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ON THE IONOSPHERIC MODIFICATION EXPERIMENT PROJECTED AT MPI LINDAU: PRACTICAL REALIZATION

H. Kopka, P. Stubbe and R. Zwick
Max-Planck-Institut für Aeronomie, 3411 Katlenburg-Lindau 3,
F.R. Germany

SUMMARY

This paper outlines the technical design of the ionospheric modification experiment described in the preceding paper. The heating facility will consist of 10 100 kW transmitters, feeding into arrays of 5 x 6 corssed dipoles. There will be three such arrays to cover the frequency range 2.75 - 8.00 MHz.

1. INTRODUCTION

To produce the ionospheric modifications described in the preceding paper, one needs power densities of the order

$$2 \text{ m W/m}^2 \text{ at } 80 \text{ km height (D-region)}$$
$$0{,}1 \text{ m W/m}^2 \text{ at } 300 \text{ km height (F-region)}$$

These densities correspond to an effective isotropic radiated power of about 150 MW. In practice, of course, the power is radiated upwards to the region where it is most effective, rather than isotropically. Thus the required power densities in the region where they are needed are achieved with an upward directed beam using high gain antenna arrays and transmitter of much lower power.

The appropriate antenna gain is determined by the propagation conditions, by the region which can be observed and by the spatial resolution of the diagnostic equipment.

For the most interesting F-layer effects, the excited plasma instabilities, only those rays are effective which reach a level of reflection at which the "heating" frequency is equal or very near equal to the local plasma frequency. Within the magnetic meridian plane this is given by those rays which produce the "spitze" phenomena. For the geomagnetic conditions near Tromsø this leads to a beam width for the antenna array of about $\pm 6^0$.

The beam width of the modifying array for effects within the D-region is determined by the beam width of the diagnostic equipment, which involves mainly partial reflection measurements. This implies a circle of 25 km diameter at D-region heights or a beam width of $\pm 10^0$. As a compromise we decided on a beam width of 8.5^0; that is, an antenna gain of 22-23 dB. With this gain, a total transmitter power of 1 MW is required.

For the modification experiments one needs - depending on the type of modification - to be able to select either of the two characteristic waves. Thus the antenna must be able to produce circularly polarized waves with either sense of rotation. This can be done most easily by using crossed linear single antennas, with a phase difference of 90^0 between each corssed pair. An antenna gain of 22-23 dB can be realized with an array of 5x5 crossed pairs of single half wave linear antennas, including the ground reflection.

The frequency range is fixed at the lower end at twice the gyrofrequency; i.e. 2,75 MHz. At the upper end the frequency must reach the maximum value of f_0F_2, which for 1978-1982 is estimated to be about 8 MHz.

2. Transmitter

The power of 1 MW could be obtained from a single transmitter. But the problems of distribution with the correct phase over the total frequency range, including maintaining the 90° phase difference, are formidable. The 90° phase difference could be obtained by using two transmitters but the distribution of high power with correct phase over a wide frequency band to 25 single antennas still presents a major technical problem. Further, the construction of 500 kW transmitters is beyond our experience and because of the high cost the purchase of commercial units is out of question. We therefore decided to use 10 transmitters each of 100 KW. Two transmitters feed each row of 6 crossed pairs of linear antennas (a 5 x 5 array fulfills the power requirements but a 6 x 5 array makes the interconnections simpler) with one linear antenna of each pair fed from one transmitter and the orthogonal linear antenna fed from the other transmitter. The 90° phase shift between the two halves of each row is made at the transmitter input side of the system.

The use of 10 transmitters has two important advantages in addition. First it makes it very easy to shift the antenna beam in the plane perpendicular to the row direction merely by varying the phase difference at the inputs of the transmitters connected to the 5 rows. Secondly it makes it possible to transmit two frequencies simultaneously by dividing the transmitters and rows into two groups and using two frequency generators. Thus the planned double frequency experiments become very easy. Fig. 1 shows the diagram of a transmitter. It is a linear class AB amplifier, using a solid state wide band exciter and driver (driving power 1,5 KW), so that only the transmitter output section has to be tuned and matched. The output π - L circuit is designed for a VSWR $<$ 2:1, output impedance 50Ω and 40 dB harmonic suppression.

Due to the coupling between the antennas the antenna input impedances change for all antennas, if at one row the matching conditions, i.e. the input current of its antennas is changed. By a computer simulation for the antenna array (based on the Hallêen integral equation [1], [2]) we have found, that the process of tuning and matching converges within 4 or 5 steps by tuning and matching the transmitters one after another (during tuning and matching of one transmitter the nine others are fixed) and repeating the whole procedure, after tuning and matching the series of ten.

The tuning and matching are done by an automatic control. The control units are based on a conventional technique, using a phase discriminator between grid and anode voltage and a voltage discriminator between the output terminal and a certain part of the anode of voltage.

The tuning elements are controlled by special equipment, after they have been preset to approximately correct positions for the selected frequency by a small minicomputer associated with the Dynasonde (see basic diagnostics). The same minicomputer controls the sequence of successive transmitter tuning and matching and its iteration. A flow diagram of the control system for each transmitter and for the total system is shown in Fig. 2 and 3.

3. Antenna

As useful antennas for the full frequency range of 2.75-8 MHz we first considered log. periodic antennas arranged as crossed pairs with 25 pairs in a 5 x 5 array. Each log. periodic antenna should radiate downwards and be reflected at the ground. This requires that the radiating region of the log. periodic antenna should always be about 0.25 λ above ground. The spacing between the antennas should be 0.4 λ at the lowest frequency. Although it is possible to construct a single log. periodic antenna with these properties ($\approx$ 0,25λ height, radiation downwards) with a max. VSWr < 2:1 over a frequency range of 3:1 this is no longer true for a large log. periodic antenna array [3], [4]. In an array the mutual coupling between the different antennas produces strong resonances in the frequency range, especially at frequencies at which normally the transition from one main radiating element to the next (using a coarse structure) would occur. In the case of an array either the VSWR would be much higher than 2:1 or the log. periodic structure must be made much finer by using a smaller apex angle, which means using higher antenna towers.

Cost estimates have shown, that it becomes cheaper to use three narrow band antennas in the form of arrays of simple folded dipoles or parallel wire full wave dipoles. To cover the frequency range of 2.75 - 8 MHz the range is divided into three parts each with a relative bandwidth of 37%. A bandwidth of 37% can be covered easily either with folded dipoles (Fig. 4) [4] or fullwave dipoles with frequency compensation. Calculations show that the VSWR for these "narrow band" antennas is better than 1.6:1. Further the required height for the lowest frequency band is 22 m, which is considerable less than the 30 m for the log. periodic antennas envisaged previously (and this was for an isolated log. periodic antenna and not for an array).

Additionally, the inter-element spacing within each array varies by only 37% over the frequency band, so that the spacing can be such as to give almost maximum gain over the whole band (Fig. 6). In this way we get an avarage additional gain of about 1,5 dB.

On the other hand, of course, we need three times the number of baluns, power dividers, approximately 2.5 times the length of cable and additionally 30 coax-switches. But fortunately, due to the narrow band requirements of the baluns and power divider it is possible to use simple line elements and $\lambda/4$ transformers, instead of the very expensive wide band ferrit core baluns and transformers. The input impedance of a single antenna (folded dipole or full wave) is approximately 500-600Ω. It is rather complicated to make line baluns for these impedances using conventional coaxial cable for the feeder system. Instead, we connect a pair of parallel dipoles by balanced open 600Ω lines and connect the midpoint of the line by a 4:1 balun to 75Ω coaxial cable. To do this we need an even number of antennas in each row. However, the new arrangement using 6 antennas per row and 5 rows requires only 3/5 the number of baluns and about 3/5 the length of cable that of the previously planned 5 x 5 array. In prices the changes nearly compensate, so that we have now decided on an antenna field of 6 x 5 crossed dipoles which gives a gain of approximately 24 dB or 250 MW effective power. This is more than necessary for the most F-layer modification experiments but for the D-region modification we want as much power as possible.

The three 75 coax lines of each row are connected to power dividers consisting of simple 50Ω to 25Ω transformers (Input 50Ω/100 KW, output 3 x 75 in parallel). These power dividers are constructed from two $\lambda/4$ transformer lines with Chebycheff behaviour for the reflection coefficient. The mismatch over the frequency range is less than 1.05:1. The transformers with a total length of $\lambda/2$ (corresponding to each band midpoint frequency)are part of the feeding system and shorten the line length considerably. They are constructed from aluminium tubing of 100 mm outer diameter. The same tubing is also used as the outer conductor for the 100 KW coax lines. This coax line construction is similar to that used in the Boulder experiment and originally in the Jicamarca equipment [5], [6]. However, the weather conditions at Tromsø require additionally, that the connections of the tubes be waterproof. The total feeding system consists of 9000 m line for 100 KW (100 mm outer diameter) and 9000 m for the 35 KW (60 mm outer diameter).

4. Basic diagnostic equipment

The main diagnostic instrument will be the EISCAT facility, the partial reflection equipment and photometers. Additionally as an integral part of the heating facility a digital ionosonde will be used. (Dynasonde[7]) which will be constructed at Boulder. With this instrument we can measure the time delay, phase and amplitude of a wave reflected by the modified ionosphere. Their interpretation is partly done in real time by using the available software developed by J.W. Wright et al and additional software developed for the heating experiment. We shall thus be able to determine and set very quickly the optimum frequency, power and special program of measurements by using the Dynasonde computer, which communicates directly with the minicomputer that controls the transmitters. A further (and in practice very important) use of the Dynasonde computer lies in the automatic documentation in print and tape storage form of the various programmes and their parameters.

Additionally the Dynasonde will be used as probe transmitter and receiver for a complementary cross-modulation experiment, in which the heating transmitters are used as the disturbing transmitter in a complementary manner. That is, instead of using short disturbing pulses, we will use a CW heating signal which is pulsed off with short pulses. In this way we can use the cross modulation technique for investigating the modified D-region.

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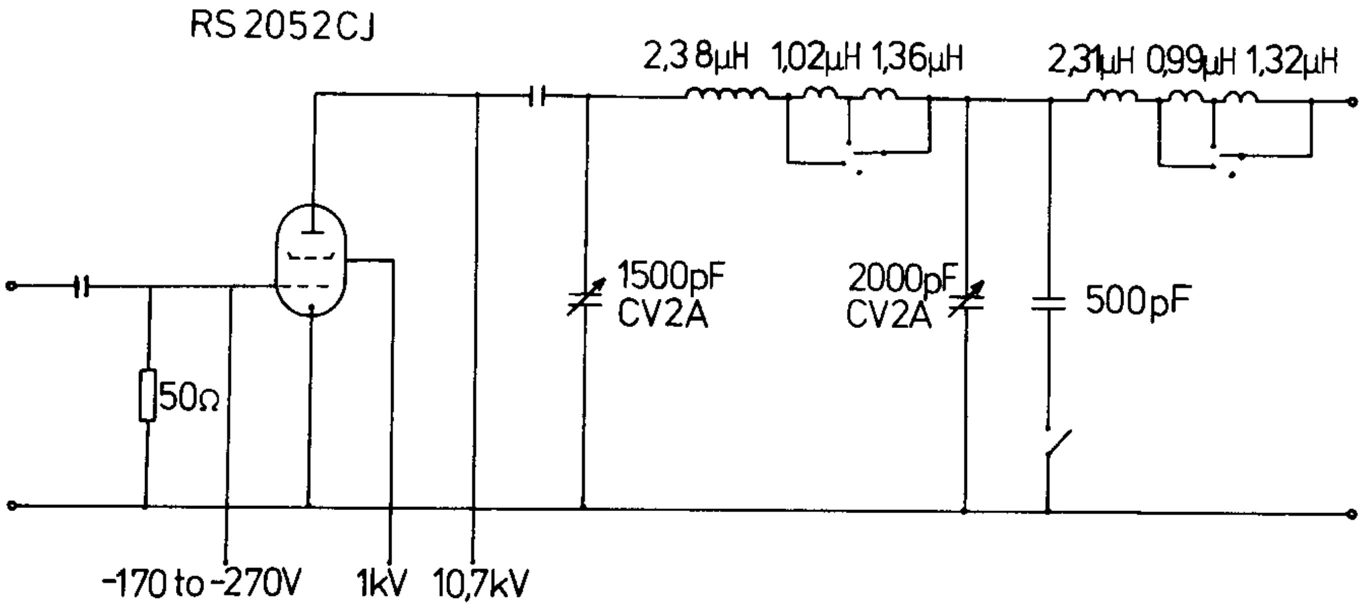


Figure 1

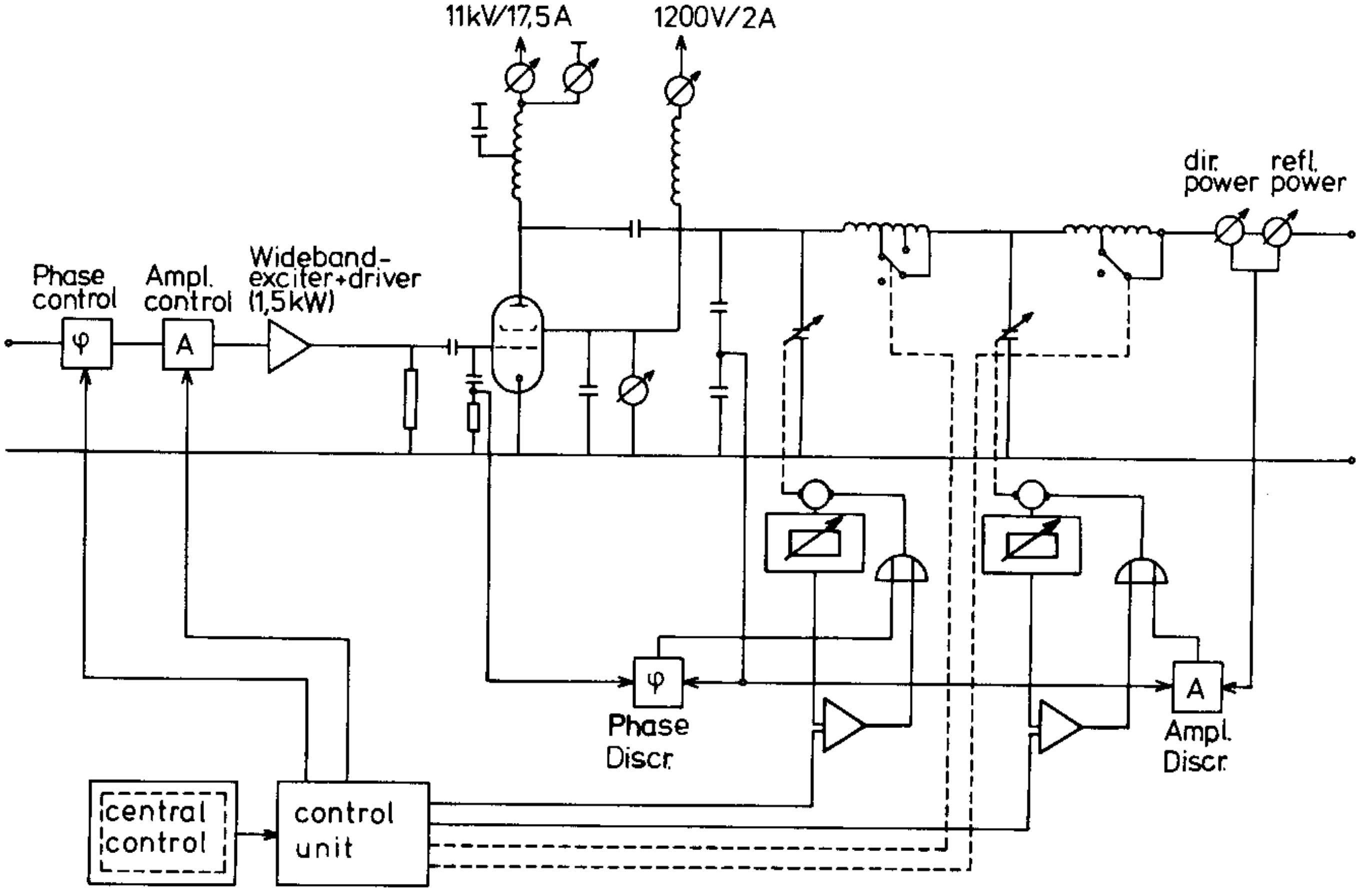


Figure 2

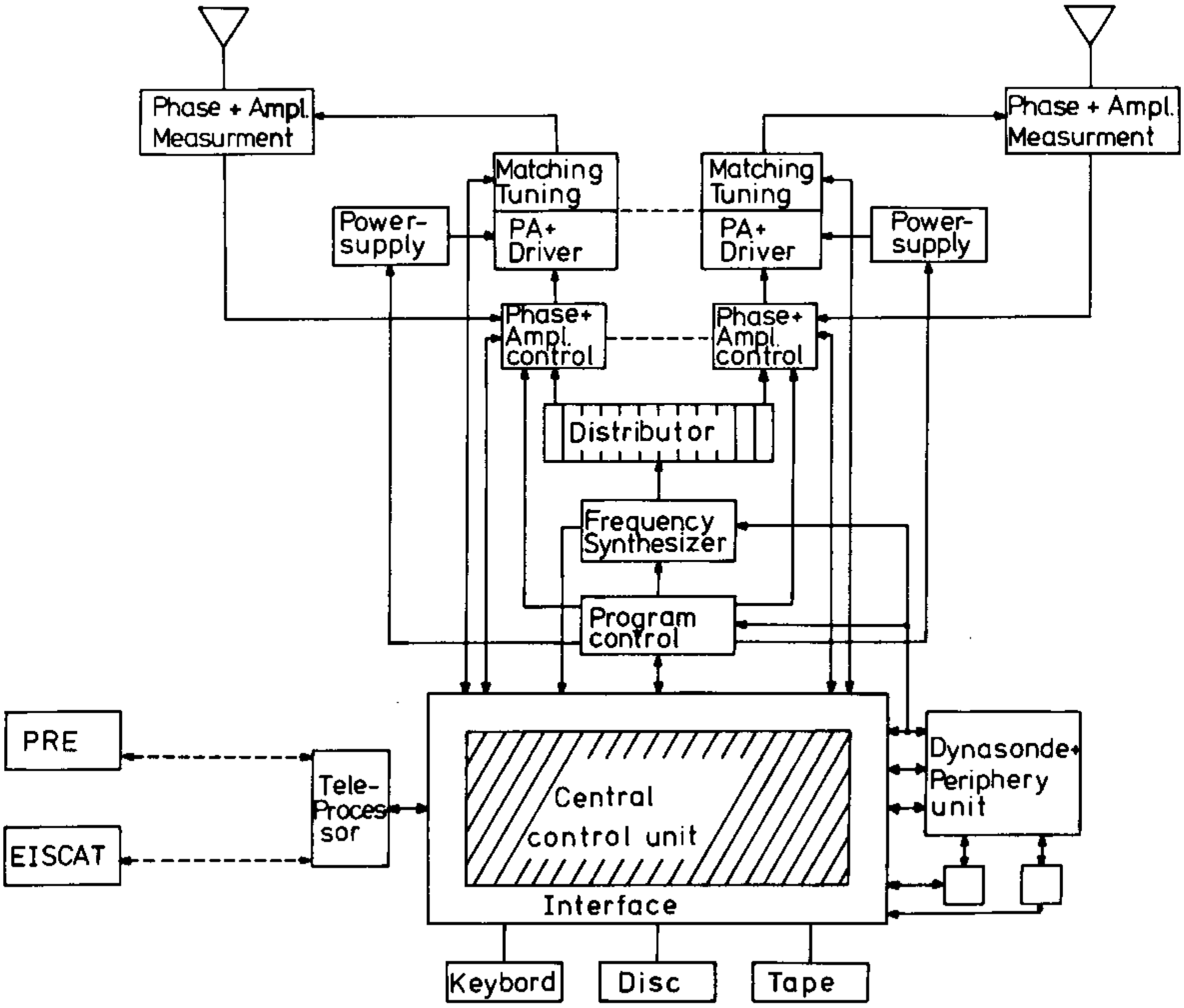
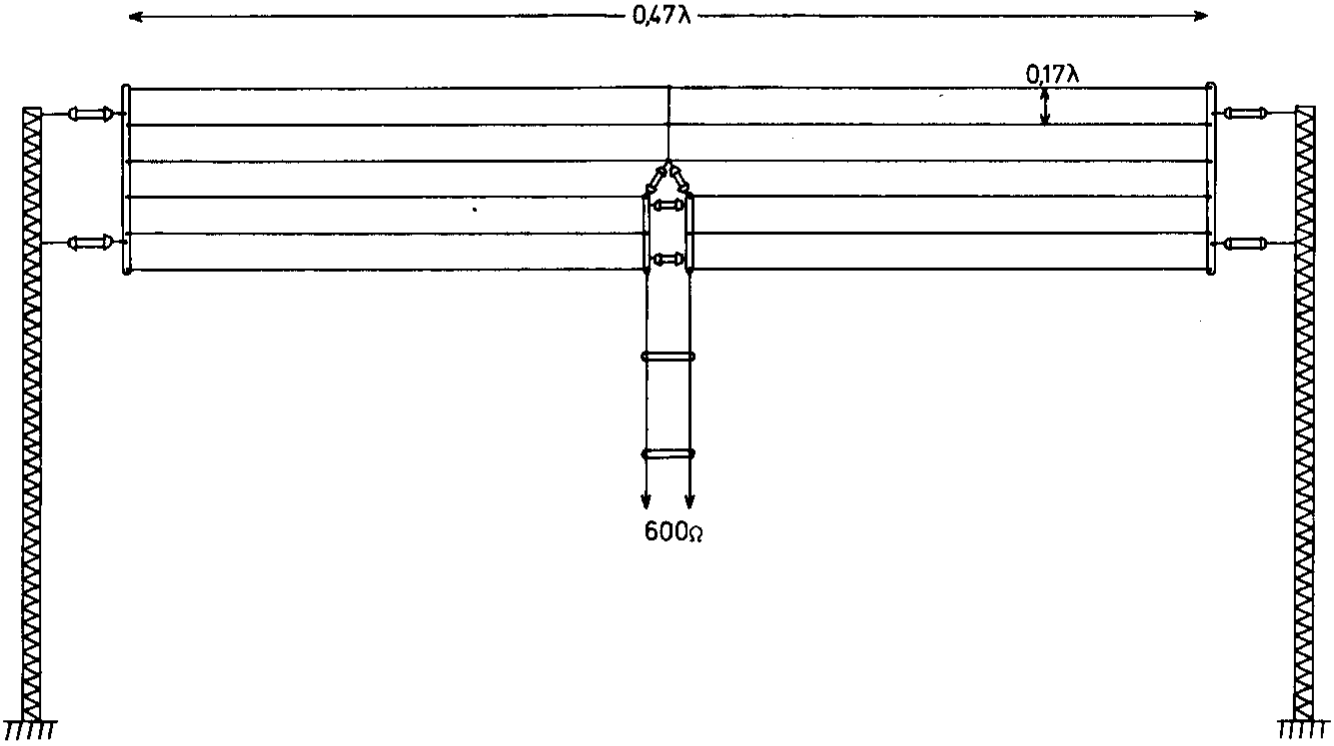


Figure 3



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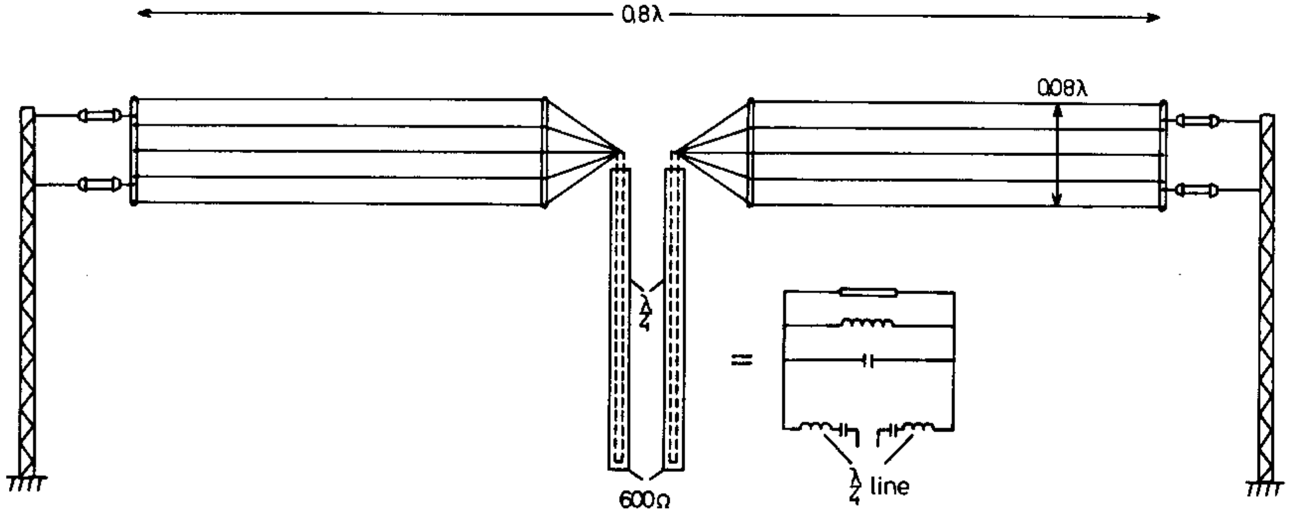

Figure 5

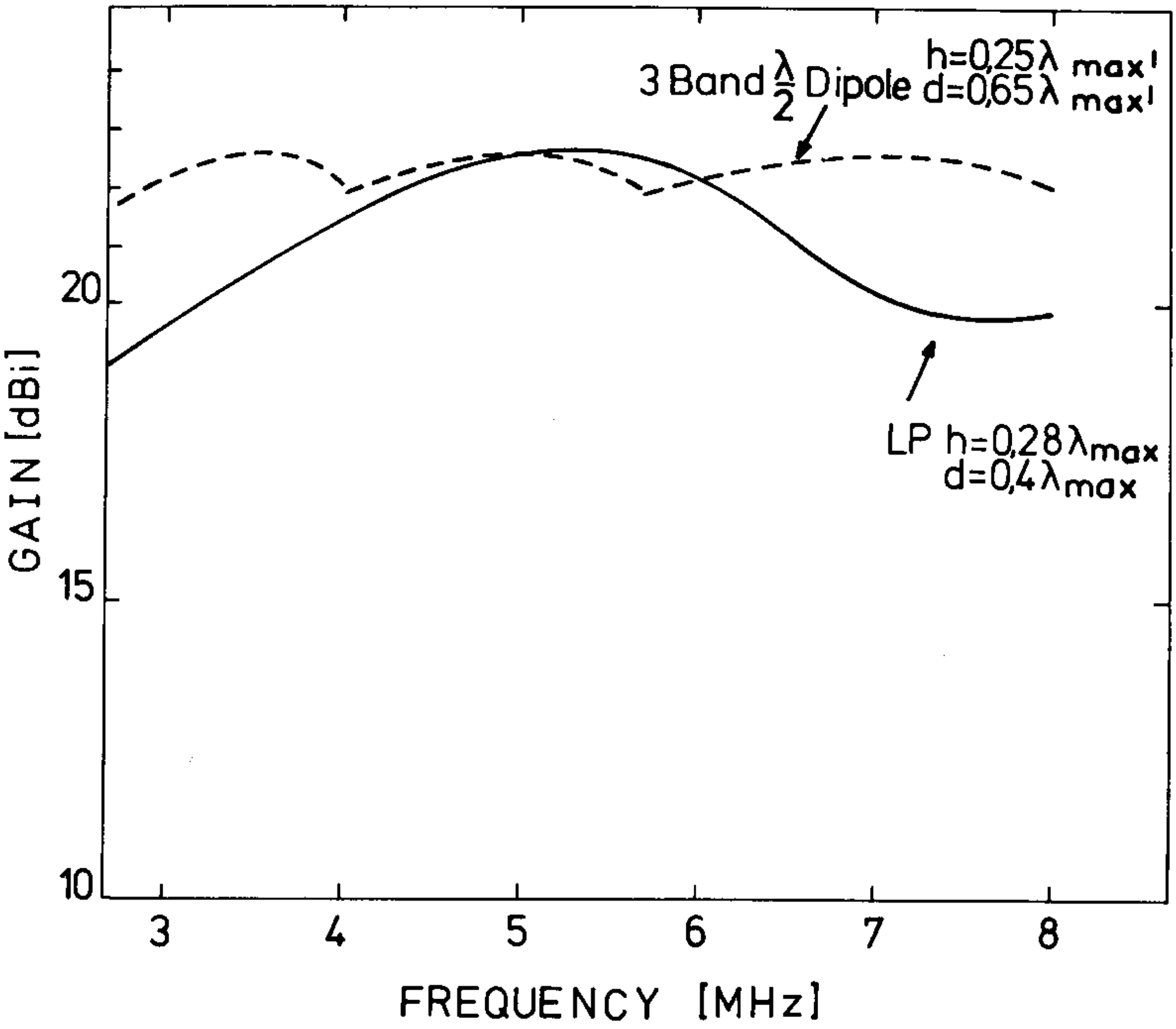

Figure 6