The Ins and Outs of Audio Transformers

How to Choose them and
How to Use them

Steve Hogan

Product Development Engineer, Jensen Transformers

1983 – 1989

Designed new products and
provided application assistance to Customers

VP Engineering, Jensen Transformers

1989-2003

Re-designed entire product line from JE-xxx to JT-xxx
using computer-controlled winding equipment and
improved materials and methods

Audio Transformer Basics

- Audio Transformer is a device consisting of a (driven) primary winding wound around a core of magnetic material.
- One or more secondary windings wound around the same core.
- AC Voltage on the primary creates a changing magnetic flux in the core.
- Changing magnetic flux in the core generates a signal in the secondary winding(s).
- Signals can be sent from the primary side to the secondary side without any direct connection since they are magnetically coupled.

Galvanic Isolation

- Audio Transformers allow one to connect two pieces of equipment together “without connecting them together”.
- No direct contact between primary and secondary windings allows each winding to be at a different DC potential. Phantom power causes the mic primary to be +48V higher than the secondary.
- Transformers can break “Ground Loops” and solve “Pin 1 Problems”

Voltage Transformation

- Transformers can step the secondary voltage up or down relative to the primary voltage.
- Voltage change = Ratio of primary turns and secondary turns.
- **Vpri/Vsec = Npri/Nsec**
- Power (Volts x Amps) is same on both sides.

Voltage and Current Relationships

- 10V @ 10mA 1:1 turns ratio = 10V @ 10mA
- 10V @ 10mA 1:10 turns ratio = 100V @ 1mA
- 10V @ 10mA 10:1 turns ratio = 1V @ 100mA

Source and Load Impedance

- Load Z is the load placed on the secondary winding(s). It may be resistive only, or it may be complex with capacitive or inductive reactance.
- For example a passive equalizer with an input Z of 600 Ohms will present a 600 Ohm load Z to the secondary of an input transformer placed in front of it.
- Source Z is the impedance in series with the voltage produced by the device driving the primary winding.
- For example, a Shoeps mic with 12 Ohms output Z has a source Z of 12 Ohms to the transformer primary.

Impedance Transformation

- Impedance is changed in BOTH DIRECTIONS.
- **Zpri/Zsec = (Npri/Nsec)^2**
- Step-up allows low Z sources (microphones) to match amplifier noise characteristics for lowest noise
- Step-down allows vacuum tubes to drive low Z speaker loads.

Impedance Relationships

- 150 Ohm Mic   1:10 turns ratio   150k load resistor
- Voltage ratio is 1:10, Impedance ratio is 1:100 (10^2)
- Microphone sees a 150K / 100 = 1K5 Load Z
- Amplifier sees 150 Ohm mic * 100 = 15K as a source.
- Above calculations do not include winding resistances.

Leakage L (Inductance)

- An inductor is an electronic component that opposes the change in current through the device. Its reactance (measured in Ohms) increases with increasing frequency.
- Leakage Inductance is a parasitic series inductance in series with the transformer. It is caused by incomplete magnetic coupling of the primary winding to the secondary winding(s).
- It can affect the frequency and transient response of the transformer when the secondary has capacitive loading (like driving a long cable).

Faraday Shields

- Copper Foil Shield between primary and secondary layers in the transformer assembly.
- Greatly reduces capacitive coupling between primary and secondary, thus giving the transformer excellent common-mode rejection.
- Used in input transformers.

Input Transformer

Input Transformers

- Input transformer primary must be fed from various devices with various source impedances not under control of the user.
- Input transformer secondary can be loaded as required for best performance, since user/designer has control of the load.
- Input types typically use multiple interleaved layers of primary and secondary to reduce Leakage L, and Faraday shields to provide inputs that are capacitively balanced with respect to ground.
- Input transformers have excellent CMRR.

Using Input Transformers

- Input type faraday shielded transformer has excellent CMRR.
- Input transformers have limited bandwidth and are good at rejecting out-of-band unwanted signals like RFI.
- Balanced primary can be reversed to obtain polarity reversal.
- Steps should be taken to eliminate any DC on Primary, since DC will increase THD and reduce headroom.

Output Transformer

Output Transformer

Output Transformers

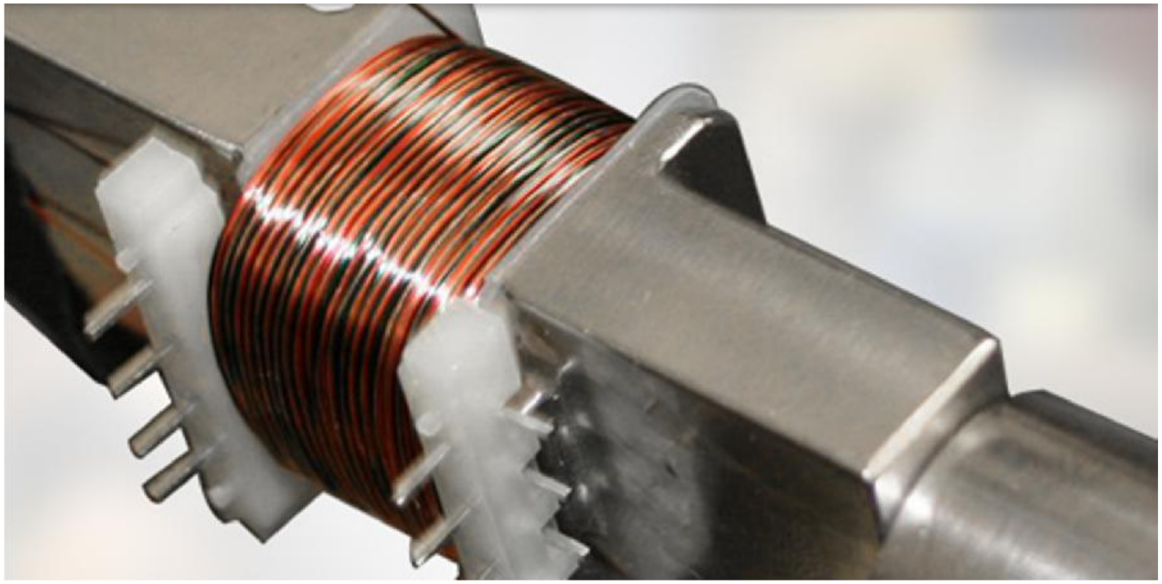
- Output transformer primaries are typically driven by line driver amplifier stages controlled by the user/designer.
- Output transformer secondaries must drive long cables or short cables, no load or heavy load with no load induced frequency response or transient errors.
- Typically they are wound multifilar for minimal Leakage L. They have very high winding to winding capacitance, however.

Bifilar Wound Output Transformer

Primary wire wound simultaneously side-by-side with secondary wire.

Almost all magnetic flux generated by the primary is “caught” by the secondary wire right next to it.

Winding to winding capacitance is high.



Using Output Transformers

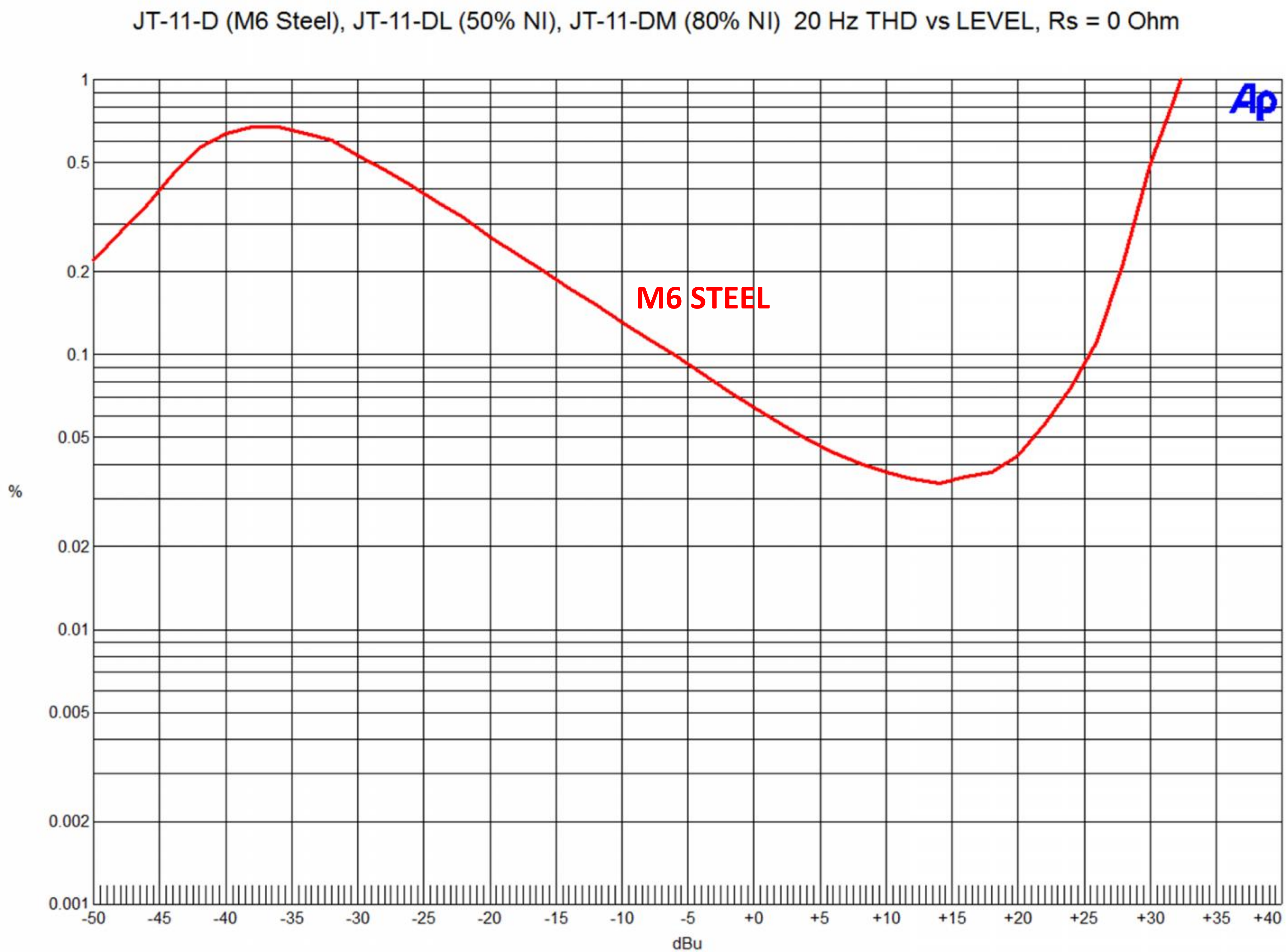
- Large capacitance between windings needs some precautions: Do not use an output transformer to reverse polarity. It puts a huge capacitive load on the line driver amplifier.
- For symmetrical drive, feed from bridge amp.
- Driving primary from single-ended amplifier allows excellent performance into both Balanced and Unbalanced Loads.
- Drive primary from very DC coupled amplifier with low output Z. DC servo is recommended to eliminate offsets.
- If you must capacitively couple to primary, use very large (>470uF) cap, to reduce sub-sonic resonance peak.

Transformer Distortion

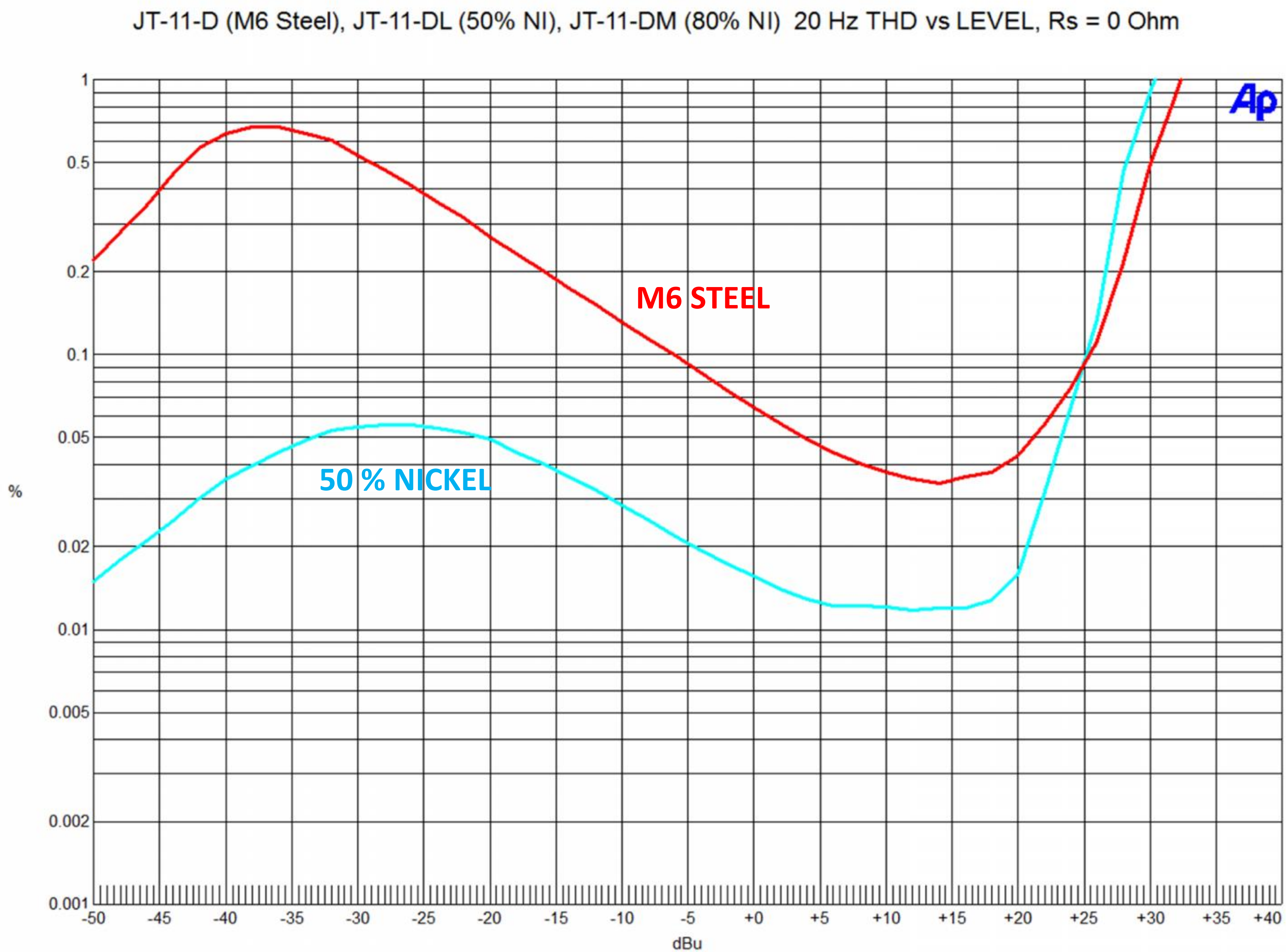
- Transformer THD is 3d harmonic until saturation. Musically related (octave + fifth).
- Transformer THD is a Low Frequency Problem.
- THD diminishes 6 dB per octave.
- Intermodulation Distortion is negligible in transformers.
- THD caused by Source Z (including primary resistance) being shunted by non-linear primary inductance.

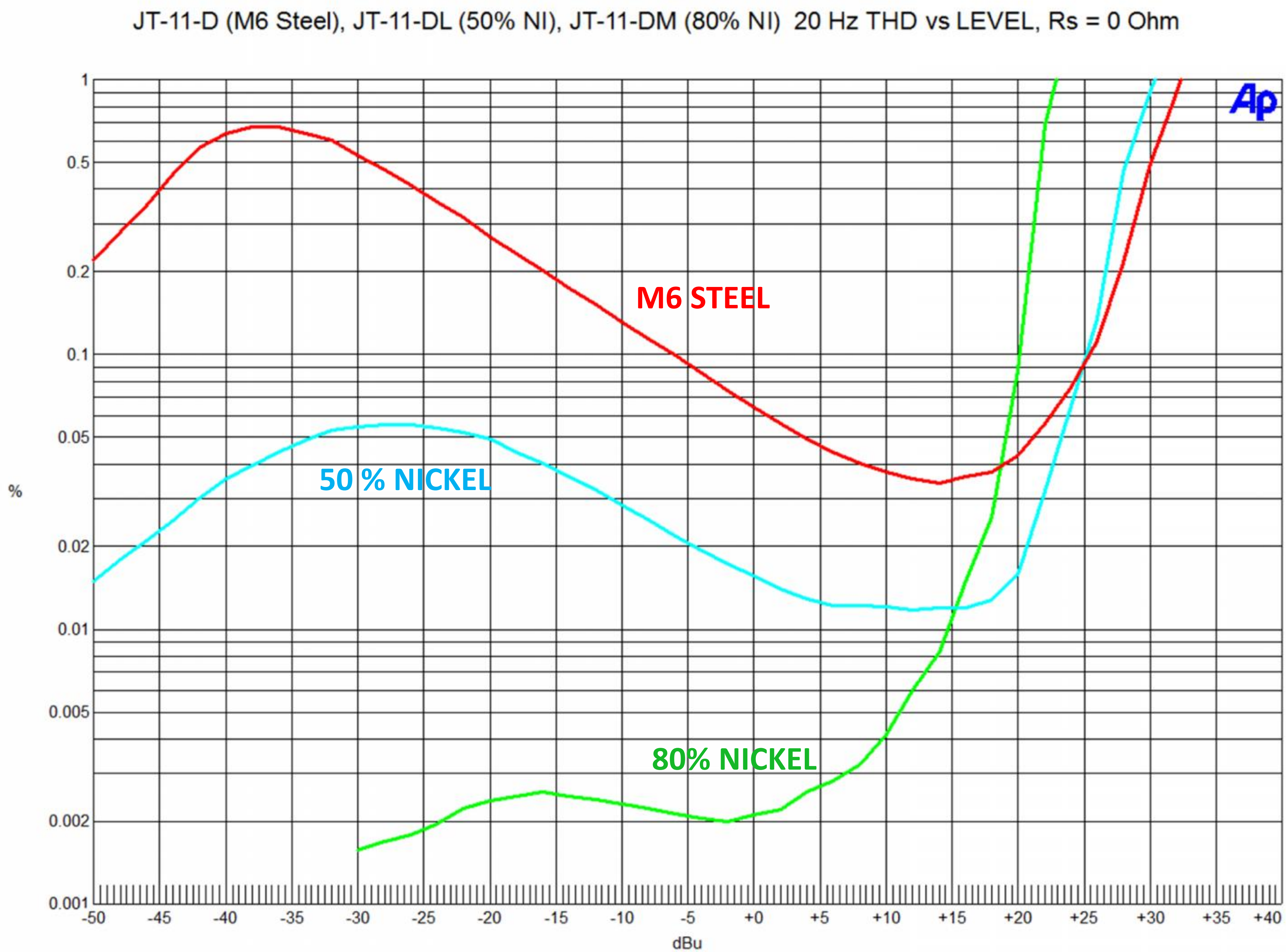
Types of Core Material

- Three commonly used types of core material used in audio transformers:
- M6 grain-oriented silicon steel: Used in output transformers, especially vacuum tube output.
- 50% nickel alloy: Used in “sound reinforcement” grade output transformers.
- 80% nickel alloy: Used in “recording studio” grade output transformers and all input transformers. Handles less maximum level, but is much more linear than the others.



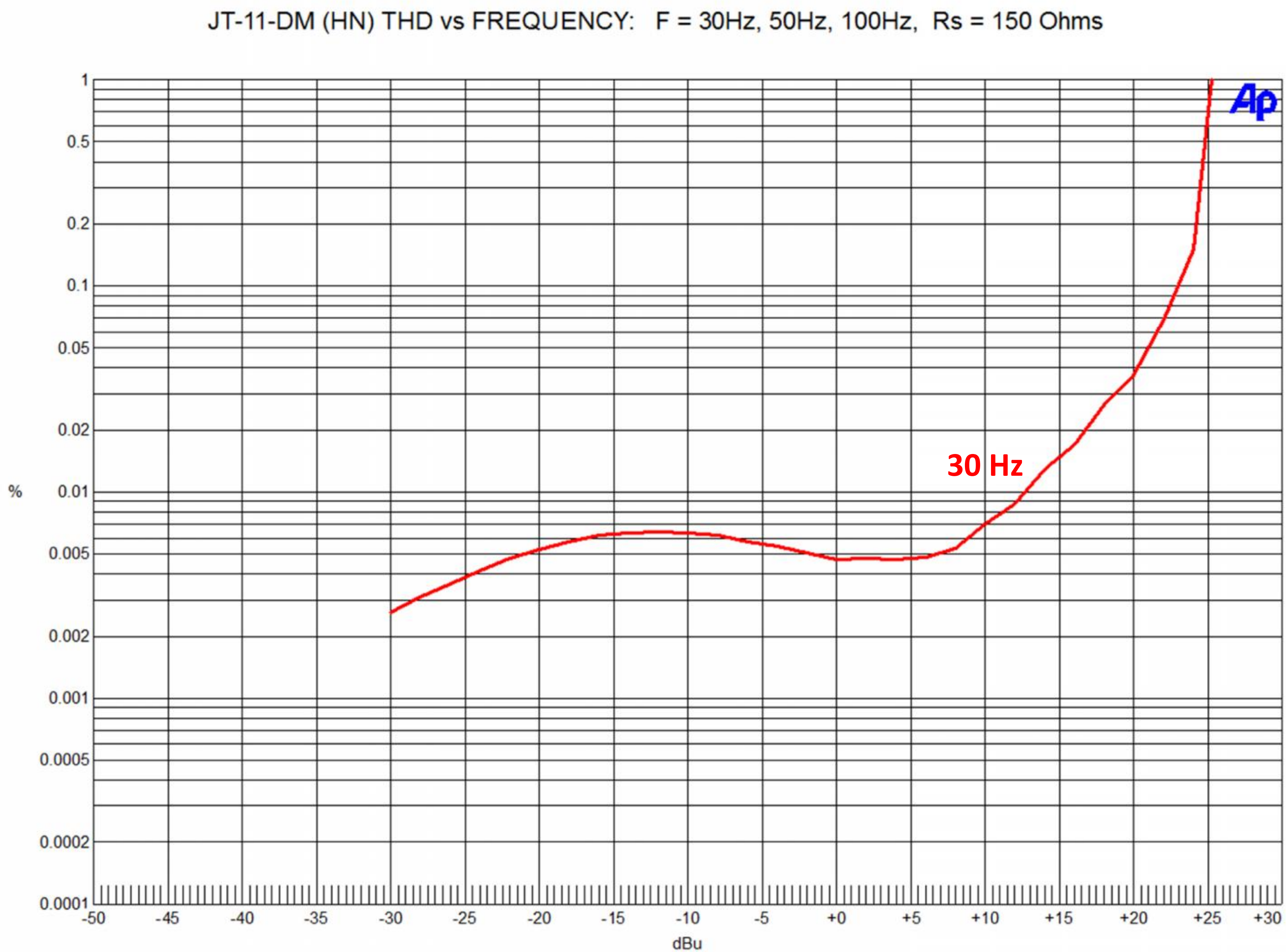
JT-11-D (M6 Steel), JT-11-DL (50% NI), JT-11-DM (80% NI) 20 Hz THD vs LEVEL, Rs = 0 Ohm
M6 STEEL
%
dBu
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50 -45 -40 -35 -30 -25 -20 -15 -10 -5 +0 +5 +10 +15 +20 +25 +30 +35 +40

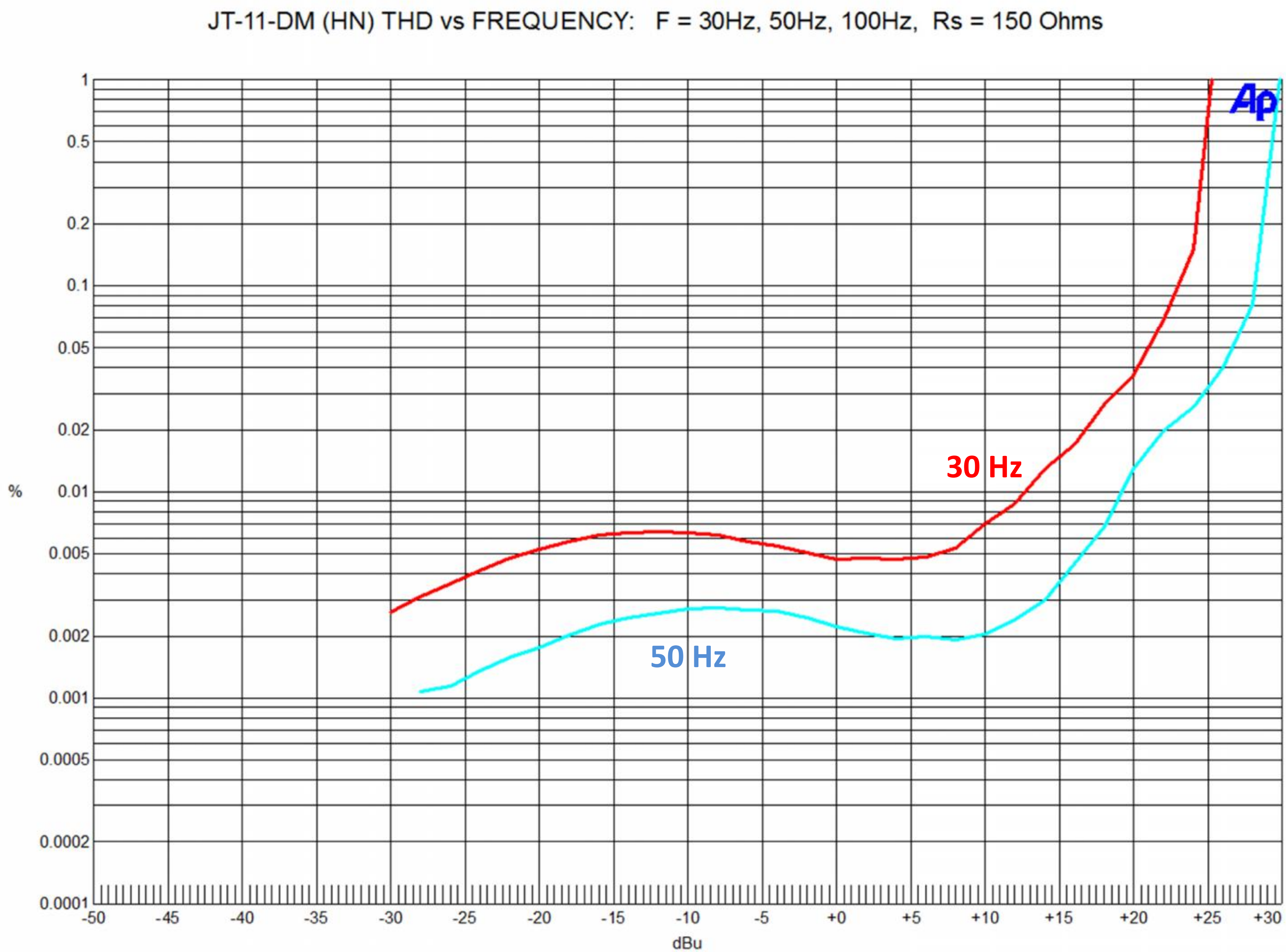

JT-11-D (M6 Steel), JT-11-DL (50% NI), JT-11-DM (80% NI) 20 Hz THD vs LEVEL, Rs = 0 Ohm
M6 STEEL
50 % NICKEL
%
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
+35
+40
dBu

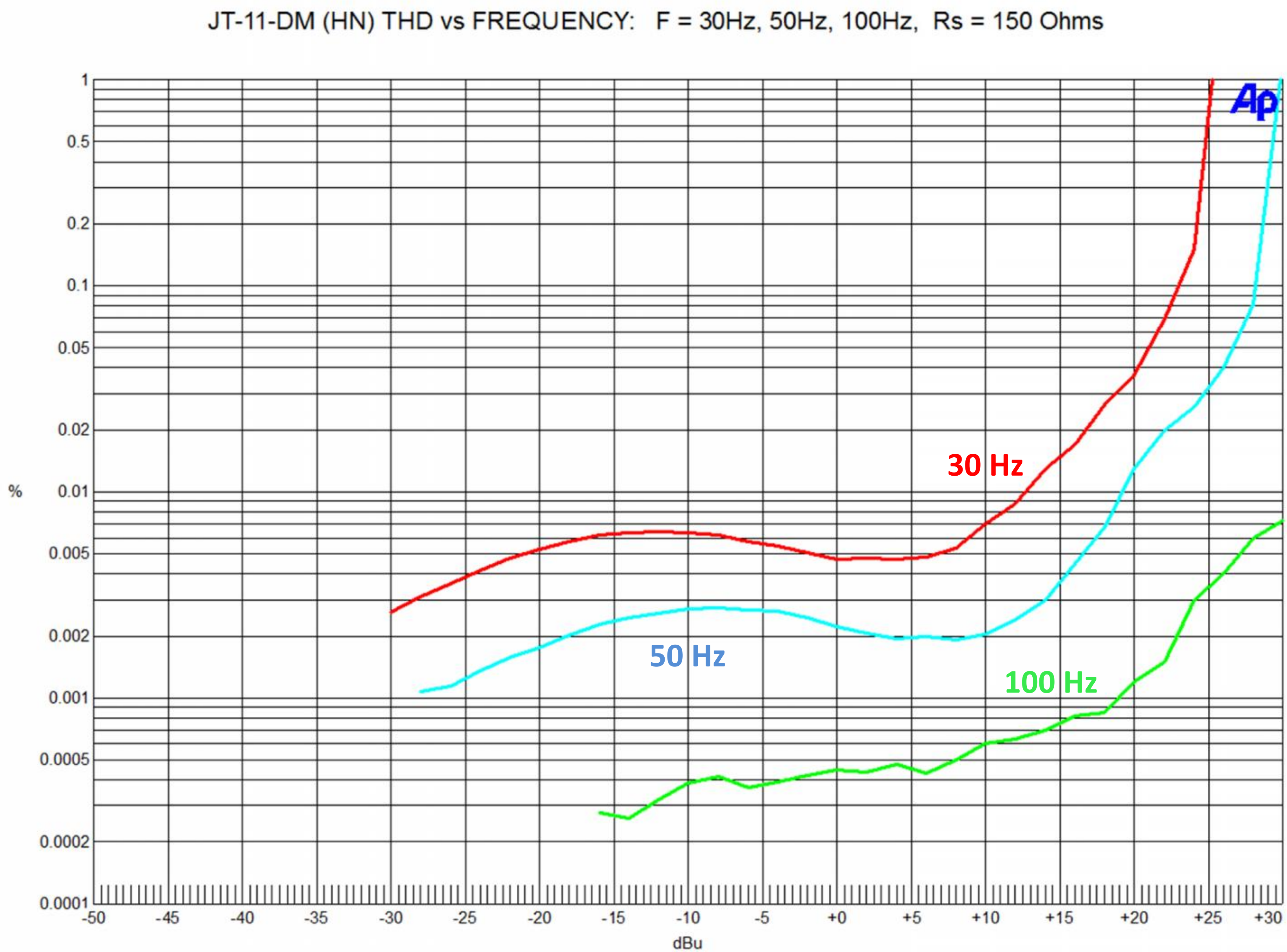


JT-11-D (M6 Steel), JT-11-DL (50% NI), JT-11-DM (80% NI) 20 Hz THD vs LEVEL, Rs = 0 Ohm
M6 STEEL
50 % NICKEL
80% NICKEL
%
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
+35
+40
dBu

- THD decreases with increasing frequency.
- Maximum Level Increases with increasing frequency.
- Following graphs show THD at various frequencies.

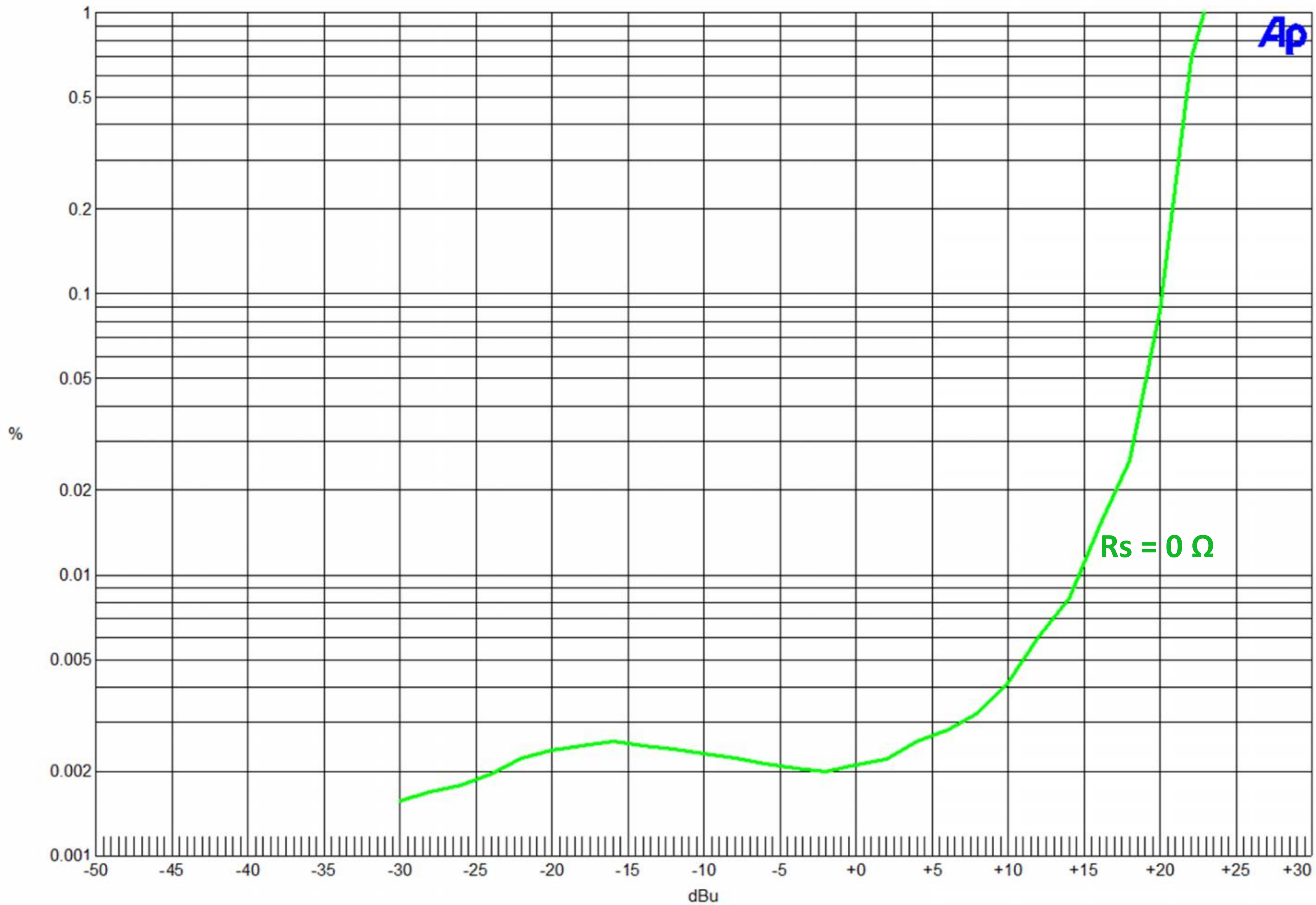

JT-11-DM (HN) THD vs FREQUENCY: F = 30Hz, 50Hz, 100Hz, Rs = 150 Ohms
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
%
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
30 Hz

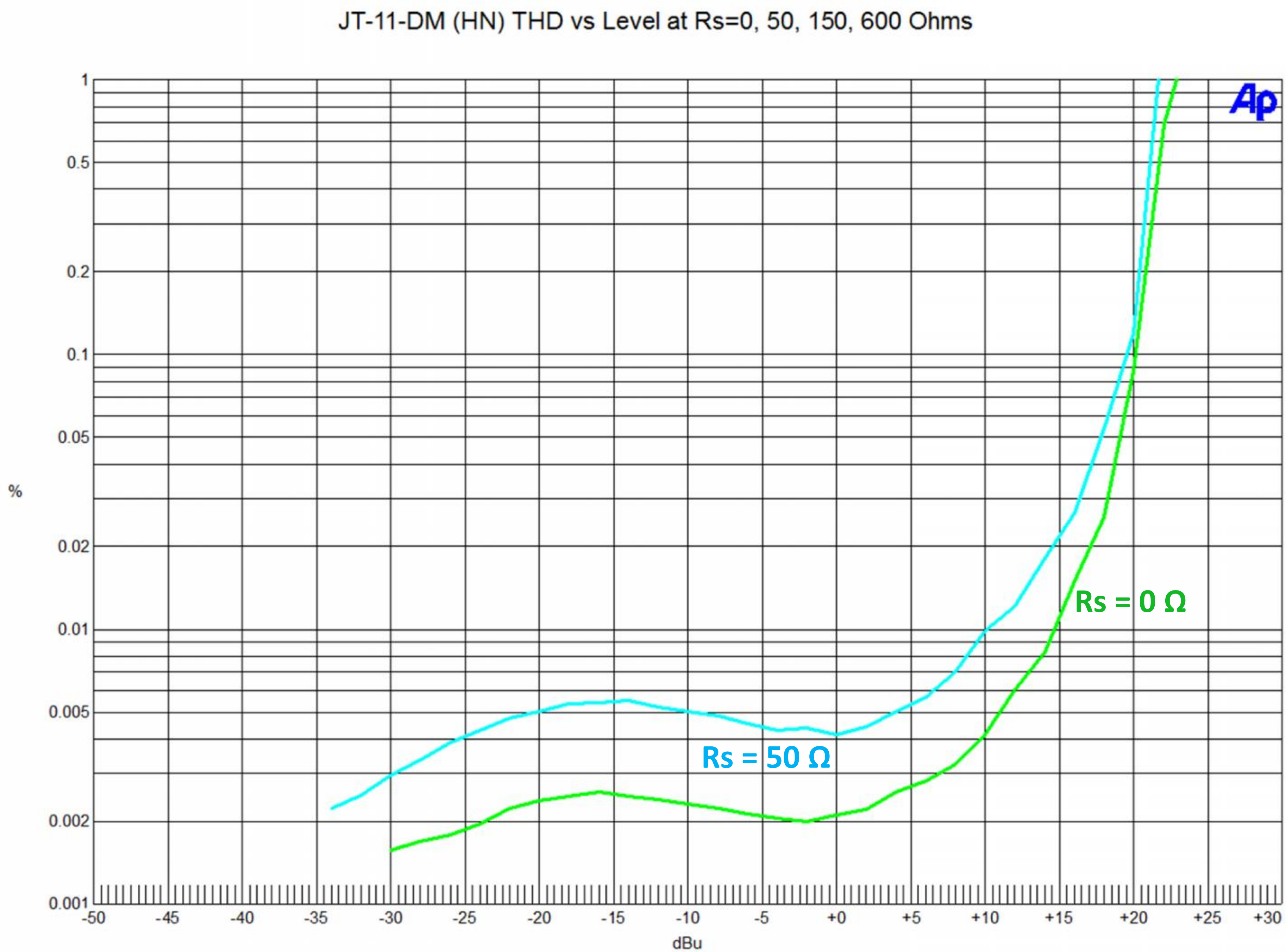

JT-11-DM (HN) THD vs FREQUENCY: F = 30Hz, 50Hz, 100Hz, Rs = 150 Ohms
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
%
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
30 Hz
50 Hz


JT-11-DM (HN) THD vs FREQUENCY: F = 30Hz, 50Hz, 100Hz, Rs = 150 Ohms
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
%
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
30 Hz
50 Hz
100 Hz
Ap

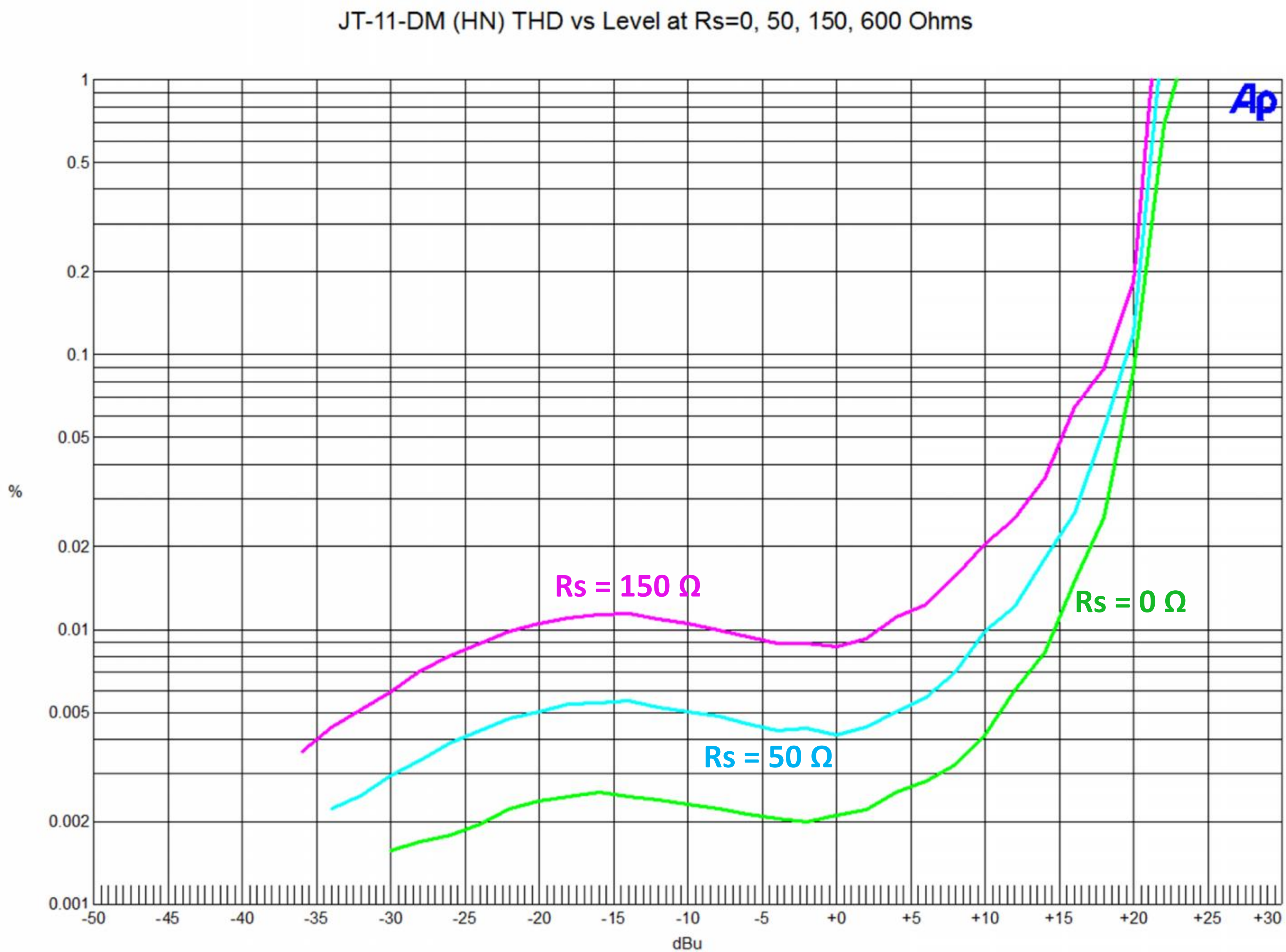
- THD increases with increasing Source Z.
- Output transformers should be driven with lowest possible Source Z.

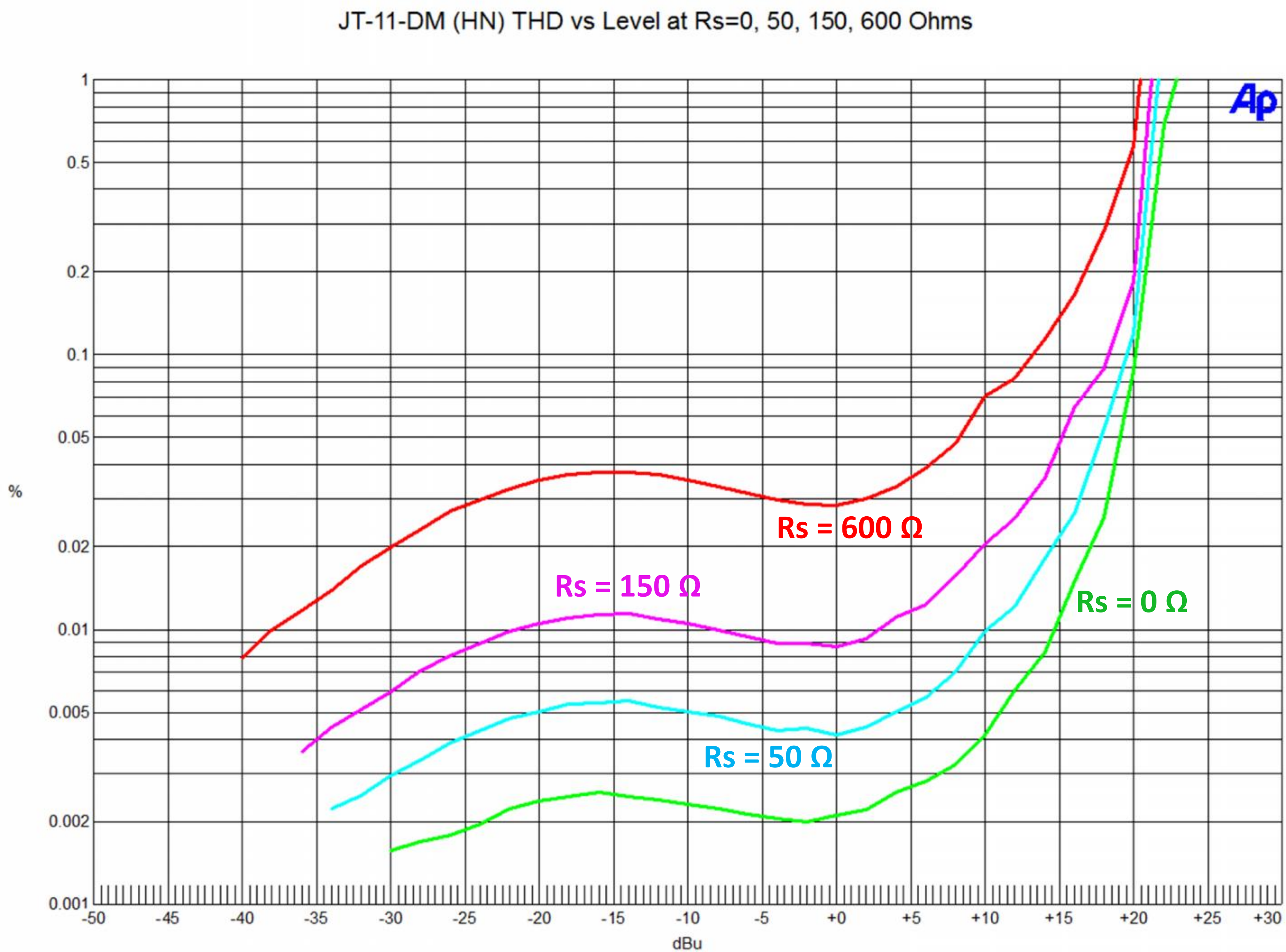
JT-11-DM (HN) THD vs Level at Rs=0, 50, 150, 600 Ohms



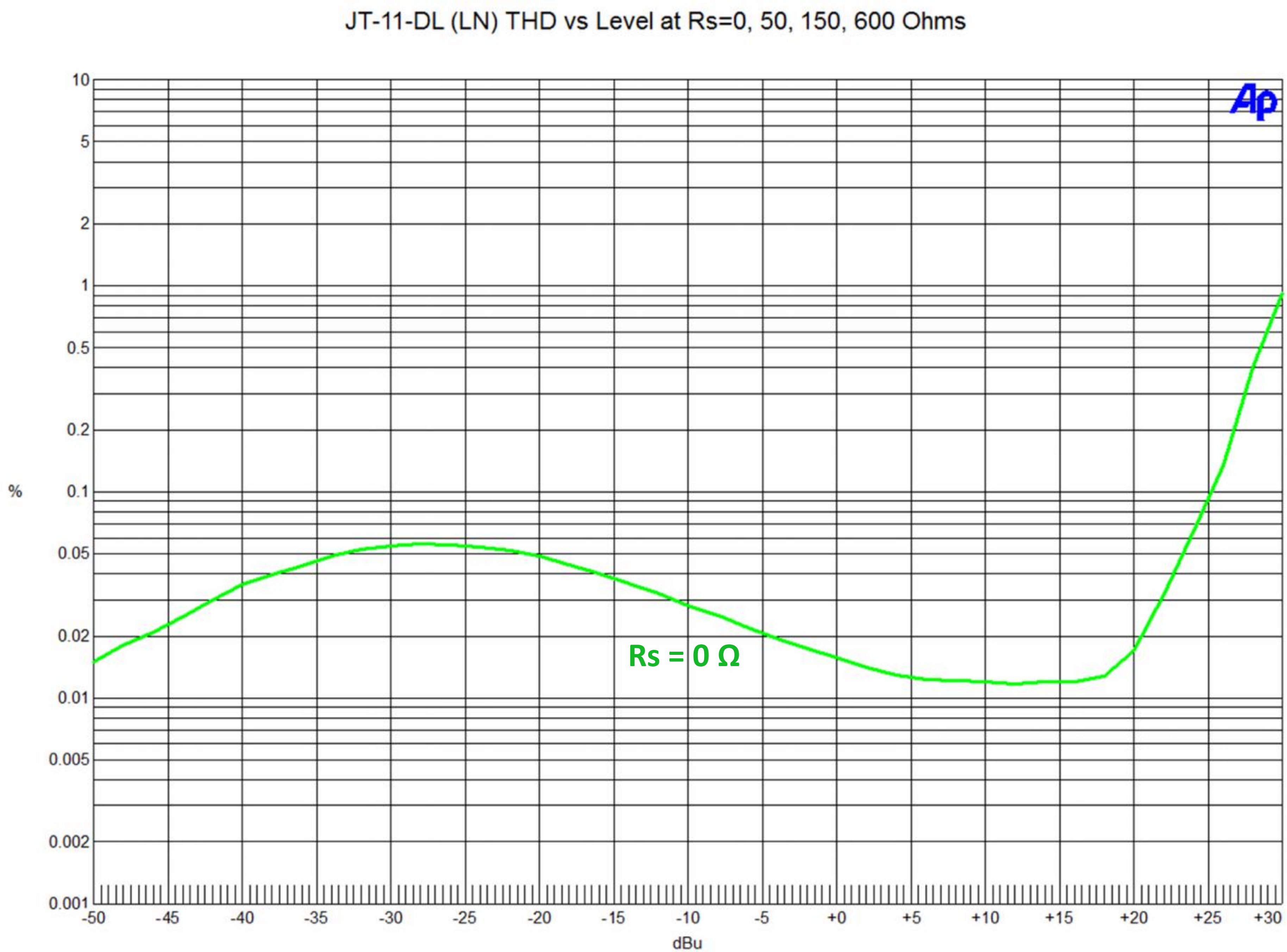


JT-11-DM (HN) THD vs Level at Rs=0, 50, 150, 600 Ohms
Ap
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
%
Rs = 0 Ω
Rs = 50 Ω
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu

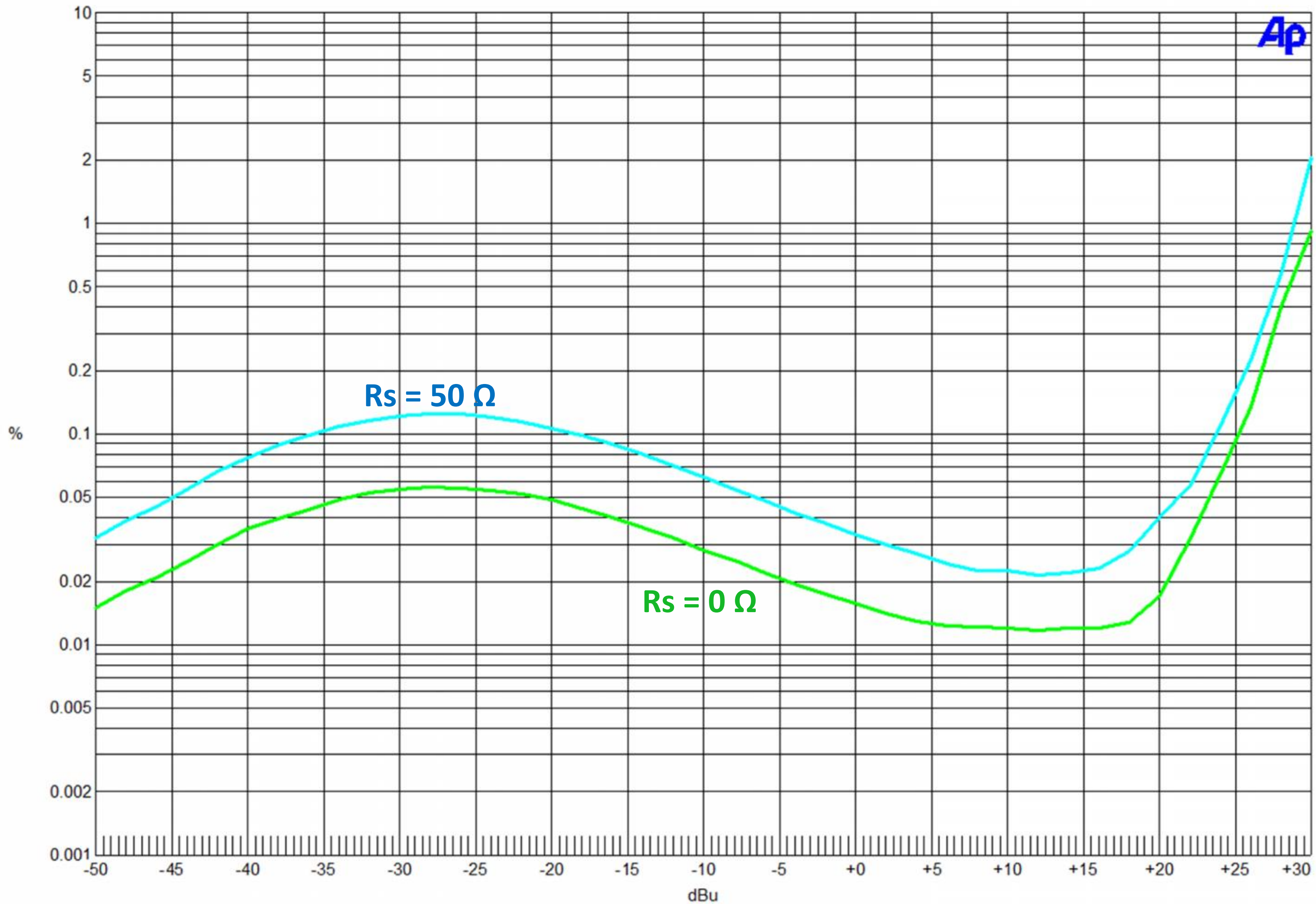

JT-11-DM (HN) THD vs Level at Rs=0, 50, 150, 600 Ohms
%
dBu
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
Rs = 150 Ω
Rs = 50 Ω
Rs = 0 Ω

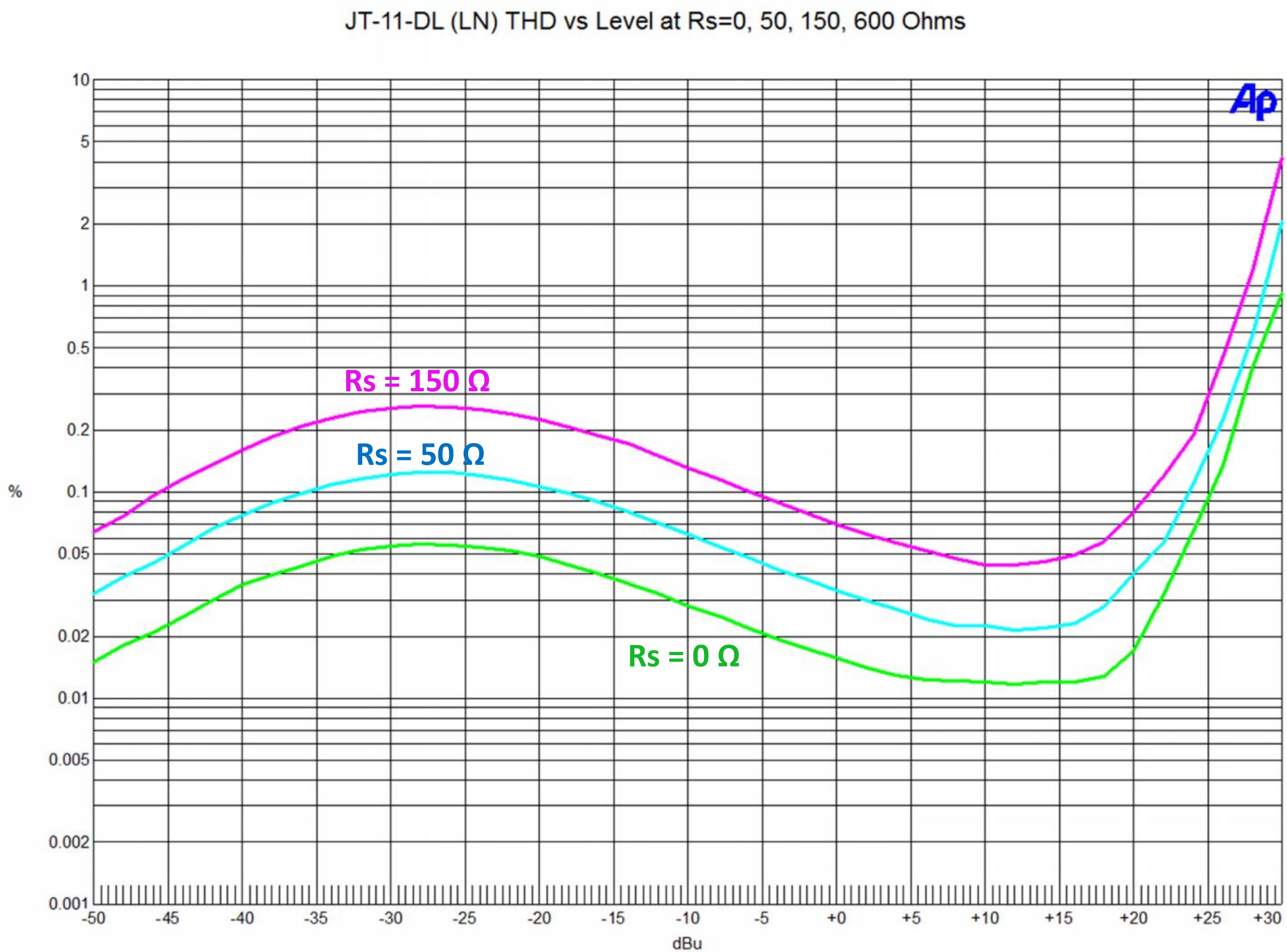


JT-11-DM (HN) THD vs Level at Rs=0, 50, 150, 600 Ohms
Ap
%
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
Rs = 600 Ω
Rs = 150 Ω
Rs = 50 Ω
Rs = 0 Ω

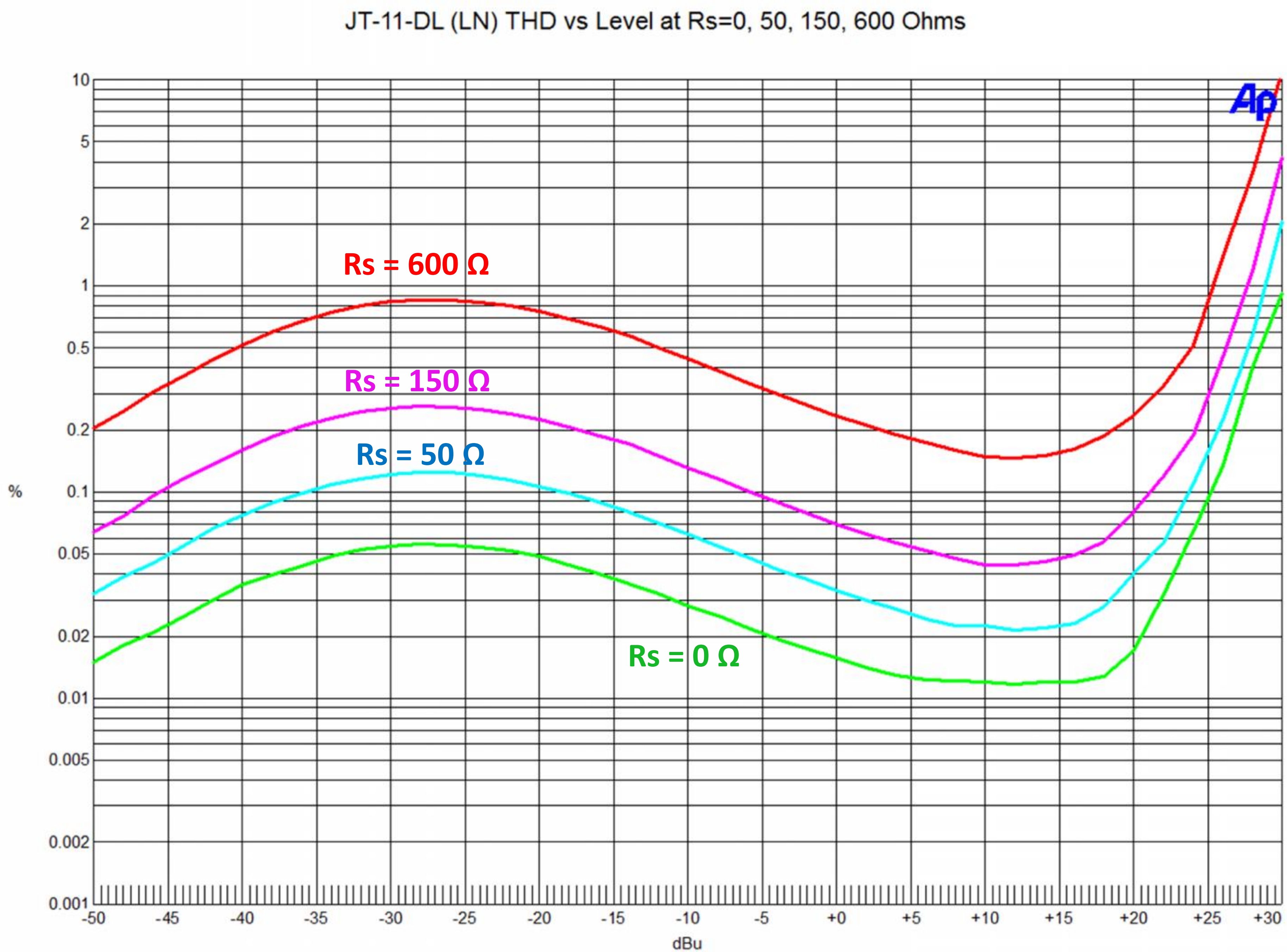

JT-11-DL (LN) THD vs Level at Rs=0, 50, 150, 600 Ohms
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
%
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
Rs = 0 Ω

JT-11-DL (LN) THD vs Level at Rs=0, 50, 150, 600 Ohms



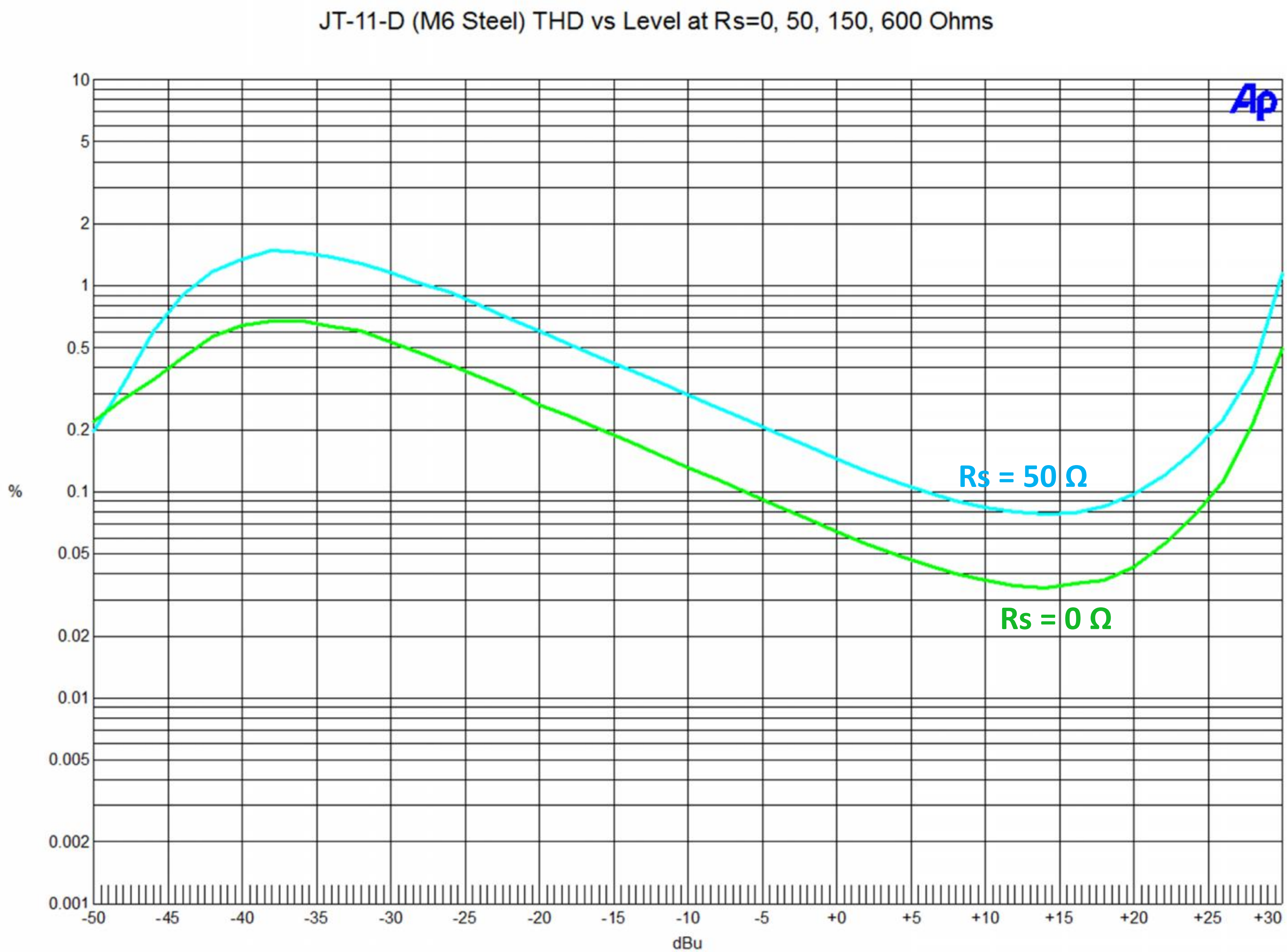


JT-11-DL (LN) THD vs Level at Rs=0, 50, 150, 600 Ohms
Rs = 150 Ω
Rs = 50 Ω
Rs = 0 Ω
%
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu



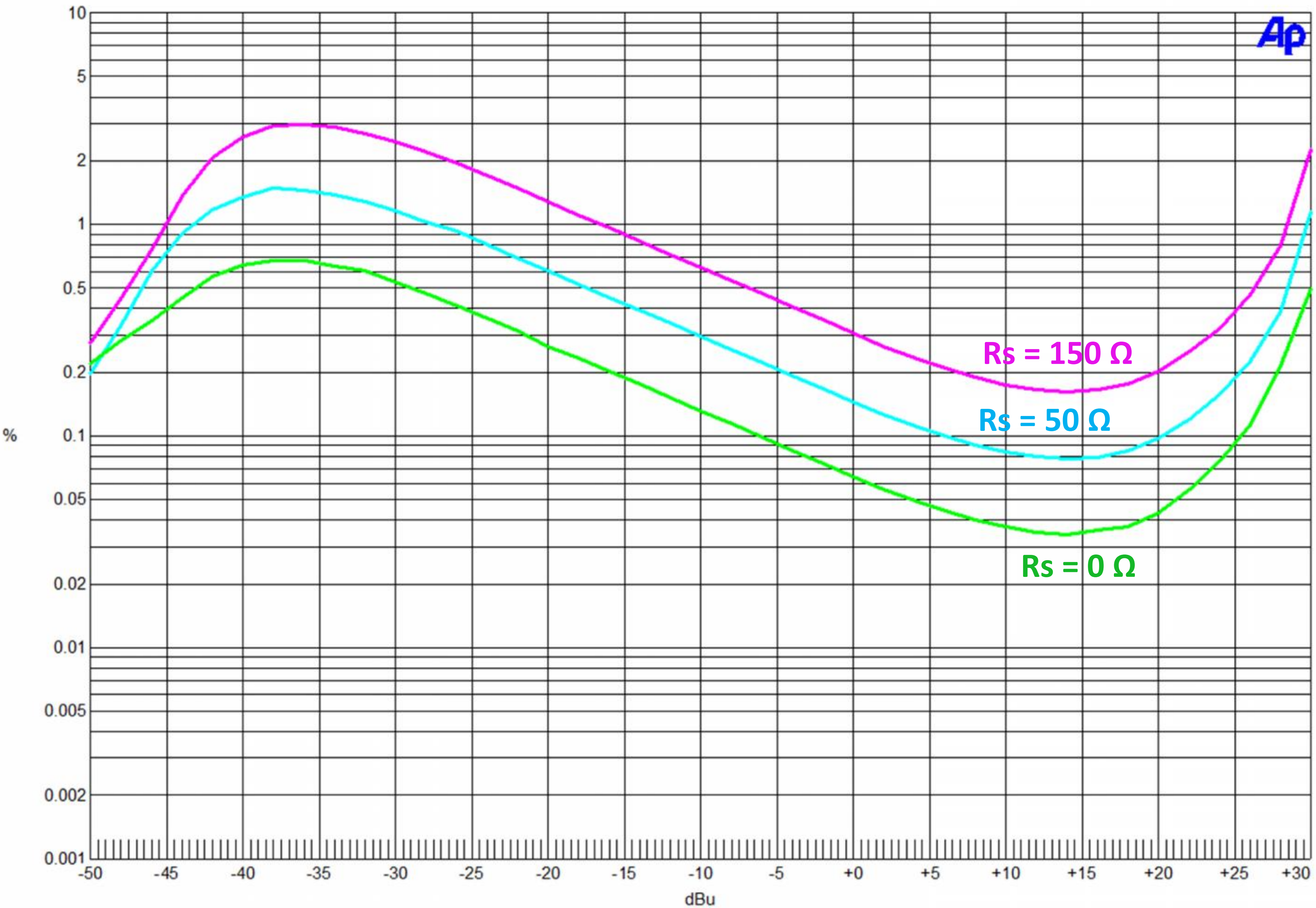
JT-11-DL (LN) THD vs Level at Rs=0, 50, 150, 600 Ohms
Rs = 600 Ω
Rs = 150 Ω
Rs = 50 Ω
Rs = 0 Ω
%
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu

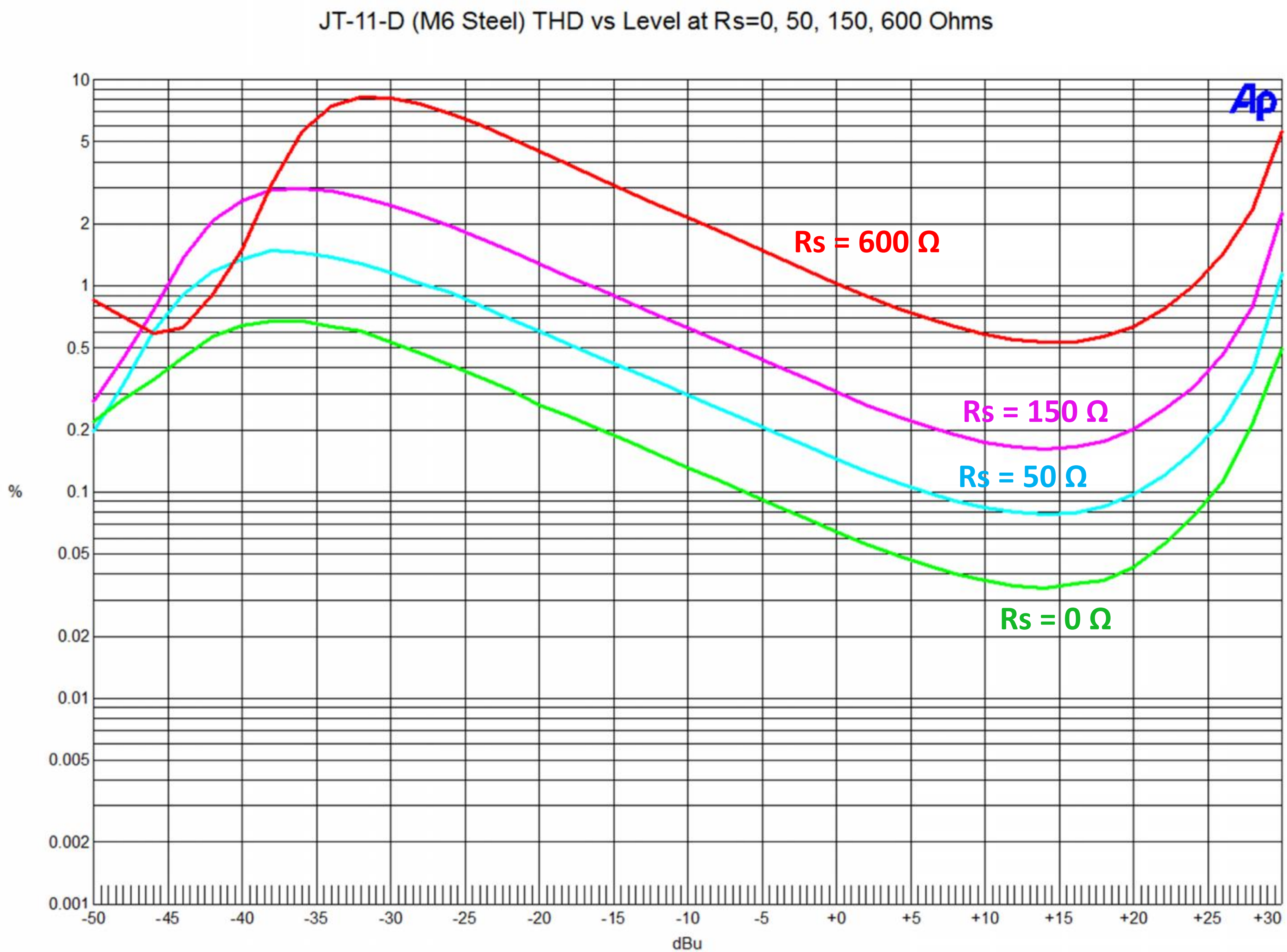

JT-11-D (M6 Steel) THD vs Level at Rs=0, 50, 150, 600 Ohms
10
5
2
1
0.5
0.2
%
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu
Rs = 0 Ω



JT-11-D (M6 Steel) THD vs Level at Rs=0, 50, 150, 600 Ohms
Rs = 50 Ω
Rs = 0 Ω
%
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30
dBu

JT-11-D (M6 Steel) THD vs Level at Rs=0, 50, 150, 600 Ohms

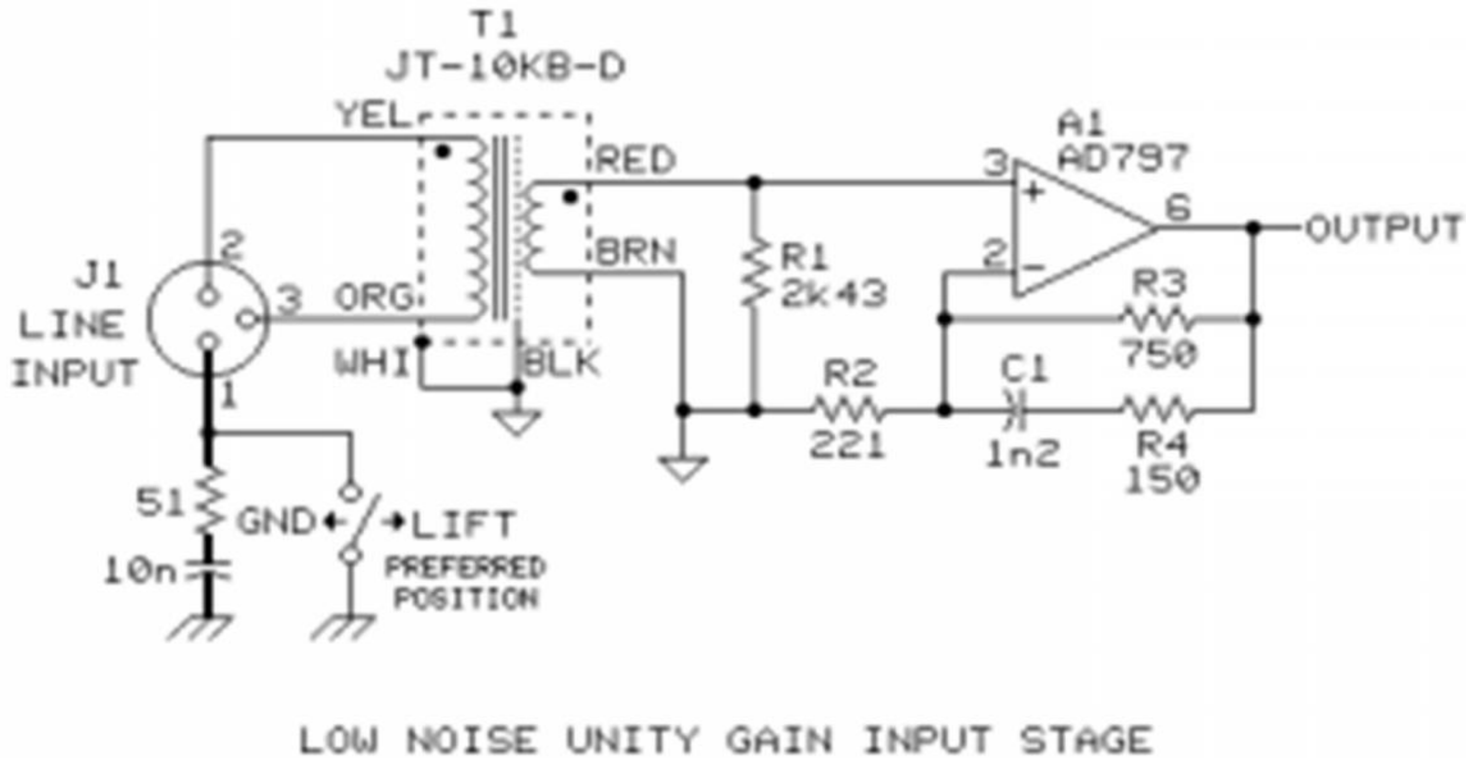




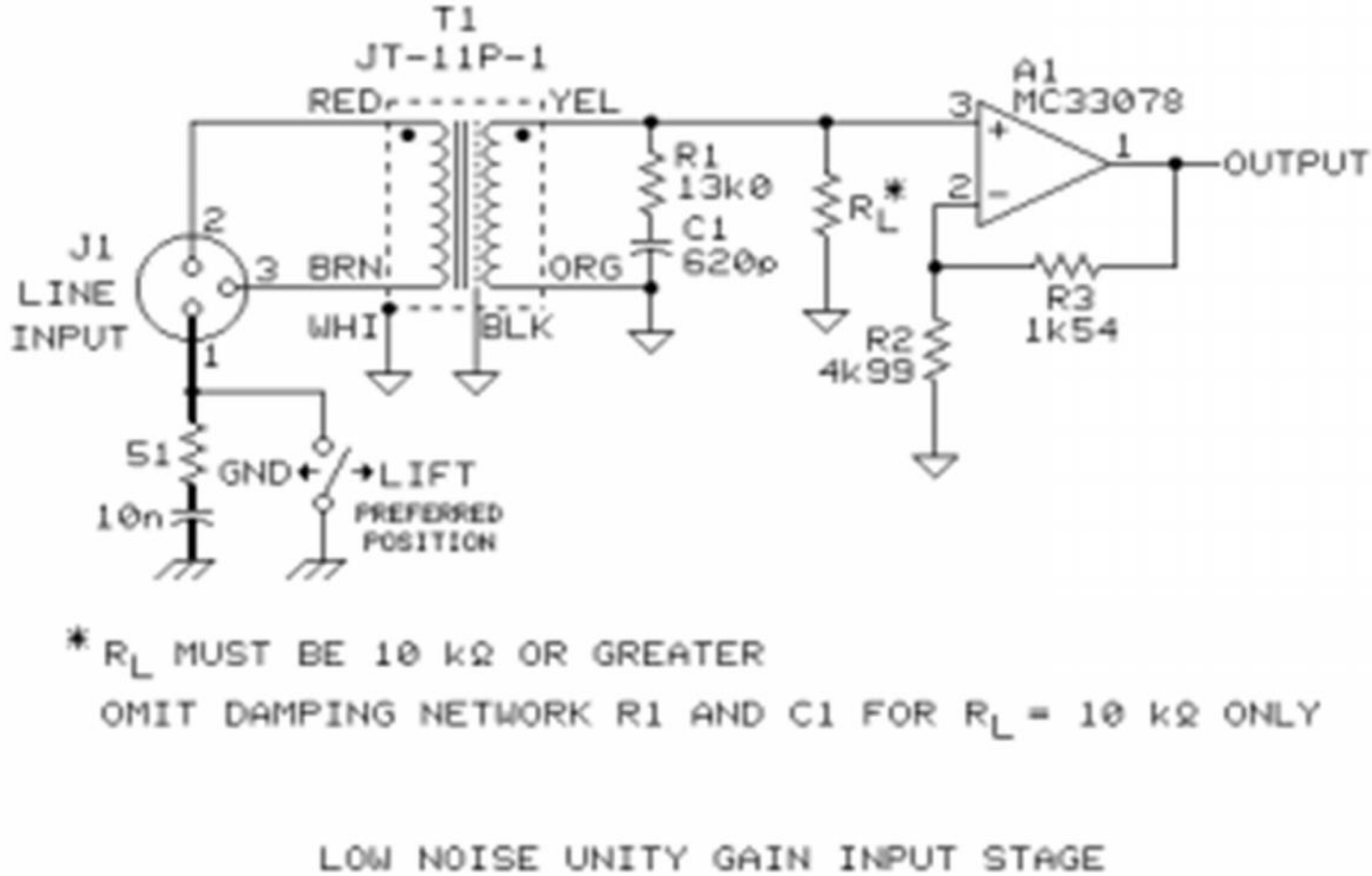
JT-11-D (M6 Steel) THD vs Level at Rs=0, 50, 150, 600 Ohms
Rs = 600 Ω
Rs = 150 Ω
Rs = 50 Ω
Rs = 0 Ω
%
dBu
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
-50
-45
-40
-35
-30
-25
-20
-15
-10
-5
+0
+5
+10
+15
+20
+25
+30

Steve's pick for Line Input Transformer

- 4:1 step-down (JT-10KB-D) outperforms 1:1 input transformer (JT-11P-1) in line input applications.
- Higher CMRR: 120dB vs 107dB
- Lower THD: 0.015% vs 0.025% at 20 Hz
- Wider Bandwidth: 180kHz vs 95kHz
- Much lower secondary source Z allows for lower noise circuitry.
- 12dB step down allows more headroom at input and minimum 6dB gain in following amplifier.



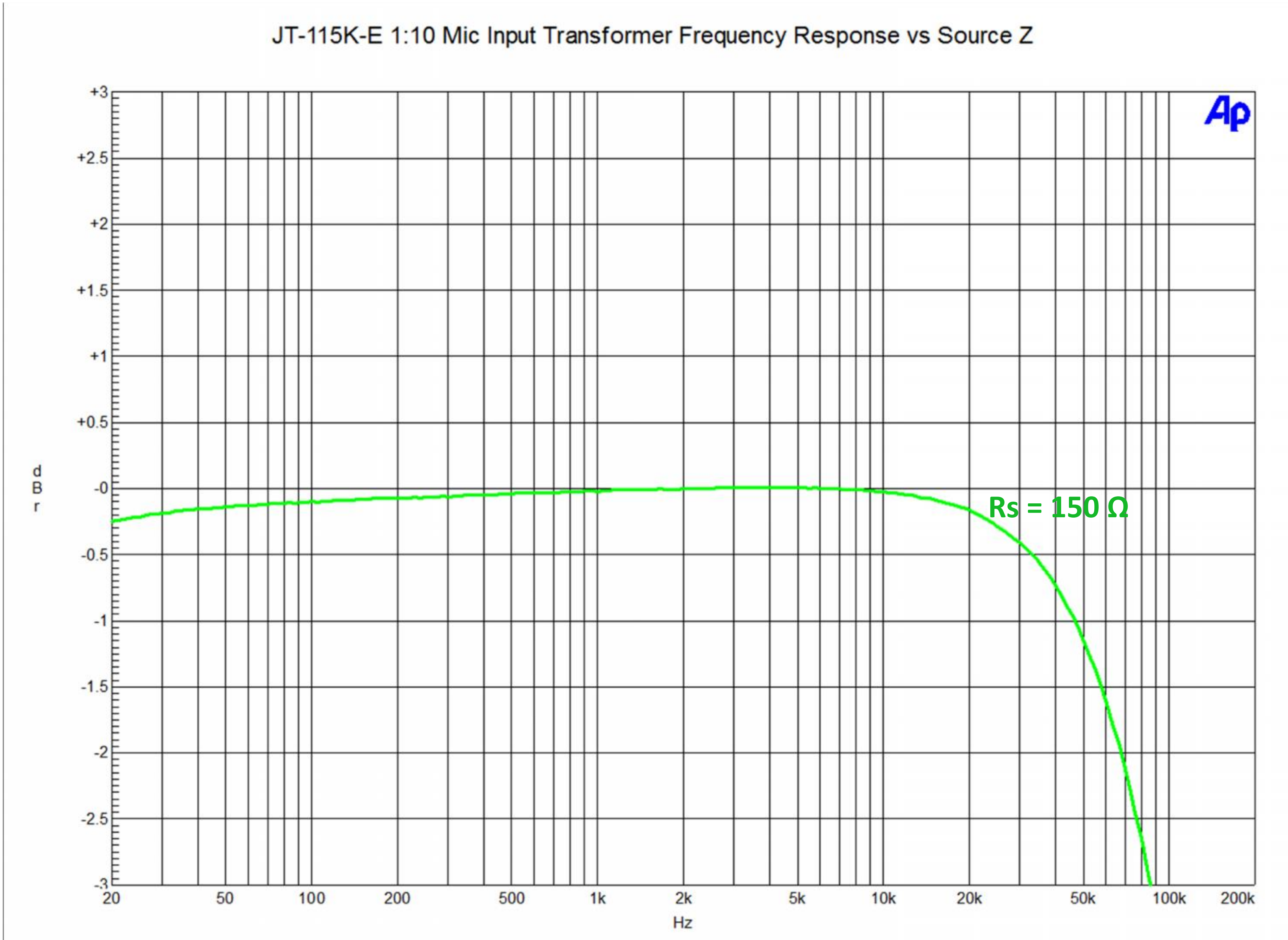
Typical Application

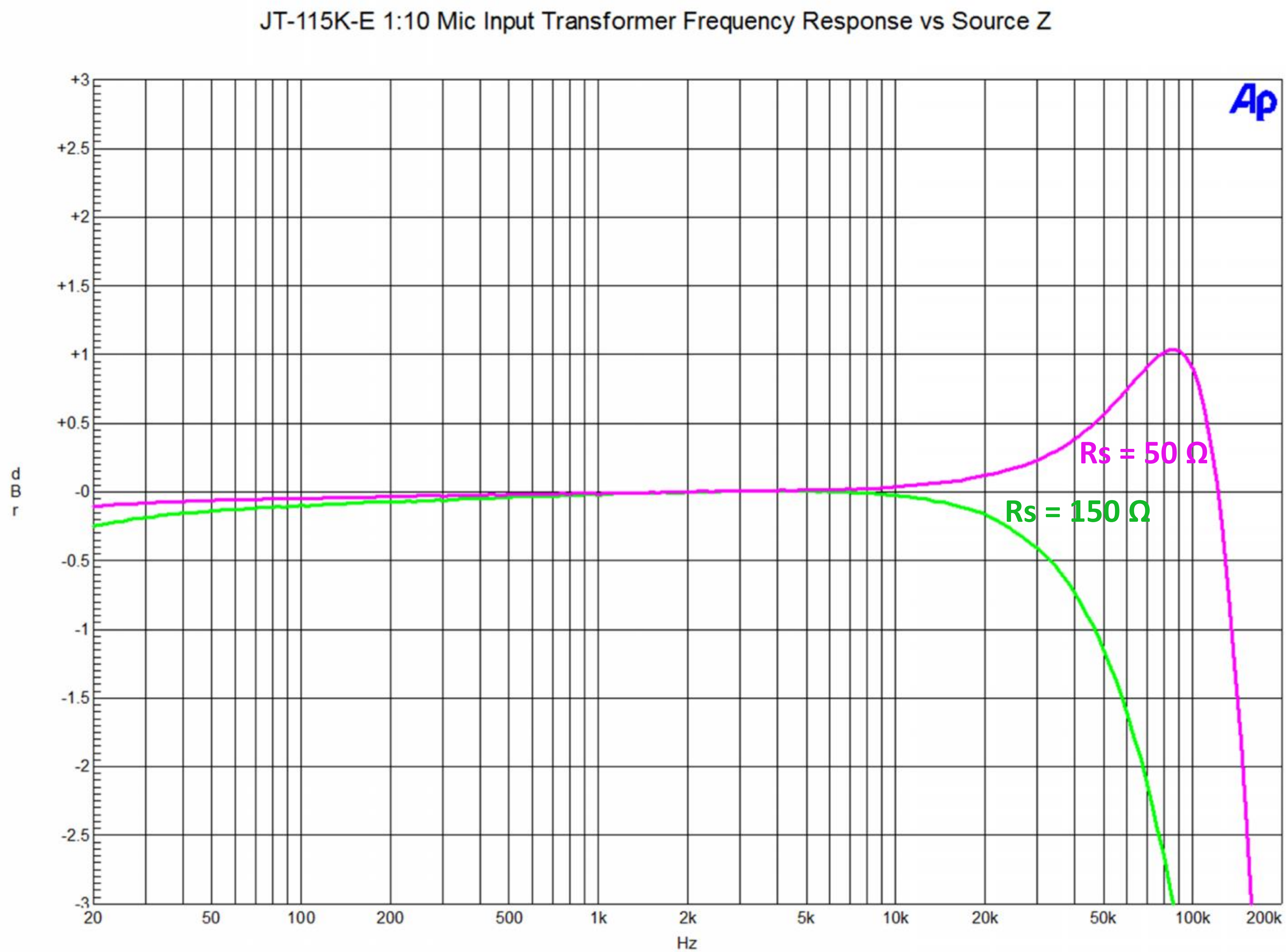


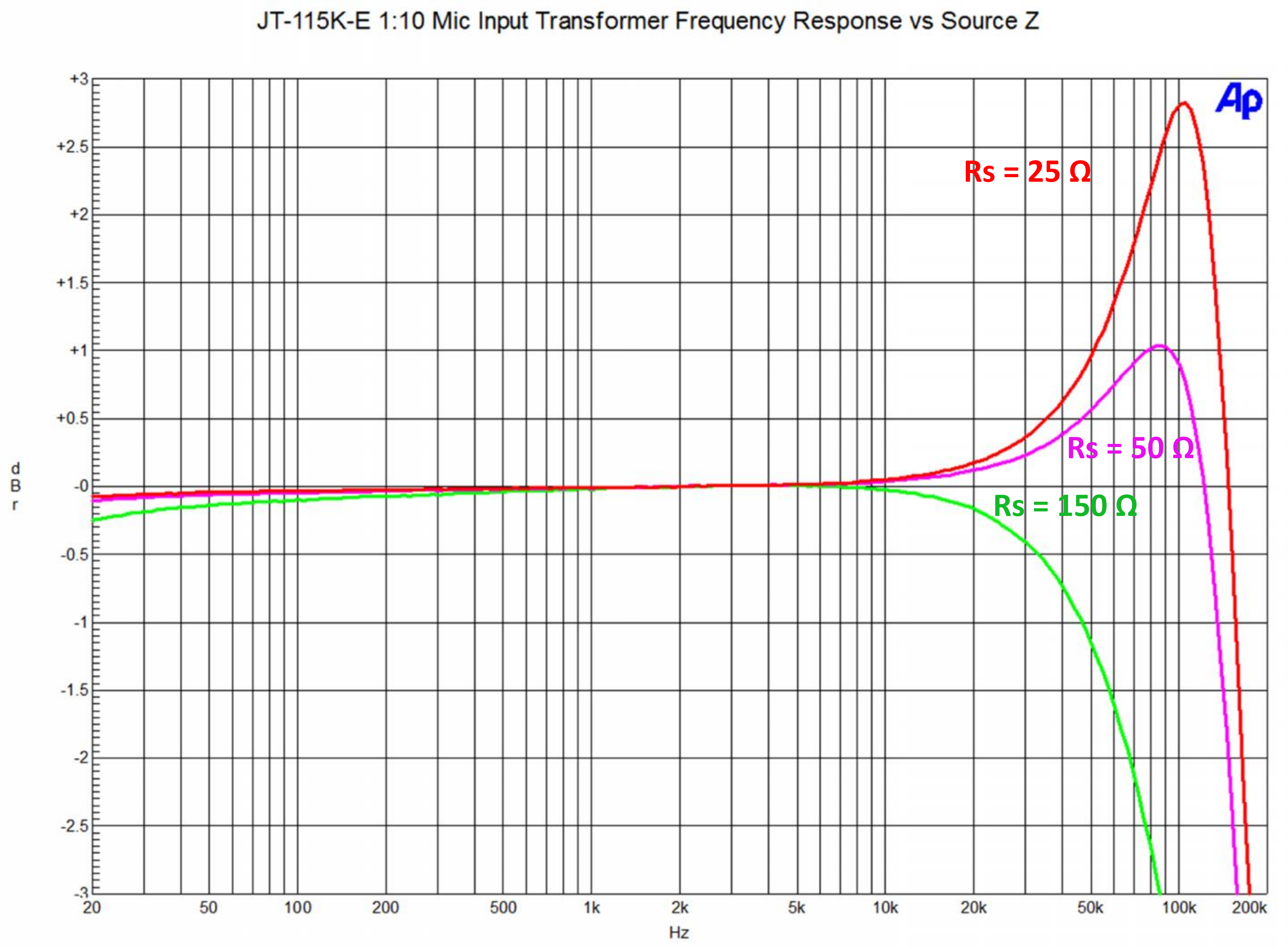
Typical Application

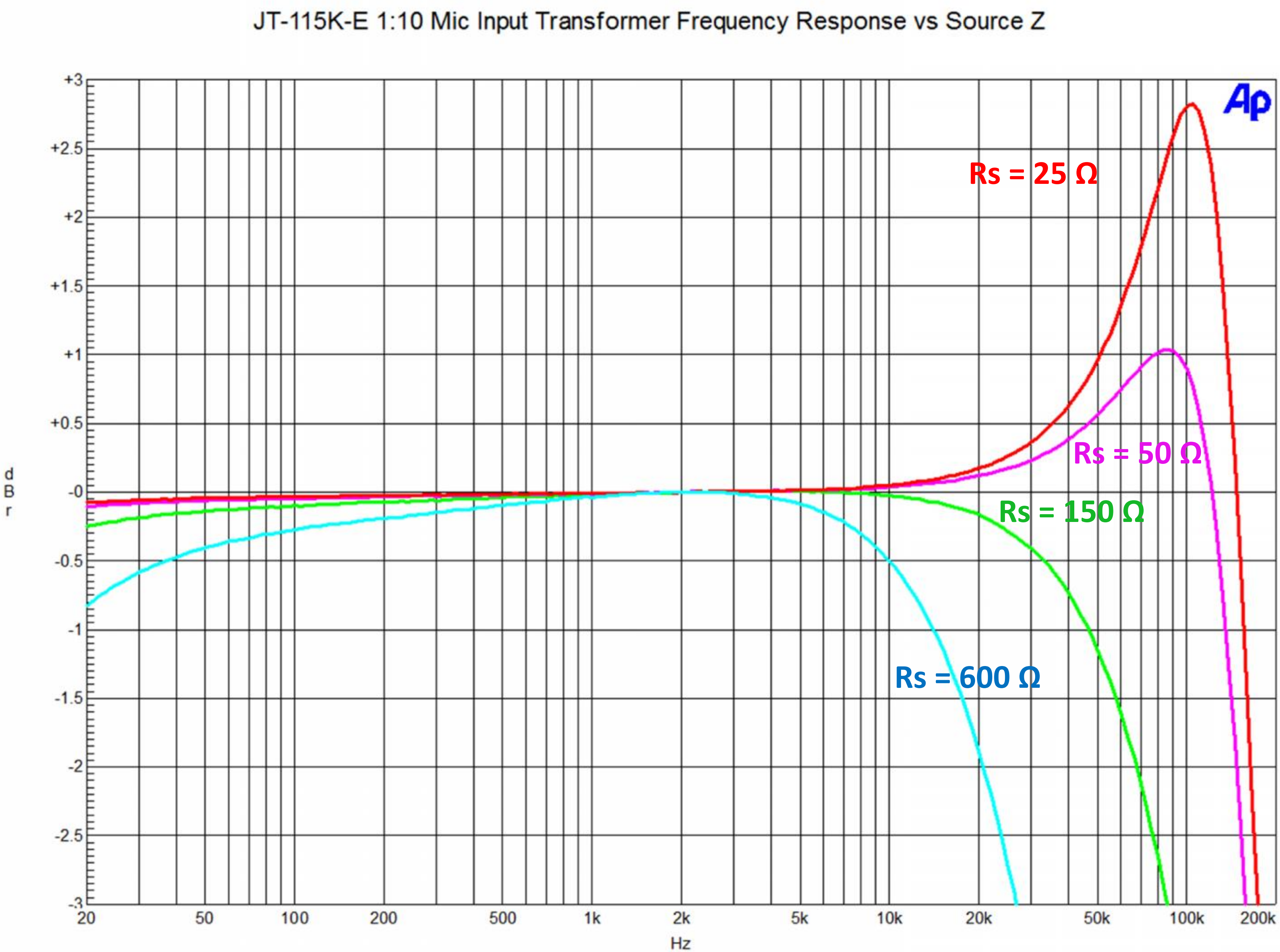
Source Z and Mic Input Transformers

- Microphone output impedance (source Z to input transformer primary) can have a significant effect on the high frequency response and therefore the transient response of a transformer-balanced mic preamp.
- Source Z will have a lesser effect at low frequencies, with higher microphone output Z causing slightly more Low Frequency THD and more Low frequency roll-off.
- The source impedance effects are more pronounced in high-ratio (1:10) step-up mic transformers than in low ratio 1:2 step-up input transformers.
- Adding resistive build-outs to low-Z mics solves this problem completely. Hence “Low-Z mic” switch in the best transformer-based preamps.
- The recording engineer who knows the output Z of his microphones is in the position to get the best sound from his preamps.

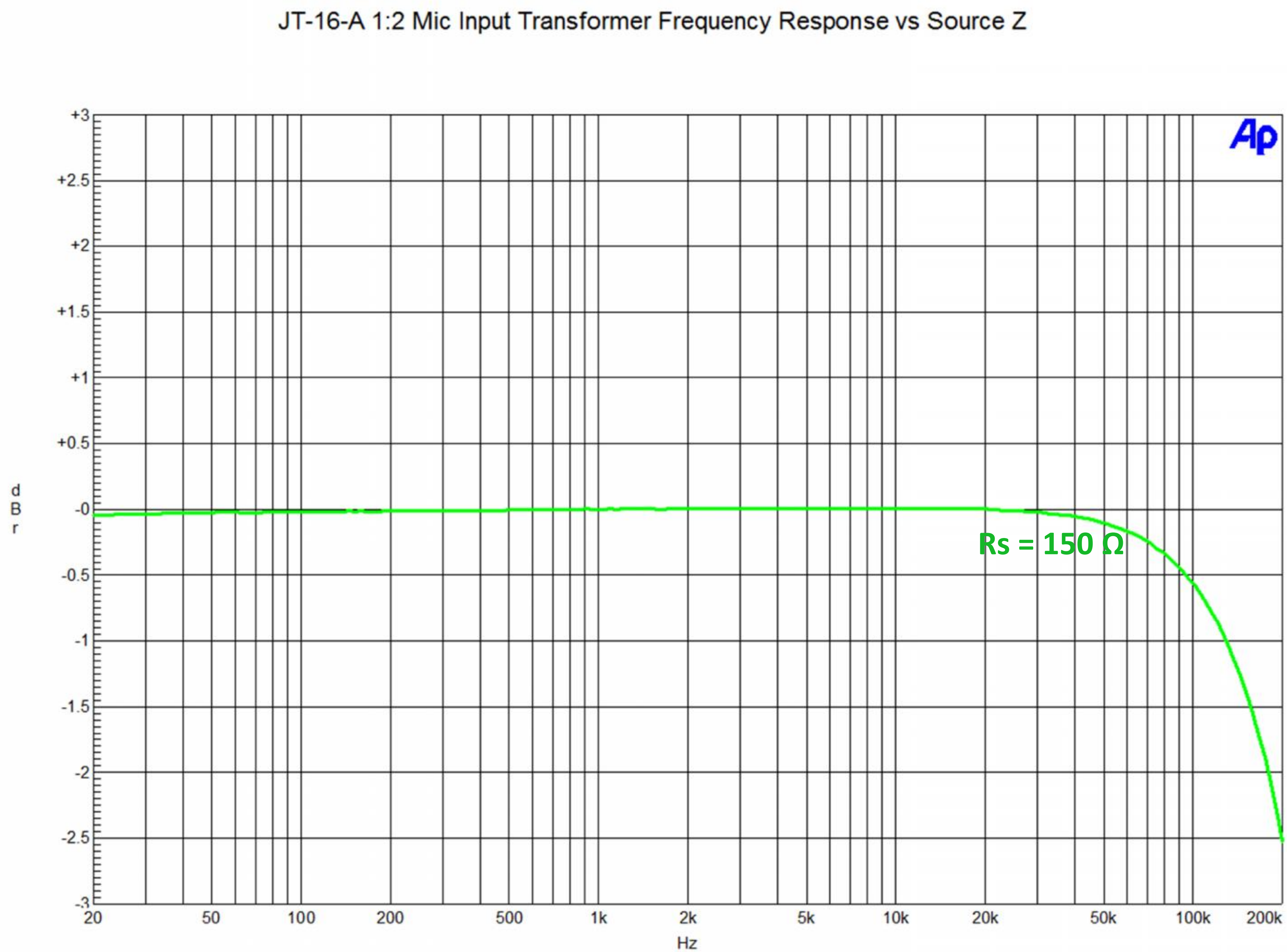

JT-115K-E 1:10 Mic Input Transformer Frequency Response vs Source Z
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
dBr
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Rs = 150 Ω


JT-115K-E 1:10 Mic Input Transformer Frequency Response vs Source Z
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
dBr
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Rs = 50 Ω
Rs = 150 Ω

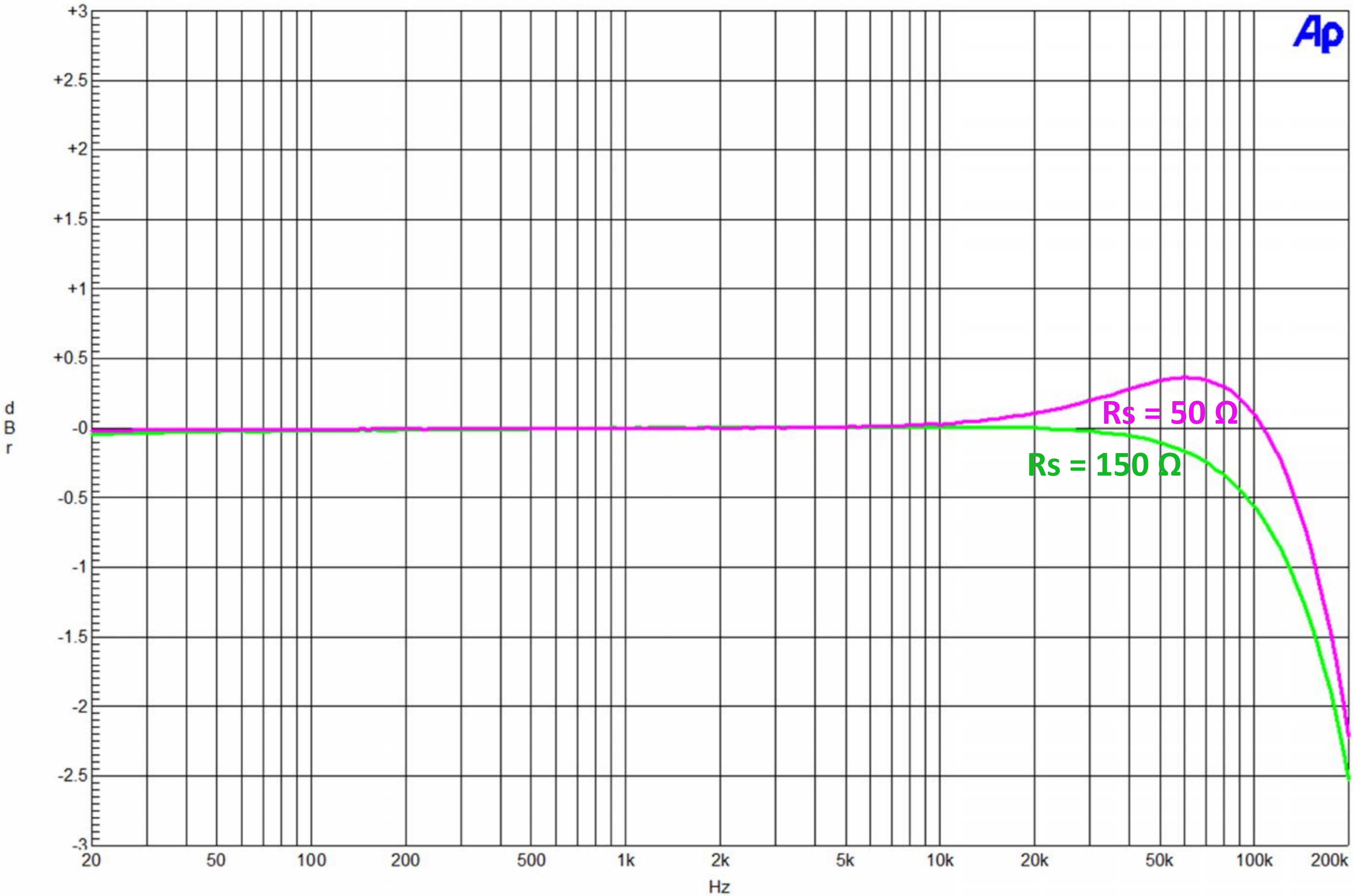

JT-115K-E 1:10 Mic Input Transformer Frequency Response vs Source Z
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
dBr
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Ap
Rs = 25 Ω
Rs = 50 Ω
Rs = 150 Ω

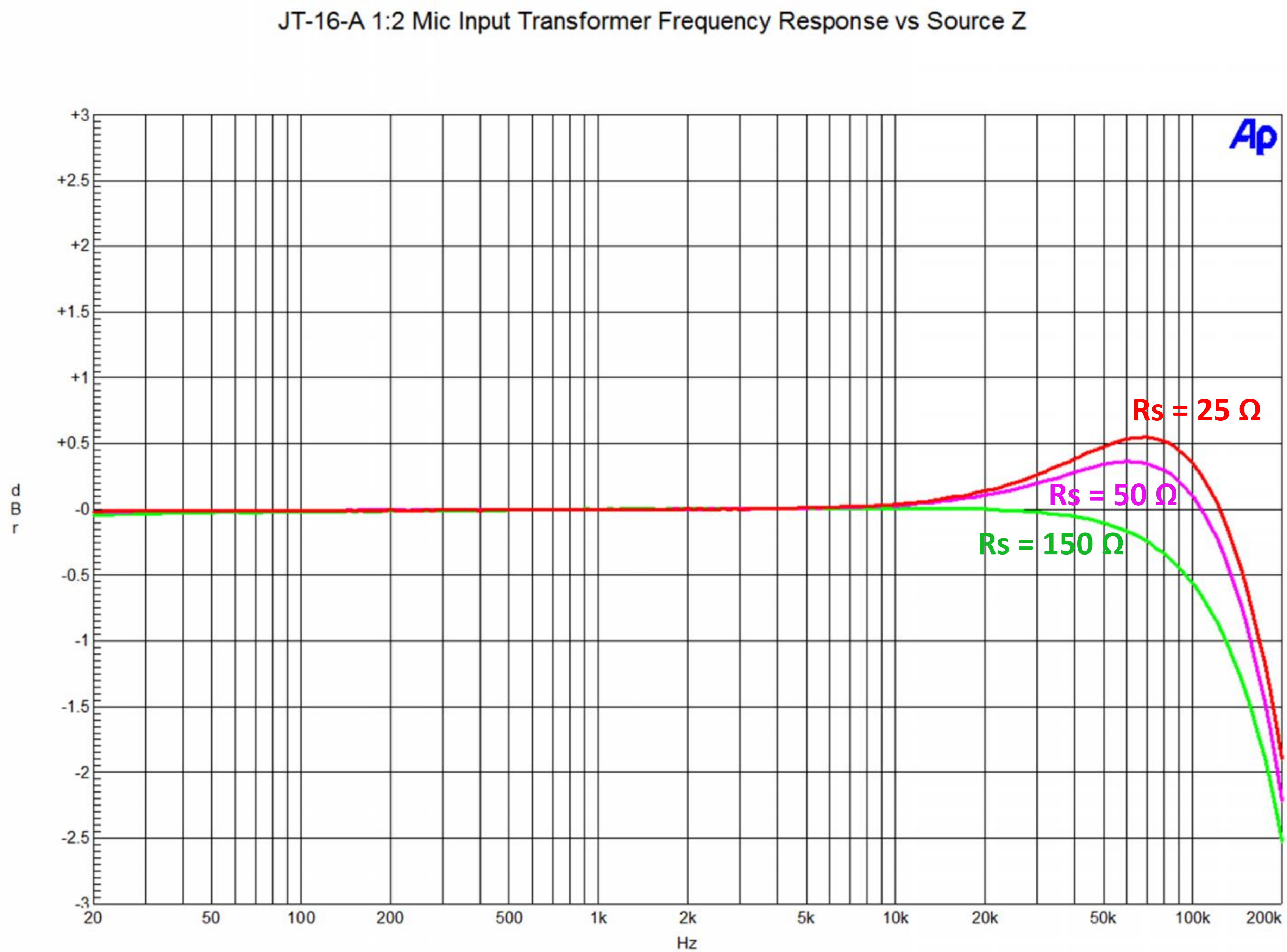


JT-115K-E 1:10 Mic Input Transformer Frequency Response vs Source Z
Ap
Rs = 25 Ω
Rs = 50 Ω
Rs = 150 Ω
Rs = 600 Ω
dBr
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz

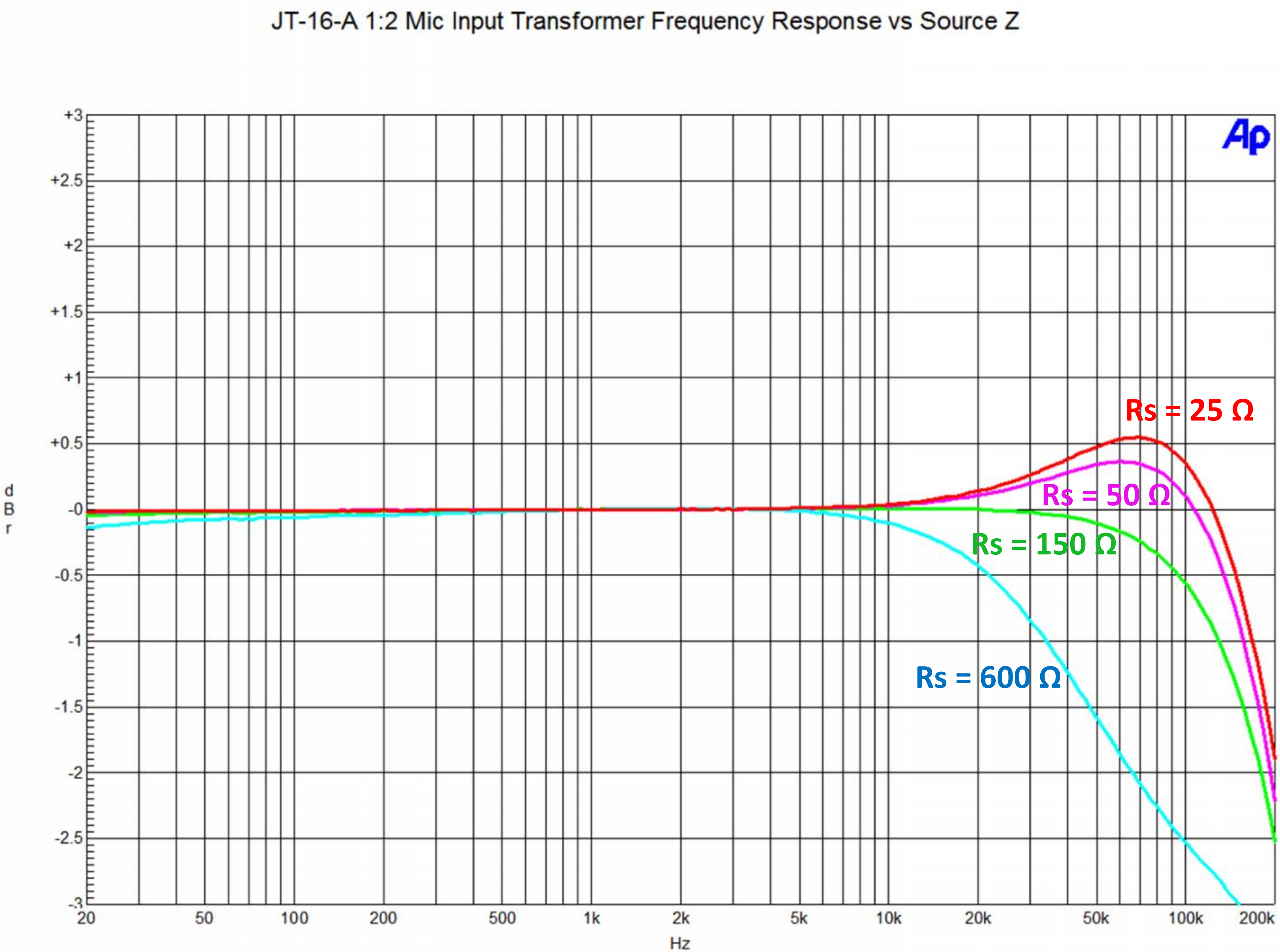

JT-16-A 1:2 Mic Input Transformer Frequency Response vs Source Z
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
d
B
r
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Rs = 150 Ω

JT-16-A 1:2 Mic Input Transformer Frequency Response vs Source Z





JT-16-A 1:2 Mic Input Transformer Frequency Response vs Source Z
Ap
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
dBr
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Rs = 25 Ω
Rs = 50 Ω
Rs = 150 Ω



JT-16-A 1:2 Mic Input Transformer Frequency Response vs Source Z
Ap
+3
+2.5
+2
+1.5
+1
+0.5
-0
-0.5
-1
-1.5
-2
-2.5
-3
dBr
20
50
100
200
500
1k
2k
5k
10k
20k
50k
100k
200k
Hz
Rs = 25 Ω
Rs = 50 Ω
Rs = 150 Ω
Rs = 600 Ω