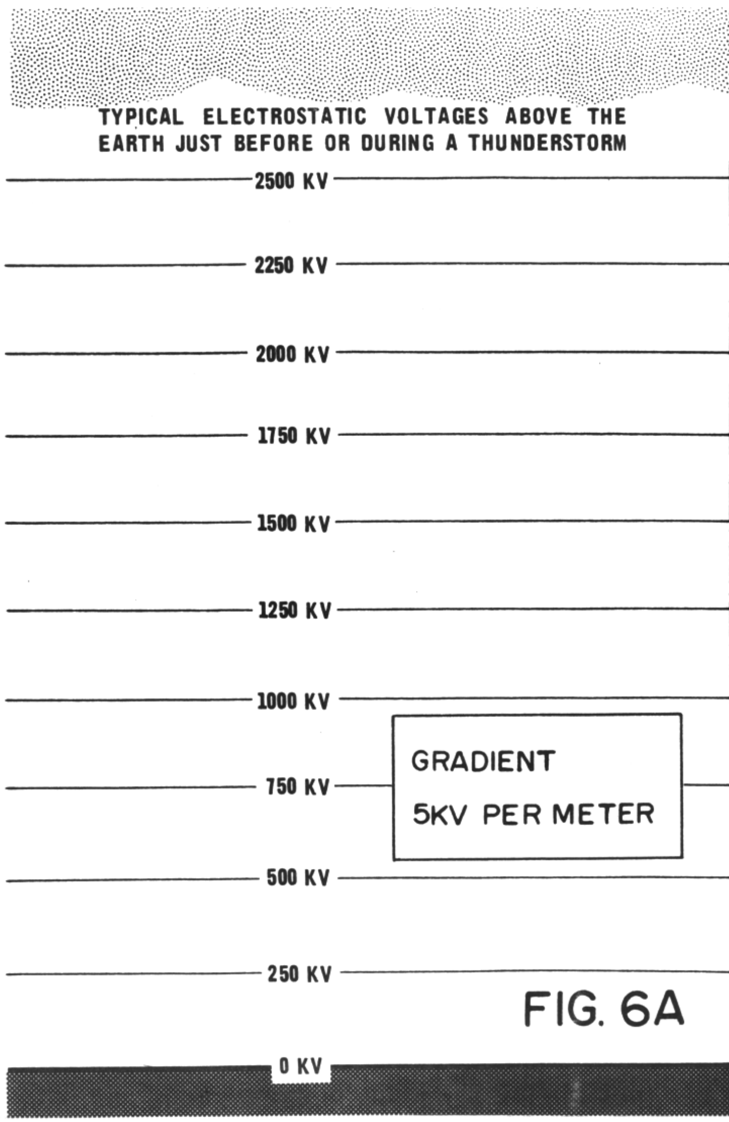

TYPICAL ELECTROSTATIC VOLTAGES ABOVE THE EARTH JUST BEFORE OR DURING A THUNDERSTORM
2500 KV
2250 KV
2000 KV
1750 KV
1500 KV
1250 KV
1000 KV
750 KV
500 KV
250 KV
0 KV
GRADIENT
5KV PER METER

FIG. 6A

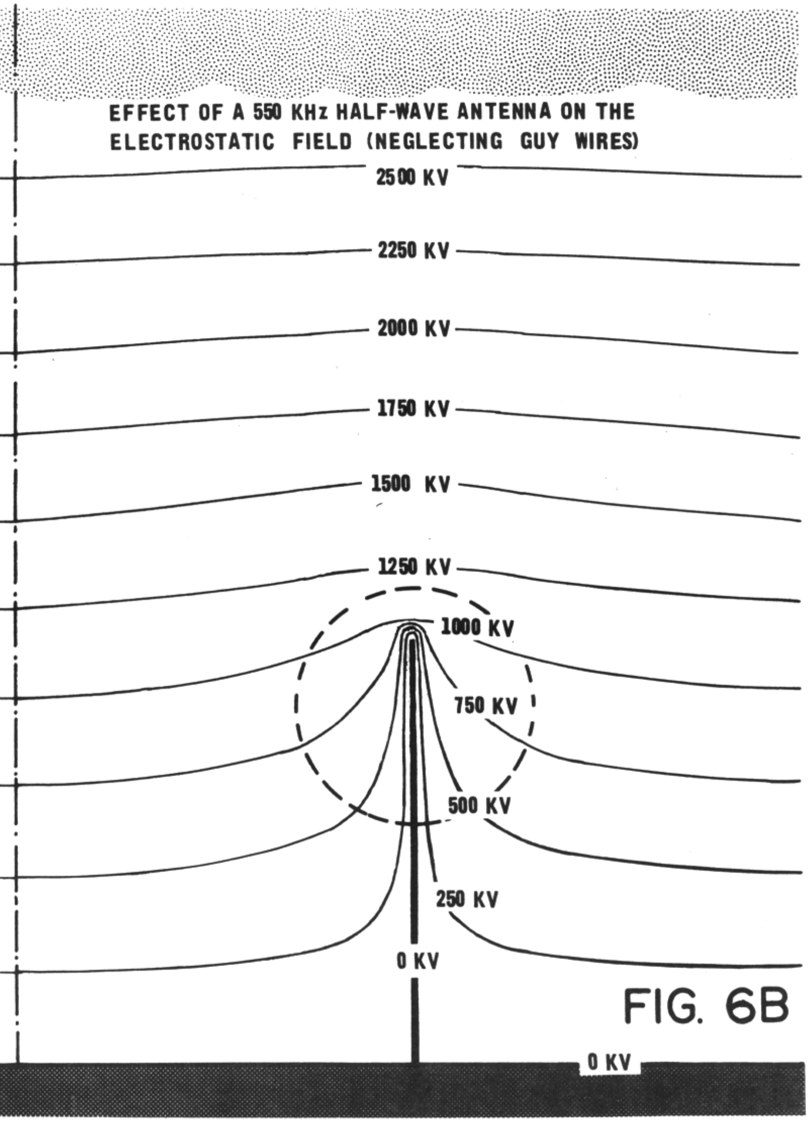

EFFECT OF A 550 KHz HALF-WAVE ANTENNA ON THE ELECTROSTATIC FIELD (NEGLECTING GUY WIRES)
2500 KV
2250 KV
2000 KV
1750 KV
1500 KV
1250 KV
1000 KV
750 KV
500 KV
250 KV
0 KV
0 KV

FIG. 6B

TYPICAL STRESS ON INSULATORS BEFORE OR DURING A THUNDERSTORM

(550 KHz HALF-WAVE ANTENNA)

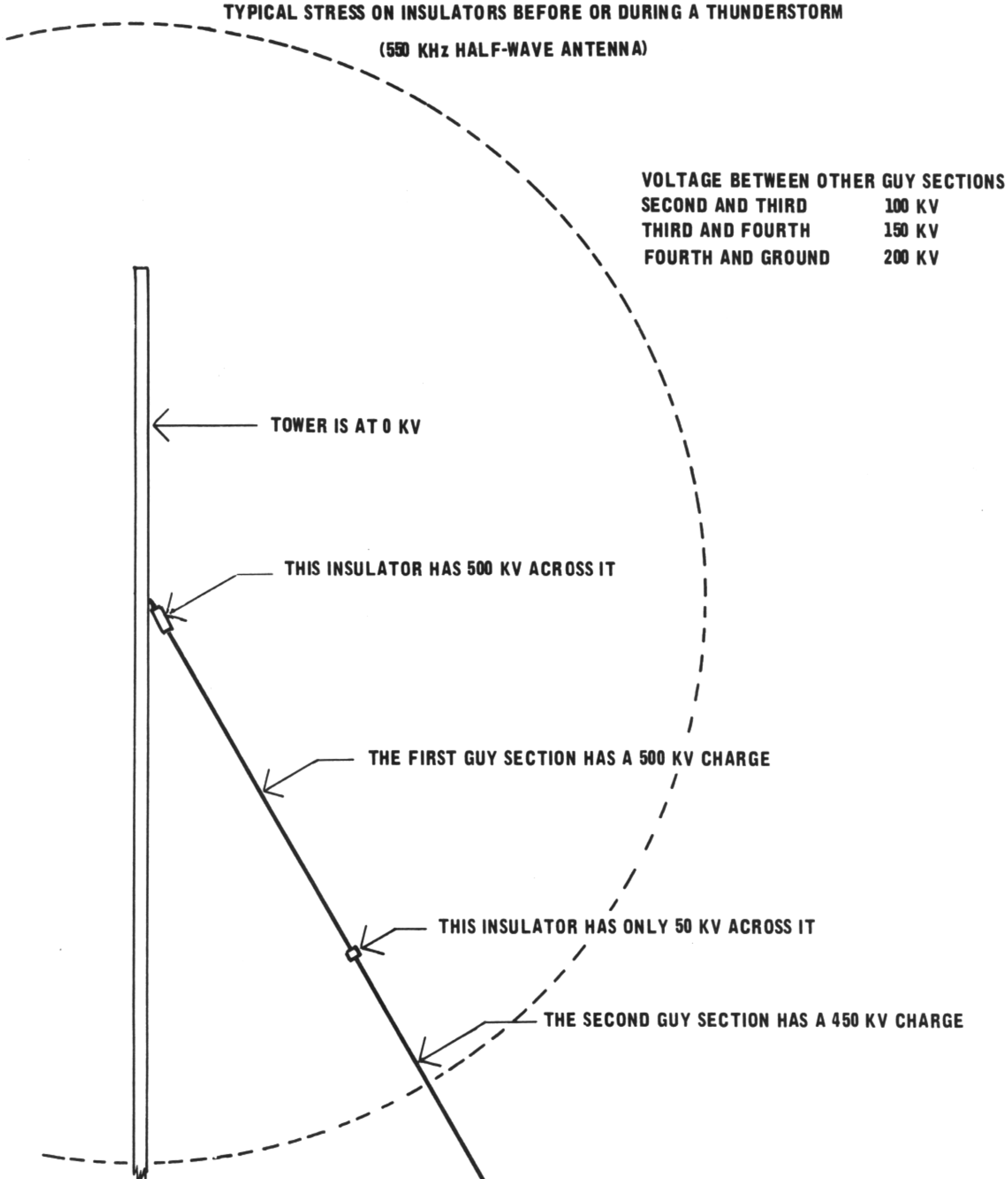
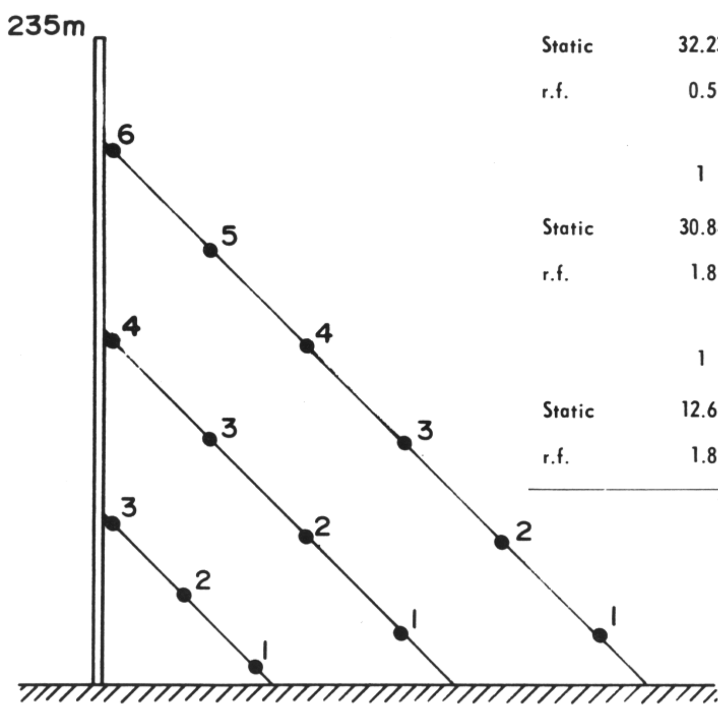


FIG. 7



Arrangement of the guy sections of the antenna tower of the main m.f. transmitter of Radio Boegrad

Static and r.f. voltages on guy insulators, in kV
(E_o = 1 kV/m, C = 50 pF; r.f. power 400 kW)

INSULATOR

	1	2	3	4	5	6
			The Upper Guy			
Static	32.23	30.57	26.75	17.68	11.44	95.79
r.f.	0.5	1.2	1.3	1.4	2.0	9.8
			The Middle Guy			
	1	2	3	4		
Static	30.84	22.20	1.20	54.25		
r.f.	1.8	2.0	1.9	3.3		
			The Lower Guy			
	1	2	3			
Static	12.63	6.19	18.83			
r.f.	1.8	4.9	11.8			

Source of data – See Reference (2)

FIG. 8

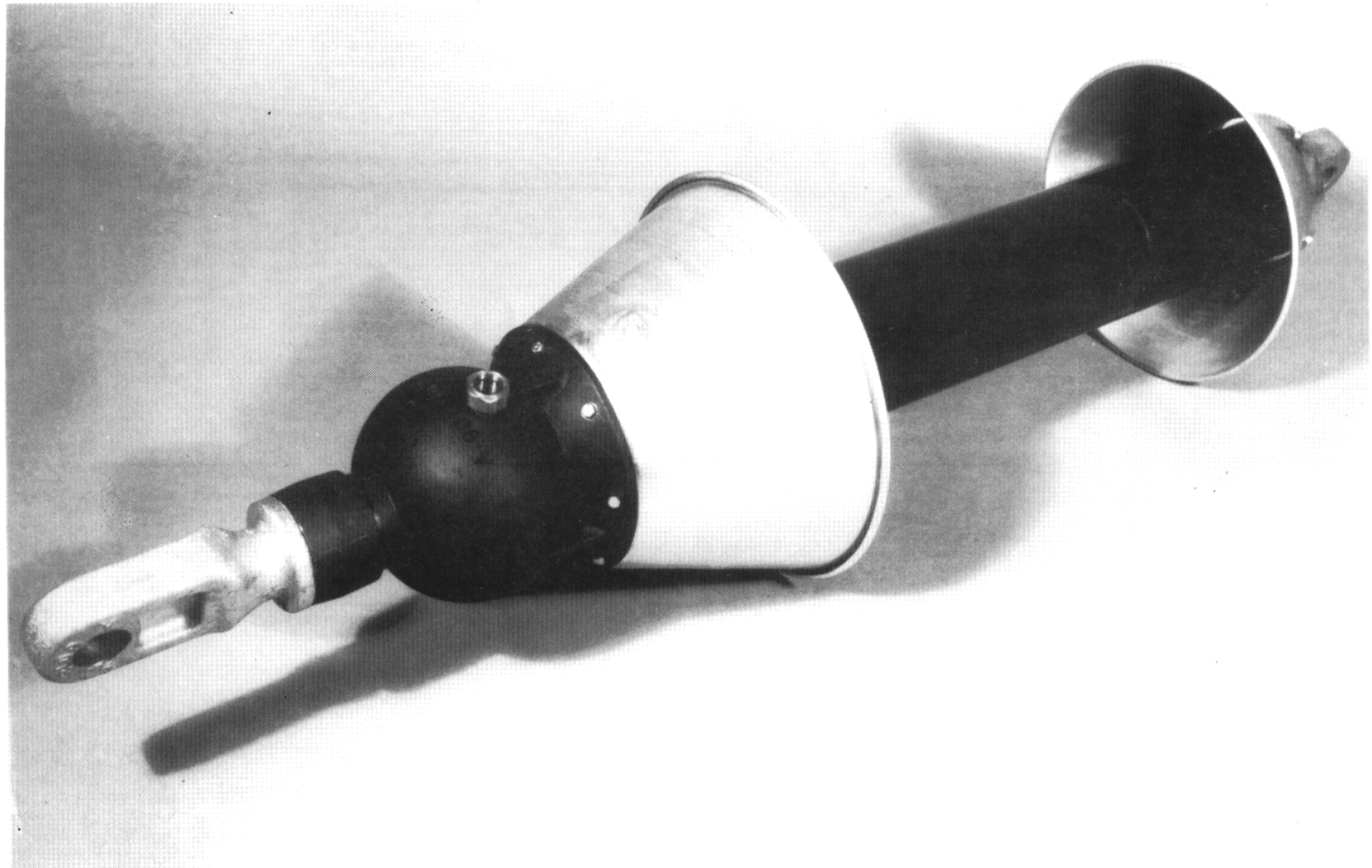


FIGURE 9

INSULATOR TYPE A-6018
40,000 lbs working load

FIGURE 10

INSULATOR TYPE A-3003
with POLYFINS