A MODEL FOR PREDICTING SURGE CHARACTERISTICS INTERNAL TO BROADBAND DISTRIBUTION EQUIPMENT

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Abstract

The characteristics of external surge waveforms and energy levels are well documented for both aerial and underground coaxial systems. The internal stresses applied to the complex electronic system of a modern broadband distribution amplifier are less known and documented. This paper presents a model which accurately predicts the magnitudes and waveshapes at certain key points in the amplifier. The results of the analysis are then used to determine proper and effective circuit design and protective device use.

1.0 INTRODUCTION

Surges and transients are a common cause of CATV failures. Ironically, major system outages can arise when the only CATV device that fails is a transient protection device. Since the surge problem can be very severe and outages are very expensive, it is important to evaluate where protection is needed in order to protect electronic equipment from whatever residual surges intrude. The following sections examine transients and surges found in CATV systems and their affect on the internal components of a broadband amplifier.

2.0 WHERE DO TRANSIENTS ORIGINATE FROM?

Transients capable of causing malfunctions are erratic in nature, come in a variety of waveforms and energy levels, and emanate from a number of sources. The transient sources most common to CATV systems are lightning and power switching.

Lightning does not need to directly strike CATV equipment to create havoc. In fact, the most frequent effect of lightning on distribution lines is longitudinally induced sheath currents. These are brought about by the inductive coupling of indirect strikes through the neutral sheath. Protection against the devastating effects of a direct lightning strike will not be considered in this paper. No matter what protection scheme and grounding measures are taken, a direct lightning strike will inflict extensive damage.

Power switching transients result when the current in an inductor is suddenly interrupted and a spike voltage proportional to Ldi/dt is generated. These can originate from either residential switching (relays, heavy machinery, etc.) or from power company faults. These surges can enter the CATV AC-to-AC power supply via the power company secondary, or be induced into the system via nearby power lines. The AC-to-AC power supply can itself generate a switching transient when the transformer primary is energized and de-energized. This particular surge is well documented and will be discussed separately at the conclusion of this paper.

3.0 WHAT DO THESE SURGE WAVEFORMS LOOK LIKE?

Although surge energies range from that of a spark of static electricity to a direct lightning hit, simplified repeatable surge standards have been designated. This is a result of extensive studies on the surge waveforms present on power grid and telecommunication networks, thus making protective circuit design both reasonable and effective. Figure 1 lists some of these surge standards.

ANSI C37.90a	IEEE C62.33
CCITT K.12	IEEE 465.1
CCITT K.17	IEEE 587
FCC 19528 Doc 68	IEEE 932
IEC 60-2	REA PE-60
IEC 255-4	REA PE-80
IEC 255-5	UL 217
IEC 255-6	UL 268
IEC 255-10	UL 943

Figure 1
SELECTED SURGE STANDARDS

Based upon actual occurrences, two representative waveforms have been designated. The first, based on indoor AC power lines, is the oscillatory waveform shown in Figure 2. These are characterized by a steep rise time and rapid decay time. The second waveform, based on outdoor power and telecom lines, is the impulse waveform shown in Figure 3. These are characterized by an undirectional, exponential rise and decay waveshape.

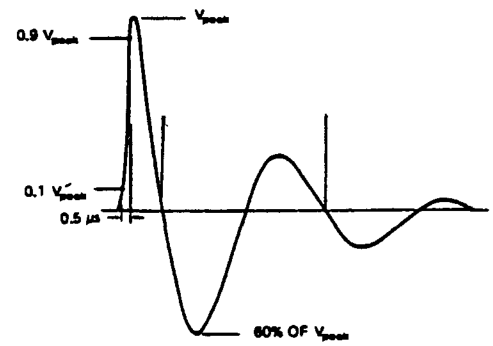


Figure 2
TYPICAL BALANCED TWO-WIRE LINE SURGE

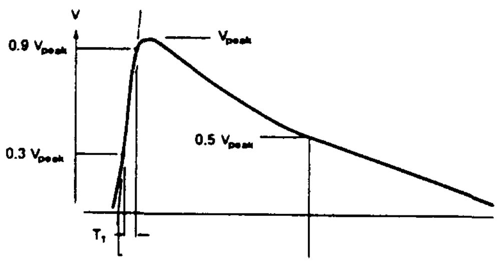


Figure 3
TYPICAL COAXIAL LINE SURGE

Most test standards show that the longer duration, uni-directional impulse wave is dominant in the communication field. This may be due to the high frequency filtering and greater shielding properties of the coaxial jacket, which tend to reduce amplitude and cause elongation of the wave. Fundamental surge data on .412 in aerial coaxial aluminum tube cable is contained in the Bell-Northern research paper on lightning surges in open wire, coaxial, and paired cable. The abstract of this paper states:

> "Oscillograms of longitudinal surge voltages occurring in open wire, paired, and coaxial cable were continuously photographed during each season using an automatic camera system especially developed for the investigation. On completion, approximately 10,000 useful surge photographs were obtained and analyzed.
>
> The results indicate that a standard test wave, with 1000 volts peak and 10 x 1000µs wave shape, simulates 99.8% of the lightning surges encountered in paired and coaxial cables."[1]

This paper also reports that "all surge protection devices were removed where possible during the investigation."

A typical coaxial cable surge is presented by Bell-Northern in Figure 4 and a distribution of surge maximum peak voltage amplitude in Figure 5.

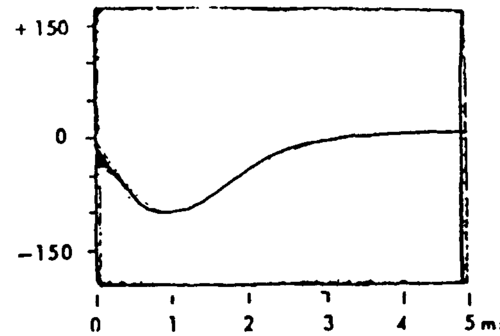


Figure 4
TYPICAL COAXIAL SURGE

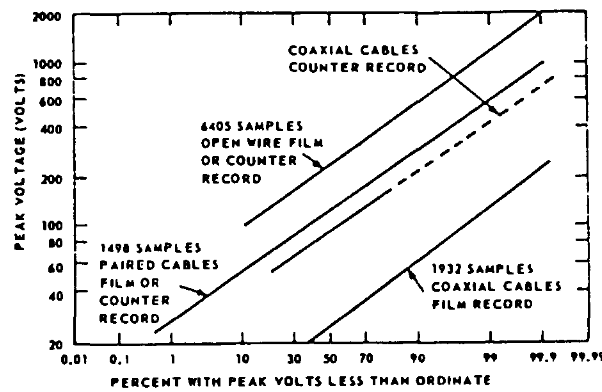


Figure 5
DISTRIBUTION OF SURGE MAXIMUM
PEAK VOLTAGE AMPLITUDE

The first step in predicting the internal surge characteristics of a CATV amplifier is to select an applicable surge standard. After evaluating the research findings and standards for telecom lines, a 1.5 kv 10 x 1000 waveform was chosen as a standard for a 'worst case' surge introduced into a CATV amplifier. An oscillatory waveform was also tested to simulate possible surges introduced through the power company secondary. No attempt was made to simulate and test for the relatively low voltage, long duration surges caused by unbalanced loading in the power grid.

4.0 WHAT INTERNAL STRESSES RESULT FROM THIS WORK?

Computer analysis on key sections of a two-way cable powered broadband trunk amplifier is useful in estimating the internal surge tolerance levels. This information can be used to help decide where protection is needed and as verification for actual lab tests.

A computer-aided transient analysis was obtained on circuit components in the baseplates, diplex filters, powered housing (power transformer and power supply), and coupling capacitors to the RF hybrids when an input port is surged by the impulse standard waveform. Key investigation points are indicated by an asterisk on the block diagram shown in Figure 6.

Along with the theoretical analysis, actual surge testing is necessary to assure the design can withstand a full-blast surge. This will assure us of an inerrant quantitative understanding of the internal surge waveforms. A KeyTek model 424 mainframe and PN241 module was used to inject our standard waveform into a conventional two-way CATV distribution amplifier. Surge photographs were taken with an HP1411 100 MHz storage oscilloscope to record surge voltage levels at key points in the amplifier. Gas-filled surge voltage protectors (SVP's) were removed from the amplifier (except where indicated) for these lab tests.

Each location lettered in Figure 6 was monitored for 20 alternating positive and negative undirectional pulses before a photograph was taken. A side-by-side comparison of lab work with the computer analysis is represented in Figures 7-12.

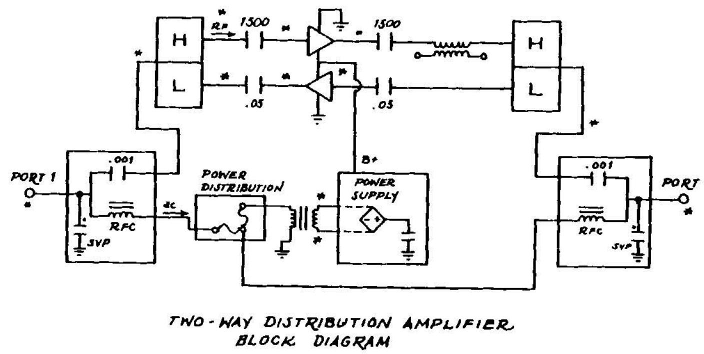
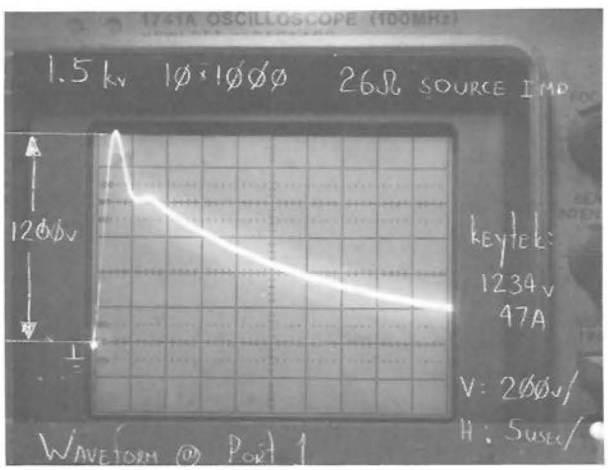


Figure 6



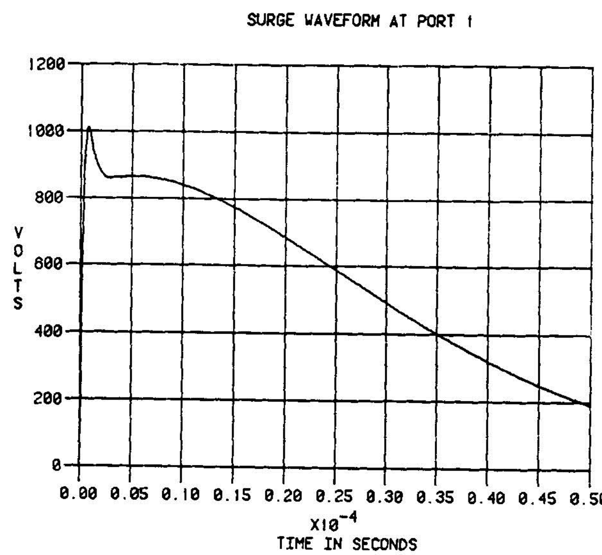
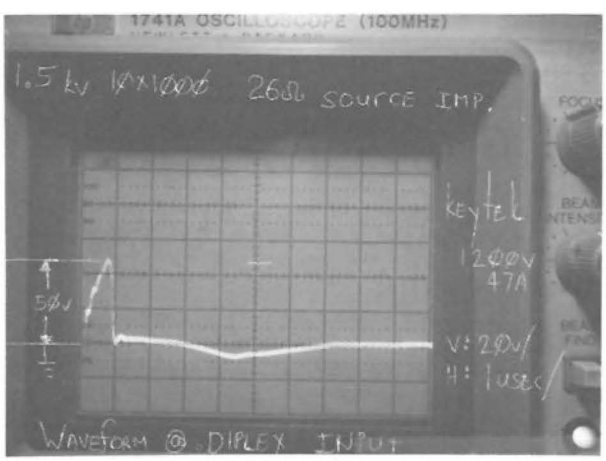


Figure 7
SURGE WAVEFORM AT Port 1



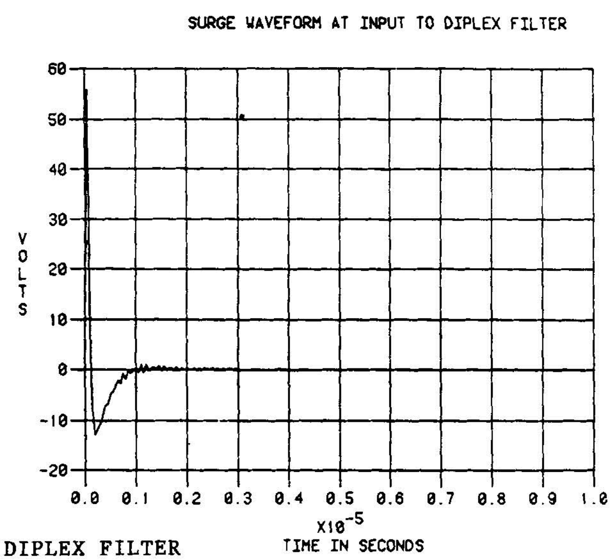


Figure 8
SURGE WAVEFORM AT INPUT TO DIPLEX FILTER

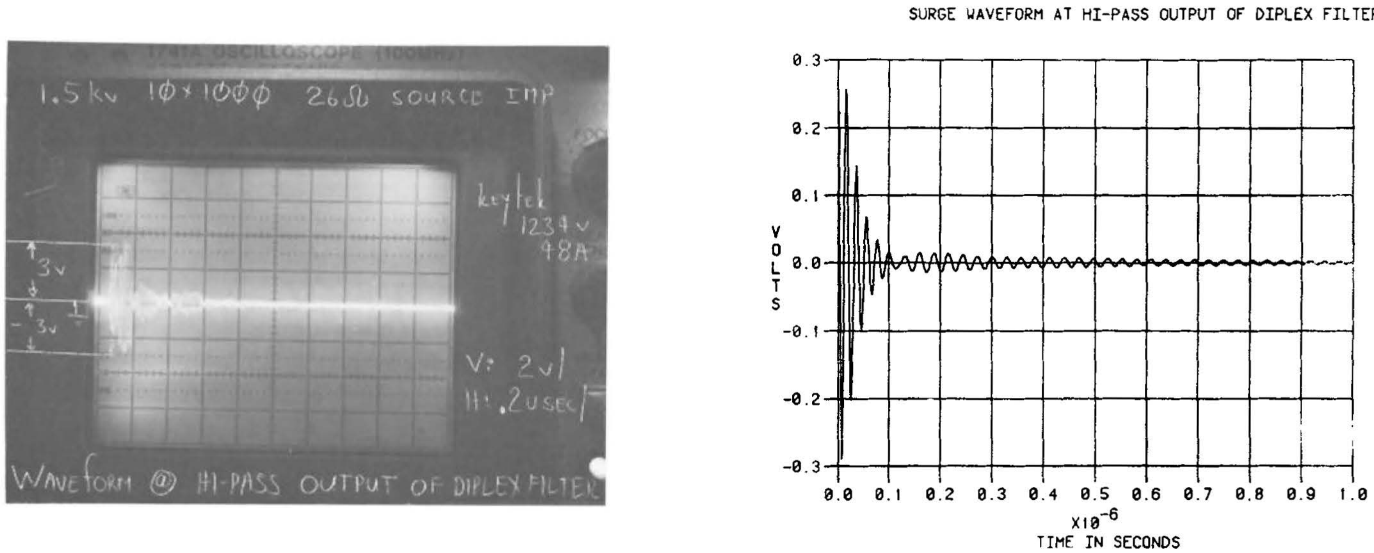


Figure 9
SURGE WAVEFORM AT HI-PASS OUTPUT OF DIPLEX FILTER

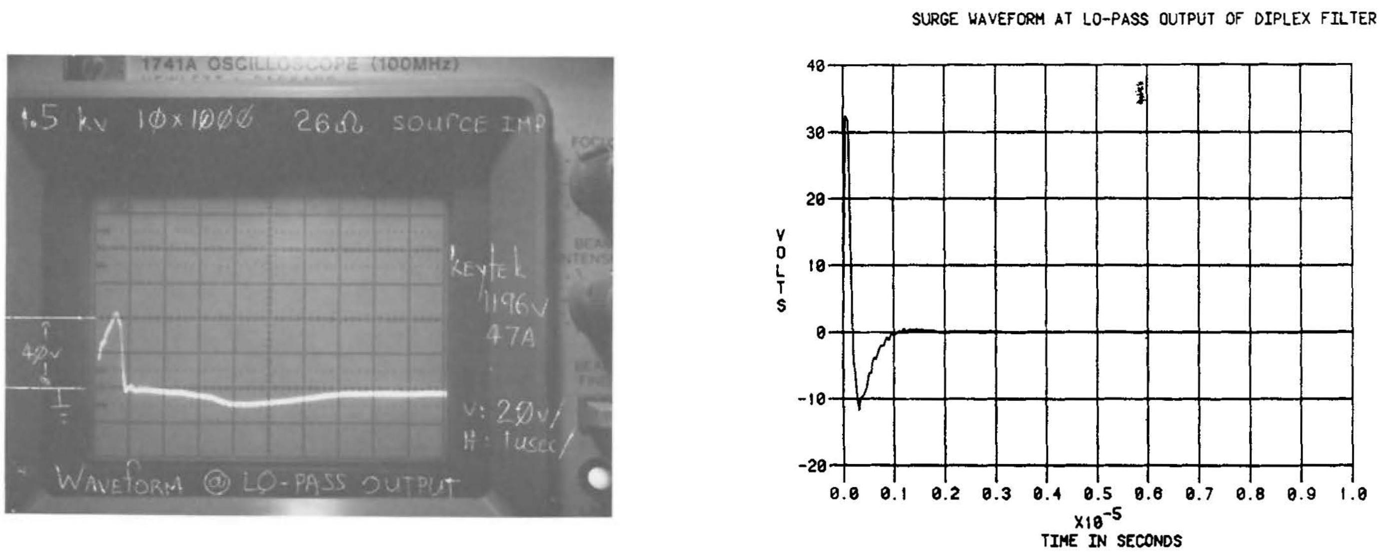


Figure 10
SURGE WAVEFORM AT LO-PASS OUTPUT OF DIPLEX FILTER

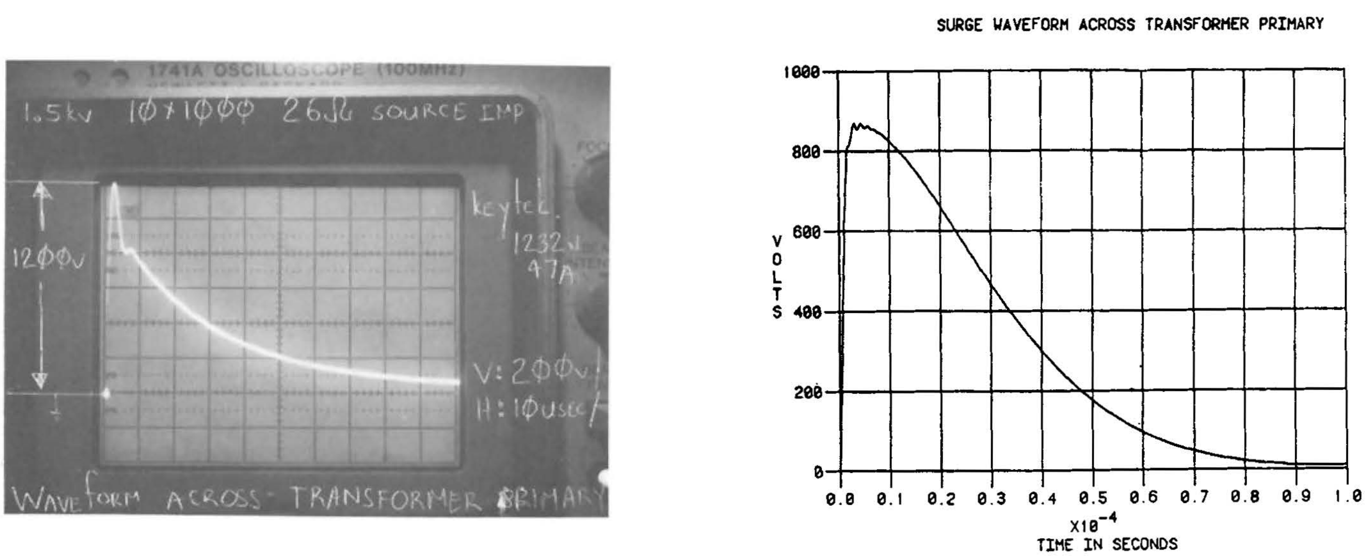


Figure 11
SURGE WAVEFORM ACROSS TRANSFORMER PRIMARY

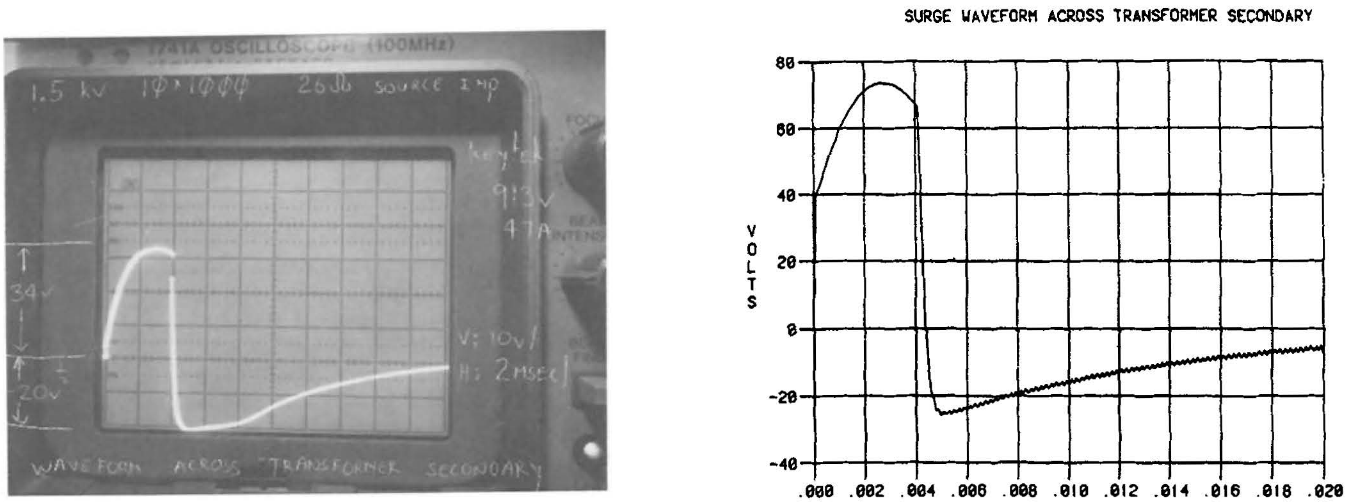
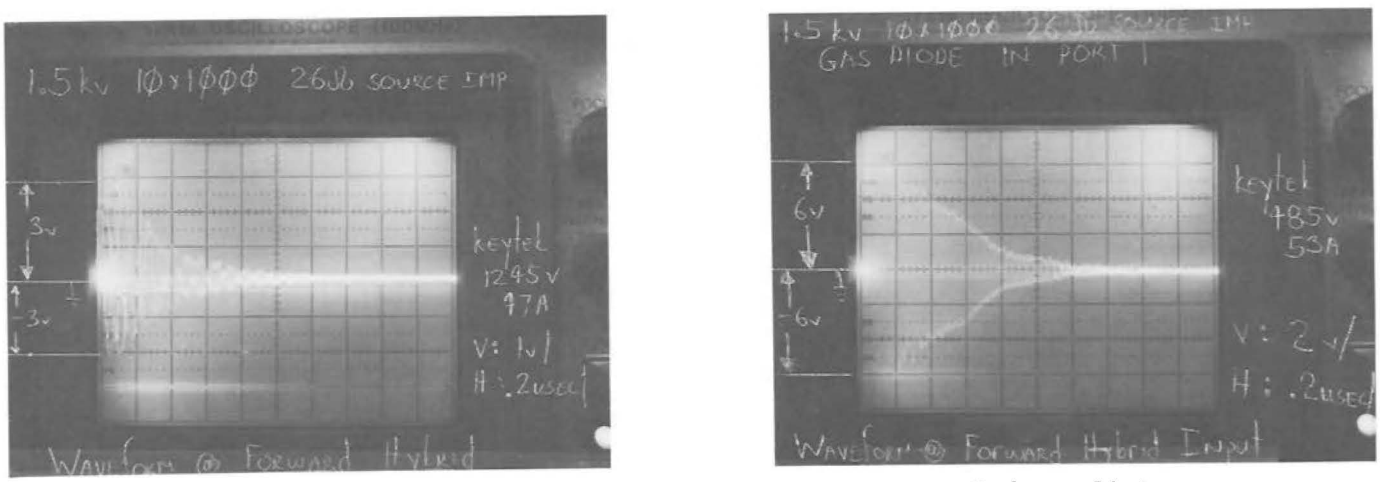


Figure 12
SURGE WAVEFORM ACROSS TRANSFORMER SECONDARY

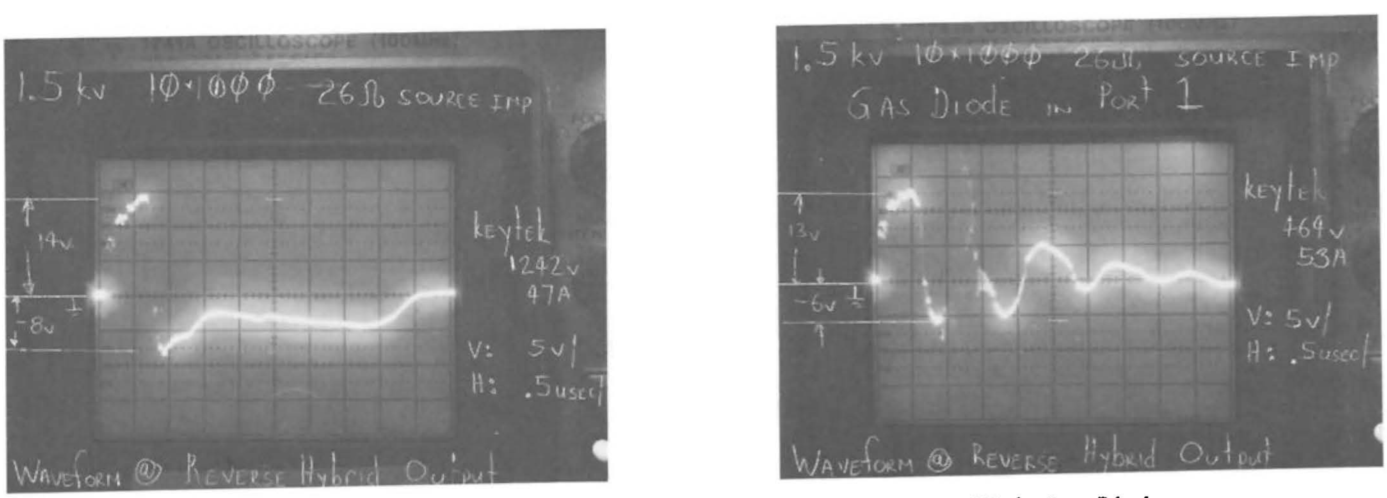
Figures 13-15 document voltage waveforms at the RF hybrids with and without gas diodes placed at port 1. Gas diodes alter the waveform somewhat, but do not significantly reduce magnitude or duration.



Without Gas Diode

With Gas Diode

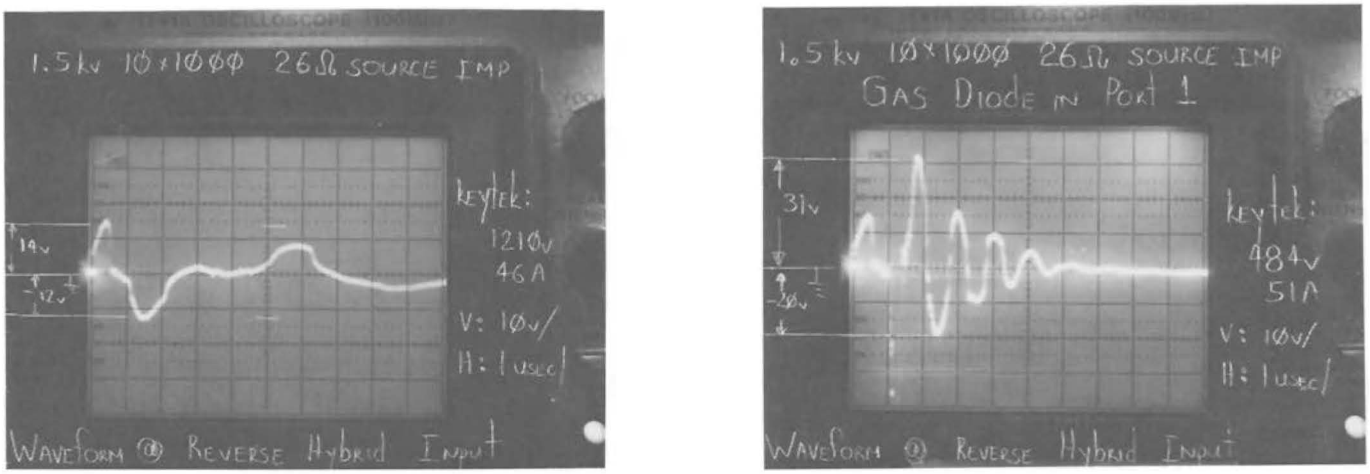
Figure 13
SURGE WAVEFORM OF FORWARD HYBRID



Without Gas Diode

With Gas Diode

Figure 14
SURGE WAVEFORM AT REVERSE HYBRID OUTPUT



Without Gas Diode

With Gas Diode

Figure 15
SURGE WAVEFORM AT REVERSE HYBRID INPUT

Figure 16 shows the surge remnant present on B+ when the switching regulator power supply is powered. Figures 17-18 show voltage waveforms at port 1 and across the transformer primary with gas diodes. Gas diodes reduce surge magnitude and duration to the power supply.

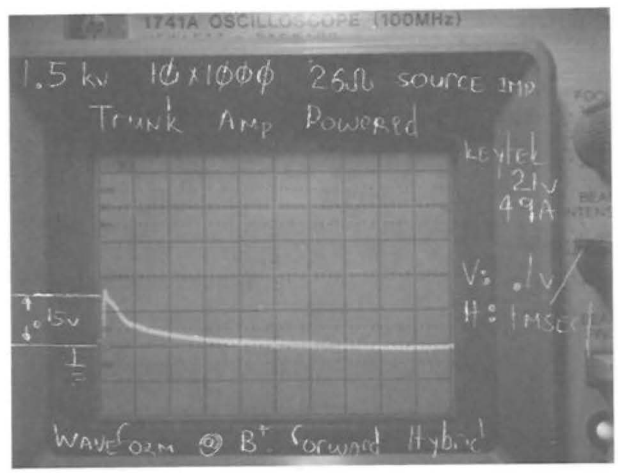


Figure 16
SURGE WAVEFORM AT B+

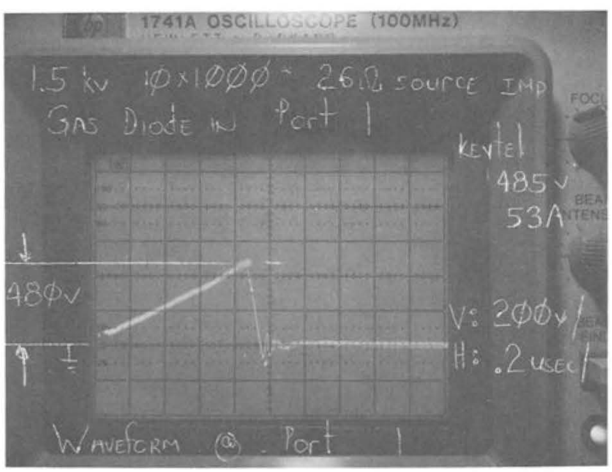


Figure 17
SURGE WAVEFORM AT PORT 1 WITH GAS DIODE

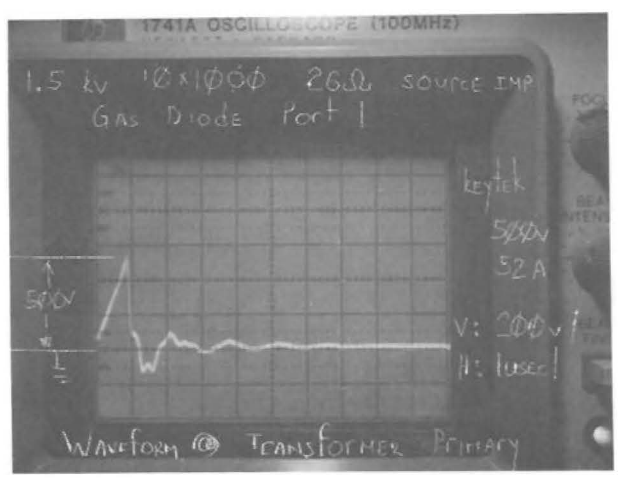


Figure 18
SURGE WAVEFORM AT TRANSFORMER PRIMARY WITH GAS DIODE

Figures 19-25 show various key points in the distribution amplifier when our standard test waveform is replaced with a 1.5 kv, .5 usec rise time, 100 KHz 'ring' wave. A KeyTek PN281LS module was used to simulate this oscillatory waveform which is typical of surges found on AC power lines.

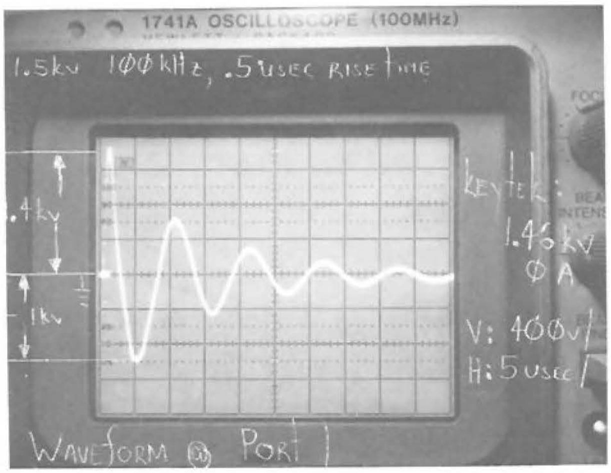


Figure 19
SURGE WAVEFORM AT PORT 1

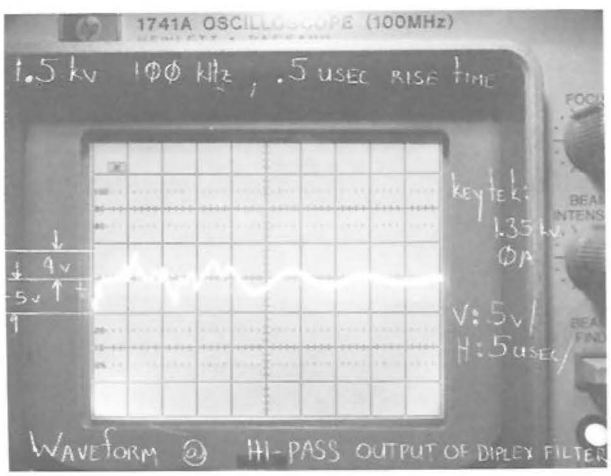


Figure 20
SURGE WAVEFORM AT HI-PASS OUTPUT OF DIPLEX FILTER

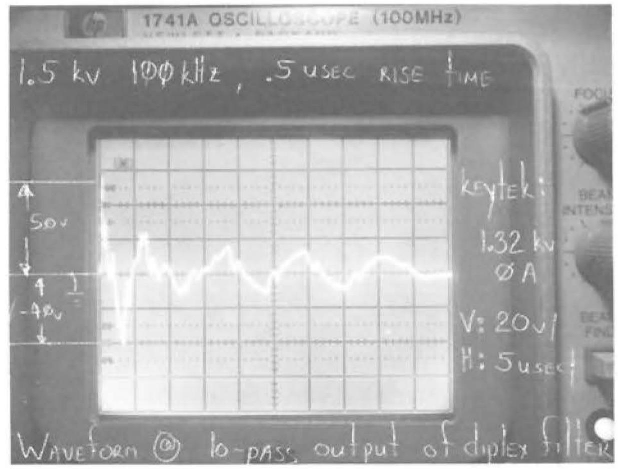


Figure 21
SURGE WAVEFORM AT LO-PASS OUTPUT OF DIPLEX FILTER

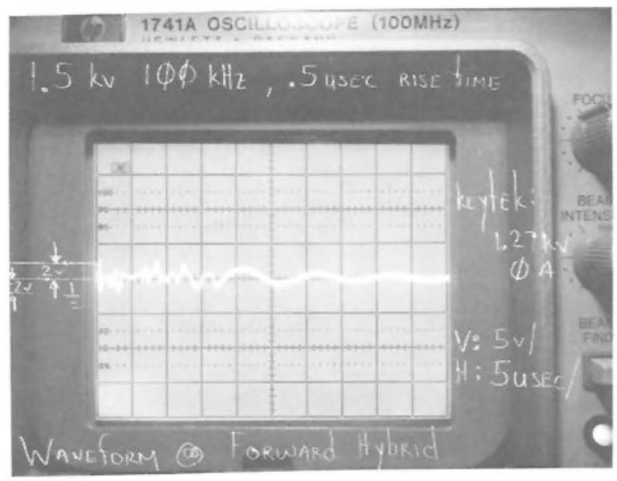


Figure 22
SURGE WAVEFORM AT FORWARD HYBRID

Figure 23
SURGE WAVEFORM AT REVERSE HYBRID OUTPUT

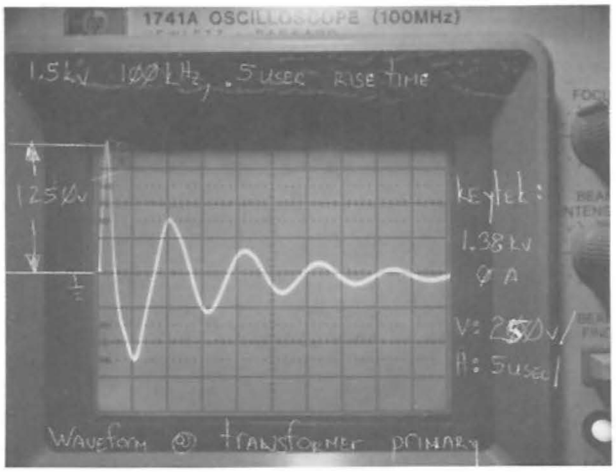


Figure 24
SURGE WAVEFORM AT TRANSFORMER PRIMARY

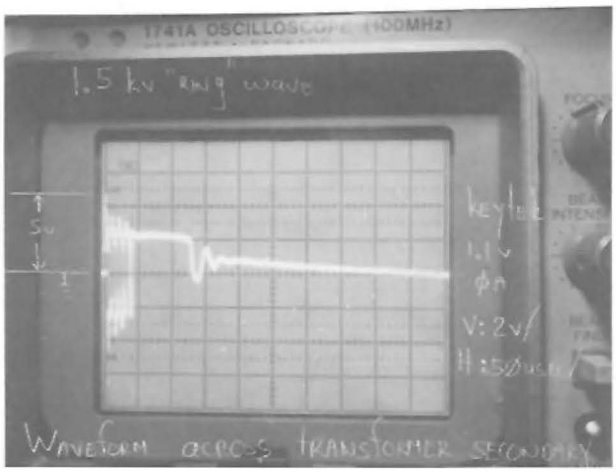
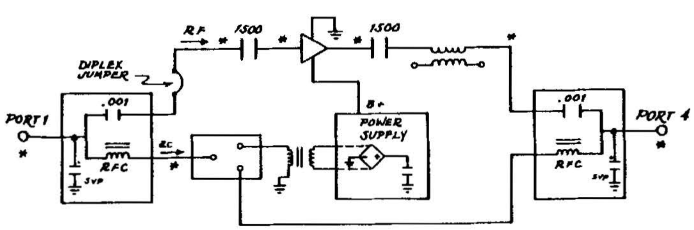


Figure 25
SURGE WAVEFORM AT TRANSFORMER SECONDARY

It is also possible to have a surge on a port where there is not a low impedance path to ground, a power supply for example. Therefore, data on a one-way trunk powered from an unsurged port will be presented here. A block diagram of such a trunk is shown in Figure 26.



ONE-WAY DISTRIBUTION AMPLIFIER BLOCK DIAGRAM

Figure 26

The lab results at Port 1, both sides of the coupling capacitor, and the hybrid input with gas diode in Port 1 are shown in Figures 27-30.

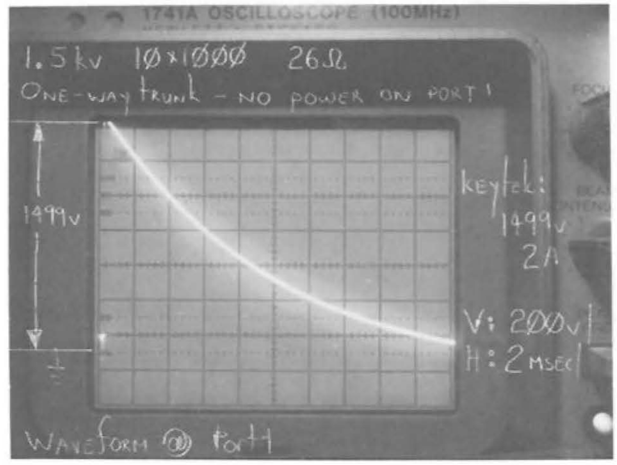


Figure 27
SURGE WAVEFORM AT PORT 1

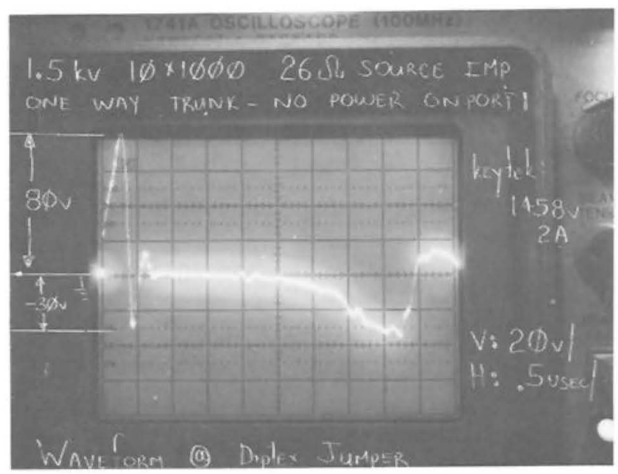


Figure 28
SURGE WAVEFORM AT DIPLEX JUMPER

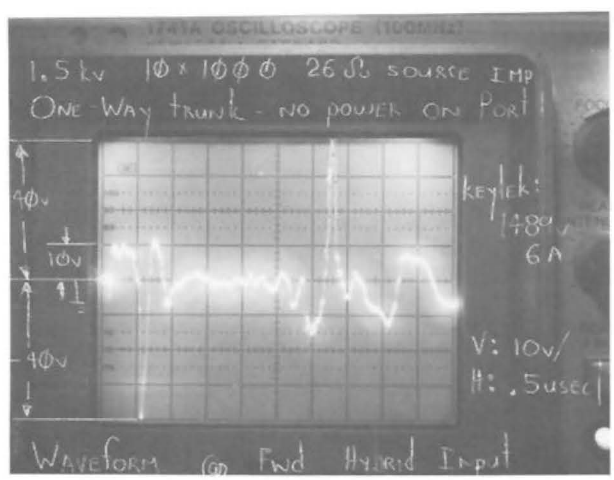


Figure 29
SURGE WAVEFORM AT FORWARD HYBRID INPUT

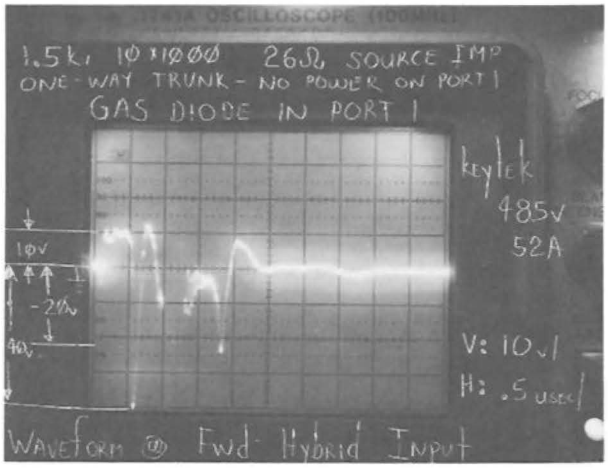


Figure 30
SURGE WAVEFORM AT FORWARD INPUT WITH GAS DIODE

5.0 WHAT NEEDS PROTECTION? (ANALYSIS OF DATA)

The preceding computer plots and lab photographs serve as excellent predictions of the internal stresses applied to a distribution amplifier when a "worst case" surge is applied. This data can now be analyzed to determine which components need protection.

Our data indicates that it is the low-pass section of the amplifier, namely, the power supply, which is most susceptable to surge damage. This is to be expected, since a Fourier analysis of our 10 x 1000 waveform will show most of the energy lies below 1 KHz. At these frequencies, the coupling impedance of our forward hi-pass section is greater than 100 K ohm and 3 K ohm for the reverse path section. We would, therefore, expect to see only remnants of the surge in the RF sections of the amplifier. The inductively coupled power supply is much more inviting for our transient (data taken for a one-way unpowered port.)

$$Z_C = \frac{1}{2\pi f(1500pF)}$$

Table 1 contains some conclusions drawn from our test results of a "worst case" surge.

3.2

Table 1

Item	Voltage Rating Required	Comments
Baseplate	All components must be able to withstand the full 1.5 kv 10 x 1000 surge	Baseplate capacitors susceptable to surge damage.
Diplex Filters	100 V components will give adequate protection	Waveform relatively "unaltered" by lo-pass section. A small remnant of the surge appears at the hi-pass output.
High & Lo RF Sections	Coupling capacitor should be a 100 V part	No surge damage through RF circuits.
RF Hybrids	No additional protection required	
Transformer	Requires a surge resistance of 1.5 kv on primary	Saturation/filtering provides excellent surge protection.
Power Supply	Normal operating voltage can dictate choice of voltage rating here when an isolating transformer is used.	Switch mode power supply damps input surges. Bridge rectifier protects electrolytics from negative surges.
SVP's	Must have a firing voltage below the rated value of the components on the baseplates.	If baseplate components can withstand a 1.5 kv surge and the above guidelines are followed, then SVP's are not needed

This table contains design guidelines for component ratings without relying on any surge limiting devices at the input to the amplifier. RF hybrid data sheets indicate that these devices can withstand a 1/40 surge of 4,410 V at the RF input, 15,624 V at the RF output, and 107-116 V on the B+ input.[2] Our hi-pass filtering, therefore, adequately protects the RF hybrids. Photographs of key points with SVP's are included to show the limitations of these devices, which are used almost without exception in the CATV industry. SVP's appear to protect only the baseplate of the amplifier.

A brief explanation for the discrepancies between the computer and lab results will be made here. When doing the computer analysis, certain factors were not taken into consideration. Saturation of the power transformer is one example. We would expect our power transformer to saturate during a test wave surge. Consequently, our secondary current will not be proportional to the turns ratio (as assumed by the computer). In addition, all filtering capacitors were assumed to be "ideal," ignoring the effects of ESR, ESL, and DC resistance. No attempt was made to take stray inductance and capacitance into consideration. Also in the 'computers circuit' we did not attempt to model the reverse RF path or RF hybrids, effecting the lo-pass section of the diplex.

In our lab work, common mode noise affected our low-voltage measurments in the hi-pass sections. To keep this to a minimum, photographs were taken in the differential mode with baluns or "co-axers" on the scope leads. This greatly reduced the problem, but at the same time the differential mode reduced the writing speed of the scope. This might have caused some additional error. Keeping in mind that the impulse was 1.5 kv, the difference between 3 V in the lab and 1.5 V for the computer analysis seems quite reasonable (see Figure 9).

6.0 WHAT ABOUT THE AC-TO-AC POWER SUPPLY TRANSIENT?

As mentioned earlier, the energizing and de-energizing of the AC-to-AC ferro-resonant power supply will produce transients in the CATV system. This transient can be as high as three times the normal operating voltage and last for two or three cycles of the operating frequency. This low frequency surge is rejected by the capacitively coupled RF circuitry, but the power supply must be protected from this type of surge. If a power transformer is used, a voltage limiting device placed across the transformer secondary can be used to protect the power supply of the amplifier from this high energy surge. This scheme has the advantage of using the impedance of the transformer in providing protection. If a transformerless supply is used, the input section of the power supply should be able to withstand the full 180 V surge.

7.0 SUMMARY

This paper described the surges and transients to be expected internal to a broadband CATV distribution amplifier. Once an understanding of the magnitudes and waveshapes of these internal stresses is obtained, proper and effective circuit protection can be accomplished. Table 1 is a chart showing design guidelines for such protection against induced overvoltages.

References

[1] Bennison E., Ghazi, A. J. and Ferland, P., "Lightning Surges in Open Wire, Coaxial, and Paired Cables," IEEE Transactions on Communications, Vol. Com-21, No. 10, October 1973.

[2] Grant, Al; Eachus, James, "Reliability Considerations in CATV Hybrids," Motorola Semiconductor Products, Inc. 1978.

[3] Palmer, James R., "Power and Lightning Surges In Coaxial Distribution Systems," C-COR Electronics, Inc., 1976-1977.

[4] "Surge Protection Test Handbook," KeyTek Instrument Corporation, Burlington, Massachusetts, 1982.

Acknowledgements

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