NEW TOOLS FOR AM NETWORK MEASUREMENTS

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Within the past year new instrumentation for making RF impedance measurements in the broadcast range has become available at modest cost. The instrument is the POWER AIM-120 from Array Solutions of Sunnyvale, Texas. The instrument is a single port vector impedance analyzer. It has a useful frequency range from 100 kilohertz to 120 megahertz making it an excellent tool for AM and FM transmission line and network measurements. The relatively high immunity to incoming RF energy makes it possible to make accurate, reliable, measurements in areas where other nearby broadcast stations are operating. The instrument can make measurements on a broadcast antenna with an RF voltage up to about 40 volts peak at its terminals. This is roughly equivalent to a 1.5 volt/meter field for a 190 degree tower, a level well beyond the range of the GR-916, 1606 and Delta OIB series RF Bridges when used with the Potomac Instruments or Delta Electronics frequency synthesizers and detectors. The accuracy of the instrument is dependent on the accuracy of the radio frequency calibration standards and the measurement technique of the operator. The instrument is used with a companion laptop computer. Both may be operated on battery power. The instrument weighs less than one pound!

The “brains” of the instrument are contained in the software used with the laptop to extract vector quantities representing the voltage across the measurement port and the current into the port. The magnitudes and angles of the two quantities are manipulated mathematically in the associated computer to extract the impedance and associated angle of the measured impedance. From this information several parameters may be calculated and displayed graphically as a function of frequency or in the form of a Smith Chart. Among the parameters are: series resistance and reactance, parallel equivalent impedance and its associated
angle, VSWR, reflection coefficient and return loss. All or any combination of the parameters may be displayed on the graphical presentations.

Multiple, user selected, markers are available for storage and retrieval of spot frequency data. This data may be exported to spreadsheet files for use in reports and analytical work.

The data may be displayed in Smith Chart form along with the marker data. A second Smith chart is available for visualization of the load orientation at any specified rotation angle. This is a very useful feature for evaluating adjustment of antenna coupling networks when preparing a system for digital transmission. The sum of the transmitter output network delay and the transmission line delay between the network input and the transmitter output may be added together and used for the rotation value of the second Smith Chart. The second chart will then display the orientation of the system at the RF Power Amplifier terminals within the transmitter. It is possible to zoom in on the plotted area of the data by factors up to 5:1 for clarity. Reviewing the marker data for this orientation will immediately confirm the orientation and symmetry of the load presented to the RF power amplifier. This is a very nice feature to have when working under pressure in the middle of the night!

The following examples are shown to illustrate some of the capabilities of the instrument.

**ANTENNA SYSTEM IMPEDANCE MEASUREMENTS**

For IBOC digital transmission, symmetry and low VSWR are required at the radio frequency amplifier output terminals within the transmitter to support the digital transmission system. This is also desirable for conventional AM transmission as it assures maximum sideband energy with minimum distortion in the transmitted waveform. In most cases, the property may not be directly measured, but may be readily modeled using the transmitter manufacturer’s stated phase shift across the RF output network in the transmitter. The stated phase shift may be entered into
the software and the resulting impedance orientation, VSWR and symmetry may be readily displayed.

Figure 1 is a block diagram of a transmission system operating on 1040 kilohertz. The system uses a transmission line, 134 feet long, with a propagation velocity of 88 percent, resulting in a phase delay of 58 degrees at the operating frequency. The transmitter is a B. E. AM-1A having a phase shift in its output network of 210 degrees. Thus the total phase shift from the RF power amplifier output to the antenna coupler input is -268 degrees.

Figure 2 is a plot of the impedance and VSWR versus frequency of the input to the antenna coupler for a +/- 20 kilohertz sweep about the operating frequency. The resistance is very nearly flat across the passband, having been adjusted to be so with relatively low reactance in the antenna coupler design. The resistance is shown as a solid orange curve. Reactance is plotted as a lime green curve (very nearly a straight line). The red curve is plotted as a solid red line. The dashed line appearing above the VSWR curve is the recommended limiting VSWR of 1.40:1. The numbered dashed red vertical lines are the seven markers at five kilohertz intervals.

Figure 3 is a Smith chart plot of the graphical data from Figure 2. The presentation has been zoomed in by a factor of 5 for clarity. The markers are shown each five kilohertz and the maximum VSWR of 1.4:1 is shown as a green circle. It can be readily seen that all sideband frequencies are well within the maximum limit of 1.4:1.

Figure 4 shows the table of data at the marker frequencies in terms of resistance, reactance and VSWR. The polar impedance and angle are also shown.

The IBOC digital system requires excellent symmetry and low VSWR at the radio frequency power amplifier terminals within the transmitter. The symmetry is readily expressed as a ratio of the VSWR of the sideband pairs. A ratio of 1.035 is the recommended maximum value within +/-5.0 kilohertz of the carrier frequency and is desirable for the entire passband. As noted in the chart, the worst case
deviation is less than 1.01 for the entire sweep. This is the result of proper design of the antenna coupling network. For proper operation of the system we must now rotate the values obtained at this point to present the proper load to the RF PA output terminals. The total required phase shift may be readily determined by rotating the Smith Chart by the specified phase shift value of the transmitter output network and viewing the resultant display. Those experienced with the Smith Chart will readily see that an additional fifty to sixty degrees of delay is required to place the final curve squarely on the parallel resonance circle in the R-X plane. Figure 5 illustrates this orientation. It should be present at the transmitter output terminals. The marker data of Figure 6 should be obtained at this point with an RF bridge or the plot may be verified by simply moving the Power Aim-120 to the transmitter output terminals and viewing the resultant Smith Chart and marker data package.

From this point, an additional 210 degrees of rotation will result in the Smith Chart display of Figure 7. This display has a total phase shift from the antenna coupler input of 258 degrees. It has nearly perfect symmetry about the resistance axis and very nearly equal and opposite reactances in the sideband pairs as shown in the marker chart of Figure 8. The system should perform very well with the IBOC system.

**TRANSMISSION LINE MEASUREMENTS**

Installation and adjustment of directional antenna systems require accurate knowledge of the characteristics of the Antenna Monitoring System. One of the critical elements of the system is knowledge of the characteristics of the transmission lines which carry the information obtained from the current sampling apparatus to the antenna monitor. Both the electrical length and the impedance of the line are needed for proper adjustment of the system. The POWER AIM-120 may be used to obtain these measurements quickly and accurately. When the approximate length of the line is known, a sweep of the first pair of open circuit resonant frequencies may be calculated. When the length is unknown, a “scattershot” may be made by starting at the lowest frequency of the instrument
(100 kilohertz) and sweeping to a couple of megahertz. The sweep may be refined based on the resulting plot.

Figure 9 shows a graphical presentation of the input impedance of a length of 3/8 inch low density foam transmission line commonly used for sampling systems in directional antenna systems. It shows the first three quarter wave open circuit frequencies. The markers numbered 1 and 4 are located at these points as shown on the Smith Chart plot of Figure 10 where markers 1 and 4 may be seen on the resistance line near the short circuit point. Markers 2 and 3 are located +/- 45 degrees from this point with marker 3 being midway between the first open circuit resonance point and the second short circuit resonance point.

Figure 11 is the marker data tabulation for this Smith Chart. The frequencies where the reactance is very low (close to zero) allow the electrical and physical lengths of the line to be calculated. The markers for the frequency pair 45 electrical degrees from the resonance point show the measured impedance of the line, in this case very near the specified impedance of 50 ohms.

There is presently a Rulemaking proposal before the Federal Communications Commission seeking to simplify the initial adjustment of directional antenna systems by use of Method of Moments modeling of the array. One of the proposed requirements for implementation of this procedure is accurate characterization of the antenna monitoring system, particularly with regard to the sampling system installation. The proposal requires periodic recertification of the sampling system. One part of the proposed commissioning and periodic recertification requires measurements of the sample lines, both the electrical lengths and impedance of the lines. The above example illustrates the use of the POWER AIM-120 to perform this task.
FIGURE-1

BLOCK DIAGRAM OF TRANSMITTER PLANT

FIGURE-2

GRAPHICAL PLOT OF ACU INPUT (SC-1)
FIGURE-3
SMITH CHART PRESENTATION OF ACU INPUT

FIGURE-4
MARKER DATA AT ANTENNA COUPLER INPUT

<table>
<thead>
<tr>
<th>Marker</th>
<th>Freq</th>
<th>SWR</th>
<th>SWR_Ratio</th>
<th>Rs</th>
<th>Xs</th>
<th>Zmag</th>
<th>Theta</th>
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<tbody>
<tr>
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<td>1.025</td>
<td>1.2318</td>
<td>1.0080 (1:7)</td>
<td>49.01</td>
<td>-10.29</td>
<td>50.08</td>
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<td>2</td>
<td>1.030</td>
<td>1.1488</td>
<td>1.0091 (2:6)</td>
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<td>-6.85</td>
<td>49.72</td>
<td>-7.91</td>
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<tr>
<td>3</td>
<td>1.035</td>
<td>1.0686</td>
<td>1.0093 (3:5)</td>
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<td>-3.26</td>
<td>49.57</td>
<td>-3.77</td>
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<tr>
<td>4</td>
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<td>1.0075</td>
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<td>49.75</td>
<td>0.28</td>
<td>49.75</td>
<td>0.32</td>
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<tr>
<td>5</td>
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<td>1.0786</td>
<td></td>
<td>49.95</td>
<td>3.78</td>
<td>50.09</td>
<td>4.33</td>
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<tr>
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<td>1.1593</td>
<td></td>
<td>50.17</td>
<td>7.41</td>
<td>50.71</td>
<td>8.40</td>
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<tr>
<td>7</td>
<td>1.055</td>
<td>1.2417</td>
<td></td>
<td>50.43</td>
<td>10.88</td>
<td>51.59</td>
<td>12.18</td>
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</table>
FIGURE 5
SMITH CHART PRESENTATION OF TRANSMISSION LINE INPUT
AT TRANSMITTER OUTPUT (SC-2)

FIGURE 6
MARKER DATA FOR TRANSMISSION LINE INPUT

SWRref = 1.40
Theta = 58
FIGURE-7
SMITH CHART PRESENTATION OF RF PA LOAD

SWR ref= 1.40
Theta = 268

FIGURE-8
MARKER DATA FOR RF PA LOAD
FIGURE 10
SAMPLE LINE MARKER DATA

<table>
<thead>
<tr>
<th>Marker</th>
<th>Freq</th>
<th>SWR</th>
<th>SWR_Ratio</th>
<th>Rs</th>
<th>Xs</th>
<th>Zmag</th>
<th>Theta</th>
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</thead>
<tbody>
<tr>
<td>[ 1]</td>
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<td>14.0988</td>
<td>1.5404 (1:4)</td>
<td>3.55</td>
<td>-0.01</td>
<td>3.55</td>
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<tr>
<td>[ 2]</td>
<td>0.248</td>
<td>10.2589</td>
<td>1.1957 (2:3)</td>
<td>9.77</td>
<td>49.65</td>
<td>50.60</td>
<td>78.87</td>
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<tr>
<td>[ 3]</td>
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<td>12.2663</td>
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<td>8.13</td>
<td>-49.53</td>
<td>50.19</td>
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<tr>
<td>[ 4]</td>
<td>0.500</td>
<td>9.1529</td>
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<td>5.47</td>
<td>-0.21</td>
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