# MEASUREMENT OF INTERMODULATION PRODUCTS GENERATED BY CORRODED OR LOOSE CONNECTIONS IN CATV SYSTEMS

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## ABSTRACT

Metal-to-metal junctions can exhibit non-linear characteristics as a result of corrosion or low contact pressure. The non-linearity can be seen on a V-I curve tracer and has been implicated in causing intermodulation interference, especially in the 5-30 MHz band. The junction behavior at RF under actual operating conditions cannot be accurately predicted from the low frequency V-I curve, however.

Measurements have been made of the actual level of 3rd order Intermodulation Products generated at RF by a variety of connections. The results are reported here, with a description of the factors found to influence the junction's behavior.

## INTRODUCTION

Junction non-linearity is receiving increased attention as a possible cause of excess noise in the troublesome 5-30 MHz upstream band. Lovern and Butler [1] have presented an extensive theoretical analysis of the effect in CATV systems, while reporting only one measurement at 60Hz, 0.5 volts A.C. and 0.15 Amps. Other researchers [2], [3] have measured the generation of 3rd order intermodulation products at microwave frequencies with incident RF power of approximately 3 watts. This paper reports the results of measurements made at typical Cable Television frequencies and power levels, with and without 60 Hz power on the junction.

A junction is linear if it obeys Ohm's Law over the range of interest (R=V/I=constant). A curve tracer will display this V-I characteristic as a straight line with slope m=1/R (dashed traces in Figure 1). Some junctions exhibit V-I characteristics more like the solid trace, however. The curvature is caused by electron tunnelling through thin Oxide or other corrosion films separating the metal contacts [4]. This is easily seen on Aluminum contacts under low contact pressure, for Aluminum is known to grow a uniform insulating layer of $Al_2O_3$ ranging from 30 to 100 Angstroms thick upon exposure to air.

Generally speaking, a junction with non-linear V-I characteristics will cause Intermodulation Products (IP's) to be generated when two or more different frequencies are incident upon it. The most commonly encountered IP is the 3rd order ($2f_1-f_2$), followed by the 5th order ($3f_1-2f_2$). In systems transmitting a range of frequencies, many IP's could fall in the 5-30 MHz band [1].

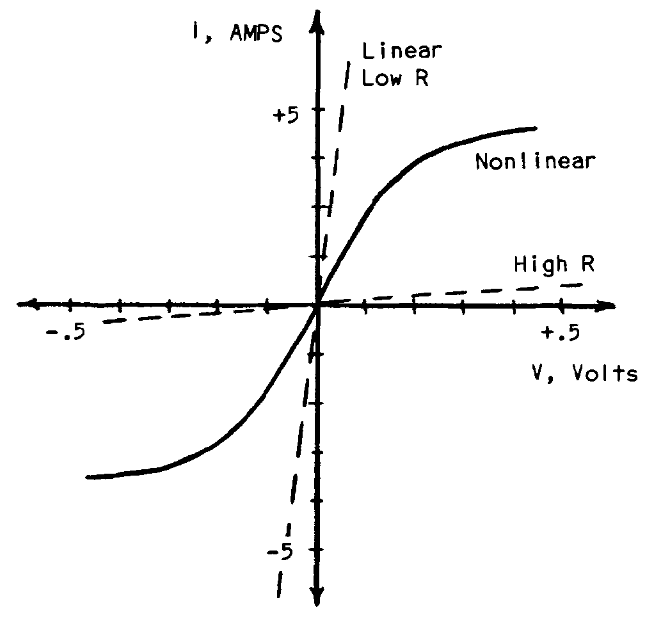

Figure 1) V-I Characteristics

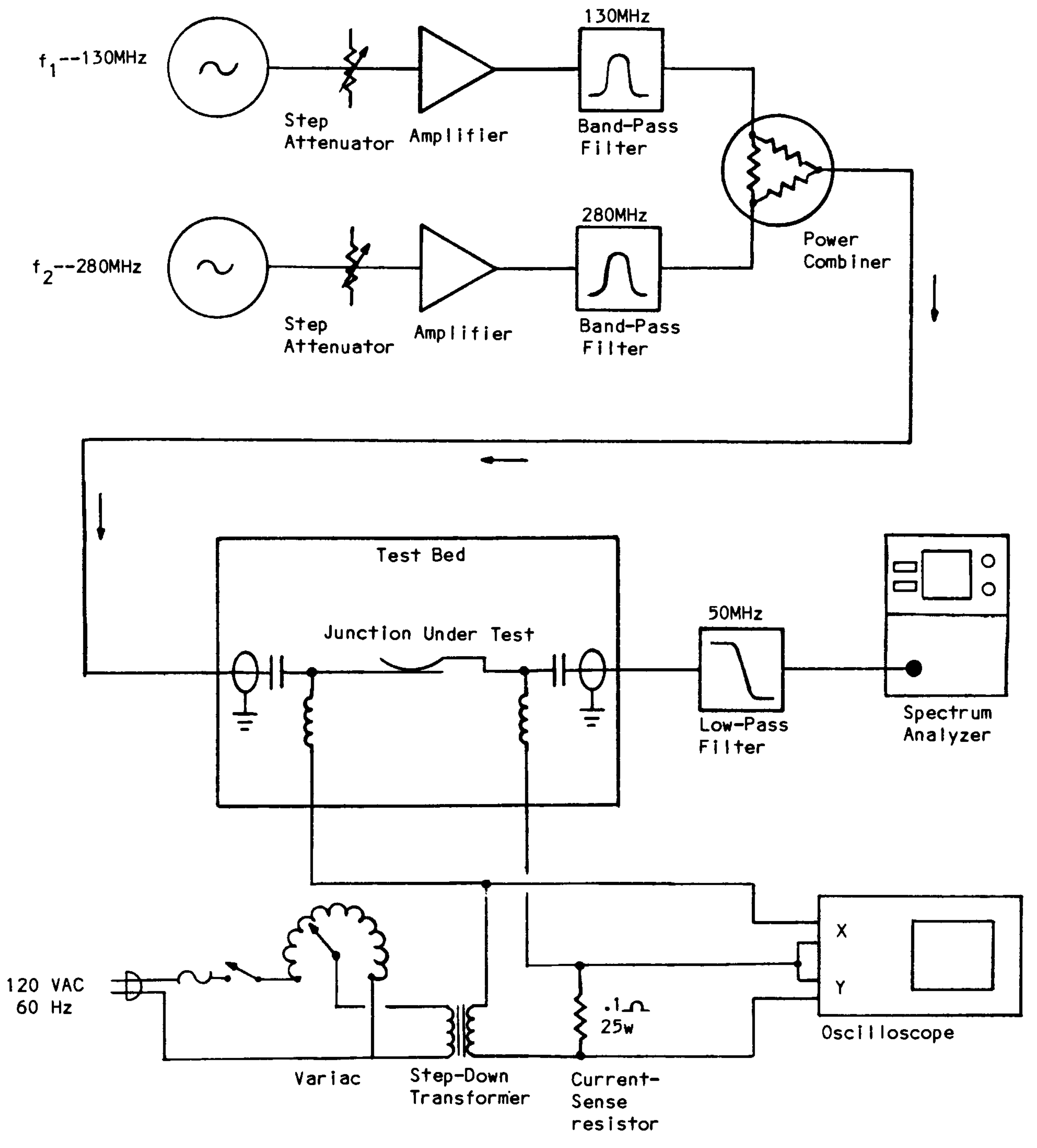

Figure 2--Test Equipment Configuration

MEASUREMENT CONFIGURATION

The actual generation of IP's was measured with the equipment set-up shown in Figure 2. 50 Ohm RF hardware was used throughout, due to availability. The fundamental signal frequencies $f_1$=130 MHz and $f_2$=280 MHz were chosen to produce a 3rd order IP at 20 MHz. The signal levels were controlled by step attenuators, then boosted by a pair of Amplifier Research 5 watt power amplifiers so that the level of $f_1$ reaching the sample could be varied from -20 dBm to +20 dBm and $f_2$ from -20 dBm to 0 dBm. The amplifiers were followed by multiple-section passive bandpass filters (BPF's) to remove any harmonic distortion from the signals and to prevent power from flowing between sources. The signals were then combined via a resistive "delta", resulting in a 6dB drop, and fed to the test bed.

The test bed was constructed by mounting two type-N connectors and a decoupling network on a copper-clad ground plane. The samples under test were secured at the ends to plexiglass support blocks, and when possible, soldered into place.

The output signal from the test bed was then fed through a 50 MHz 4-section low-pass filter (LPF) to block the high amplitude fundamental signals. If these are not blocked, the over-loaded front end of the spectrum analyzer can generate its own 3rd order IP's, indistinguishable from the ones generated by the junction under test..

The curve-tracer section of the set-up consisted of a Variac, step-down transformer, current-sense resistor, and an oscilloscope in x-y mode. The x-deflection displayed the voltage drop across the sample, while the y-deflection in volts times 10 equalled the current in amps.

Verification of the set up was accomplished by soldering a wire across the test bed in place of the sample under test and measuring the fundamental signal levels transmitted to the spectrum analyzer with the LPF removed ($f_1$=-20 to +20 dBm, $f_2$= -20 to 0 dBm). Replacing the LPF, residual 3rd order IP's were searched for. None were found down to the noise floor of -80 dBm. This performance is adequate for the testing described in this paper.

## MEASUREMENTS

Experimental Al-Al Junction The first junction that was tested was comprised of two pieces of Aluminum outer conductor that were cut from cable that had been in the field for several years. The surface appearance was gray-white with almost no metallic luster. The samples were simply rested against each other, under no external mechanical load. With no R.F. signal applied it was observed that the junction's V-I charactistic varied significantly as a function of the applied voltage. For V= 0.1 volt peak-to-peak (p-p), the V-I characteristic looked very linear with a resistance of approximately 1 Ohm. As V was increased to 0.3 volts p-p, the V-I characteristic assumed the "S" shape of Figure 1. When V approached 1 volt p-p, the junction produced an audible crackling noise, and the V-I characteristic became linear with a resistance of 50 milli-ohms. As the voltage was reduced, the junction remained linear with the same moderately low resistance. Because the junction was under no mechanical load, it was very sensitive to vibration and tapping, which showed up as broken, noisy traces on the oscilloscope. Tapping disturbed the low-resistance connection, essentially returning the junction to it's original state. The observations are summarized in Table 1.

With the curve tracer turned off, RF signals were applied to the junction, and the 3rd order IP level was recorded. The results are presented in Table 2. Again, vibration and tapping were very evident on this loose connection, with levels jumping 10 to 30 dB and broadband noise appearing during vibration.

One very important result is noticeable. Even for this very poor junction, it takes relatively high signal levels (from a CATV standpoint) to generate appreciable 3rd order IP's. This supports the curve tracer observation that for low voltages, the junction is linear.

The next experiment with the Al-Al junction was to observe simultaneously the low frequency V-I curve and the 3rd order IP's. For low curve tracer voltage (0.1 volt), the RF performance of the junction was identical to the results in Table 2. As the voltage was increased to 0.3 volts, the spectrum analyzer displayed high though intermittent levels of broadband noise, and the 3rd order IP signal fluctuated wildly. With 1 volt applied, the IP signal disappeared completely, though some broadband noise from the poor connection was still visible.

TABLE 1] V-I Characteristics of Al-Al Junction Under no Mechanical Load

| Step | Applied Voltage (p-p, 60 Hz) | V-I Curve Shape | Resistance |
|---|---|---|---|
| 1 | 0.1V | Linear | 1 OHM |
| 2 | Increased to 0.3V | "S" Shaped | Non-Linear |
| 3 | Increased to 1V | Linear | .05 OHM |
| 4 | Decreased to 0.3V | Linear | .05 OHM |
| 5 | Decreased to 0.1V | Linear | .05 OHM |
| 6 | 0.1V, Junction Tapped | Linear | 1 OHM |

TABLE 2] 3rd Order Intermodulation Product Generation
Al-Al Junction Under no Mechanical Load

| $f_2$ Level, dBm | -20 | -10 | 0 | +10 | +20 |
|---|---|---|---|---|---|
| 0 | <-80 (1)<br><-80 (2) | -50<br><-80 | -25<br>-55 | -20<br>-40 | -25<br>-50 |
| -10 | -60<br><-80 | -60<br><-80 | -50<br><-80 | -40<br>-60 | -30<br>-60 |
| -20 | <-80<br><-80 | -60<br><-80 | -40<br><-80 | -30<br>-70 | -30<br>-60 |

$f_1$ Level, dBm (3)

NOTES:
1) Maximum level of $2f_1-f_2$ in dBm observed during tapping. Always intermittent and accompanied by broadband static.
2) Maximum level of $2f_1-f_2$ in dBm observed with junction at rest. The actual level from junction at rest varied from this level to <-80 dBm in depending on tapping.
3) To convert the level in dBm in a 50 Ohm system to dBmV, add 47.

The explanation for the observed change in junction characteristics with applied voltage lies in a phenomena called "fritting" [4]. This is basically a breakdown of the thin $Al_2O_3$ film due to extremely high local electric field intensities. If a 100 Angstrom $Al_2O_3$ film has 1 volt potential applied to it, the electric field intensity is $10^8$ volts/meter, enough to cause break down. Continued current flow tends to widen the conduction path, reducing the junction's overall resistance. Reference 4 contains extensive details of fritting.

The final experiment with the Al-Al junction was to intentionally frit the junction. The curve tracer voltage was set to 5 volts, but disconnected from the circuit. High levels of RF were applied to the junction, and the 3rd order IP observed. Immediately upon applying the 5 volt power, the 3rd order IP disappeared entirely. No amount of vibration made it reappear, as the junction had been fritted. Removing the 5 volt power, no 3rd order IP was visible until tapping once again disturbed the junction.

Tap Box Set Screw-Center Conductor Connection Most tap boxes contain an Aluminum contact block with a plated steel set screw to establish contact with the center conductor. One of these assemblies was removed from a tap box and mounted in the test bed to evaluate the effect of low contact pressure. The center conductor used in this experiment was new Copper-clad Aluminum from a polyethylene-foam (PE) type cable. It had been scraped with a knife, though a very thin layer of PE still adhered to it. This is the way craftsmen often prepare the cable.

It was much more difficult to obtain the "S" shaped curve with this sample. With the set screw completely loose, the curve tracer indicated an open circuit for V=0 to 15 volts A.C. It appears that tunneling does not occur through the residual PE. Tightening the screw very gently by hand, just until contact was established, produced an immediate jump of the V-I curve to a linear low resistance state, regardless of applied voltage. The "S" shaped curve could only be produced by gently tapping the assembly with approximately 0.3 volts applied until the assembly loosened. Then the curve was unstable, tending to jump to either the short-or open-circuit condition.

The RF characteristics with no A.C. power applied were also better than with the Al-Al sample. See Table 3. The maximum $2f_1-f_2$ levels observed during tapping were more short-lived and noisy than those reported in Table 2, and it was generally more difficult to produce a stable 3rd order IP.

The behavior of this junction under simultaneous RF and 60 Hz power was similar to that reported for the Al-Al junction. Again, fritting occurred with approximately 1 volt applied to the junction, completely preventing 3rd order IP generation. Interestingly, when the curve tracer indicated an open-circuit condition, the level of fundamental signals $f_1$ and $f_2$ had only dropped by about 10 dB. Apparently there was a substantial parasitic RF coupling across the otherwise open junction.

The copper clad center conductor used for this series of tests was replaced by a Tin-plated Brass pin cut from a pin-type connector. The curve tracer generally indicated either an open-circuit or a short-circuit condition with the set screw loose --no stable "S" shaped curve was observed. An intermittent "S" shaped curve could be seen during tapping on a very loose connection. It is reasonable to assume very low 3rd order IP generation from this configuration. Regardless of the center conductor material, tightening the set screw with a screwdriver prevented any 3rd order IP generation.

**Pin-Type Connector Center Conductor Seizure** Pin-type connectors rely on some internal arrangement to press the fingers of a "pin-basket" down on the cable's center conductor to grip it and establish contact. A Tin plated Brass pin basket was removed from a connector and mounted on the test bed to simulate the worst-case condition of no externally applied contact pressure. A new Copper-clad Al center conductor (with some residual PE) completed the circuit.

The curve tracer indicated either an open-circuit or short-circuit condition, with no stable "S" shaped curve. This is not surprising, since clean Tin and Copper are excellent contact materials, and PE, when present, is a good insulator. Under RF power, this junction generated no 3rd order IP's.

A severely tarnished section of Copper-clad Al center conductor was recovered from a Styrene-foam cable that had been in the field for many years. The foam was not bonded to the center conductor so consequently water had tracked down the cable. The tarnish was black and shiny, and was determined to be Copper Oxide.

A junction consisting of this tarnished Copper conductor and the loose Tin plated Brass pin basket was mounted on the test bed. The curve tracer showed the junction to be initially non-conductive, but after some wiggling, a stable "S" shaped V-I characteristic was observed (V=0.3 volts). The non-linear characteristic was very similar to that seen with the Al-Al junction, pictured as the solid trace in Figure 1. Again, increasing the voltage across the junction to 1 volt broke down the oxide layer, resulting in a linear, low resistance

TABLE 3] 3rd Order Intermodulation Product Generation
Loose Tap Box Set Screw/C.C. Connection

| $f_2$ Level, dBm | -20 | -10 | 0 | +10 | +20 |
|---|---|---|---|---|---|
| 0 | <-80 (1)<br><-80 (2) | -65<br>-80 | -40<br>-60 | -30<br>-40 | -40<br>-40 |
| -10 | <-80<br><-80 | <-80<br><-80 | -60<br><-80 | -50<br>-60 | -60<br>-60 |
| -20 | <-80<br><-80 | <-80<br><-80 | -60<br>-80 | -50<br>-60 | -80<br><-80 |

$f_1$ Level. dBm (3)

TABLE 4] 3rd Order Intermodulation Product Generation
Tarnished Copper - Tinned Brass Junction

| F2 level, dBm | -20 | -10 | 0 | +10 | +20 |
|---|---|---|---|---|---|
| 0 | <-80 (1)<br><-80 (2) | -80<br><-80 | -60<br>-70 | -50<br>-60 | -45<br>-60 |
| -10 | <-80<br><-80 | <-80<br><-80 | -65<br><-80 | -55<br>-70 | -65<br>-70 |
| -20 | <-80<br><-80 | <-80<br><-80 | -75<br><-80 | -60<br>-70 | <-80<br><-80 |

$F_1$ level, dBm (3)

NOTES: See notes to TABLE 2

connection. The 3rd order IP levels from this junction before fritting are listed in Table 4. No IP's were found after fritting.

Aluminum Outer Conductor-To-Connector Junction Raychem, Gilbert, and LRC 1/2" pin type connectors were installed to connect Aluminum coaxial cable to taps in accordance with manufacturer's instructions. No connection demonstrated visible non-linearity on the curve tracer when new. The samples were then corroded by two month's submersion in a salt bath with daily airing. The samples built up a thick layer of salt, and the Aluminum cable developed lines of small holes shot through to the PE. When reconnected to the curve tracer, again no sample showed non-linearity, and the junction resistances were low. It appears that the original connections remained intact, perhaps protected by a surrounding $Al_2O_3$ film.

## DISCUSSION OF RESULTS

The results reported here agree with the conclusions by Bayrak and Benson [2], who reported that the highest 3rd order IP's were generated by Al-Al and Steel-Steel contacts, the lowest by Copper and Brass contacts, with intermediate levels produced by Aluminum -Copper contacts. They also reported that the highest level IP's were produced by junctions under minimum mechanical load, with IP level falling rapidly as load is applied. Finally, they confirmed that a thin insulating film of plastic (in their work, Teflon) prevented IP generation.

This paper's observation of film breakdown by fritting is strongly supported in reference 4. Anyone interested in further study of electrical contacts should locate this book. Especially relevant is the description of "applied fritting" from the telephone world, where an EMF of 48 to 60 volts with equivalent source resistance of 100,000 Ohms is maintained on relay circuits to frit the contacts for reliable connections.

The level of the 3rd order IP generation reported here is low in all but worst cases. A connection really has to be pretty poor to generate 3rd order IP's, and poor connections generate a host of other problems -- 'static', varying signal levels, voltage drops, intermittence, RFI, etc. No connection studied here generated solid 3rd order IP's without showing some of the other symptoms of poor connections.

## SUMMARY

1.) Intermodulation Products (IP's) can be generated by corroded, tarnished, or loose connections under low contact pressure.

2.) Signal levels must be high to generate significant IP's. For signals at -20dBm (50 Ohm system), 3rd order IP's were below -80dBm for all connections. Signals at -10dBm produced 3rd order IP's below -80dBm in all but the worst case of Al-Al under zero load; here they reached -60dBm intermittenly. Signals at 0dBm (+47dBmV) produced 3rd order IP's of -55dBm to -70dBm in loose connections.

3.) Junctions with more than 1 volt of 60 Hz power applied generated no IP's due to contact fritting.

4.) When observed, the IP's were always jumpy and accompanied by broadband static from the loose connection.

5.) Any reasonable amount of contact pressure prevented IP generation.

6.) Based on these observations, it is unlikely that problems in the 5-30 MHz upstream band are due to IP generation at loose connections. A more likely explanation is RF ingress, as described in [5].

## REFERENCES

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