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CATV Hybrid Amplifier Modules: Past, Present, Future

Conrad Young

Key Concepts Discussed:

- History of the Cable Industry.
- History of CATV Amplifiers and Hybrid Amplifiers.
- CATV Hybrid Amplifiers Today.
- What the Future Holds.

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Overview

The year 2008 marks the 40th anniversary of the community antenna television (CATV or "cable") hybrid amplifier packaged in the industry-recognized SOT-115J package. An understanding of the history of the CATV hybrid amplifier and its use within cable network distribution amplifiers is necessary to understand today's cable industry and the industry's future. Improvements in distribution network amplifier technology have been integral to the growth of the cable industry, while limitations with regard to amplifier technology have, at times, limited the cable industry's capability to deliver programming to its customers. Introduction of the CATV hybrid amplifier in 1968 resulted in the eventual replacement of vacuum tubes and discrete radio frequency (RF) transistors used in CATV distribution network amplifiers. Since its inception the CATV hybrid amplifier has been the central component in determining the capability and performance of CATV distribution equipment. The introduction and continual improvement in performance of the CATV hybrid amplifier has provided the foundation for the cable industry's continued growth and prosperity since 1968. Today's CATV hybrid amplifier uses the same package as those first used in Lindsay Broadband line amplifiers in the early 1970s to provide today's Rogers Cable with 35-channel 300 MHz capacity.

A Historical Perspective of the Cable Industry

Cable distribution amplifier development is intertwined with the cable industry's ability to offer new and improved services. A complete understanding of the cable industry today and the ability to correctly anticipate future trends depends partly on knowledge of the cable industry's history.

The roots of cable started with the development of television (TV) and the TV broadcasting industry. The TV broadcasting industry[1] developed in densely populated areas where the substantial number of viewers within the broadcaster's transmission range made the system commercially viable. These areas became known as TV markets. [2]

The electromagnetic spectrum available for allocation to the TV signal broadcast industry was (and remains) limited. Unlimited geographic expansion of the TV signal broadcast service in the US was restricted because of:

1. Questionable commercial feasibility in sparsely populated areas
2. Signal interference among closely located TV stations sharing channels

The FCC (Federal Communications Commission) allocation of the UHF spectrum (470 MHz to 870 MHz) to the TV broadcast industry in 1951 helped alleviate signal interference problems; however, most early TV receivers were not equipped with UHF tuners. Viewers needed a separate UHF antenna for best reception and the continuous UHF tuners available at the time were difficult to use. In the 1960s, population centers of less than 50,000 almost certainly had no TV broadcast station. Somewhat larger population centers may have had one, but only large population centers had affiliate TV broadcast stations for all three major networks and PBS (Public Broadcasting Service). As a result of these factors, reception in areas outside the major markets was poor, incomplete, or nonexistent.

Thus, the cable industry was born to fulfill a need for improved reception of TV signals in smaller population centers. The electromagnetic spectrum allocated to broadcast TV relied primarily on line-of-sight propagation modes. For this reason, signal reception was significantly enhanced by using elevated mast antennas with good directivity. By sharing the cost of a well-designed and well-positioned antenna (in an early form of "head end" (HE)) and distributing these higher signal-to-noise signals via twin lead antenna wire ("ladder wire") at first and followed by the use of coaxial cable (forming the earliest "distribution system" or "cable plant"), communities were able to upgrade their TV signal reception. These systems soon became known as CATV. In 1948, John and Margaret Walson of Mahanoy City, Pennsylvania, built one of the first CATV systems to increase TV receiver sales in their appliance store.

Except in isolated cases, the typical early CATV system provided a community with an affiliate's signal for each major TV network, a PBS station, and one or two

1. The broadcasting of a United States National Television System Committee (NTSC) television signal started in 1946.

2. Markets are known as Designated Market Areas, as defined by Nielsen Media Research. In 2008 the largest market is New York City with 7,391,940 TV households, the smallest market is Glendive, Montana, with 3,890 TV households (down from 5,300 in 1987). (http://www.nielsenmedia.com/nc/nmr_static/docs/2007-2008_DMA_Ranks.xls)

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independent stations. In many cases, the signal-to-noise ratio at a TV receiver was poor for distant transmitters. Co-channel signal interference was often a problem because some locations were nearly equidistant from stations sharing the same channel. Variations in propagation conditions caused intermittent signal interference. Signal reception quality often varied considerably among channels, depending upon distance between the TV receiver and the tuned station transmitter. Taller and higher performance antennas helped overcome these difficulties to a degree; however, the justifiable expense and the performance of early CATV systems matched the size of the customer base.

CATV systems from 1948 through the 1960s were typically small, independently owned “mom and pop" operations. In some cases, they were literally one-person operations. In those days, small towns were the primary market for CATV. Isolated dwellings in rural areas were difficult to serve because of the expense and performance of long coaxial cable runs.

From the industry's infancy in the early 1950s to 1965, the number of CATV subscribers grew to approximately 1,500,000, representing only a small fraction of total TV households. CATV remained in the background of national attention and simply provided a technique for extending the coverage of TV broadcasts. Although a few TV broadcasters foresaw competition from the CATV industry, most were indifferent toward CATV in its early days.

Factors Encouraging Early Growth

Factors encouraging the cable industry's earliest growth period between 1948 and 1954 were:

1. The first NTSC broadcast in 1946 and the subsequent introduction of broadcast TV in select markets.
2. World War II (WWII) provided both the technical training and initial key hardware (war surplus) to fuel the cable industry. Many early cable industry pioneers were trained as a result of direct military service or service within the defense industry during WWII. WWII accelerated the advent of radar and advanced radio frequency (RF) communications techniques with associated hardware (twin lead cable, RG11U coaxial cable, vacuum tube amplifiers, and electron tube amplifiers). The GI Bill provided the means for many early cable pioneers to receive the education required to become contributors to the cable industry's early technical accomplishments and growth.
3. The master antenna television (MATV) market helped accelerate the development of hardware and broadcast TV signal reception enhancement techniques that benefited the CATV industry. Examples include Jerrold Electronics' initial use of coaxial cable to connect multiple TV receivers within multiple dwelling units (MDUs) and commercial buildings; TV receiver boosters (such as the Jerrold MUL-TV preamplifier inserted between a MATV antenna and TV receivers within apartment houses; Blonder-Tongue Laboratories broadband TV antenna booster) equipped with variable very high frequency (VHF) tuners with channel 2 through 13 capability that amplified broadcast TV signals at an individual TV receiver; vacuum tube based "stagger-tuned" strip amplifiers manufactured by companies such as Alliance, Benco, Blonder-Tongue Laboratories, Electro Voice, Jerrold, RCA, and SKL.
4. After World War II, the mass development of television was delayed by a six-month moratorium on the issuing of television broadcasting licenses by the Federal Communications Commission (FCC). That six-month moratorium was designed to let the FCC essentially draw a road map for itself on where it wanted television to go. Making the decisions of where to go was more complicated than previously thought and the six-month moratorium was extended to four years. This became known as the era of the Big Freeze. The FCC placed a moratorium on the issuance of new broadcast TV transmitter licenses nationwide (due to co-channel interference issues) in the period 1948 through 1952. In 1952, the FCC released procedures for administering licenses under their 1952 amendments with "Provisions Governing the Granting, Renewal and Transfer of Construction Permits and Licenses."
5. In 1948, there were 16 broadcast TV stations operating on the air. By 1953, there were 126.
6. Direct US government (FCC) regulation of the cable industry did not begin until 1958.
7. AT&T permitted the lease, by contract, of utility poles required to mount early CATV distribution network amplifiers. Both TV broadcasters and AT&T falsely assumed that once the 1948 FCC moratorium on broadcast TV transmitter licenses was lifted that the burgeoning CATV industry would wither and die. Conventional wisdom within the TV broadcast community in 1952 was that every US citizen would soon have access to over-the-air TV signals within a few years. The reality is that even today there are many locations within the US that still do not have full TV

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broadcast coverage (all major affiliate signals, plus PBS).

Early cable systems from 1949 to the early 1960s consisted of tower-mounted antennas with preamplifiers that drove flexible coaxial cable with dispersed vacuum tube amplifiers. These systems employed little or no HE signal processing and did not require set-top converters. The TV receiver was simply tuned to a channel provided by the coaxial cable, as if tuning to a channel broadcast off-air using VHF channels 2 through 13. CATV systems naturally evolved into well-defined segments: HE, distribution (the CATV or cable plant), and subscriber (customer premises) equipment.

In areas where TV signals were available from more than three or four TV broadcast stations, CATV systems could often receive TV broadcast stations on adjacent allocated channels. Because some or all broadcast stations were distant, propagation conditions caused the received TV signal levels to vary independently. When adjacent channels were occupied, the TV receiver only functioned properly if the TV signal levels on these channels were within ±3dB of the tuned channel. If a TV broadcast station's signals were stronger than those of other nearby broadcast stations, frequency selective networks were used to attenuate the stronger channel and thus equalize the TV signal levels.

Simple frequency selective networks did not, however, correct for propagation-induced signal level variations. To better maintain constant signal levels on each channel, signal processors with intermediate frequency (IF) automatic gain compensating (AGC) networks were introduced. Signal processors were also used to translate UHF stations into the VHF spectrum for carriage on the CATV system. These and other factors, such as the substitution of standby carriers for lost carriers, automatic program origination, and improved satellite technology, initiated the evolution of the complex HE systems used today.

The mid-band spectrum from 88MHz to 174MHz between NTSC channels six and seven was allocated for FM radio broadcast, aeronautical, and mobile two-way services. This spectrum could have been used on closed CATV systems except for two problems:

1. Early distribution amplifiers were single-ended, which resulted in a buildup of second order distortion beats in the mid-band channels.
2. The TV receiver did not tune mid-band channels.

Practical, high frequency, solid state, bipolar transistors became available in the early 1960s and led to improvements in distribution amplifier design. In the late 1960s push-pull amplifier circuitry was used to greatly reduce second order distortion. The development of the set-top converter eventually overcame the TV receiver limitations.

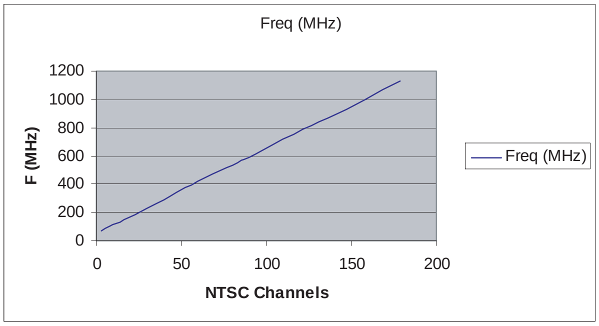
The need to use the mid-band spectrum led to the development of the set-top converter by Jerrold and Alps. Some CATV systems imported signals by terrestrial microwave links. This allowed these systems to provide additional programming, which enhanced their marketability. By 1974, numerous independent TV broadcast stations were in operation, thus increasing the number of broadcast stations CATV systems could carry. Though the 216MHz CATV system popularly in place through the early 1970s was capable of carrying 12 NTSC channels, the average CATV system actually carried seven channels of programming until the mid-1970s.

Table 1. US CATV System Channel Capacity (1948-2008)

Year	NTSC Channel Capacity	Upper Frequency Limit (MHz)
1948	3	162[a]
1949	5	174[a]
1950	8	192[a]
1951	12	216[a]
1974	35	264
1980	52	378
1988	83	552
1992	91	600
1993	116	750
1995	136	870
2000	158	1002
2008	179	1128

a. Includes 90MHz for FM radio and other restricted-use frequencies.

Figure 1. US CATV NTSC Channel Capacity (1948-2008)



By 1975, CATV system technology had matured. HE systems resembled the form, functions, and performance of pre-1995 hybrid fiber coaxial (HFC) cable systems. The CATV hybrid amplifier, now the cornerstone component in modular distribution optical nodes and amplifiers, was well established. Two-way CATV technology was well understood. During the 1970s, 30-channel, 300 MHz components became readily available, but the embedded base of installed CATV systems primarily consisted of 12-channel, 216 MHz systems. As late as 1988, 17% of CATV systems were only 12-channel capable and served 4% of all cable subscribers.

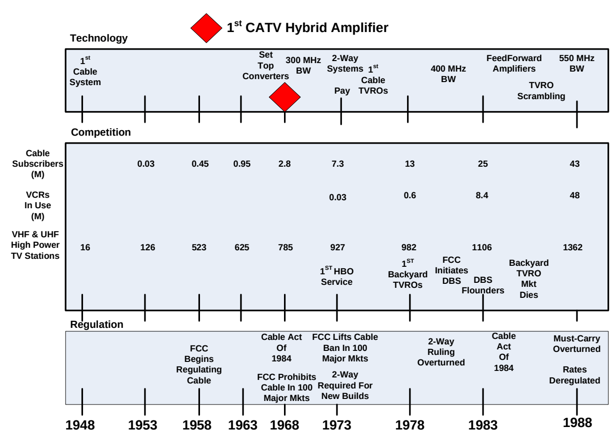
Table 2. CATV Systems / Subscribers by Capacity (1989)

Channel Capacity	Systems	% Of Systems	% Of Subscribers
54 or more	679	7.53	20.53
30 - 53	4502	49.93	66.25
20 - 29	1420	15.75	8.87
13 - 19	292	3.24	0.61
6 - 12	1202	13.33	2.22
5	31	0.34	0.01
Fewer than 5	7	0.08	0.01
Not Available	883	9.80	1.50
TOTAL	9016	100.00	100.00

Source: *Cable Television Developments* (Washington, D.C.: National Cable Television Association, May 1989)

By the late 1950s TV broadcasters knew the cable and broadcasting industries competed. In 1958, the FCC began regulating CATV. To protect TV broadcasting, the FCC created must-carry rules in 1972. These rules requiring cable companies carry various local and public TV stations within a cable provider's service area have had a dramatic history. Designed to ensure local stations did not lose market share with increased competition from cable networks competing for a limited number of cable channels, must-carry rules have at times been ruled unconstitutional and gone through numerous changes. To further protect TV broadcasting, the FCC enacted importation rules in 1972. These rules prevented CATV systems from importing the TV signals of more than one distant affiliate (such as an affiliate outside the area covered by the cable system) if the corresponding network had an affiliate in the CATV system coverage area. The FCC also limited the number of independent broadcast stations that could be imported. The FCC reduced the extent of the importation rules in 1981.

Figure 2. Cable Industry Timeline (1948-1988)

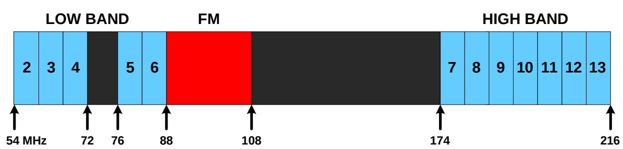


Cable Television Amplifiers (1948-1968)

Early cable systems consisted of tower-mounted antennas with preamplifiers that drove flexible coaxial cable with dispersed vacuum tube amplifiers. The first cable systems were 12-channel forward path only (Figure 3) and the frequency plan was based on characteristics of VHF television receivers manufactured in the US from 1948 to the late 1970s. These early systems employed little or no HE signal processing and did not require set-top converters. The TV receiver was simply tuned to a channel provided by the coaxial cable, as was done when tuning to a TV channel broadcast off-air (VHF channels 2 through 13). Cable systems naturally evolved into well-defined segments consisting of HE, distribution (the cable plant), and subscriber (customer premises) equipment. These cable systems carried FM radio on 88MHz to 108MHz and the 108MHz to 174MHz (known as mid-band) range was unoccupied to maintain consistency with television signal broadcast standards.

In areas where TV signals were available from more than three or four TV broadcast stations, CATV systems could often receive broadcast stations on adjacent allocated channels. Because some or all TV broadcast stations were distant, propagation conditions caused the received TV signal levels to vary independently.

Figure 3. Typical Frequency Plan, 12-Channel System, One Way (1948-1989)



The original 12-channel cable system amplifiers used vacuum tubes. The triode Audion (three-electron) vacuum tube amplifier, invented and patented by Lee de Forest in 1907, boosted the amplitude of radio waves as they were received, allowing the human voice, music, or any broadcast signal to be heard loud and clear. The vacuum tube became the key component of all radio, telephone, television, computer systems, and radar before the invention of the transistor in 1947. The earliest high performance cable television amplifiers were developed using surplus military vacuum tubes and associated power supplies. Milton Jerrold Shapp developed a system in 1948 that allowed one master antenna to provide a signal to all TVs in a department store in Philadelphia, Pennsylvania. Shapp's system was notable because it employed coaxial cable (from military surplus) and self-made signal boosters (amplifiers constructed using surplus military triode vacuum tubes) capable of carrying multiple signals at once with high fidelity. Shapp is credited with establishing the first commercially viable MATV systems. In 1948, Shapp formed a company, Jerrold, to manufacture, sell, install, and support his MATV hardware in the eastern United States. At nearly the same time, John and Margaret Walson installed the first (CATV) system in Mahanoy City, Pennsylvania, to facilitate the sale of newly introduced General Electric (GE) TVs at their Service Electric appliance store. The Walsons formed Service Electric Cable TV Incorporated in 1948, still operating today as Service Electric Cablevision, the oldest cable TV multiple system operator (MSO) in the US. The Walson's charged $100 installation fee plus $2 a month for delivering two to three Philadelphia broadcast TV network signals to TVs sold by the Walsons. The Walson's first CATV system used ladder wire (twin-lead antenna wire) and homemade amplifiers. After the Walsons established their CATV system, Bob Tarlton built the first CATV system in Lansford, Pennsylvania, with the express purpose of charging a monthly fee for service (earlier systems were constructed by TV set retailers to facilitate the sale of TV sets). Tarlton modified Jerrold MATV booster amplifiers and used them to amplify his CATV system signals. When Milton Shapp visited Lansford and saw Tarlton's CATV system, he returned to Philadelphia, restructured his company to serve the new CATV business, and quickly became the largest and most important CATV equipment supplier in the US. Bob Tarlton joined Jerrold and became a key contributor to Jerrold's growth as both a cable TV industry equipment supplier, and multinational, far-reaching MSO. The company that was once Jerrold is now part of Motorola's broadband business operated from Horsham and Hatboro, Pennsylvania, among other worldwide locations.

Figure 4. Evolution of Jerrold

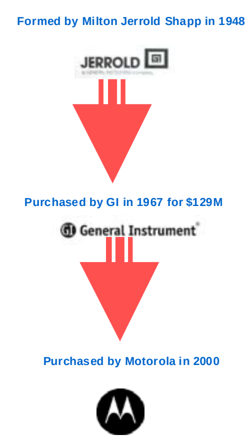


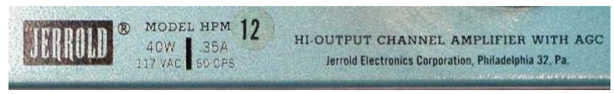
Figure 5. Vacuum Tube Technology: the Jerrold 12-Channel SDA-4 Super Distribution Amplifier

Source: http://theoldcatvequipmentmuseum.org

Figure 6. Vacuum Tube Technology: the Jerrold HPM-12 Channel 12 Amplifier

Source: http://theoldcatvequipmentmuseum.org

Figure 7. Vacuum Tube Technology: the Jerrold HPM-12 Name Plate



Source: http://theoldcatvequipmentmuseum.org

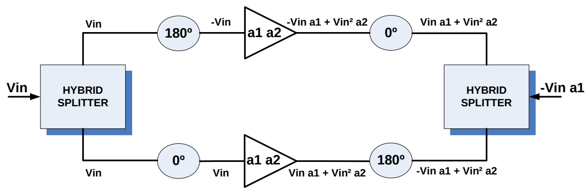
Table 3. Manufacturers of 1- to 12-Channel Vacuum Tube Amplifiers Employed in CATV & MATV Systems (1948-early 1970s)

Company Name	Notes
Alliance	The Alliance Manufacturing Company, Alliance, Ohio.
Astatic	Manufactured the AT-1 All Channel Television Booster.
Benco	Benco Television Associates, Limited, Toronto, Canada.
Blonder Tongue Laboratories	Established in 1950 in Westfield, New Jersey, by Isaac (Ike) S. Blonder and Benjamin (Ben) H. Tongue to develop, sell, install, and support MATV broadband TV antenna boosters (vacuum tube-based amplifiers) connecting individual dwelling units in apartments and hotels to a master antenna, typically on the roof of each building. Still a CATV and MDU equipment supplier to the worldwide CATV/SATCOM industry today.
Community Equipment Company (aka Community Engineering Corporation) - CECO	Owned and operated by Haller, Raymond, and Brown (HRB), State College, PA, incorporated as C-Cor in 1953 (due to the CECO name copyright infringement). C-Cor acquired by Arris Corporation in 2007.
Electro Voice	Electro Voice Incorporated, Buchanan, Michigan. Became well known for professional audio equipment, including horn-loaded loudspeakers and audio amplifiers.
Entron	Acknowledged to have introduced the first five-channel broadband amplifier with linear (low cross-modulation) performance.
Jerrold	Company formed by Milton Jerrold Shapp, later a two-time Governor of Pennsylvania, in 1948 to develop, sell, install, and support MATV system hardware. Enabled and dominated early CATV and MATV equipment industries and became a significant MSO and CATV test equipment manufacturer.
RCA	Radio Corporation of America, formed by David Sarnoff, acknowledged by many as the father of the present day television broadcast industry.
SKL	Spencer-Kennedy Laboratories, Boston, Massachusetts.

The Birth of the CATV Hybrid Amplifier (1968-1974)

Starting in the early 1960s, semiconductors began to supplant vacuum tube technology within CATV and MATV amplifiers. Expansion beyond the 12-channel system required the development of push-pull amplifier circuitry to minimize second order distortion. The cascade push-pull amplifier configuration typically incorporates four (4) transistors. Figure 8 is a simplified block diagram of an ideal push-pull amplifier.

Figure 8. Simplified Block Diagram of Ideal Push-Pull Hybrid Amplifier



Block Diagram of Ideal Push-Pull Hybrid Amplifier

Source: William "Bill" Lambert, "Second-Order Distortion in CATV Push-Pull Amplifiers," Proceedings of the IEEE, Vol. 58, No. 7, 1970. Created while Bill was employed by Jerrold Electronics Corporation, Willow Grove, PA.

In the period 1963 through the late 1970s, most CATV and MATV amplifiers, designed to boost broadcast TV antenna signals or provide video via extended distance cascades, used solid state discrete transistor-based amplifiers. The advantages of solid state transistor-based CATV and MATV amplifiers versus vacuum tube-based amplifiers included:

- lower input voltage (from life-threatening voltages in the hundreds of volts required to drive vacuum tubes, to <30Volts DC)
- cheaper, smaller power supplies
- increased reliability
- smaller amplifier housings
- lower cost

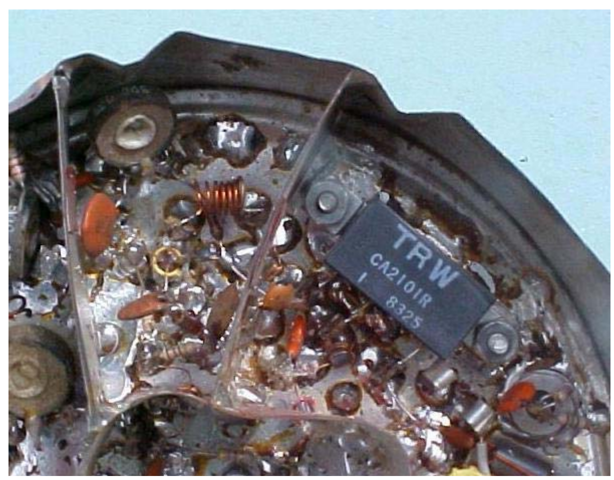
Disadvantages compared to vacuum tube-equipped amplifiers included:

- limited number of transistor suppliers
- new methods required for cooling both the transistor devices and amplifier housings
- need to invent transient voltage protection techniques, technology, and installation
- field replacement of discrete transistors soldered to printed circuit boards was not practical

A key advantage that CATV hybrid amplifiers have enjoyed over discrete transistors and other packaged amplifier solutions is ease of field replacement: only a screwdriver is required. The SOT-115J is designed with easily accessible pins for CATV and MATV amplifier pin and socket insertion and removal without need for soldering.

Early CATV hybrid amplifiers were employed in CATV and MATV amplifiers. Some of these amplifiers were known as "coffee can" amplifiers, which combined a broadband linear amplifier with one or more taps built into a modified coffee can. Each amplifier was assembled by hand, with components soldered directly to the can. Early versions used discrete transistors; later versions incorporated integrated circuits, including CATV hybrid amplifiers. The history of the coffee can amplifier is somewhat of a mystery: several of them were made, but the identity of the person who made them is in doubt. It is likely that several persons assembled them. A few coffee can amplifiers still exist in museums and private collections today.

Figure 9. Coffee Can Amplifier with TRW CATV Hybrid Amplifier (c. 1983)



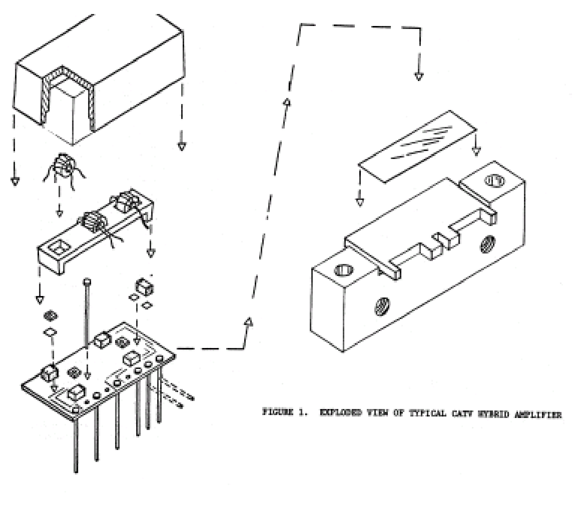
Source: Neal McLain and http://theoldcatvequipmentmu-seum.org

Table 4. Manufacturers of 1- to 20-Channel Solid State Transistor Amplifiers for CATV and MATV Systems (1948-early 1970s)

Company Name	Notes
Ameco	Introduced the NO STEP amplifier in 1963 for CATV cascades employing solid state transistor amplifiers (no vacuum tubes). NO STEP nomenclature came from the stencil used by Ameco to warn installers and cable TV technicians not to step on the amplifier housing.
Blonder Tongue Laboratories	Established in 1950 in Westfield, New Jersey, by Isaac (Ike) S. Blonder and Benjamin (Ben) H. Tongue to develop, sell, install, and support MATV broadband TV antenna boosters (vacuum tube-based amplifiers) connecting individual dwelling units in apartments and hotels to a master antenna, typically on the roof of each building. Still a CATV and MDU equipment supplier to the worldwide CATV/SATCOM industry today.
C-Cor	Owned and operated by Haller, Raymond, and Brown (HRB), State College, PA, incorporated as C-Cor in 1953 (due to the CECO name copyright infringement). C-Cor acquired by Arris Corporation in 2007.
Jerrold	Company formed by Milton Jerrold Shapp, later a two-time Governor of Pennsylvania, in 1948 to develop, sell, install, and support MATV system hardware. Enabled and dominated early CATV and MATV equipment industries and became a significant MSO and CATV test equipment manufacturer.
Sylvania	Sylvania's CATV amplifier division acquired by Texscan in the 1980s.
Theta-Com	Wholly owned subsidiary of Texscan.
Vikoa	Founded in 1955 by Arthur Baum.

In the early 1970s, TRW Semiconductor introduced to the CATV market what is today the standard package and hybrid circuitry for cable television system amplifiers. Development of the CATV hybrid amplifier as we know it today began at TRW in 1968. The aluminum heat sink employed as the transistor die and thin film circuit base plate in the SOT-115J (a non-JEDEC standard designation which is generally accepted today to describe the standard CATV hybrid amplifier package) was derived by removing the feet from a 1960s era metal chair.

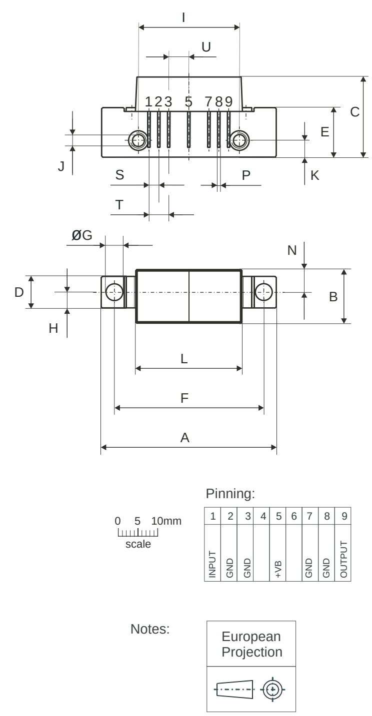
Figure 10. Exploded View of Typical CATV Hybrid Amplifier



Source: Excerpt from *IEEE Transactions on Cable Television*, Vol. CATV-3, No. 1, January 1978. "Reliability Considerations in CATV Hybrids," by Al Grant and Jim Eachus of Motorola Semiconductors.

CATV hybrid amplifiers in the period from 1968 to the mid-1990s employed transistors based on silicon bipolar processes. Many CATV hybrid amplifiers available in the SOT-115J package and designed for upstream (return path) frequencies (typically 5MHz to 200MHz) still employ silicon bipolar amplifier die today. "CATV Amplifier Timeline" on page 20 details the development and manufacturer's histories of the SOT-115J packaged hybrid amplifier.

Figure 11. SOT-115J Package Dimensions



All Dimensions in mm:

	nominal	min	max
A	44,6 ± 0,2	44,4	44,8
B	13,6 ± 0,2	13,4	13,8
C	20,4 ± 0,5	19,9	20,9
D	8 ± 0,15	7,85	8,15
E	12,6 ± 0,15	12,45	12,75
F	38,1 ± 0,2	37,9	38,3
G	4 +0,2 / -0,05	3,95	4,2
H	4 ± 0,2	3,8	4,2
I	25,4 ± 0,2	25,2	25,6
J	UNC 6-32	-	-
K	4,2 ± 0,2	4,0	4,4
L	27,2 ± 0,2	27,0	27,4
M	11,6 ± 0,5	11,1	12,1
N	5,8 ± 0,4	5,4	6,2
O	0,25 ± 0,02	0,23	0,27
P	0,45 ± 0,03	0,42	0,48
Q	2,54 ± 0,3	2,24	2,84
R	2,54 ± 0,5	2,04	3,04
S	2,54 ± 0,25	2,29	2,79
T	5,08 ± 0,25	4,83	5,33
U	5,08 ± 0,25	4,83	5,33

Until the mid-1970s, when Motorola Semiconductors introduced its first CATV hybrid amplifier, TRW Semiconductors was the sole supplier of CATV hybrid amplifiers.

Rogers Cable of Canada adopted the TRW CATV hybrid amplifier as the central amplifier technology within its 300 MHz downstream upper frequency-capable (35 downstream NTSC channels) trunk, bridger, and line extender (LE) CATV amplifiers in 1973. Rogers installed 300 MHz 35-channel NTSC cable systems throughout Canada from 1973 to 1980. Rogers also used the TRW CATV hybrid amplifier in 300 MHz-capable systems installed in Europe from 1974 to 1980.

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Technology Comes of Age (1968-2008)

Cable equipment manufacturers from 1968 to the early 1990s specialized in the construction of high performance trunk, bridger, and line extender amplifiers, as well as the internal functions of these amplifiers, enabling long distance cable system cascades. Likewise, CATV hybrid amplifier and semiconductor manufacturers have specialized in hybrid amplifiers with minimal noise and distortion. The parallel development of hybrid amplifier techniques and higher performance trunk, bridger, and line extender amplifiers made possible the increased channel capacity and bandwidth of modern cable systems.

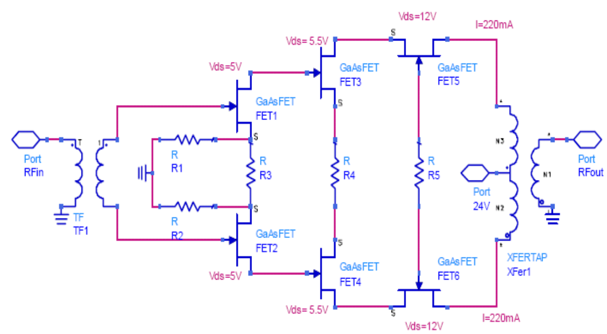
Since the introduction of the first HFC optical node by ONI in 1986 and the installation of HFC networks beginning in the early 1990s, CATV hybrid amplifier performance requirements have steadily increased. The CATV power doubler (known as the “parallel hybrid” at the time of its introduction by Amperex in 1984 and registered by Magnavox/Philips as the "power doubler" in the late 1980s) has enabled the implementation of HFC networks without traditional trunk and bridger amplifiers while simultaneously reducing the number of installed traditional line extender amplifiers. HFC networks with "fiber deep" capability, where the optical node is placed to within 1.5km or closer to end customer houses or MDUs, is feasible as a result of the ever-increasing performance of the CATV hybrid amplifier power doubler.

Semiconductor technology has made significant progress between 1968 and today. Gallium arsenide (GaAs)-based die were introduced into prototype CATV hybrid amplifiers in the early 1990s. Early GaAs die-equipped CATV hybrid amplifiers demonstrated questionable performance advantage versus the best silicon bipolar based hybrids of the era. However, semiconductor manufacturers embarked on a continuous improvement effort and, by the early 2000s, GaAs die-equipped hybrids had surpassed silicon bipolar-based hybrids in every meaningful performance measurement, including bandwidth to 1GHz, multi-carrier distortion (CSO, CTB, XMOD, CIN), RF output power, and power efficiency.

Steady improvement has been made in the design and manufacture of the magnetics components required to implement CATV hybrid amplifiers. Figure 8 is a simplified block diagram of an ideal push-pull hybrid amplifier. The design of an ideal push-pull hybrid amplifier (as shown in Figure 8) requires an ideal set of hybrid splitters. In the 1970s most suppliers that constructed amplifiers attempting to leverage the advantages of the push-pull architecture fell short of desired performance levels, primarily due to inadequate hybrid splitter performance.

Power doublers (PDs) achieve improved RF output power and multi-carrier distortion over standard push-pull (PP) hybrid amplifiers by operating two cascade PP circuits in parallel and by combining their outputs. To coherently combine the outputs, the phase paths through each half must be equal in length. This is accomplished by carefully designing an input signal splitter that drives each hybrid amplifier half with identical signals. The outputs are recombined in a similar signal combiner. The overall gain is the sum of each individual hybrid amplifier's gain, minus the small loss in the two signal splitters. The RF output power is 3dB greater than each individual hybrid amplifier, minus the loss in the output signal combiner. Power dissipation and thermal demands are increased versus standard PP hybrid amplifiers, but each optical node or line amplifier output stage employing a power doubler has at least 3dB additional RF power output capability at reduced multi-carrier distortion levels.

Figure 12. Simplified Schematic of Three-Stage GaAs Power Doubler



In the 21st century this type of magnetic is designed, manufactured, and fielded with performance unimagined by CATV amplifier designers in 1970. From 1970 to today, push-pull and, by association, modern power doubler hybrid magnetics have extended bandwidth performance from 216MHz to beyond 1.2GHz while simultaneously reducing manufacturing and assembly cost and increasing assembly yield.

CATV Hybrid Amplifiers Today

The introduction in 2008 of the first Gallium Nitride (GaN) die-based CATV hybrid amplifiers (1GHz bandwidth 20dB and 23dB gain power doublers from RFMD) has heralded the next generation of CATV hybrid amplifiers. For the first time in the history of CATV amplifier development, network system designers have the option to employ CATV hybrid power doublers within optical nodes and line amplifiers that can simultaneously produce twice the RF output power (an increase of 6dBmV) with an order of magnitude (10dB) decrease in carrier intermodulation noise[3] (CIN) over temperature without increasing dissipated power as compared to the world's best available GaAs die-equipped power doubler. Figure 13 illustrates this performance comparison between the new GaN die PDs (RFMD's D10040230PH1 shown on the left as an example) and the world's best available GaAs die PDs.

Figure 13. GaN-die PD (D10040230PH1) compared to GaAs-die PDs. For CIN versus temperature, GaN-die PD produces 6dBmV higher RF output.

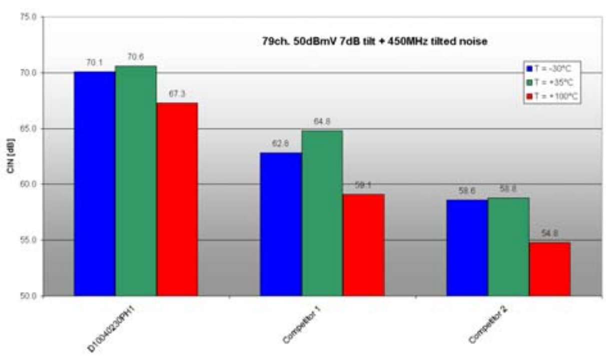


Figure 14 shows 2008 GaN die-based PDs' composite triple-beat (CTB) performance while amplifying a mixed signal 54MHz to 1002MHz waveform (54MHz to 550MHz NTSC analog carriers spaced at 6MHz video carrier interval plus 551MHz to 1002MHz QAM signals starting at 6dB signal level below the average analog video carrier level and increasing with slope). "RFMD" denotes the new GaN die-equipped PDs, "9188" and "1042H" denotes competitor GaAs die-equipped PDs.

Figure 14. GaN PD Compared to GaAs PD. CTB versus RF Power Out

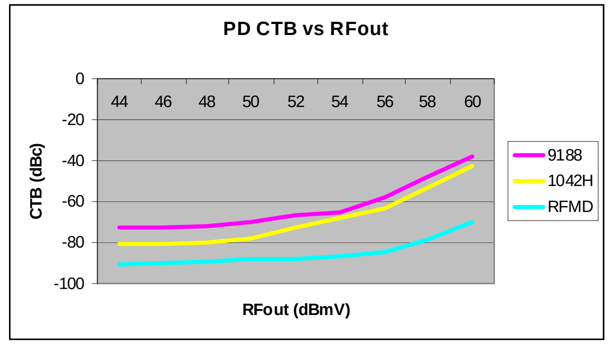


Figure 15. Test Conditions

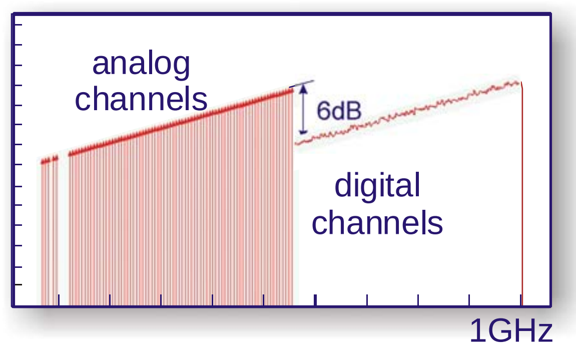


Table 5 shows how 2008 GaN die-equipped PDs compare to the world's best available GaAs die-equipped PDs in key specifications such as CTB, CSO, XMOD, CIN, noise figure (NF), and power dissipation. Presently available GaN die-equipped PDs can achieve improved performance while simultaneously reducing power dissipation by approximately 1W to 2W per PD installed.

Table 5. GaN versus GaAs PD Competitive Analysis

GaN Die PD Strengths versus GaAs Die PDs	SOIC-16 GaAs Die PD	SOT115J GaAs Die PD	SOT115J GaN Die PD
CTB / dBc	-74.0	-72.9	**-78.9**
CSO / dBc	-67.0	-69.2	**-73.5**
XMOD / dBc	-61.0	-71.5	**-77.1**
CIN / dBc	-58.0	-58.1	**-66.2**
NF/dB, max	6.5	5.5	**4.0**
PD / W	12.48	11.38	**10.44**

3. CIN: The ratio of the CW carrier to the noise-like signals generated by the non-linearity of a broadband transmission system carrying a combination of analog signals and digitally modulated signals. These distortion products are analogous to the CSO and CTB products generated by analog carriers, but due to the pseudo-random nature of the digital modulation signals, appear as a noise-like interference. When CIN products fall within the analog portion of the spectrum, their effect on the analog signal is similar to increasing thermal (random) noise. Since CIN is a distortion product, its contribution is dependent on the output signal level. Source: ANSI/SCTE 17 2007 "Test Procedure for Carrier to Noise (C/N, CCN, CIN, CTN)," dated 05 October 2007.

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Worldwide PD usage in the years 2009 through 2013 is estimated at 1.5 million units. If every PD installed was a 2008-generation GaN die-equipped PD, the world energy savings would be approximately 26 billion watt-hours (Bw-hrs) of electrical energy in calendar year 2013 alone.

Table 6 lists the major manufacturers of CATV hybrid amplifiers from 1968 through today and their unofficial industry standard mold cap colors. CATV hybrid amplifier mold cap colors were clearly differentiated in order to allow CATV installers and repair technicians an easier time when removing and replacing individual amplifiers in the field, in a service provider vehicle, or in a repair facility.

Table 6. CATV Hybrid Amplifier Manufacturers (1948-2009)

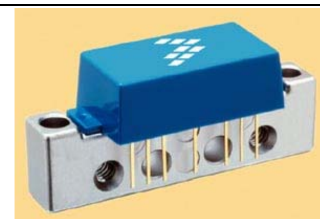
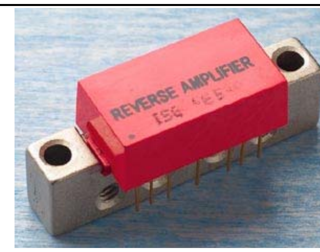
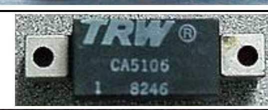
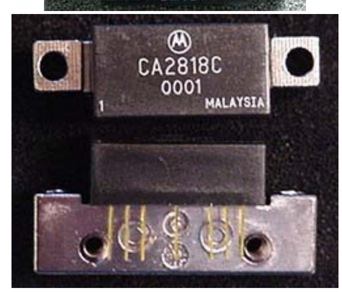
Manufacturer	Mold Cap Cover Color	Photo
Freescale/Motorola Semiconductor	Blue	
NEC/CEL/ISG	Red	
TRW/Motorola Semiconductor	Black	 
NXP/Philips Semiconductor	Green	

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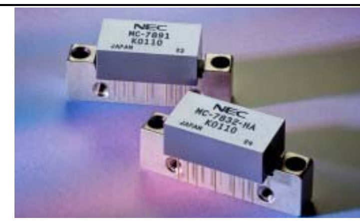
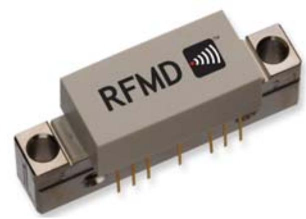
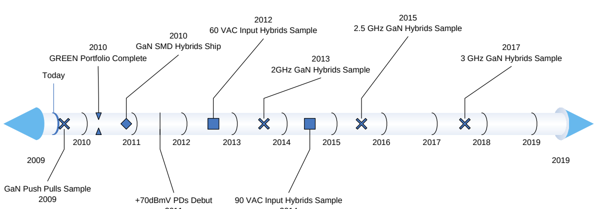
Table 6. CATV Hybrid Amplifier Manufacturers (1948-2009)

NXP (People's Republic of China (PRC) Only)	Translucent	
NEC/California Eastern Laboratories (CEL)	Grey	
RFHIC	Black	
RFMD/Premier Devices Incorporated/Motorola Semiconductor/ General Instrument/Alcatel/Temic	Off White	

What the Future Holds

Figure 16. CATV Hybrid Amplifier Future Development Timeline (2009-2018)



Over the next few years, HFC networks will continue to face tremendous pressure from competing alternative network and multimedia delivery systems such as fiber-to-the-premises (FTTP), passive optical networks (PON), RFoG (RF over Glass), DPON (DOCSIS over PON), SATCOM-DBS, and burst mode wireless technology.

To remain viable and cost-competitive with emerging editions of competing network technologies, the HFC option must continually improve in the following ways:

- Lower cost of delivered bits
- Lower total accounted cost, that is, the entire cost of ownership including capital expenditure, anticipated upgrade, and operating expense
- Much higher optical node RF output capability with no reduction in multi-carrier distortion performance
- Optical nodes with capacity of 16 or more nodes
- Ability to deliver high quality signals in an ever more narrowcasted form
- Installation bandwidth and spacing upgradeability and flexibility
- Peak data rate delivery capability competitive with optical fiber and SATCOM-DBS (200 Mbps peak by calendar year 2015)
- Ability to expand bandwidth to the limit of high grade coaxial cable (3 GHz) by calendar year 2018
- Ability to seamlessly utilize high order digital modulation anywhere in the network (such as 1024-QAM)

- "Smart" optical nodes that are reconfigurable in near real-time via remote signal control ("reconfigurable" means network traffic can be switched to any connected node at any time to accommodate instantaneous traffic requirements)

In 2009...

GaN die-equipped CATV hybrid amplifiers that form a "green" portfolio of 1.2GHz-capable push-pull and power doubler types with a range of gain values will sample. Green hybrid amplifiers will allow reduction of DC power dissipation by more than 40% as compared to today's typical GaAs die-equipped PDs (from 12.5W to 7W). This reduction in DC power dissipation will be achieved without sacrificing multi-carrier distortion performance or RF output power as compared to today's best GaAs die-equipped PD devices. Green PDs will have the means to reduce worldwide HFC network electricity usage by up to 289 billion Watt-hours (Bw-hrs) from 2010 through 2013.

Customers will be able to select the green PD DC power dissipation versus multi-carrier distortion versus RF output level from a published set of data curves. Once a desired set of performance parameters has been selected, the customer will have the option of adding a resistor to a presently unused CATV hybrid amplifier pin that sets the desired performance parameters.

Figure 17. Proposed GREEN PD with Pin 4 Performance Curve Resistor

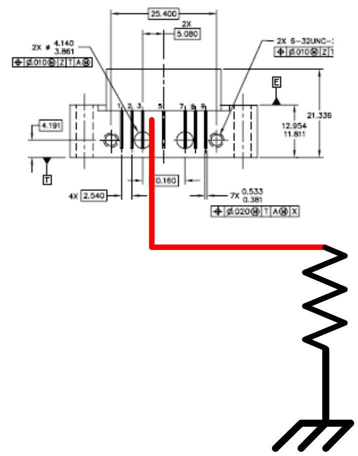


Table 7 shows how the availability of ultra-linear, efficient GaN die-based PDs provide today's fiber deep HFC network system designer's options never available before.

Table 7. Fiber Deep HFC Network Comparison by Amplifier Technology

Die Type	Node To Last Home Distance (miles)	Line Amps	N+x	Hybrid Amps	P_{DISS} (W)	Total Homes Passed (HP)
GaAs	1.00	12	3	29	244	288
GaN v01	1.33	12	3	29	247	384
GaN v02	1.33	12	3	29	224	288
GaN v03	1.00	8	2	21	167	224
GaN NG	0.125	0	0	5	49	96

Figure 18 shows a fiber deep HFC network based on typical 1GHz bandwidth GaAs die-equipped PDs. Figure 19 shows a fiber deep HFC network option if today's generation GaN PDs are employed within both the four-port optical node and as final stage amplification within network line amplifiers. (e.g., bridger, mini-bridger, and line extender (LE) amplifiers). GaN v.01 can provide a 33% increase in reach beyond the optical node and up to a 33% increase in number of homes passed (HP) with equivalent installed system P_{DISS} and no sacrifice in multi-carrier distortion performance versus a GaAs-die based HFC network (Figure 18).

Figure 18. GaAs Die "Last Mile" Fiber Deep HFC Network

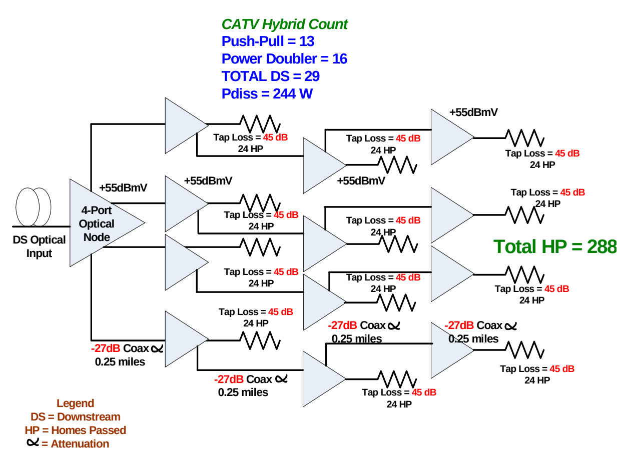


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Figure 19. GaN v.01: Present GaN “Last Mile” Fiber Deep HFC Network: Longer Reach with More Homes Passed (HP)

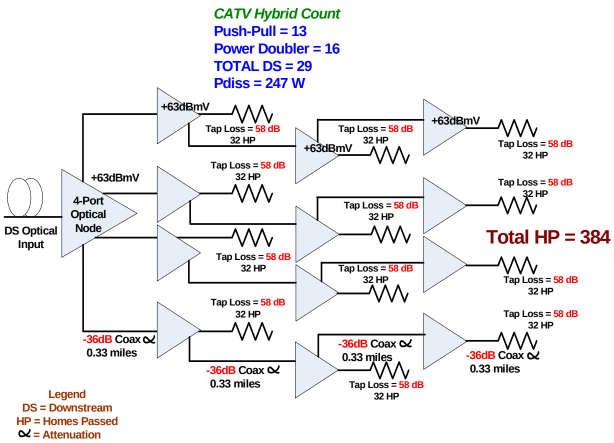


Figure 20 shows a fiber deep HFC network employing the first-generation green GaN die-equipped PDs shown in Figure 17 that can achieve a 33% increase in network reach, with a 9% reduction in total P_{DISS}, while connecting the same number of homes, again without impacting multi-carrier distortion.

Figure 20. GaN v.02: 1G Green GaN HFC Network

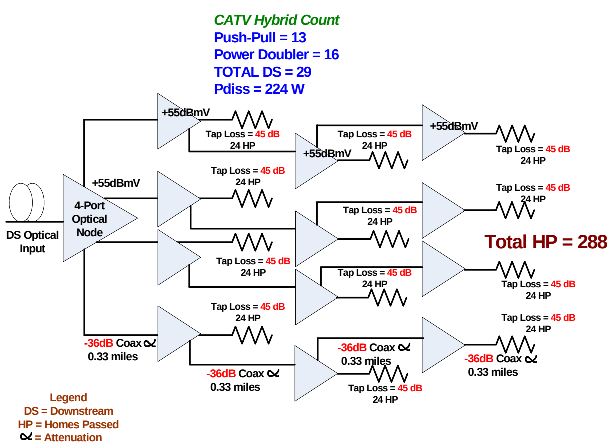


Figure 21 shows a present generation GaN die-equipped PD fiber deep HFC network that matches a GaAs die-equipped network's reach while eliminating one-third of the required line amplifiers, yielding a 27% reduction in hybrid amplifier count, and reducing P_{DISS} by 32%.

Figure 21. GaN v.03: Present GaN Fiber Deep HFC Network: Equivalent GaAs Reach with Lower P_{DISS} and Fewer Amplifiers

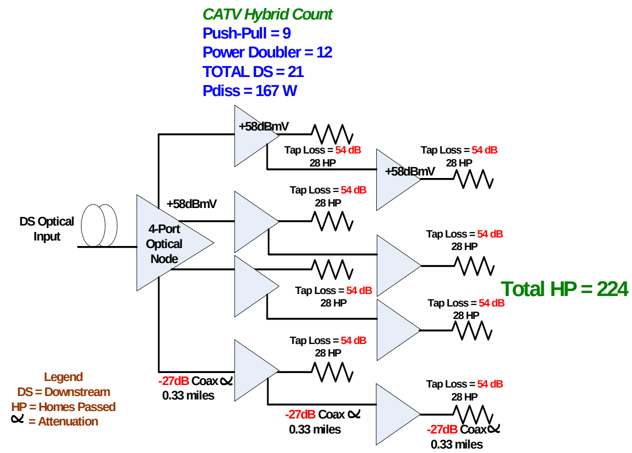
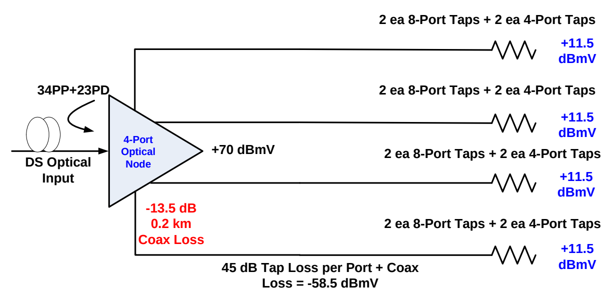


Figure 22 shows a "node+0" HFC network constructed using a next-generation (NG) GaN die-equipped optical node. The NG GaN HFC network utilizes only five hybrid amplifiers and reduces P_{DISS} by 80% versus today's GaAs die-based HFC networks.

Figure 22. Next Generation (NG) GaN: 96 Homes Passed Fiber Deep HFC GaN Amplifier-Enabled “Node+0”



In 2010...

GaN die-equipped push-pull, power doubler, and optical receivers in surface mount device packages will sample.

Some of these amplifiers will be equipped with automatic gain control, allowing HFC network designers to deliver optical nodes, bridger amplifiers, and line extenders into fiber deep networks without regard to detailed advanced system planning.

GaN die-equipped PDs with pre-distortion circuitry will sample. These green PDs will provide an even greater potential reduction in DC power dissipation while maintaining next-generation multi-carrier distortion levels.

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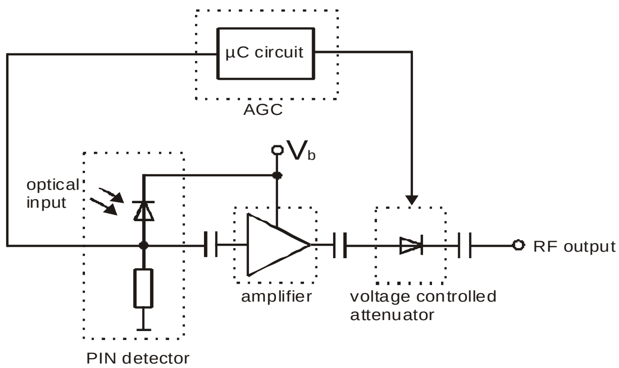
Some of these green PDs will dissipate <6W total DC power while delivering +60dBmV RF power out at 1.2GHz.

In 2011...

Second-generation green push-pull and PD hybrids equipped with GaN die and pre-distortion circuitry in combination with 1.2GHz optical receivers with AGC will allow HFC network designers to employ a new class of "flexible install" optical nodes with up to eight ports.

Figure 23. 1.2GHz Optical Receiver with AGC



Ultra-high output GaN die-equipped PDs and high gain GaN die-equipped push-pull amplifiers will sample. Together these new hybrids will facilitate the design and delivery of a new class of optical node capable of delivering 1.2GHz mixed signal bandwidth at up to +70dBmV RF power output.

In 2012...

4-, 8-, and 16-Port "super nodes" cut FTTN power consumption by >50% by using:

- Low-current GaN PDs with AGC and 70+dBmV RF_{OUT}
- Low-current GaN PP, GaN return with AGC, 90V GaN
- Two-way "mini-nodes" that replace RFoG and xPON ONTs
- E-QAM HEs and hubs with QAM sharing and integrated optical switching that will make narrowcasting the norm
- 16-Port optical hubs with ROADM that will replace optical network units

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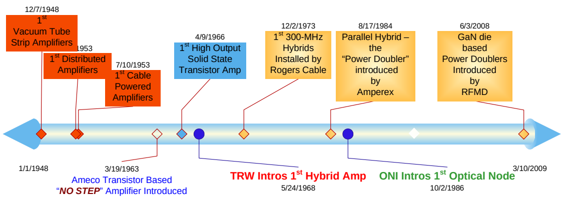
Appendices

CATV Amplifier Timeline

- 1968 - TRW develops 1st CATV hybrid amplifier module using the SOT115J package design (50 to 300MHz BW for Lindsay Broadband, Dave Atman)
- 1970 – Jerrold introduces trunk & feeder amplifier push-pull design using discrete ICs (Bill Lambert)
- 1976 – Feed Forward design patented by Bell Labs
- 1976-1985: TRW & Motorola dominate CATV hybrid amplifier module market
- 1982 – Philips enters CATV hybrid amplifier business
- 1983 – Feed Forward CATV hybrid amp introduced
- 1984 – Power Doubler CATV hybrid amp design developed (Jay Staiger & Philips)
- 1986 – ONI develops 1st optical node
- 1988 - TRW television/CATV semiconductor division sold to Motorola
- 1990 – 1st Power Doubler CATV hybrid amplifier (550 MHz)
- 1990 – NEC offers CATV hybrid amplifiers
- 1991 – 1st 750 MHz CATV hybrid amplifiers
- 1993 – Philips assumes CATV hybrid amplifier market leadership
- 1993 – 1st 870 MHz CATV hybrid amplifiers
- 1994 – Temic enters CATV hybrid amplifier business
- 1994 – TCI installs 1st operational 750 MHz HFC network (CT)
- 1995 – 1st 1GHz CATV hybrid amplifiers
- 1996 – Anadigics develops +12Vdc SOIC-16 CATV hybrid amplifier
- 1997 – Alcatel acquires Temic
- 1999 – General Instrument (GI) acquires Alcatel CATV hybrid amplifier business
- 1999 – Anadigics intros +24Vdc SOIC-16 CATV hybrid amplifiers
- 2000 – Motorola acquires GI
- 2004 – Motorola spins off CATV hybrid amplifiers as Freescale
- 2004 – PDI acquires CATV hybrid amplifier business from Motorola
- 2006 – SMDI acquires PDI
- 2006 – Philips spins off CATV hybrid amplifier business under NXP
- 2007 – RFMD acquires SMDI/PDI
- 2008 – Freescale exits CATV hybrid amplifier market
- 2008 – RFMD introduces 1st GaN die based power doublers
- 2008 – NXP ceases 870 MHz power doubler production
- 2009 – RFMD introduces 1st 1.2 GHz CATV hybrid amplifier modules
- 2009 – RFMD introduces GREEN Push-Pull & Power Doubler portfolio

CATV Amplifier Technology Timeline (1948 - 2009)



Vaccum Tube Era 1948-1966	Discrete Transistor Era 1963-1976	CATV Hybrid Era 1968-Today
***Enablers*:**	***Enablers*:**	***Enablers*:**
Coaxial Cable	Transistor Invented in 1947	Push-Pull Hybrids
Low Leakage Connectors	RCA 2N3866 5W Si Transistors	Feed Forward Hybrids
Test Equipment	Thermal Design	Splitter_Transformer Design
216-MHz BW Designs	AC Power Ports, Trunk Amps	Optical Node
Coaxial Cable Powering	Push-Pull Architecture	Power Doubler
	Transient Voltage Protection	GaAs Die
		The Internet
		Digital TV & HDTV
		VoIP
		GaN Die
		1 to 3 GHz Passives

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Conrad Young received his Bachelor of Science degree in Electrical Engineering (B.S.E.E.) with Honors and a minor in Mathematics from Memphis University, Memphis, Tennessee, USA. He has completed post graduate study in Electrical Engineering at Memphis University, University of Dayton, Dayton, Ohio, USA, and the Air Force Institute of Technology (AFIT), Wright-Patterson Air Force Base, Dayton, Ohio, USA with emphasis on electromagnetics, antennas, and advanced radar design. He is the former Engineering Manager, reporting to William "Bill" Lambert, at Texscan Corporation, El Paso, Texas, USA, now part of Arris Corporation, where he helped design, develop, and install the first Texscan GateKeeper™ 4-port HFC optical nodes. He is presently Director, Broadband and Optical Business Development for RF Micro Devices, Inc. (RFMD), at their Greensboro, North Carolina, USA world

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